IC 8740

Bureau of Mines Information Circular/1977

Mechanized Longwall Mining

A Review Emphasizing Foreign Technology

UNITED STATES DEPARTMENT OF THE INTERIOR

U.S. Bureau of Mines.

Information Circular 8740

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By James J. Olson and Sathit Tandanand

March 3, 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
Cecil D. Andrus, Secretary

BUREAU OF MINES

This publication has been cataloged as follows:

Olson, James J

Mechanized longwall mining, a review emphasizing foreign technology / by James J. Olson and Sathit Tandanand. [Washington] : Bureau of Mines, 1977.

201 p. : ill. ; 26 cm. (Information circular - Bureau of Mines ; 8740)

Bibliography: p. 73-198.

1. Mining engineering. 2. Coal mining machinery. 3. Mining engineering - Bibliography. I. Tandanand, Sathit, joint author. II. United States. Bureau of Mines. III. Title. IV. Title: Longwall mining. V. Series: United States. Bureau of Mines. Information circular - Bureau of Mines ; 8740.

TN23.U71 no. 8740 622.06173

U.S. Dept. of the Int. Library

For sale by the Superintendent of Documents, U.S. Government Printing Office
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Stock Number 024-004-01913-1

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MECHANIZED LONGWALL MINING

A Review Emphasizing Foreign Technology

by

James J. Olson[1] and Sathit Tandanand[2]

ABSTRACT

This report summarizes the results of a review of foreign coal mining literature conducted under the Bureau's Advancing Coal Mining Technology program. In addition to a discussion on the historical development of mechanized longwall systems, and the current state-of-the-art method in Europe, this report summarizes the previous and ongoing Bureau efforts to adapt longwall technology to U.S. conditions. The bibliographic section of this report, divided into major categories such as mine design, face management, roadway development, strata control, powered roof supports, coal winning, conveying, and automation, contains over a thousand individual entries. The purpose of this report is to provide U.S. mining engineers with background information on longwall methodology and equipment developed in foreign countries (principally Europe). The Bureau of Mines, as part of its Advancing Coal Mining Technology program, is funding R&D projects to demonstrate that the longwall mining method, successfully used in the deep mines of Europe, can boost productivity and improve safety in certain U.S. mines.

INTRODUCTION

Declining domestic supplies of oil and gas coupled with rising prices for petroleum imports have revitalized coal as an important energy source for the near future in the United States (48, October 1974, 148, 183)[3] and other countries (48). Mineral economists have estimated that known U.S. coal deposits represent about 400 years supply at present consumption rates. To make a significant contribution in meeting the country's energy needs, however, the coal industry must increase output from existing mines and must open new mines to reach the Project Independence goal of doubling coal production from 600 million to 1.2 billion tons by 1985.

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[3] Underlined numbers in parentheses refer to items in the list of references preceding the bibliography and appendixes.

Longwall mining has been seen by some authorities as the underground mining system of the future, which could improve working conditions in U.S. coal mines (201). Two of the principal improvements identified for application of the longwall method in the United States involve automation and remote control technologies. The present trend toward concentration of mining activities into fewer sections also favors adaption of longwall mining (91). The U.S. mining industry has successfully applied longwall and shortwall mining (particularly longwall shield supports) in several operations where the geologic factors are favorable (43, 97, 149, 160, 166). The Bureau has established a specific goal of accelerating the use of longwall mining technology both to recover a greater percentage of the coal and to mine seams which are either deeply buried or are overlain by badly faulted ground (200). The Bureau's program of advanced coal mining technology has several subprograms which include projects involving longwall or shortwall mining (165, 200). The subprograms relevant to longwall technology include systems for automated longwall (40, pp. 94-95, 143), continuous face-to-preparation-plant coal haulage systems (94), mining systems for western coal (196), high-speed mine development systems (40, pp. 95-96, 53-54), and advanced mining systems (177).

As part of the advanced mining systems subprogram, the Bureau reviewed foreign coal mining literature to search for technologies which might boost the productivity of U.S. mines and increase total coal production. Although surface coal mining was included in the review, the principal emphasis was on underground mining. This review demonstrated that most foreign research and development (R&D) funds have been expended to refine existing technology rather than to develop new systems, reflecting the belief that no dramatic technological developments would be forthcoming (24), at least in the medium term (171). Recent British opinions on the R&D needed for increased productivity in underground coal mining reflect a shift toward the type of investigation that would be more likely to produce a dramatic improvement rather than the type of study which would refine existing techniques (49). Such a change represents a new technology and its development is in the future. Accordingly, the existing foreign coal mining technology offering the best promise for an effective transfer to U.S. underground operations is the longwall mining method.

The improvements in longwall equipment have been important to increasing the productivity of foreign longwall operations. During the past two decades, Great Britain, West Germany, the Soviet Union, and Japan have expended considerable funds on equipment development. Particular attention has been directed toward developing more powerful, reliable components and developing remote control systems for operation under adverse ground conditions. This report reviews some of the improvements in the equipment and methodology reported in foreign literature during the last decade. The bibliography contains over 1,000 references subdivided into functional areas, such as Management, Design, Strata Control, and Powered Roof Support Systems. The report provides interested engineers with a review of the present state of overseas longwall mining.

BACKGROUND

Previous Bureau Efforts To Apply Longwall Mining Technology to U.S. Conditions

Reviews of Methodology and Equipment

Early Bureau evaluations of longwall mining as a technique for extracting coal and other minerals from U.S. deposits included a survey of longwall techniques used by mines in the Midwest in 1936 (184), a comprehensive review of coal mining practices (including longwall) in Europe in 1939 (153), descriptions of two German coal winning machines published in 1946 (5, 25), a summary of conditions and practices (including longwall mining) at coal mines in the Ruhr District in Western Germany in 1950 (12), and a 1951 review of roof control practices in longwall coal mines of the United Kingdom (28). More recent Bureau surveys include an evaluation of the Dosco[4] In-Seam Continuous Miner for driving development entries for a longwall system in flat lying seams (176), an economic analysis of the longwall methods used to mine uranium at Hecla Mining Co.'s Radon Mine in San Juan County, Utah (56), a review of the successes and failures experienced in using either advancing or retreating longwall systems at seven bituminous coal mines (170), and a summary of the hydraulic powered roof supports used in U.S. longwall operations in 1969 (10).

Experimental Investigations

The Bureau's experimental work on applying specific pieces of longwall equipment or the entire method to U.S. coal deposits has been focused in two operational areas--coal winning and strata control.

Coal Winning

As part of a comprehensive research program on the mechanical mining of anthracite (107), the Bureau evaluated several cutting machines similar to those used in European longwall mines (26-27, 29).

After termination of the anthracite mechanization program, the Bureau continued to experiment with longwall techniques for coal winning through a cooperative venture with Eastern Gas and Fuel Associates and Mining Progress Inc. The project sought to evaluate German coal plows for modified longwall operations in the Pocahontas No. 4 coal seam (Stotesbury 11 mine), Helen, W. Va. Two project reports published in 1952 (74) and 1954 (75) described the successful first phase where three panels were mined at a performance level of 12.3 tons per man-shift, an improvement over conventional methods, 10.0 tons per man-shift. The last progress report issued in 1957 (73) summarized attempts to extend the concept to five different operations by mining over 1.5 million tons of coal. Although the experiment demonstrated that plow-equipped longwall faces in U.S. thin coal seams could increase productivity over conventional mining methods, the German plows did not perform as well in thicker, harder seams and seemed to be adversely affected by water

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[4] Reference to specific equipment (or trade names or manufacturers) does not imply endorsement by the Bureau of Mines.

accumulation on the working face. The overall conclusion was that the plow has potential for successful operation in U.S. deposits particularly where geologic conditions were favorable and conservation of coal reserves was important. In addition to field experiments with German coal plows, the Bureau designed and tested a pneumatic coal planer which demonstrated that parameters such as power requirements for longwall planing of anthracite were within practical operating limits (30). Further research was recommended on optimizing the planer operation at the face and development of an integrated roof support system.

Eastern Association Coal continued to evaluate the longwall coal plow in U.S. deposits through further tests started in 1960. The Bureau reported on test mining about 0.5 million tons of coal from four panels of the Pocahontas No. 3 seam (Keystone mine), Keystone, W. Va. (76). Maintaining and operating the plow-equipped longwall faces cost less than comparable sections mined with conventional methods. The plow sections were significantly more productive than sections extracted with the continuous miners. Although extra support capability was added in the tail entry to counteract effects of the retreating longwall face, satisfactory roof control was achieved, at the face, with self-advancing hydraulic props, a new development which superseded the cumbersome mechanical steel props and wooden cribs previously required.

The Bureau also investigated the feasibility of extracting coal in a Pennsylvania anthracite mine with a drum shearer-loader (106). This project also analyzed friction-type yielding steel props used to control the roof (23). Neither technique worked very well. The yielding steel props did not facilitate breaking of the roof at the appropriate position and serious subsidence destroyed the continuity of the roof in the production area. The inability of the shearer-loader to cope with roof and floor undulations and seam thickness changes led to additional maintenance and increased costs.

Strata Control

The initial Bureau of Mines study of strata control with equipment and procedures similar to those of European longwall mines was part of the series of projects on mechanical mining of anthracite. The first experiments measured loads on roadway supports (3), evaluated a pneumatic packing machine (100, 189) and investigated the feasibility of combining yielding steel props with backfilling to remove pillars in areas of the mine excavated by conventional (room and pillar) methods (77). Some elements of the longwall technique proved workable in U.S. anthracite deposits, but numerous technical problems remained, particularly in optimizing the overall system.

After the Mechanical Mining of Anthracite program ended, the Bureau continued field experiments on longwall strata control, under a cooperative venture with Barnes and Tucker in the company's Lancashire No. 15 mine, Bakerton, Cambria County, Pa. (11). This was the first instrumented investigation of the relative strata movements associated with longwall mining in the United States; it demonstrated that the instrument data helped the mine operators understand the process of roof failure--a critical factor in the success of the longwall technique. Further Bureau experiments at the Wanamie No. 19 mine near Wanamie, Pa., demonstrated that yielding steel props were not mobile and reliable enough to properly support the roof in a typical U.S. anthracite mine (23). The Bureau identified a need for self-advancing roof supports that would accept high loads over a sustained time.

In 1969 the Bureau reviewed the specifications of longwall supports used in U.S. operations (10) and developed an in situ method to determine the bearing capacity of mine roofs and floors to prevent punch-type failure (9).

Current U.S. Longwall Layouts

Longwall mining in the United States is usually classified as retreat, advance-retreat, or alternating retreat (98). Retreat is the most commonly used longwall system in the United States with faces ranging in length from 500 ft (approximately 150 m) to 650 ft (approximately 200 m). Because of ventilation requirements, advancing longwall systems are more difficult to initiate. In the retreat system, longwall extraction starts after the working face has been completely blocked out by two sets of butt entries and the face is retreated between them. In the advance-retreat system, longwall extraction is achieved by simultaneously developing two panel entries in advance of the face line and working the longwall face between these entries in the same direction as the development headings. In the alternating retreat system, submains are extended from the main entries. The distance between the submains determines the length of the panel and panel entries are developed between the submains. The retreat of panels begins after the wall has been developed between two submains and two panel entries.

Retreat

After development of the butt or panel entries (fig. 1), the longwall retreat operation consists of plow or shearer extraction of the coal along the panel until the longwall face is mined back toward the main entry. The disassembled equipment is then removed for setup at another face. Mines with especially fragile roof and floor conditions are often left with stub or dead-ended breakthroughs in the side of the recovery area near the completed retreating face. These precautions are necessary when the geologic conditions do not permit longwall advance into the recovery area.

Advance Retreat

Figure 2 shows the layout of a longwall advance-retreat operation. This system is used in three general situations: (1) When butt or panel entry development lags and cannot be completed for the retreat method; (2) when the delay in obtaining coal must be minimized and; (3) when the geological or physical characteristics of the strata dictate that entry development be restricted. Because the development entries (escapeways, haulageways, and airways) require more maintenance, the advance-retreat system costs more than retreat mining (98).

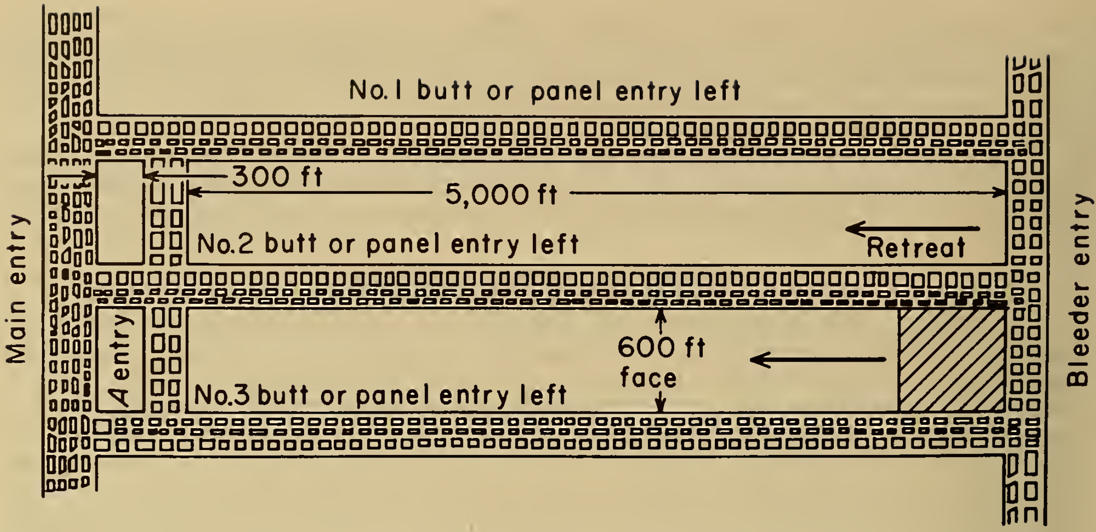


FIGURE 1. - U.S. longwall retreat layout (after 98).

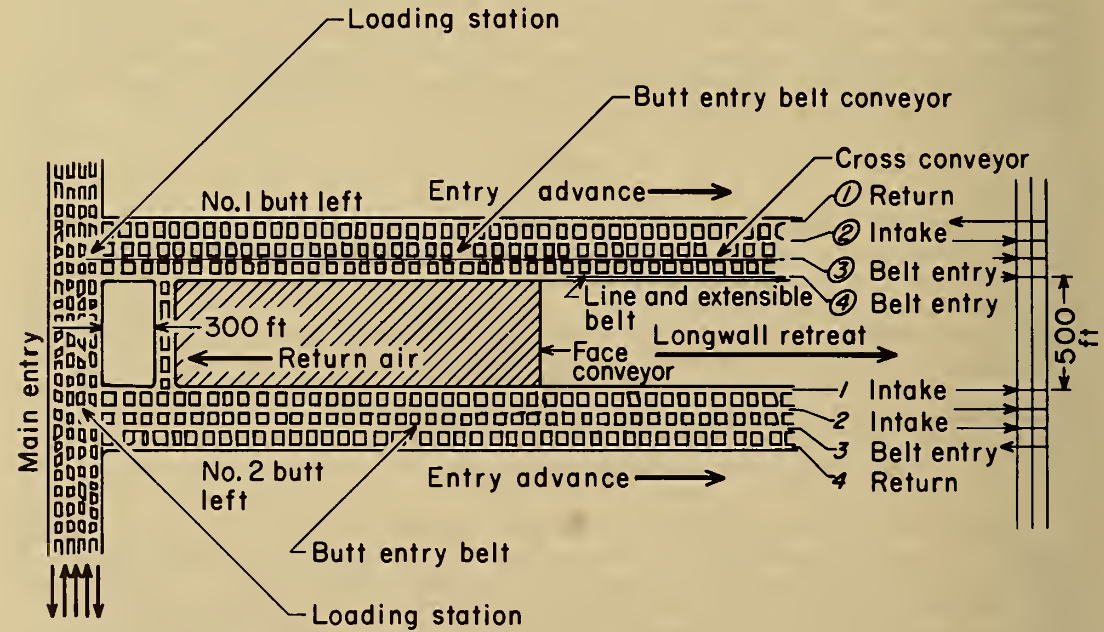


FIGURE 2. - U.S. longwall advance-retreat layout (after 98).

Alternating Retreat

The principal advantage of alternating-retreat longwall mining (fig. 3) is the reduced time required for moving the equipment from one face to another. Because the equipment does not have to be completely dismantled, hoists and tractors can shift the equipment rapidly. Although the alternating retreat system is ideal for many geological and physical conditions, more detailed planning and more development workings are required than for the other systems.

The three-heading entry has been incorporated as the standard practice for U.S. entry systems. This layout permits reasonable production from development units, although coal left in the chain pillars for ground support is lost. During development work, shuttle cars are used to transport coal from the continuous miner or loading machine to district belt conveyors. Bolts are used to control roof in the roadway. Equipment and techniques developed for room and pillar mining have been used to good advantage in driving these multiple entry systems.

Although multiple entry systems have become standard in the United States, their development has often proven troublesome when ground control is difficult. The Bureau in cooperation with Kaiser Steel Corporation and the Mining Enforcement and Safety Administration (MESA) is presently conducting field research to test the hypothesis that a single entry system is equivalent to or better than a multiple entry system (146-147, 156). This research is described in greater detail later in this report. The single entry system has several advantages. Chain pillars, crosscuts, and intersections can be eliminated to reduce associated ground control problems. Coal recovery is improved. Finally, dust control and ventilation are improved through the passage of the total air stream across the exposed coal face (42).

Current Bureau Research on Longwall Mining

As part of its mission to develop more efficient mining methods the Bureau is evaluating the feasibility of using new longwall equipment and

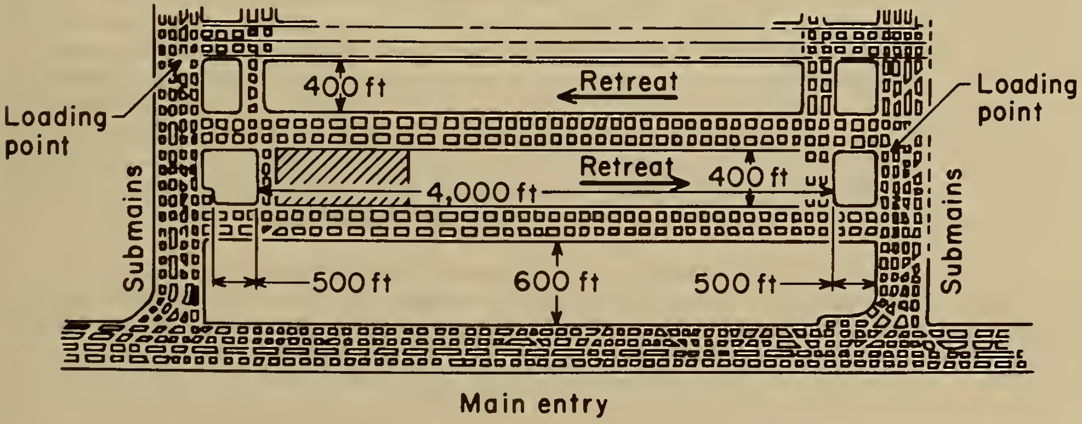


FIGURE 3. - U.S. longwall alternating-retreat layout (after 98).

methodology in U.S. coalfields. The Bureau has reviewed some of its past investigations on longwall strata control in a technology transfer seminar on ground control (185, pp. 97-129) and examined the differences between U.S. and West German longwall techniques as practiced in 1971 (55). The principal longwall projects are parts of three subprograms: Automated longwall, continuous face-to-preparation plant haulage systems, and high-speed development systems (165, 200).

The automated longwall subprogram emphasizes field demonstrations. Examples include a shortwall demonstration with an advancing tailgate in the Valley Camp Mine (Pittsburgh coalbed) in the Upper Ohio Valley and the use of longwall shield supports in a 10-ft-thick coalbed in Kaiser's York Canyon mine in New Mexico (143, 202). The Bureau, under its Coal Mine Health and Safety Program, is demonstrating shortwall mining technology in Beth Elkhorn's Hendrix No. 22 mine (142-144). Additional work includes a contract with NASA and General Electric to develop sensors which detect the coal/roof or coal/floor interfaces, a large effort to obtain strata control data for a wide range of longwall and shortwall operations in the United States and the development, at the Bureau's Mining and Safety Research Center in Pittsburgh, Pa., of a mine roof simulator and a fully equipped scale longwall face. Relevant parts of the continuous face-to-preparation plant haulage subprogram include efforts to develop an improved continuous haulage system for shortwall mining and to develop a higher capacity, more reliable conveying system for high-production longwall faces (94).

Because efficient operation of longwall mining layouts depends on the ability to develop new panels, almost all projects conducted under the Bureau's high-speed mine-development subprogram could accelerate the use of longwall mining techniques (53-54, 99). Another effort in entry development, funded under the Bureau's Coal Mine Health and Safety program, is the cooperative venture with Kaiser Steel Co. and the Mining Enforcement and Safety Administration (MESA) to determine whether a single entry supported in the Center by open cribs and divided by a fire-resistant panel could be considered equivalent or better than the multiple entry system presently required for U.S. longwall mines (146-147, 156). The project is being conducted at Kaiser's Sunnyside mine about 150 miles southeast of Salt Lake City, Utah. Although the single entry system has advantages over multiple entry systems in certain ground conditions, several important questions about safety and production of the new system are addressed. The questions include whether the fire resistant panel can protect one side of the entry from a fire in the other side, whether the line of cribs can support side abutment loads, and whether heavy development equipment can work in the confined space. To date ventilation and ground control have been satisfactory (53).

Appendix A briefly summarizes other examples of Bureau in-house or cost-sharing projects involving longwall mining technology. The Bureau has also funded contracts to enhance the productivity of present longwall methods or to improve equipment (appendix B).

EUROPEAN METHODOLOGY AND EQUIPMENT FOR MECHANIZED LONGWALL MINING

Historical Development of Longwall Mining

References to coal and its use occurred in ancient times. For example, Theophrastus (372-287 B.C.), the principal disciple of the philosopher, Aristotle, observed "those fossil substances that are called coals, and are broken for use, are earthy. They kindle, however, burn like wood-coals. They are found in Liguria--and in Elis, on the way to Olympia over the mountains. They are used by smiths" (81). Other evidence indicates that coal was mined and used by Europeans prior to the Middle Ages, but most of the oldest documents referring to coal mining are Scottish church records dating from the 13th century (161). In 1200 the digging of "coles" on the Firth of Forth and at Linlithgow is mentioned in the records of Holyrood and Newbattle Abbeys. A charter dated 1210 grants the monks of New Castle Abbey near Preston the right to mine coal. In these primitive operations coal was extracted either from outcrops or shallow beds underground. The underground method was a variable system of partial extraction known as "pillar and stall" or "stoop and room" in Scotland. Coal was extracted by hand picks from the stalls or narrow roadways, and the stoops or pillars were left as ground supports. The coal was hand-loaded into trucks and hand-trammed or hauled by horses to the mine portal.

Coal produced from the Middle Ages until the 18th century was limited to home use. During the industrial revolution the advent of such power machinery as the steam engine and locomotive greatly accelerated the demand for coal, world production went from 36 million tons in 1835 to 422 million tons in 1885, and coal became a primary source of energy for the industrialized countries of the world.

As the demand for coal in Britain increased, the best reserves were rapidly exhausted in many parts of the country. The pillar and stall system was criticized as restricting output and wasting reserves. Toward the end of the 17th century an alternative system of mining was developed in Shropshire (98). The coal was extracted from a long working face and the new method was appropriately titled "longwall." The longwall method developed into the most economical method for seam conditions prevailing in the coal mines in Britain. After 1910 the pillar and stall method was gradually replaced by longwall. Longwall technology has been strongly influenced by the level of mechanization and efforts to improve the method fall into two principal periods. The early developments, from 1850 to 1950, involved cyclic activities of extracting, loading, and packing with lots of manual labor. From 1950 to present, longwall methods have been integrated into a more sophisticated technology.

Early progress resulted from economic pressures and constituted gradual improvement of the manpower intensive longwall system. The first British patent for a coal cutting machine, granted in 1761, involved heavy chains to drive a series of saws or cutting tools (4). The motive force was not defined, but later versions of cutters were operated by hand or by a horse on a treadmill. The development of compressed air (1850) and electricity (about 1900) as power sources for underground mining were a major advance toward the eventual mechanization of the coal face. During 1850-1900 coal cutting machines using picks or chains, disks, and bars were proposed for kerfing. Some were built and tested. The horizontal disk machines, in particular, became quite popular in British longwall mines of the 1880's. These early longwalls were actually just advancing total extraction systems for removing pillars and were generally known as gateway longwalls. The development of face conveyors in the 1920's was the first step to the development of efficient longwall equipment. In the 1930's the cutter loader, a machine which would cut and load simultaneously, was introduced. Although these units were the forerunners of the modern longwall power loader, little resemblance is evident today. Since these early developments, British equipment manufacturers have focused their attention on longwall machines with the pick cutter, while manufacturers on the continent (particularly in Germany) concentrated on refinement of the coal plow.

Until the 1930's timber was generally used as the ground supports in longwall mines. The timber systems were cumbersome and time consuming to install. Although cutting and conveying technologies had been improved, the longwall system could not significantly increase coal production until better face and roof support capabilities were developed. Early efforts in this direction were focused around the power loaders developed for use in British mines and designed for operation with a belt conveyor. Rigid steel props and "w" section roof bars were used as support at the face.

Since power loaders and face conveyors markedly increase the rate of face advance, efficient operation required rapid setting props that can be functioned without delay as the face is advancing. During World War II the prop-free front system with a flexible chain conveyor was developed in Germany. The system utilized friction or mechanical props that could be set more rapidly than previous support units. Great Britain adopted the German innovation of the flexible chain conveyor in 1947 but replaced the friction props with domestically designed hydraulic supports developed in 1946. Plows were almost exclusively used in these installations. The friction and hydraulic props were gradually superseded by hydraulic-powered self-advancing supports which could counteract the immediate roof and floor loads and could be highly maneuverable. A full-face installation of powered supports together with a single-ended trepanner prototype has been cited as the first modern European longwall system (169). These and other developments have contributed to the modern European system of continuous longwalls.

Planning and Layout of Modern Longwall Workings

Modern longwall operations remove coal from the long faces (about 100 to 200 meters) laid out between two parallel panel entries or roadways. Because no pillars are left to support the workedout panel areas, the method can obtain excellent recovery percentages (approximately 80 percent). Sophisticated hydraulic systems and equipment, such as armored face conveyors, coal shearers and plows, and self-advancing roof supports, have enabled longwall mining to become almost continuous. The main advantages of this kind of mining include rapid advance of a single working face (resulting in high productivity), concentration of men and equipment in limited areas of the mine (reducing burden on supervisors), and the adaptability of the method to adverse ground conditions and remote control. Despite the ability of the longwall method to cope with difficult roof conditions, strata control has received much attention from foreign researchers, who have stressed the need for prompt caving action to reduce the pressure of the overlying strata on the face supports. In most successful longwall operations, the caved area (called goaf or gob) compacts and, after initial subsidence, the caved ground supports the overburden.

Behavior of Roof and Strata

Recent foreign literature on strata control in longwall mines is summarized in the bibliography section of this report. In addition, the University of New Mexico in Albuquerque has compiled further references on longwall strata control and many other subject areas grouped under the broad category of deep coal mining technology (186). Accordingly this discussion is limited to the most significant factors which ultimately affect the design and operation of longwall mines.

Before the extraction begins in longwall workings, the upper and lower rock strata are in equilibrium and are intimately in contact with the coal seam. Each stratum is subject to overburden pressure--the specific weight of the overlying rock times the depth of the stratum. The overburden pressure, approximately 1 psi/ft (22.6×10^{-3} MN/m^2/m) of depth, is uniformly distributed over the coal seam. Because of the confinement and the deformability of the rock, lateral pressures are also present in each stratum. In geologic provinces, previously subjected to tectonic activity, the lateral pressure may be increased by any residual stress field. The magnitude of the lateral pressure, where no residual stresses are present, depends on the overburden pressure and Poisson's ratio of the rock. If the rock can be regarded as incompressible, the stresses are the same in all directions (hydrostatic).

When an opening is made underground, the state of stress in its vicinity is changed. To maintain equilibrium, the overburden pressure previously sustained by the extracted portion is transferred onto both sides of the opening and the surrounding rocks are deformed.

Using field observations and rock mechanics theory, researchers in the U.S.S.R. have divided the area around a freshly excavated opening into five distinct zones (61). In zone 1 the rock strata act as multiple beams on fixed supports (fig. 4). Deflections of the strata come from the body force and the lateral pressure. Differential deflection of each stratum occurs and varies depending on the thickness and flexural rigidity of the component layers, and the span between the supports. Bed separations may occur when each layer is deflected differentially. The deflection of each overlying layer, however, varies with the decrease of effective span widths. In zone 2 the locus of minimum deflections in each layer forms a dome-shaped envelope with its vertex at the point where the overlying stratum remains intact. In zone 3 the vertical and lateral pressure approach their original values. Floor heave may occur in zone 4 with the same mechanism as in zone 1; however, the uplift is alleviated to some extent by gravity. In zone 5, the rock or

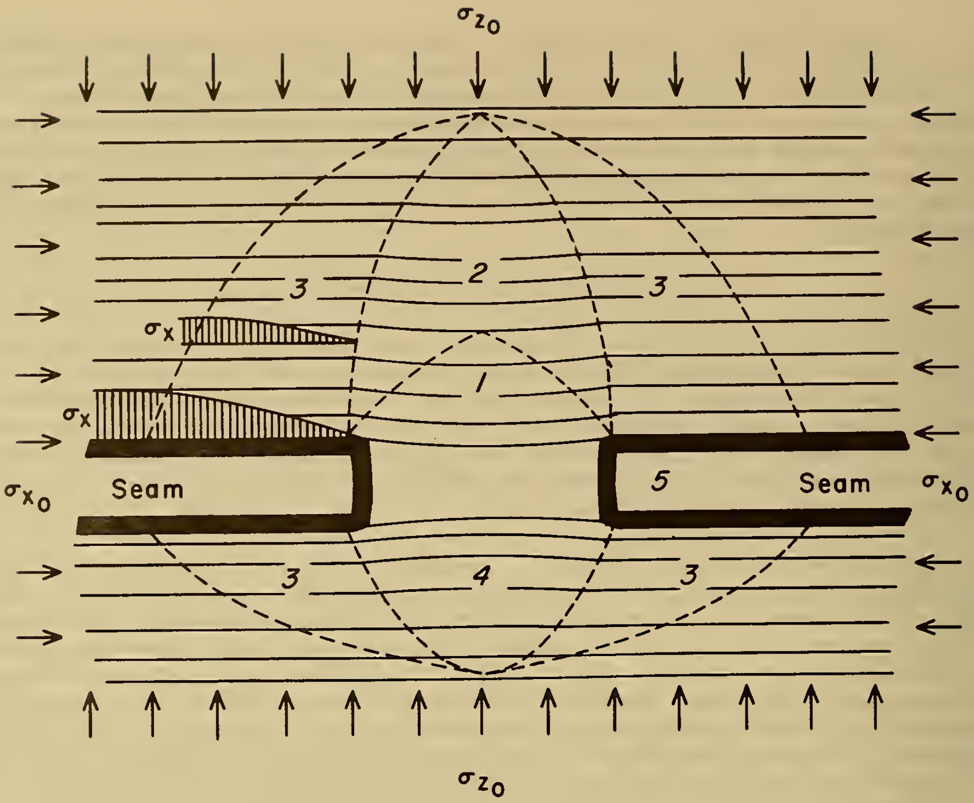
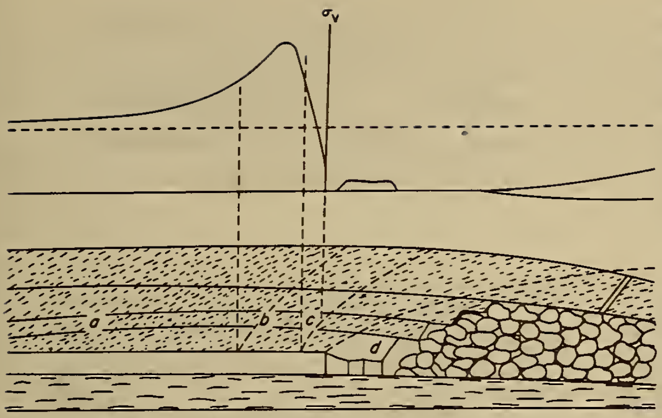


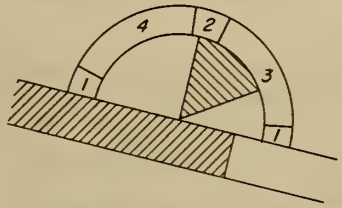
FIGURE 4. - Zones of disturbance produced by excavation in layered strata (after 61).

coal seam acts as an abutment. Lateral deformation occurs at the ribs and causes seam extrusion toward the excavation as the result of the vertical pressure and free surfaces.

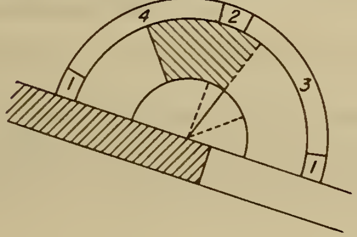
Stress distribution around an actual longwall opening is somewhat different from the theoretical prediction. The highest vertical pressure is concentrated inside the ribs instead of being at the boundary. A starting face in a seam produces the same effect when it is viewed through a section across the working face. However, the deflection and caving of the roof and consolidation of the caved rock behind the face significantly alters the stress profile as shown in figure 5A. Josein (89) divides a vertical section across a working longwall face into four zones of influence. At a distance of over 30 m (about 100 ft) in front of the coal face (zone a in fig. 5A), the vertical pressure above the seam is the original overburden pressure. The vertical pressure, however, rises rapidly toward the face and reaches a maximum between 10 m (about 33 ft) and 2 m (about 6.6 ft) ahead of the face (zone b in fig. 5A). The coal seam and the overlying stratum are subjected to high stress in zone b and undergo a large deformation in the plane of the stratification. The maximum deformation in the seam is at the free surface. The vertical pressure starts falling and vanishes at the end of zone c. At the same time, vertical displacement takes place in the overlying strata in and beyond zone d. Excessive deformation has two significant effects: (1) The separation of the immediate roof, that is, the layer or layers of rock immediately above the opening, from the main roof lying above, and (2) the opening of breaks that lead to roof falls that cause large convergence and eventual surface subsidence.



A Pressure profile of the roof (vertical stress = σ_v)



B Direction of primary fissuring (zone *b*)



C Direction of secondary breaking (zone *c*)

FIGURE 5. - Stress profile and roof deflection in longwall faces (after 89).

The roof falls in a longwall mining operation are two types--roadway and face (86). The roof in a roadway usually breaks in a slab parallel to the stratification of the rock strata and reflects the working cavities caused by the bed separation. The roof over the face commonly breaks in slices at an angle or sometimes normal to the stratification. Some breaks occur ahead of the face; however, the plane of breaks is usually parallel to the face. The primary breaks formed in zone b (fig. 5B) range from normal to 45 degrees toward the goaf. This direction depends on the characteristics of the seam and the bottom layer of the immediate roof. When two layers, in intimate contact, have the same deformation characteristics, the breaks will be parallel to the direction of maximum principal stress, that is, normal to the stratification. When differential deformation exists between those two layers, friction or tangential stress develops at the contact surfaces. The primary breaks then incline and dip toward the goaf. The secondary breaks can form in zone c (fig. 5C), where a large deformation is taking place, and in zone d where the roof is exposed because of the stratification and displacements imposed on the immediate roof (fig. 5A). Figure 6 depicts a postulated sequence of roof fall steps which lead to eventual settling of the main roof.

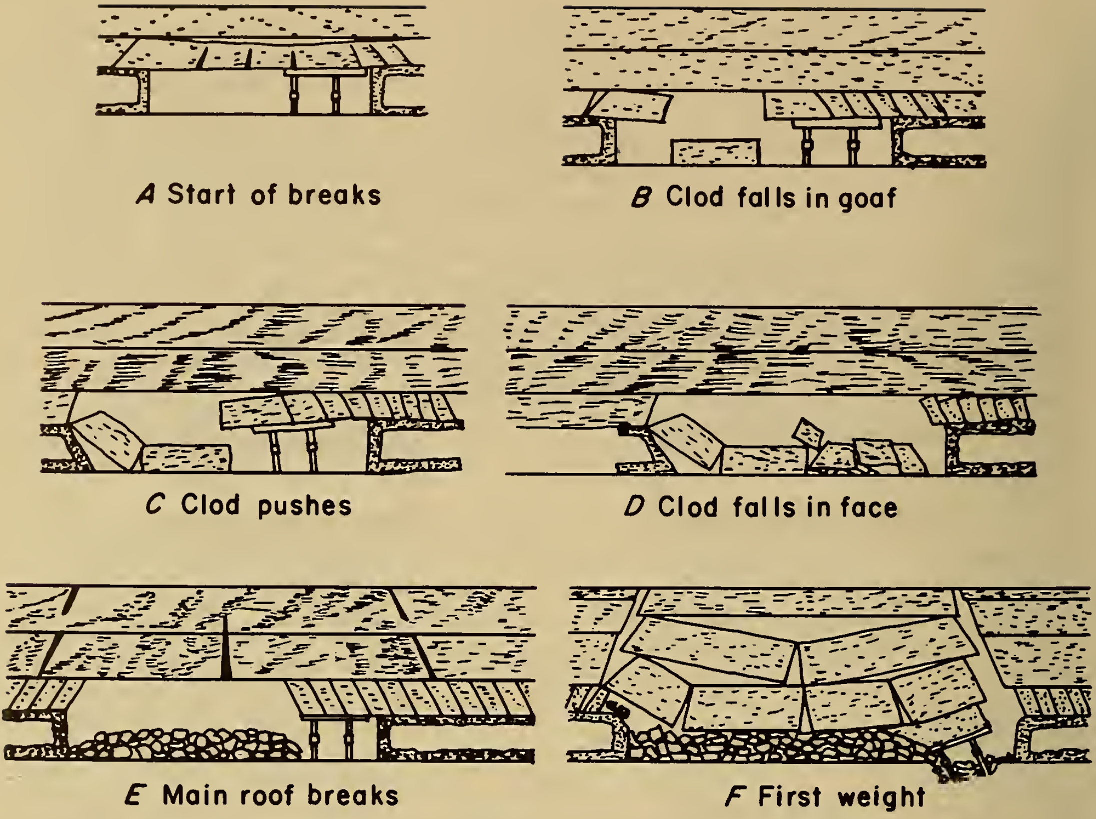


FIGURE 6. - Sequence of roof fall followed by the settling of the main roof (after 86).

The phenomena of roof and floor movement and breakup in roadways and faces have been analyzed in several papers (32, 36, 71, 86, 89, 193). These references and others in the Strata Control portion of the bibliography contain further details on how to interpret the relevant factors and how to select appropriate ground support systems.

Principal Factors Influencing Longwall Mine Planning

The major problems associated with the longwall method include ground control and support, roadway drivage, dirt disposal, equipment withdrawal and reinstallation, safety, and supervision. European mining engineers have stressed that the success of a longwall mining plan ultimately depends on the effectiveness of the roof control system which, in turn, is influenced by the layouts of the panels, working faces, and the entire mining district. Existing ground conditions and characteristics of the coalbeds such as thickness, inclination, depth, and continuity of the seam all complicate the operation.

The design of a longwall working can be influenced by human and natural factors. The factors resulting from mining practice or even legal regulations can sometimes be altered to fit a particular situation, but the overall character of the coal, geological abnormalities, depth and pitch of the seam and the surrounding strata, gas emission rates, and other natural features cannot be changed, so the layout must be planned around them. Variables such as lengths of the face and panel, method and direction of working, rate of extraction, pillar widths, shape and size of roadways, and the characteristics of the support system can all be varied to fit parameters which are fixed by law or nature.

The objectives of the longwall designer are the same as those for planners using other mining methods, that is to provide a suitable environment for both men and machines to achieve their highest production performances and to safely recover the maximum amount of the coal resource. For efficient layout development, special attention is given to design features that facilitate continuous operation. The choice of equipment based on production requirements and suitability for the strata conditions at the particular mine site should be made using an analysis of all relevant factors.

Development of new mines in European countries such as Great Britain is characterized by extensive planning and analysis (195). At the outset target objectives for the new district are established in terms of product quality, output, and timing. Subsequently, all known data on the fixed factors are compiled and evaluated. Particular attention is paid to the geology, depth of overburden, total thickness of the seam, restrictions on surface subsidence, presence of old workings, water, or gas and danger of spontaneous combustion. The workable reserves in the area and the seams to be worked are delineated. Further decisions involve the method of development, the thickness of seam to be extracted, both for production and for development roads, the size and output per face, the direction of working, number of faces to be operated at any one time, and the possibility that the layout will require multiple-seam workings. Finally, a sound knowledge of strata behavior in terms of pressure distributions and deflections of roof and floor is essential in the determination of support systems for rib sides, faces, and roadways. Mathematical and physical models sometimes are required to simulate the system under study and to implement the results in the layouts.

The many fixed natural factors which influence the design of longwall workings have been analyzed by Blades and Whittaker (17). Table 1 explains the effects of these factors on overall layout planning as practiced in Great Britain.

TABLE 1. - Factors influencing design of longwall layouts (17)

Problem area	Specific factor(s)	Effect on layout planning
Reserves	Virgin area	Extraction sequence must be well defined.
	Value of reserves	Percentage extraction may be a problem.
	Location of reserves	Access costs may be high.
	Quality and working conditions.	More exploratory work may be needed.
Depth	Shallow depth	Planner might use rectangular profiles.
	Roadway stability in deep sites.	Drivages in solid may not stand. Floor lift problems may preclude retreat layouts.
	Roadway shape in deep sites.	Arched profile requires more development.
Geologic conditions	Rock type and character	May determine type and amount of support.
	Gradient	May affect direction of working.
	Severely fractured ground.	Face lengths may be limited Special supports or additional exploration may be required.
Seam thickness	Thick	Mechanization usually more successful. Roof control more difficult because convergence is increased. Reduced panel widths may be required.
	Thin	Strata control on face usually no problem. Less effect on neighboring seams. Smaller roadways can be used. Special support systems often required at the face ends.
Interaction	Old workings	Accurate data required on location of old workings.
	Old goaf areas	Affords protection to faces and roadways.
	Rib edges and remnant pillars.	Faces crossing rib areas may encounter difficult ground control problems. Roadway deformations higher in area of remnants.
Working	Gas emission	Special precautions required.
	Spontaneous combustion.	May limit extraction and method of working.
	Water in neighboring aquifer.	May control direction of working; restrict extent of extraction. Special goaf support may be required.
	Water in workings	Working conditions difficult.

Current European Longwall Layouts

The general layouts of European longwall systems fall into three broad categories: (1) Full retreat; (2) semiretreat; and (3) advancing faces. Working panels on the full-retreat faces between predriven roadways are more prevalent on the continent, especially for seams less than 5 feet in thickness. Single-entry development is predominantly used for the extraction of both flat seams and steeply inclined seams.

Full Retreat

Longwall mining by the full-retreat system extracts the coal using roadways driven to their ultimate boundary. Retreat mining seeks to separate roadway development from coal production so that the rate of face advance can be increased and a better return on invested capital secured (35, 159).

In 1971 only about 4 percent of the total coal production was won by the retreat method in Great Britain, compared with 37 percent in Germany, 50 percent in France, and 40 percent in Poland (159). Although the principal obstacle to wider use of retreat mining techniques in Great Britain may be simply resistance to change, the ability of the advance method to quickly develop areas of coal for working has certainly been a favorable factor for that method. In isolated areas retreat mining is not well suited because of the nature of the strata immediately above and below the coal seams, which require large development and maintenance costs (88). Keeping roadways open in the solid and achieving the rapid advance rates necessary to extract the reserves quickly are problems which must be solved before retreat mining is more widely used (35). The retreat mining technique, however, is widely recognized by British mining engineers as being a potentially significant improvement for coal production in Britain, when strata conditions are favorable (17, 35, 41, 82, 88, 157, 175, 197).

Semiretreat

Longwall mining with the semiretreat or advance-retreat techniques generally involves single or double headings in advance of the face line (84). One roadway is driven to an existing airway at the boundary of the panel. A face is subsequently opened out and retreated, the second roadway for the face is formed as the installation moves away from the back pillar. This latter roadway serves as both a return airway and a supplies gate. The main gate is salvaged during retreat when economically advantageous. Sufficient roadway protection is left to keep the gate road open for ventilation. A general plan for the semiretreat system is shown in figure 7.

Advancing Faces

In longwall advancing, either with or without advance headings where there is sometimes a stable in advance of the general face line, the coal is worked away from main entries. Roadside packs or a substitute are necessary for ground support in roadways and ventilation openings. The stable is merely a short drivage or space excavated at the face-end in advance of the face line.

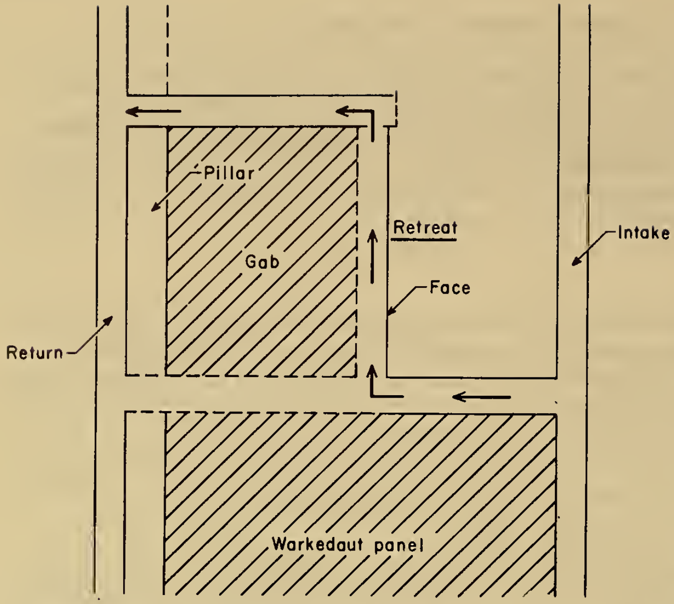


FIGURE 7. - Typical longwall semiretreat layout as used in Europe (after 84).

The stable provides room for the face conveyor drive and an opening for the face loader to pass at the end of the run. In addition the stable can be used for turning the face cutting machine drum.

A modification of the advancing heading method has been developed in Great Britain to eliminate the stables substantially in advance of the face line, to improve the face performance, and to reduce dirt packing problems (169). Keeping the stable in line with the face provides more effective ground support. The improved support at the face-ends reduces stress on the roadways and improves safety conditions. Coal can be excavated up to each rib side or road side by the integrated system of face equipment developed for cutting roadway profiles. In addition the coal can be loaded directly onto the face conveyor. In thick seams ranging shearers win coal at the face and rip the roof and/or floor of the roadway to form the stables. Eliminating the stable in advance of the face line also improves ventilation of the face-ends (162).

Another modification is the half heading (or half head) system where the roadway is formed a considerable distance back from the face. This system has improved roadway conditions and has reduced activities around the face transfer point. The system is also well suited to maingate stable elimination.

Roadway Development

Design Requirements

Roadways for longwall mines are classified as either main or gate roadways. The former are the set of entries driven through a coal seam to form the haulage arteries for the underground mining process. The latter are closely associated with the development and operation of the production faces. Because of their function, main roadways may have several years of life and may be regarded as a semipermanent structure of the mine. Gate roadways, however, have a life from a few months to a few years, depending on the time taken for panel extraction.

Roadways of both types are routes for transport of materials, coal and broken rock, roads for traveling into and out of a mine section, and airways for ventilation. Gate roadways can serve as exploration roadways in advance of panels working in virgin ground, as in retreat mining, and also serve as passages for withdrawal of usable equipment and supplies after a panel has been mined out.

Any roadway cross section must be large enough to provide ventilation for safe operation. The gateroad must also be compatible with the face and associated equipment. The roadways must be designed for maximum stability throughout their life expectancy. Modern longwall layouts achieve high productivity by concentrating mining activities at fewer faces. Increased face production accelerates the rate of face advance and face life becomes shorter. Faster roadway drivage is needed to serve the high-output faces, and much European research and development funds are expended on rapid development. The bibliography contains references on roadway design, development methods and equipment, and on strata control.

Gateroads must also facilitate operation of the coal-getting equipment at the face ends. Five essential activities are involved: (1) Move the AFC (Armored Face Conveyor) forward and prepare the machine to travel in the opposite direction; (2) advance the stageloader and the belt conveyor system; (3) set the face-end support system; (4) accomplish further ripping and set roadway supports; and (5) install the necessary packing or auxiliary support after the face advances. In addition, requirements for servicing face equipment and establishing the airflow for ventilation of the face also affect the design of face-end layouts.

Because the efficiency of the longwall operation depends mainly upon effective face-end arrangements, the roadway operations must be planned around factors such as the capacities of the machines, face length, support systems, seam thickness, and the type of power loader. Great Britain's National Coal Board has emphasized developing optimum face-end layouts for specific mining conditions using either stable hole elimination or stable mechanization (118-120, 125-127, 134-135).

Problems in Roadway Development and Maintenance

The two basic types of longwall working systems--retreat and advance--need different roadway formation methods. As mentioned previously, the retreat system mines coal from a face between two parallel roadways already driven to their ultimate boundary. This layout separates roadway development from coal production to increase the rate of face advance. In practice, the speed of roadway drivage is 1-1/2 times the face advance for proved geological areas and 2-1/2 times or more for poor and unknown ground conditions. The main problems for retreat systems are the need to drive roadways fast enough to cope with the high-output face and to keep roadways open in the solid. These problems have been analyzed by British engineers in terms of equipment, techniques, and the overall management (34-35).

Four different methods are used to form gate roadways in longwall advancing systems: The advance heading, gate formation at face line, conventional ripping, and the half-heading (or half-head) system (191).

In the advance heading layout which involves in seam driving or ripping of roof and floor, roadways are driven at a distance ahead of the face line (fig. 8). This system lets the longwall face advance at a faster rate. Gate formation can be at the face line, when the mine is in a thick seam or when dinting is to be used as opposed to a rip. Conventional ripping is done when the roadway is essentially formed at a short distance behind the face line. The half-heading system entails a small heading within the extracted seam height to provide access between the face and the gateroad. A width of solid on the rib-side equal to approximately half of the roadway width is left for later ripping. The half-heading system has flexibility which lends itself to mechanized getting and loading, as well as dirt packing whenever necessary.

Although roadway development differs for longwall retreating and advancing systems, particularly at the face ends, problems such as stability and rapid drivage, are common to both. The principal factors which induce convergence and side closure of gate roadways in front and behind the longwall faces are change in the direction of principal stress and increased deformation around the roadways as a result of nonuniform stress distribution when the roof caves or the goaf settles. Convergence is intensified by the interactions of an adjacent face and from workings above and below the working horizon. This interaction is particularly severe in a deep mine since strata pressures increase with depth. The problem of strata control in roadways has received a great deal of attention in the foreign literature (16, 33, 38-39, 83, 87, 92, 102, 168, 193).

The references cited in the preceding paragraph are British. Work from other countries is cited in the bibliography section on Strata Control in Roadways.

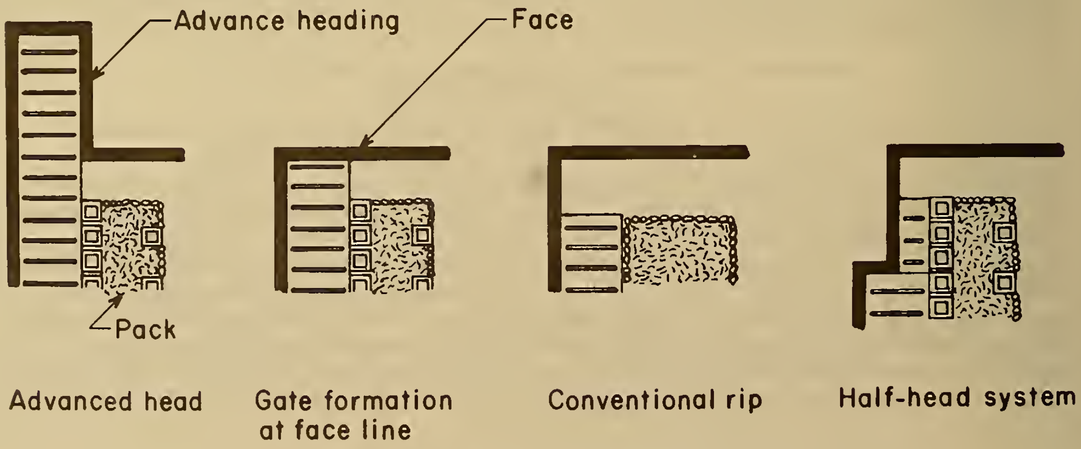


FIGURE 8. - Four gateroad formation methods (after 191).

Drivage Methods

Three distinct operations are involved in the drivage of mine roadways: Breaking the ground, disposal of debris, and setting supports. These operations can be performed in a number of ways, depending on the mining layout, system of work, roadway shape, and ground conditions. Two methods of drivage--the conventional drill-blast and machine cutting--are in current practice in Europe.

Drill Blast

The drill-blast method has been used for roadways both in rock and through the coal seam. The cross sections range from 7 to 25 m^2 (76 to 272 ft^2) and the drilling depths range from 1.5 to 3.5 m (4.9 to 11.5 ft). Recent improvements have been made in blast patterns and shot-firing procedures. Infusion shot-firing can reduce the risk of firedamp (methane) explosion and water stemming cuts down the concentration of airborne dust. Gel ampoules are also frequently used for stemming. European shot-firing practices differ from country to country in the choice of explosives and the type of detonation delay sequence. Variations of statutory restrictions for health and safety in the mines and changes in mining conditions cause most differences (103, 137).

Although the drill-blast technique is still widely used in the entries and headings in Europe, the trend of roadway drivage is shifting toward the use of mechanized cutting machines. These machines avoid the cyclic nature of the drill-blast method and minimize the support problems which arise when roof rock is shattered by the explosive charges. This shattered zone may extend several feet from the charge location into the rock mass and may lead to roof deterioration (141, 174).

Mechanical Cutting

Fully mechanized roadways entirely driven in coal use coal cutting machines such as drum-type continuous miners. These machines cut a square or rectangular profile in soft materials. When the roadway height is greater than the seam thickness, the harder strata of the roof or floor must be excavated by machines designed for full-face excavation such as the boring-type continuous miner or the tunneling machine. The selective heading machines such as boom-type machines, road-headers, and impact rippers which can cut roadways of varied sizes and shapes are replacing the drill-blast methods in difficult applications.

The development of boring-type continuous miners and tunneling machines and some of their applications to mining have been outlined by Cox (52) and Robinson (154). Schenck (164) has reviewed recent developments in fully mechanized rock excavation systems. The road-heading machines used extensively in Europe are relatively rare in the United States. Although 37 road-heading machines were in U.S. mines in 1974, all were imported. The road headers are best suited to the advance longwall system which requires rapid advance of gateroads through both rock and coal. To date, several models of the boom-type road headers have cut roadway cross sections up to 6 m^2 (about 65 ft^2) and at gradients of ±10° in coal and soft rocks in the U.S.S.R. (180). Further use of the roadheaders in the United States appears promising.

Ripping for Face-End Development

In early applications of the advancing longwall system, the stable at the face end was usually excavated by hand, by conventional drill blast or by a separate machine in advance of the face such as the Dawson Miller Stable Hole machine shown in figure 9. Stable hole development also requires excavation of a ribside pack-hole for roof control and waste disposal. This process is labor-intensive and slow. The main concern, especially in Great Britain where advancing longwall is the principal coal mining method, has been to synchronize the face end development with the face advance. These innovations lead to mechanized systems which cut, load, and pack the rock or other systems which eliminate stable holes. Five different approaches to the face-end problem, using conventional, swinging-arm ripping machines, boom rippers, impact rippers, ranging power loaders, and the NCB-Dosco in-seam heading machine are discussed below.

Swinging Arm Rippers

The early versions of the swinging-arm type ripping machine consisted of a radial arm fitted with three picked drums with their axes parallel to the roadway (fig. 10) or a single cutting drum mounted on a radial axis. The cutting drums traverse the full section of rock for arched roadways. Machines have also been modified to employ four cutting heads, each with two or three heavy-duty picks which mill the face (101). Although some swinging-arm rippers are still used, these machines have, to a large degree, been superseded by the modern heading machines discussed in the paragraphs that follow.

Boom Rippers

Because swinging arm rippers were limited to soft rocks, European manufacturers developed boom-type ripping machines which incorporated a rotary cutting action and could excavate harder strata. The boom rippers can cut a variety of opening profiles with minimum interference to other face-end operations. Although boom-ripper excavation becomes uneconomical when the rock being excavated has a uniaxial compressive strength greater than 12,000 psi (83 MN/m^2), narrow bands of much harder material can be cut. The serious problems with ripping machines using rotary cutting action or pick-type cutters include dust and possible hazard of frictional sparking when the rock's silica content exceeds 30 percent. Although the dust levels can be reduced to some extent, the concentrations during cutting remain high. Much work has been done in Europe to prevent the ignition of gas due to sparking during rock cutting (152). For example, the National Coal Board advises that the geologic character of the site be examined carefully and that the silica content be determined (19).

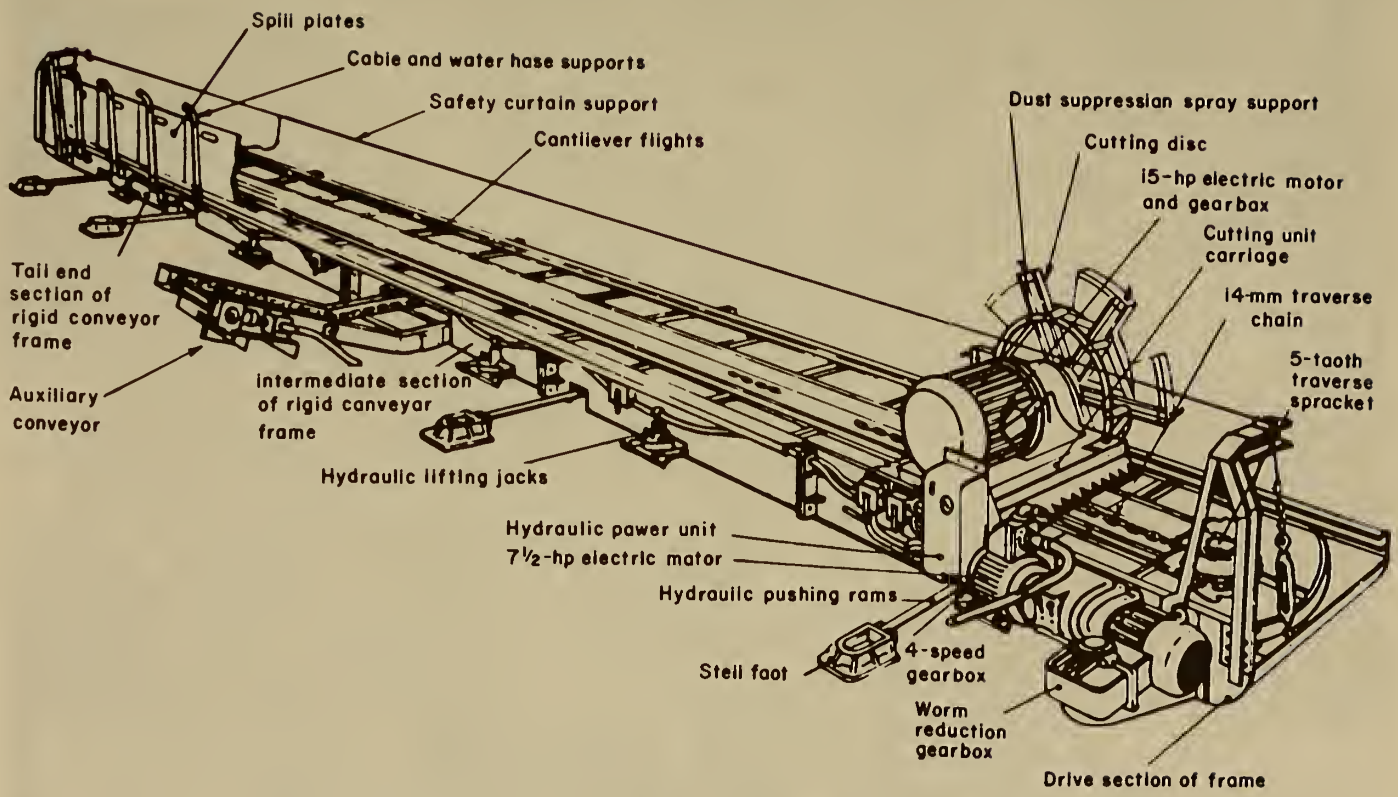


FIGURE 9. - The Dawson Miller stable hole machine (after 101).

FIGURE 10. - Early version of the swinging arm ripper. *(Courtesy National Coal Board.)*

Figure 11 shows a skid-mounted boom ripper used as part of a main gate face-end system in a typical advancing longwall. In such applications, the boom ripper is used to mechanize ripping and packing in the gate roads. Additional operational flexibility is obtained by mounting the boom ripper on a crawler-equipped base with a gathering arm loader and flight conveyor to handle the muck (figs. 12-14). Potential applications of boom-type excavators for mining and tunneling have been summarized by Kogelmann (95).

Impact Rippers

To improve efficiency and safety of mechanical breakage, the National Coal Board has developed and experimented with impact rippers for roadway development in hard coal measure strata (113). The NCB's development essentially augments the pneumatic pick by incorporating a higher energy per blow coupled with maximum maneuverability. Usually a walking base carries a heavy-duty rig with the impact unit mounted on a boom. The impactor can be maneuvered to excavate various roadway profiles. The ripper is powered by a hydraulic or hydraulic nitrogen gas-spring power system which transmits the percussive blows of the striking hammer onto the tool. The NCB's MRDE (Mining

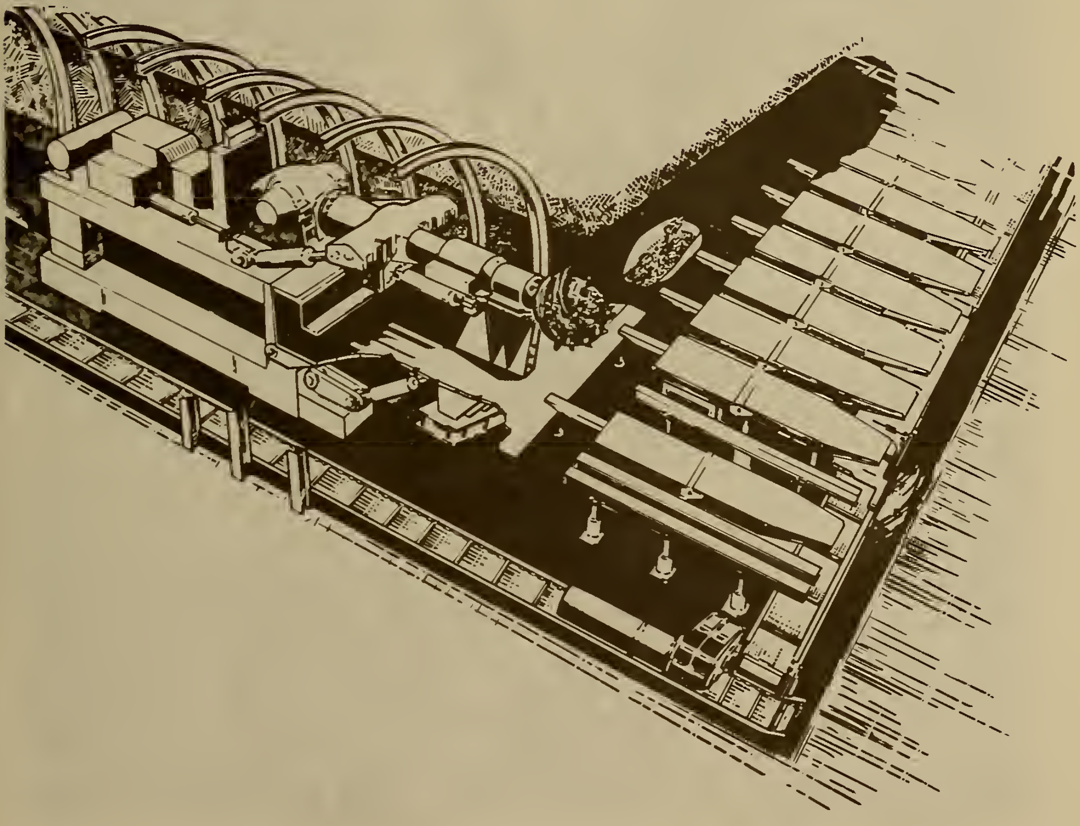


FIGURE 11. - Skid-mounted boom-type ripper used for gate development in an advancing longwall system (after 125).

FIGURE 12. - Alpine AM-50 miner. *(Courtesy Alpine Equipment Corporation.)*

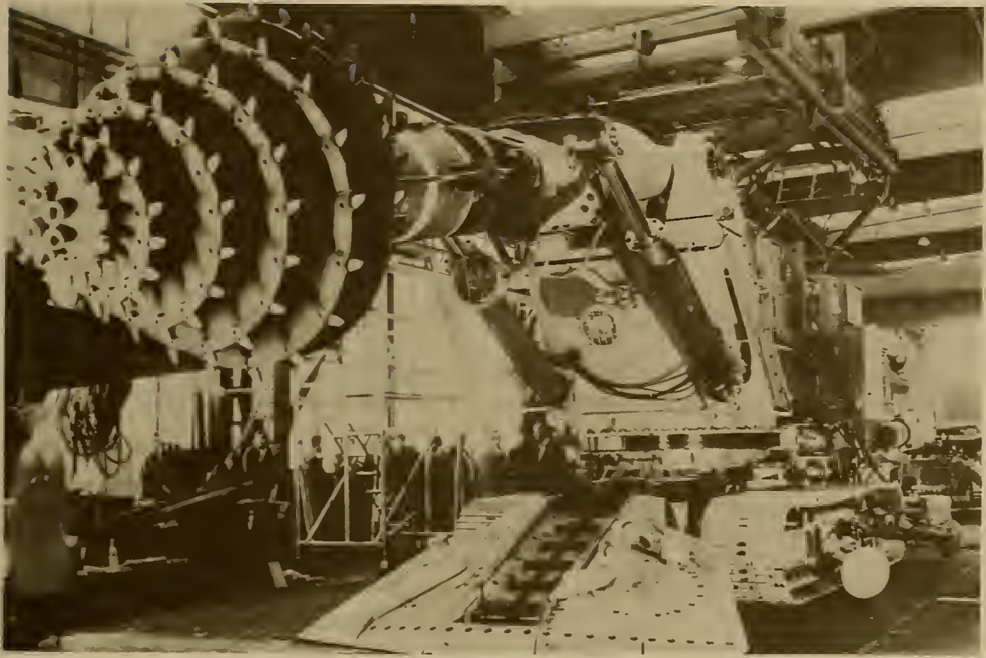


FIGURE 13. - Eickhoff heading machine EVR-200.
(Courtesy Eickhoff-National Mine Company.)

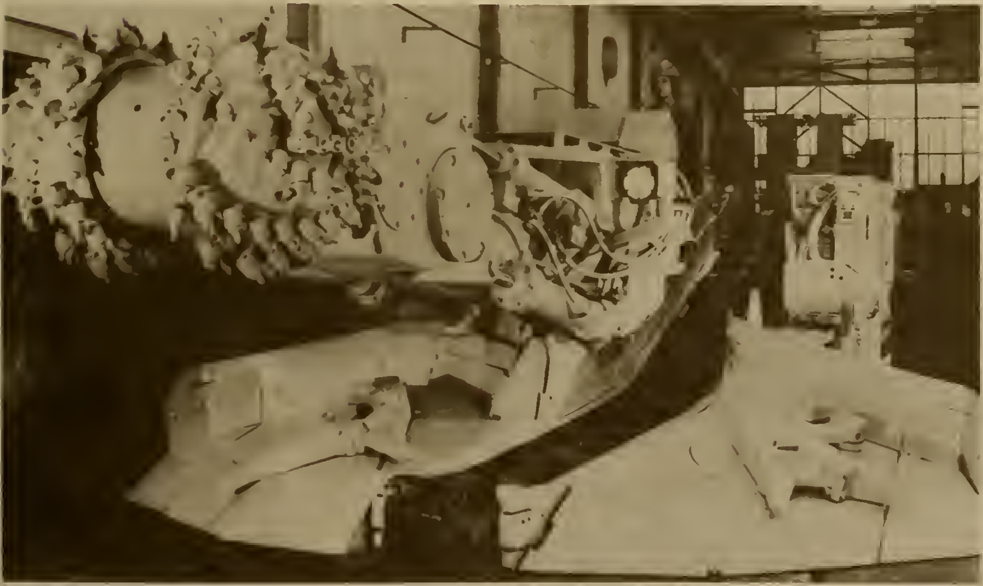


FIGURE 14. - Eickhoff heading machine EVA-160.
(Courtesy Eickhoff-National Mine Company.)

Research and Development Establishment) impact ripper is shown in figure 15. Additional information on the British developments of the impact rippers has been summarized in National Coal Board publications (121-123) and other articles (31, 46, 65, 112). Although past developments have produced impact rippers that can handle most of the strata encountered in British coal mines, further advances appear necessary to improve reliability and the overall strength of the units (65, 164). The impact rippers are more efficient for roadway ripping than for taking material at the floor level. Recent efforts have also been made to extend the impact breakage concept at high blow energy levels to excavation of very hard rock in the United States (59, 64, 80, 138-140) as well as other countries (51, 67, 187). Most investigators have concluded that, although the impact breakage tools have promise in driving mine development openings, serious problems remain and further research and development (R&D) is needed to increase the blow energy levels and improve the ability of the tools to withstand the dynamic loads imposed by impacts on hard rock.

Ranging Power Loaders

The need for increased production in British coal mines has led to new techniques and equipment to solve face operation problems, such as the need to excavate the stable hole--the area needed to turn face-cutting equipment around. Because the advance of the production face in the advancing longwall system must follow the development of the two gate roads, two approaches have been used. The alternatives, as mentioned previously, are either mechanized stable development or a modified power loader which excavates its own stable hole (stable elimination). The equipment just discussed mechanizes the process. Cook (50) has described early efforts in stable elimination.

Presently stables can be eliminated by the power loader in both tail and main gates, in coal seam sections on the order of 3-1/2 ft (1.1 m) or less, as in the case of the British Jeffery Diamond (BJD) B51. The loader has an extended boom, which together with modifications of the armored flexible conveyor gearbox, lets the unit cut roof and floor. The technique has been detailed by Carr (33) who stressed how an integrated system can improve the gate road operations. Figure 16 shows how roadway profiles are cut with a ranging power loader.

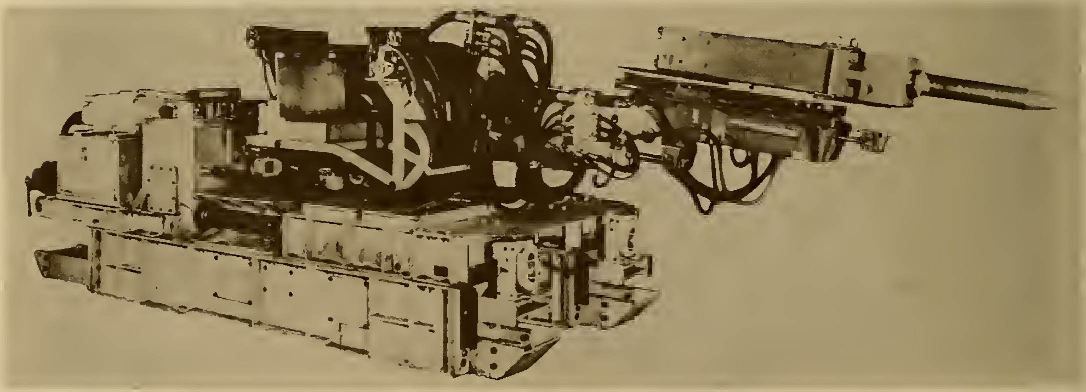


FIGURE 15. - MRDE impact ripper. *(Courtesy National Coal Board.)*

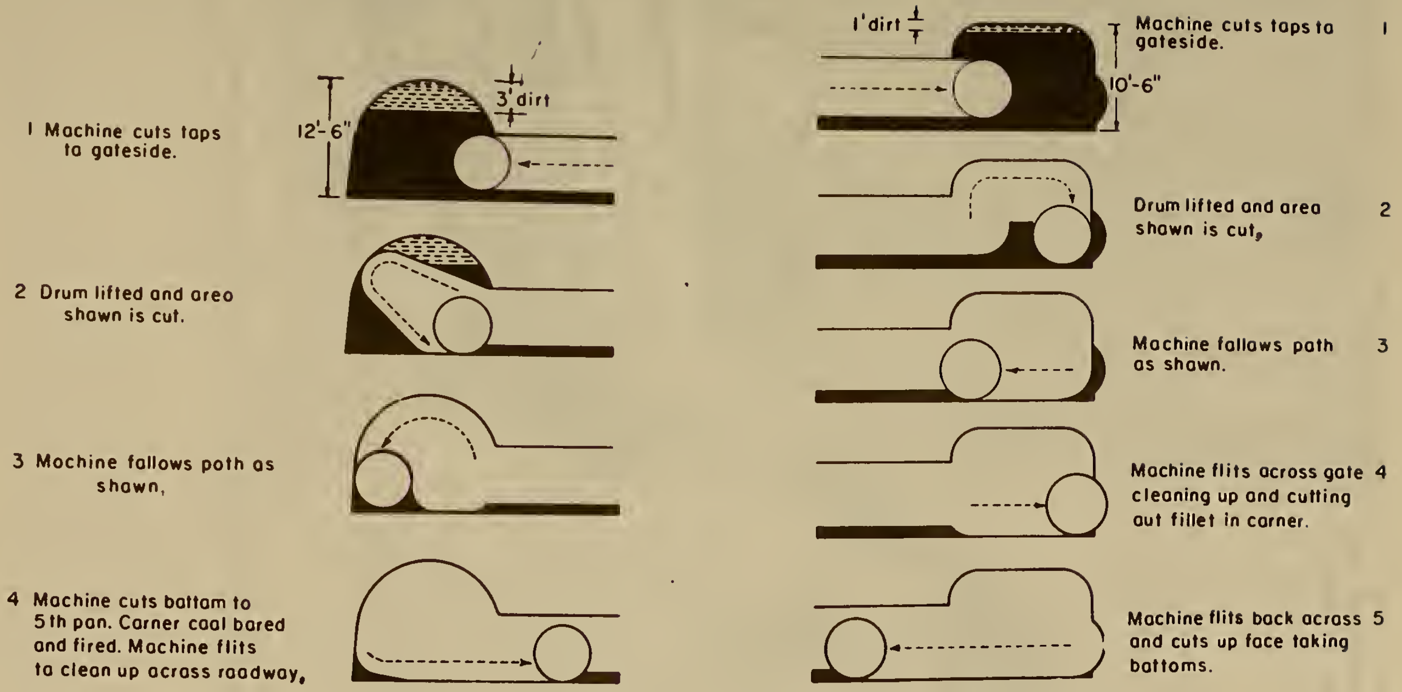


FIGURE 16. - Operating pattern for cutting roadway profiles with a ranging power loader (after 135, May 1973).

The problem of stable elimination has been solved with an Eickhoff short-face ranging shearer EW-LK mounted on a curved conveyor (fig. 17). EW-LK is also used for development of gate roads and headings and for extracting the coal in short face layouts. The system consists of the ranging shearer, curved conveyor (capable of negotiating 90° bends), stationary haulage box, electrical remote controls, position indicator, and powered supports (fig. 18).

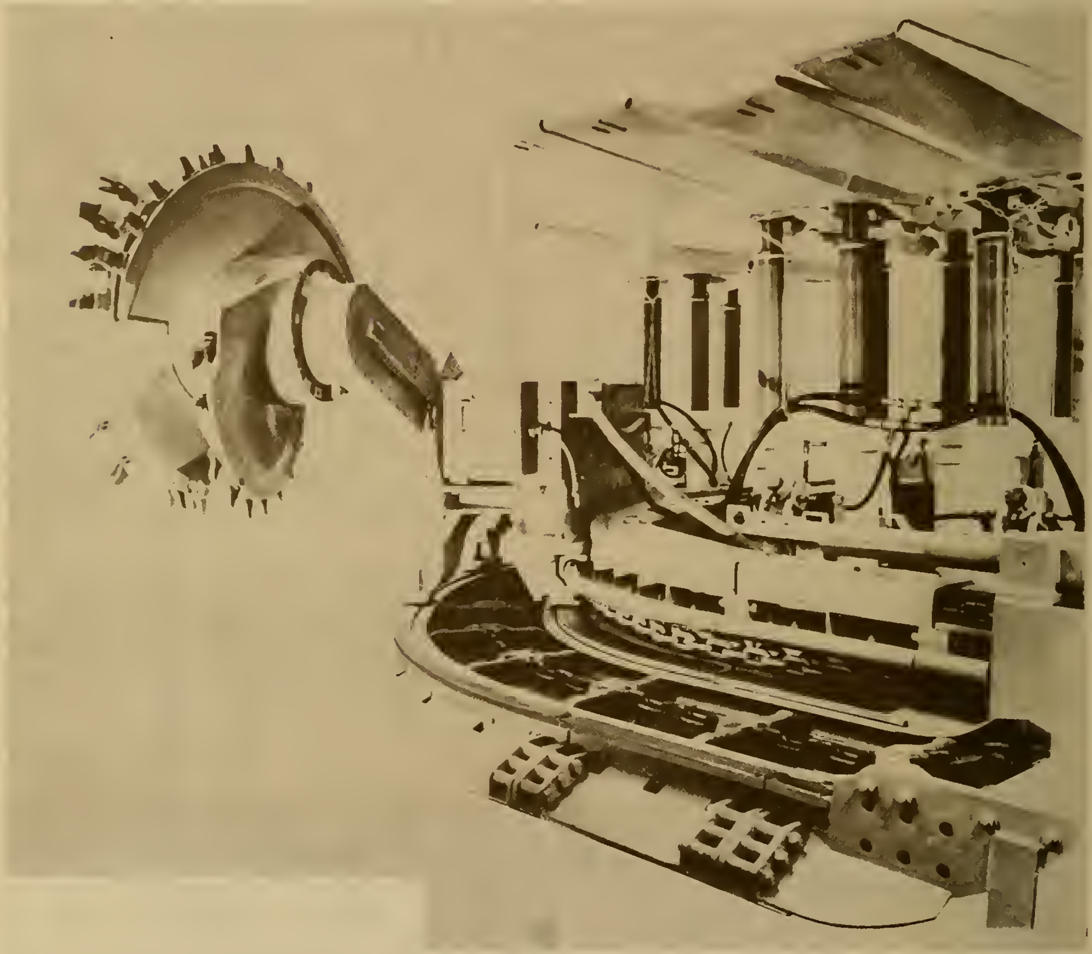


FIGURE 17. - The Eickhoff short-face ranging shearer EW-LK.
(Courtesy Eickhoff-National Mine Company.)

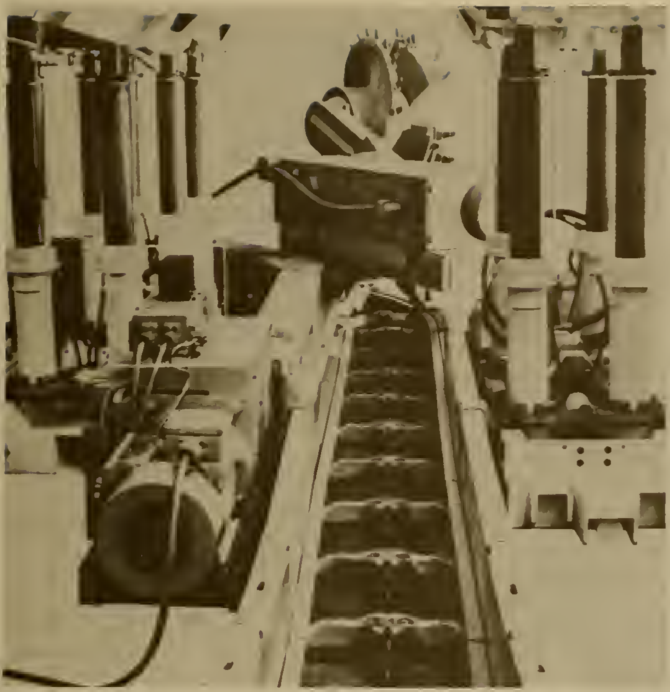


FIGURE 18. - Component parts of the Eickhoff short-face ranging shearer EW-LK. *(Courtesy Eickhoff-National Mine Company.)*

The Westfalia VM 08 shortwall-heading machine, a cutting and loading unit, is another approach to mechanize the stable (fig. 19). The machine, developed in Germany, consists of a double-ended hydraulic ranger, a face conveyor designed in either T or L shapes, hydraulic steering and ramming systems, and the power packs for cutting, haulage, and advancing. The coal, roof, and floor are cut by twin-picked drums mounted on a ranging arm. The VM 08 shortwall-heading machine can be used for stable hole development or in-seam operations.

Anderson Mavor Ltd. of Great Britain has developed a shuttle heading machine which can drive roadways rapidly. The unit is essentially a double-ended ranging drum shearer with a minimum distance between drums. Because the drums trepan and shear, the shuttle heading machine can cut many different-sized and different-shaped openings.

NCB-Dosco In-Seam Heading Machine

Thin seams presented a serious problem in face-end operation in British mines using the advancing system. Modern stable-elimination techniques usually could not be applied and roadway space for face equipment turn around had to be excavated by labor intensive methods. The National Coal Board (NCB)-Dosco in-seam heading machine (fig. 20) was originally designed to solve face-end problems in thin seams. Recent field tests have demonstrated that the in-seam heading machine was effective under three different heading applications (7).

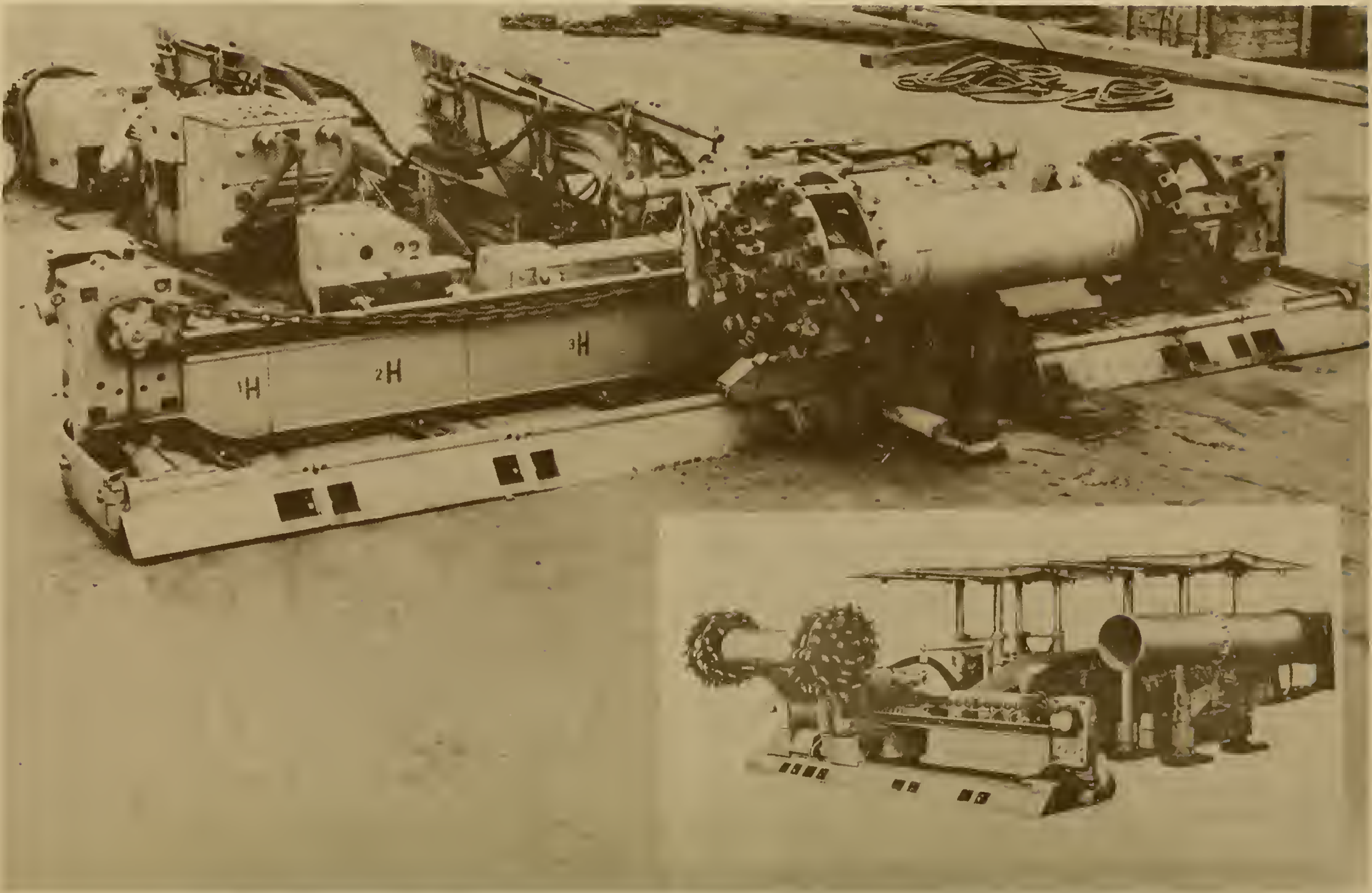


FIGURE 19. - The Westfalia VM 08 shortwall-heading machine. *(Courtesy Mining Progress, Inc.)*

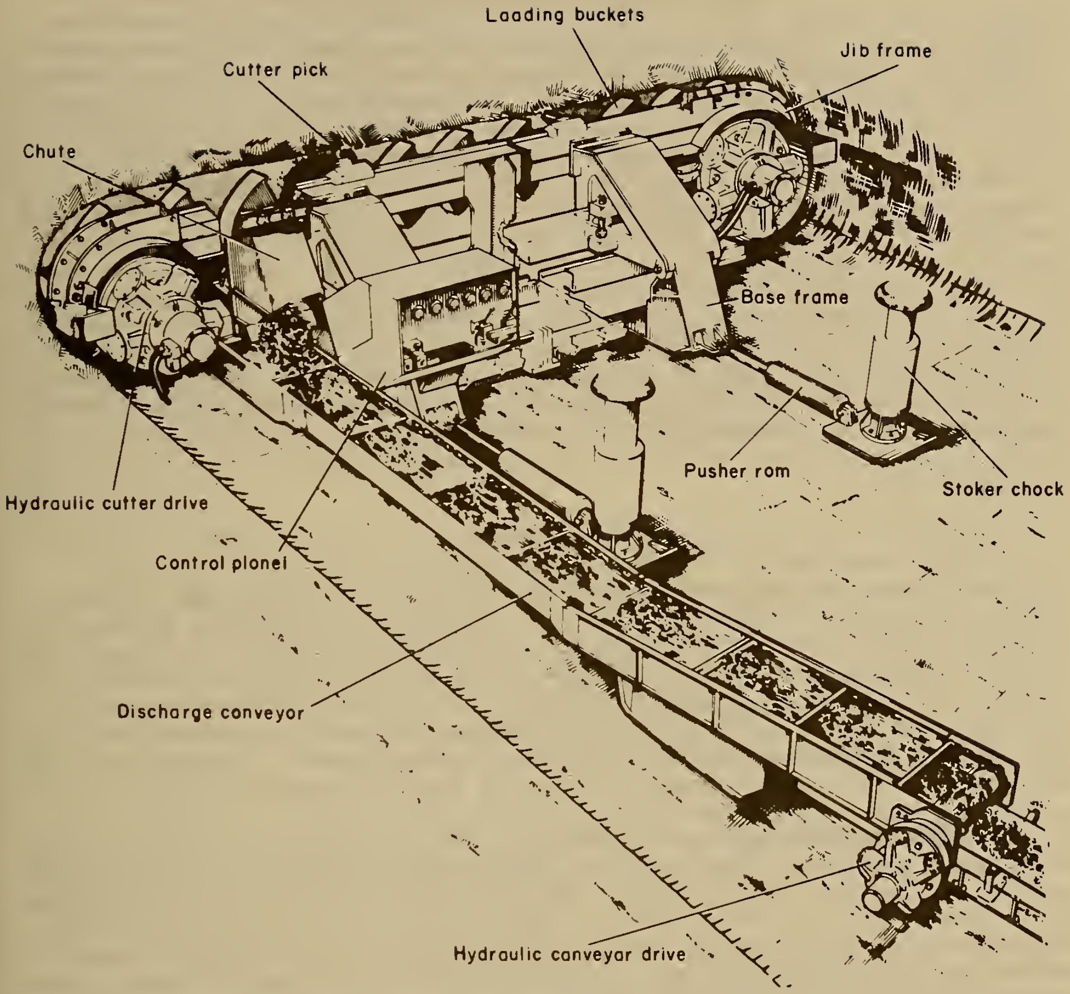


FIGURE 20. - The NCB/Dosco in-seam heading machine. *(Courtesy The Dosco Corporation.)*

The Bureau's efforts to evaluate the in-seam heading machine for U.S. longwall operations have been made in cooperation with Kaiser Steel Corporation at the company's Sunnyside mine in Utah. Initial advance rates of 4.5 m/hr (15 ft/hr) have been obtained. Potential advantages of the machine include simplicity, improved noise and dust reduction, and the ability to support the roof immediately after excavation (53).

Mechanized Dirt Disposal and Roadside Packs

The disposal and/or use of dirt (waste rock) excavated during the operation of a longwall panel is a significant problem especially in the advancing system. The dirt produced by cutting and ripping of roadways can either be left in the mine or taken out. The overriding factor in European operations seem to be cost. All dirt from roadway formation in German mines is removed. Although some dirt is re-imported into the collieries as stowing material, the Germans believe that, for their operations, it is more economical to separate the coal and dispose of the dirt on the surface (13, 179). British dirt disposal practices are mainly centered around the use of the dirt for roadside packs which reduce the closure of the roadway when the seam is extracted on one side of the gate road. The dirt is loosely stowed or rammed tight between the roof and the steel linings. Good packings provide the needed roadside support and at the same time prevent air leakage across the goaf area. The packs must be strong enough to resist the roof convergence and to induce breaks at the waste edge along the line of packs. The yielding characteristic of pack material, caving behavior of the roof, and bearing capacity of the floor must be considered. In addition, the packs must offer early resistance to prevent excessive roof deflection. Lewis (102) and Breer (22) have reviewed European roadside techniques.

Packing Machines

Packing can be done by hand or by discharging the dirt from an adjacent area through machines to a packwall built to some convenient width. The principal mechanized disposal techniques are slushing and pneumatic stowing. Slushers are widely used because they are simple. The slusher is often mounted within the ribside packhole area to provide a straight run for the ropes. Successful jet stowing has been achieved with compact units which enter the pack hole. A compressed air jet picks up and delivers ripping dirt into the pack hole through stowing pipes. Although jet stowers can be used in many packing operations, the noise levels are high. The National Coal Board is working to reduce the noise to less than 90 decibels (130).

Several dirt packing systems have been recently developed to work with machine-cut rippings. These systems include the plow packer, ram packer, and cam packer (Becorit, Webster, MRDE, and Joy) and the Mini-Dozer (19, 47, 121-122). After trials in the collieries where comparisons were made among various methods of packing and slushing, Deakin (57) concluded that the Webster packer was the simplest and most efficient machine. General features of this packer and its operation have been summarized by the National Coal Board (127, pp. 2-3).

Pump Packing

In some mines operators have great difficulty in constructing a suitable pillar from the rock obtained from ripping in roadways. Wood chocks and concrete blocks are alternatives but they create extra problems in materials handling. The National Coal Board is investigating the feasibility of forming roadside packs by mixing dirt, bentonite, water, and a setting agent. The mixture is pumped into forms and allowed to set (128, 133). Although this technique has worked well in some cases, further improvements are needed before it attains the effectiveness of the anhydrite packing techniques (utilizing pneumatic stowing) widely used in West Germany (15, 55) and now being evaluated by the National Coal Board (6).

Coal Face Production Equipment

Many technical problems with operating a longwall face have been solved by developing integrated systems of powered supports, coal winning equipment, and face conveyors. Because the various components of the longwall systems are designed to be compatible with the geologic environments, production needs, and working methods commonly encountered in the country of manufacture, a great deal of technical judgment is needed to select and use equipment from the world market. A helpful guide to longwall equipment (particularly power supports) has been prepared by the Naval Surface Weapons Center, Dahlgren, Va., under Bureau Contract S0144128 (104). The contract report summarizes the technical specification of powered supports presently available from longwall equipment manufacturers having offices in the United States. In addition, the report provides interface requirements among roof support systems, winning machines, and armored flexible conveyor (AFC) units and lists U.S. longwall and shortwall operations working or planned as of October 1974. Because new equipment improvements are constantly coming on the market, detailed technical specifications on current equipment items can best be obtained directly from manufacturers.

Powered Supports

Experience gained with friction and hydraulic props in the late 1940's and with the armored face conveyors originally developed in Germany led to the first full-face installation of powered supports in Great Britain during 1954. Since this first application powered supports have developed to the current state where adverse strata conditions can be safely controlled and nearly continuous coal-getting operations can be achieved. The support system must provide room for the cutting and conveying operations and must effectively support the mine roof very close to the face. Recent developments have made the support system more mobile, stable, and adaptable to such changes in seam conditions as a broken roof. A support system for inclined seams requires special attention, since factors such as ease of installation, dismantling, and relocation are critical.

Powered supports designs in the major European coal-producing countries such as Great Britain, Germany, the U.S.S.R., and France have progressed along slightly different paths in response to natural and human factors. The following references provide a good summary of past developments and future trends (1, 14, 71, 78, 85, 105, 150, 155, 199).

The developments of the 40's and the 50's led to the current family of powered supports which are of three principal types--frame, chock, and shield.

Face Support Systems

Frame Type

Frame supports are two pairs of hydraulic props (fig. 21) mounted on separate base and connected into two parallel frames with a roof-bar structure on top of the props. The base of each frame has leg stabilizers, and a foot plate mounted under each prop to prevent floor penetration. These two frames are linked at their bases by a common ram. As one frame is taking the load, the other frame can be lowered and moved using the ram. Figure 22 shows a heavy-duty frame type support designed for difficult strata control conditions. Because these frame-type supports are not attached to the conveyor, the operation is more flexible and the supports are more adaptable to the plow faces. One disadvantage was that the units tended to wander. Frame supports can be adapted for shearers by adding a push bar to the shifting ram.

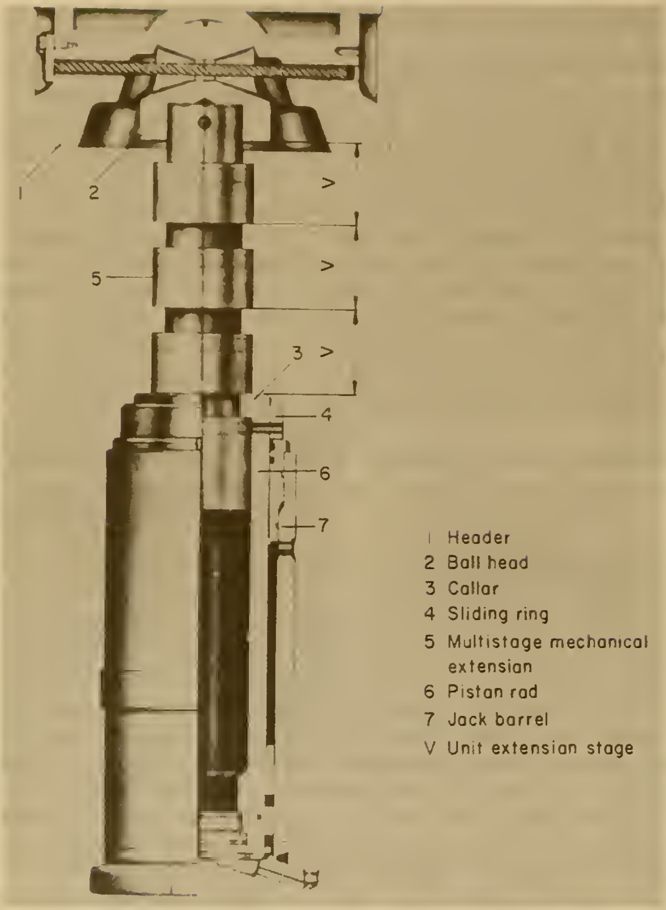


FIGURE 21. - Hydraulic prop for frame-type support
(Courtesy Mining Progress, Inc.)

Frame-type supports have been widely used in Germany for a wide range of seam thickness and inclinations. For steep seams, three or more frames may be connected into operating units for greater stability (85).

Chock Type

The chock-type supports consist of three to six hydraulic props or legs assembled into a single unit by a rigid or flexible base which slides on the floor. Because of robustness and general reliability, these supports are quite popular in British mines. The unit has a roof beam to transmit the load action of the legs to the roof. When the chock-type supports are operating the double-acting hydraulic ram, located at the base, is attached to the conveyor. This ram advances the conveyor and the chock. Each leg is equipped with a stabilizer to keep it upright and provide resiliance to the unit. Typical chock-type supports are shown in figures 23 and 24.

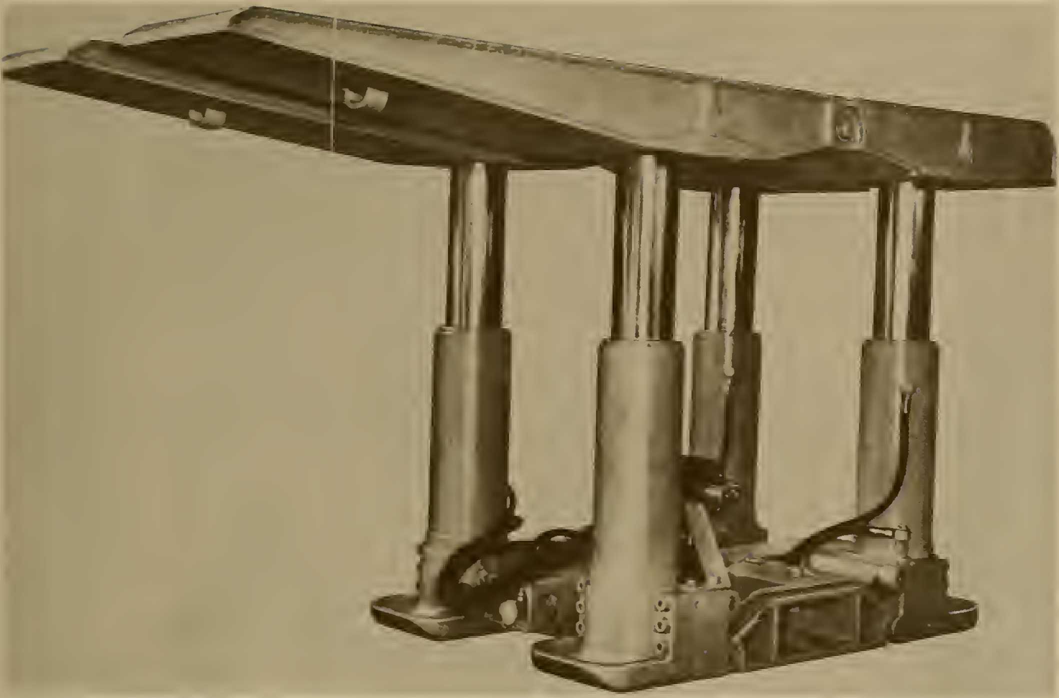


FIGURE 22. - A typical frame-type support. *(Courtesy Mining Progress, Inc.)*

Shield

Shield supports are an Eastern European innovation. In the 1960's the U.S.S.R. pioneered the development of shield supports such as the single-prop OMKT type and the twin-prop AKD type. Successful operation with the OMKT prototype dates from 1962 (58, 63, 66, 90). At the same time Hungary successfully developed its own shield support known as the Ursitz type (2).

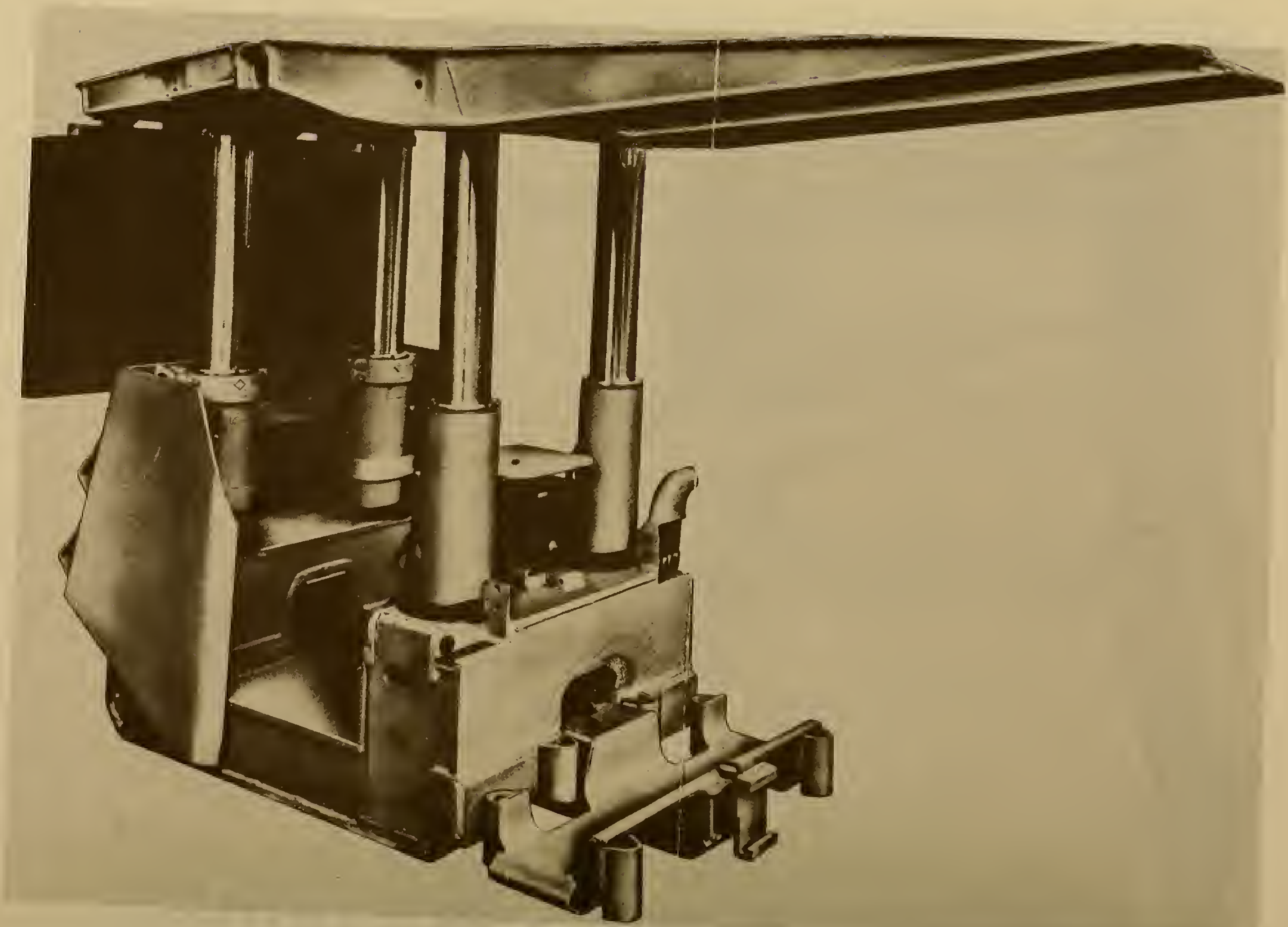


FIGURE 23. - Westfalia heavy-duty chock type B2:1. *(Courtesy Mining Progress, Inc.)*

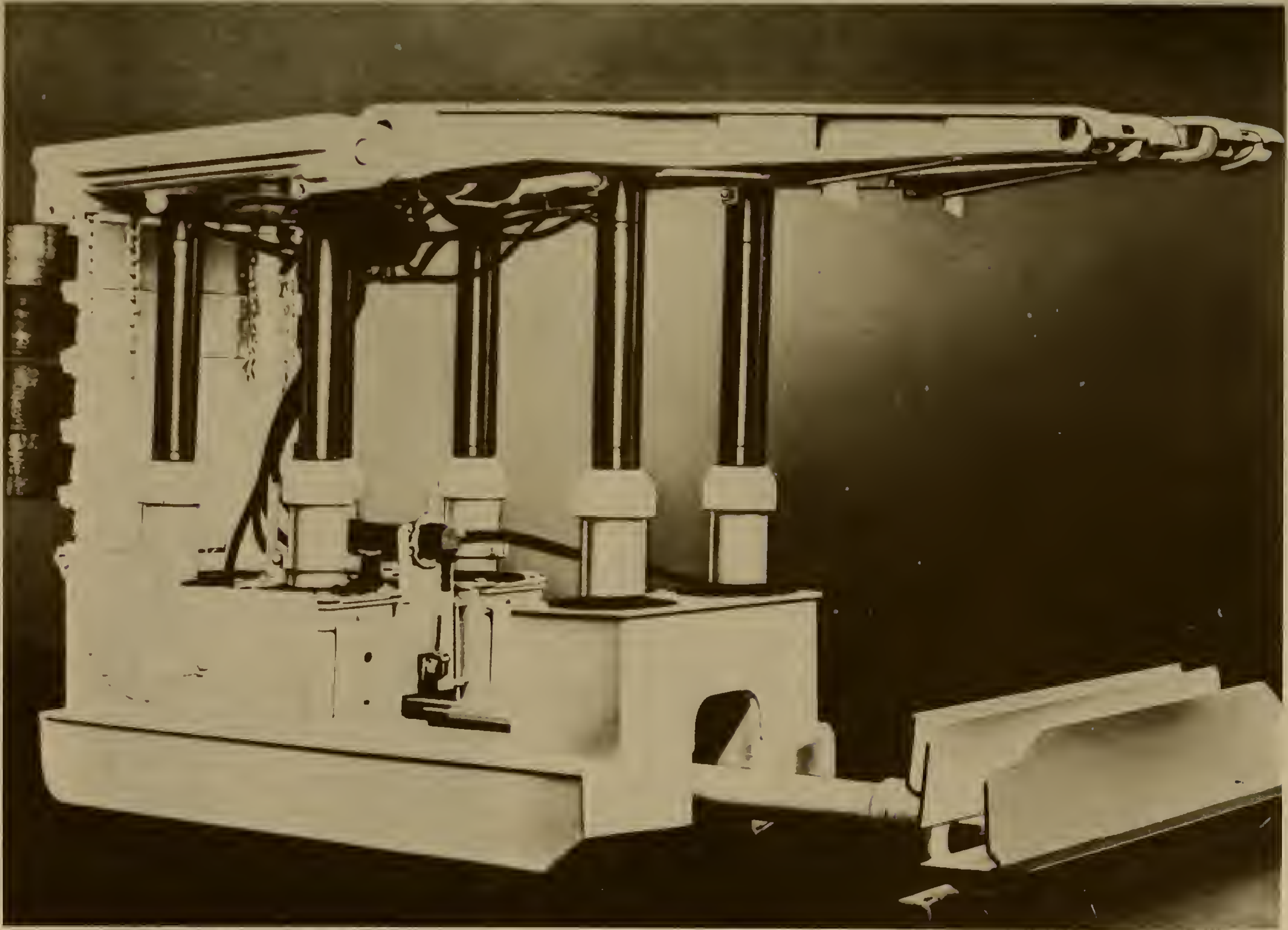


FIGURE 24. - Joy rigid base chock. *(Courtesy Joy Manufacturing Company.)*

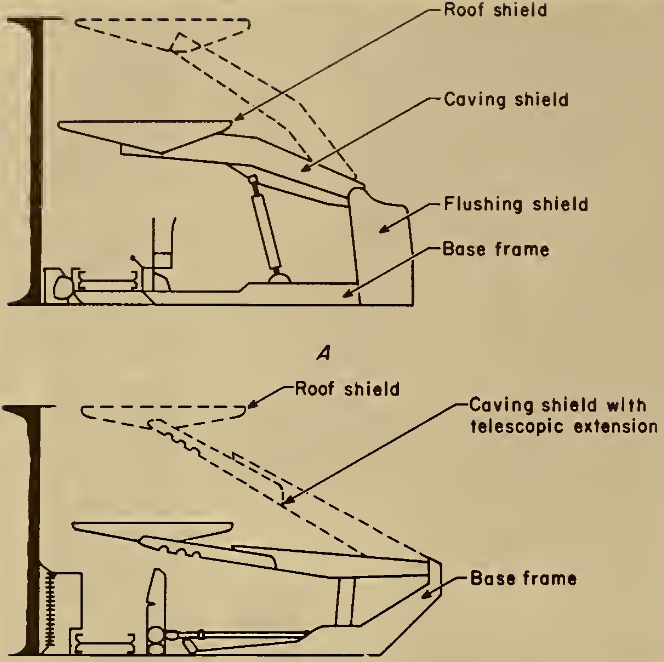


FIGURE 25. - Structural members of long *(A)* and short *(B)* caliper shields (after 78).

The structural members of a typical shield support include roof, caving, and flushing shields, together with a base frame or floor beam, and the ram and hydraulic props. The usual arrangements of these major components is shown in figure 25.

The shield support systems have different configurations from the conventional frame or chock-types; they also have different kinematics of application. Theoretically, all conventional powered support systems are inherently unstable. External forces exerted by the translational movement of the roof tend to shift from the face to the gob side. As conventional supports yield under increasing loads, lateral displacements of the roof beam cause the legs to tilt from the upright position. In the case of the shield support, however, the roof shield moves toward the face because of the rotational displacement of the caving shield as the load increases. Because of this design feature the shield support can react against high shearing forces and can be readily advanced under the load. The roof shield, pivoted near the end of the caving shield, is adaptable to changing roof conditions. Because the distance between the bar tip and the fulcrum can be adjusted, the roof shield can be kept close to the coal face during operations at various seam heights. In short, more uniform load distributions can be achieved with the roof and caving shields of the shield supports than with the roof bar configurations of the frame and chock-type supports.

Shield supports may be subdivided into two broad categories--caliper and chock shields. The caliper-shields are short and long types depending on the length of the floor bar. The floor bar for the long shield reaches under the conveyor supporting frame (fig. 26) whereas the bar tip of the short shield is behind the conveyor (fig. 27).

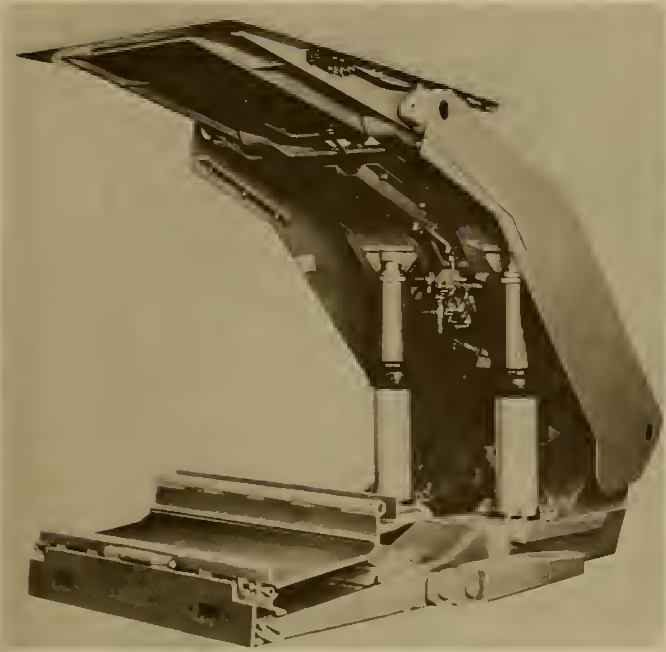


FIGURE 26. - Long caliper shield. *(Courtesy NMS Longwall Company.)*

The chock shield is a hybrid incorporating features of the chock-type support and the caliper shield. The modifications improve the bearing surface of the roof shield, the travelway for the operators between the front and rear props and the ventilation system at the face. Immediate roof support and coverage from coal face to goaf are achieved by a hydraulically adjustable cantilevering canopy and by the shield canopy. The upper goaf and lower goaf shields are pinjointed together. The upper goaf shield is hinged to the rear of the roof shield canopy and the lower goaf shield is attached to the base frame for complete shielding against caved materials. Figure 28 shows a typical example of the chock-shield support developed in Germany. A version of the chock shield has been developed in Japan (114) and successfully used in large-scale extraction of coal under the Pacific Ocean near Kusniro City, on the eastern coast of

FIGURE 27. - Short caliper shield. *(Courtesy NMS Longwall Company.)*

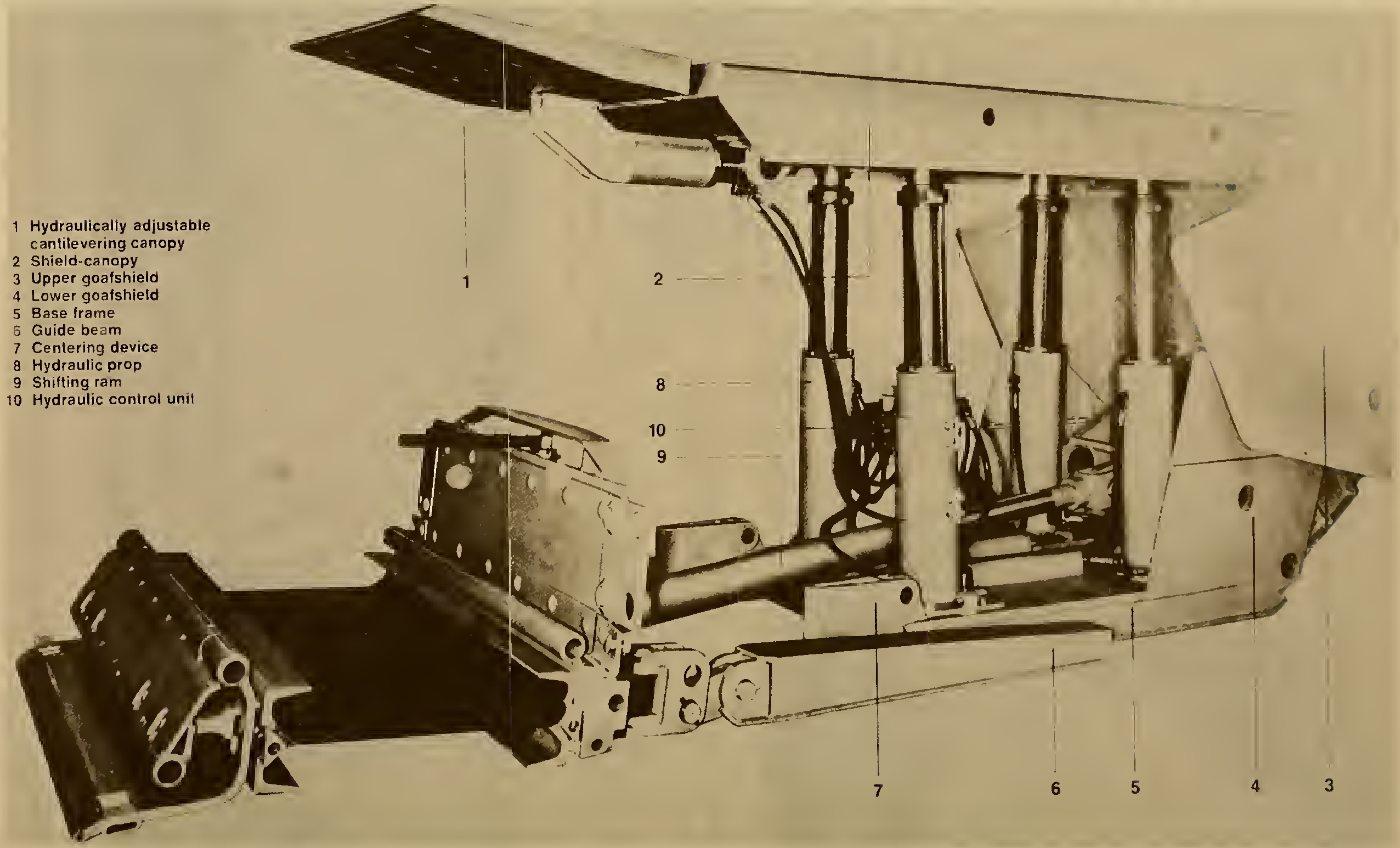


FIGURE 28. - The Westfalia-Lunen heavy-duty shield support type B.S. 2.1. *(Courtesy Mining Progress, Inc.)*

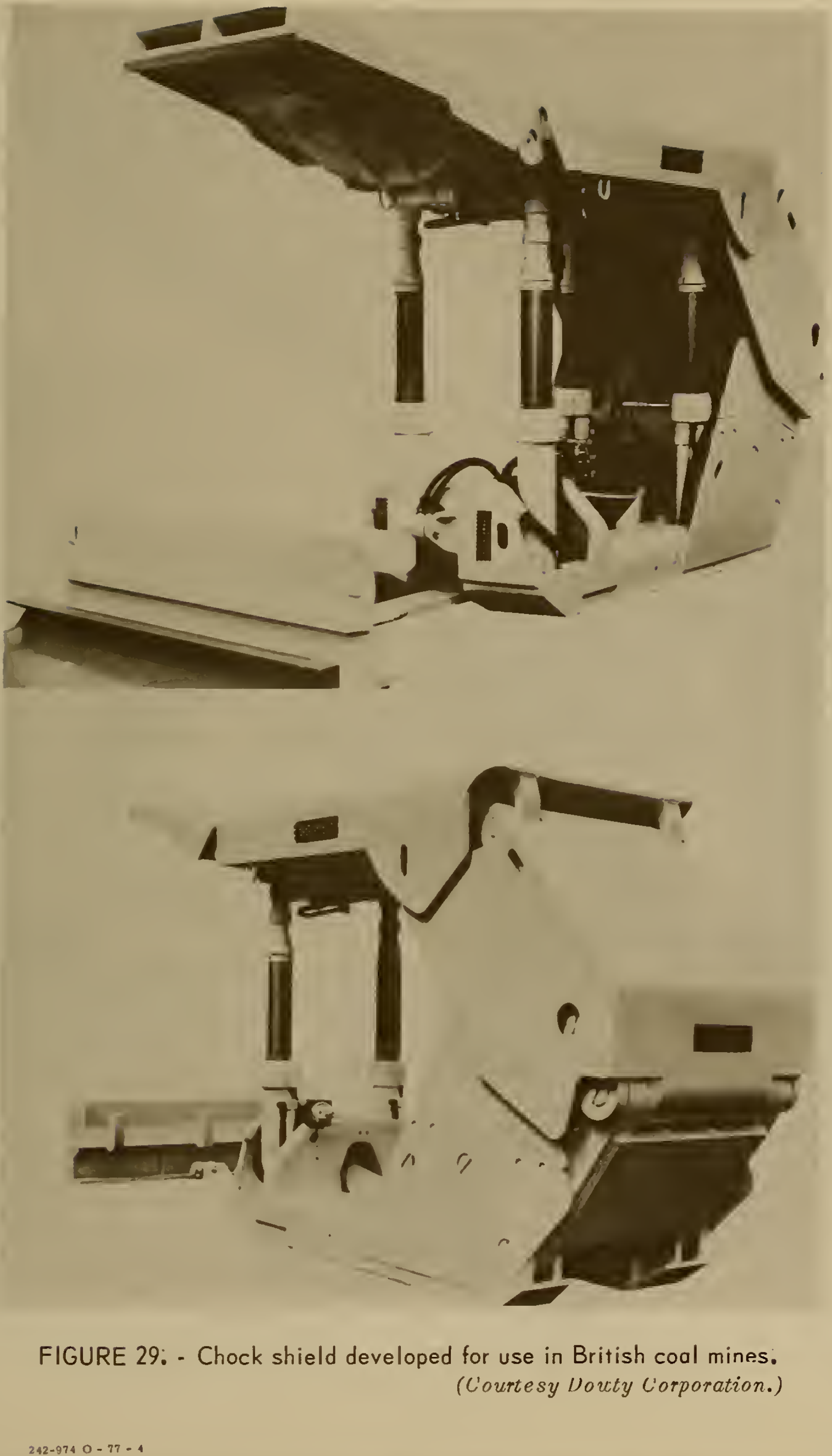


FIGURE 29. - Chock shield developed for use in British coal mines.
(Courtesy Dowty Corporation.)

Hokkaido (115). An example of the type of chock shield developed for use in the coal seams of Great Britain is shown in figure 29.

In the United States, Joy Manufacturing has designed new shields which incorporate a pantograph-type movement to keep the same distance between the canopy and the face throughout the travel. The minishield (fig. 30) has an operating range of 48 to 94 inches (approximately 1.2-2.4 meters), while the conventional two-leg model (fig. 31) has a range of 71 to 114 inches (approximately 1.8 to 3.7 meters). Both models feature interlocking, side extension seals which effectively isolate the working face from the gob area reducing the amount of canopy-generated roof dust.

The feature of constant distance between the tip of the shield canopy and the coal face is also incorporated in the "lemniscate" system used in the Hemscheidt G-type shield (fig. 32) and the Dowty advanced shield support (fig. 33). Other features of these supports include direct connection of the legs and roof canopy (providing high-resistance levels) and the ability to provide an unimpeded travelway even in the advanced position.

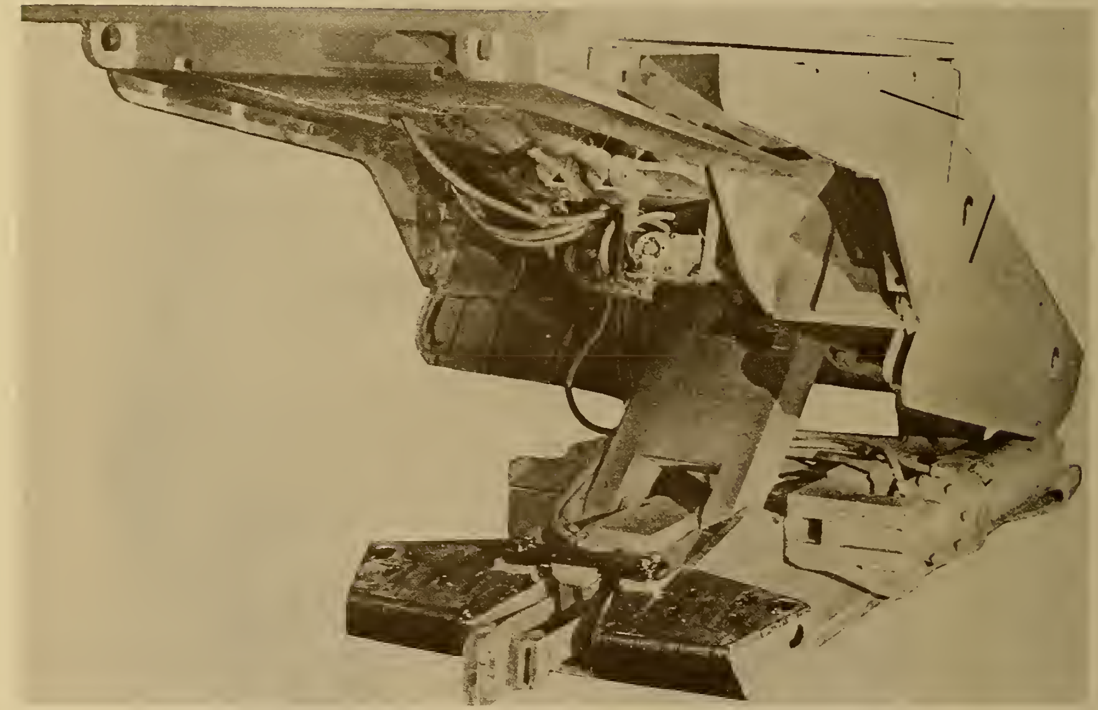


FIGURE 30. - Minishield support featuring pantograph-type movement. *(Courtesy Joy Manufacturing Company.)*

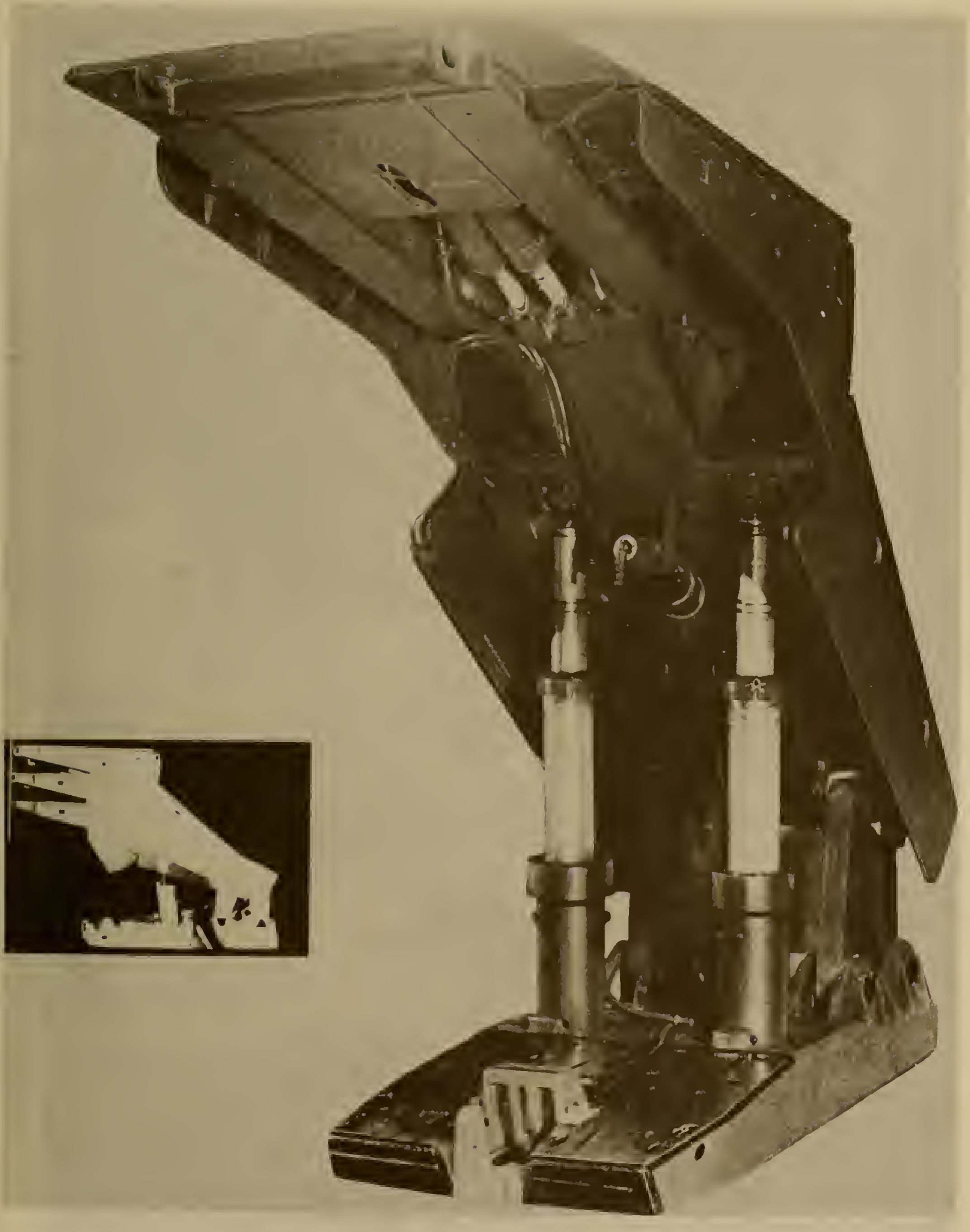


FIGURE 31. - Shield support featuring pantograph-type movement.
(Courtesy Joy Manufacturing Company.)

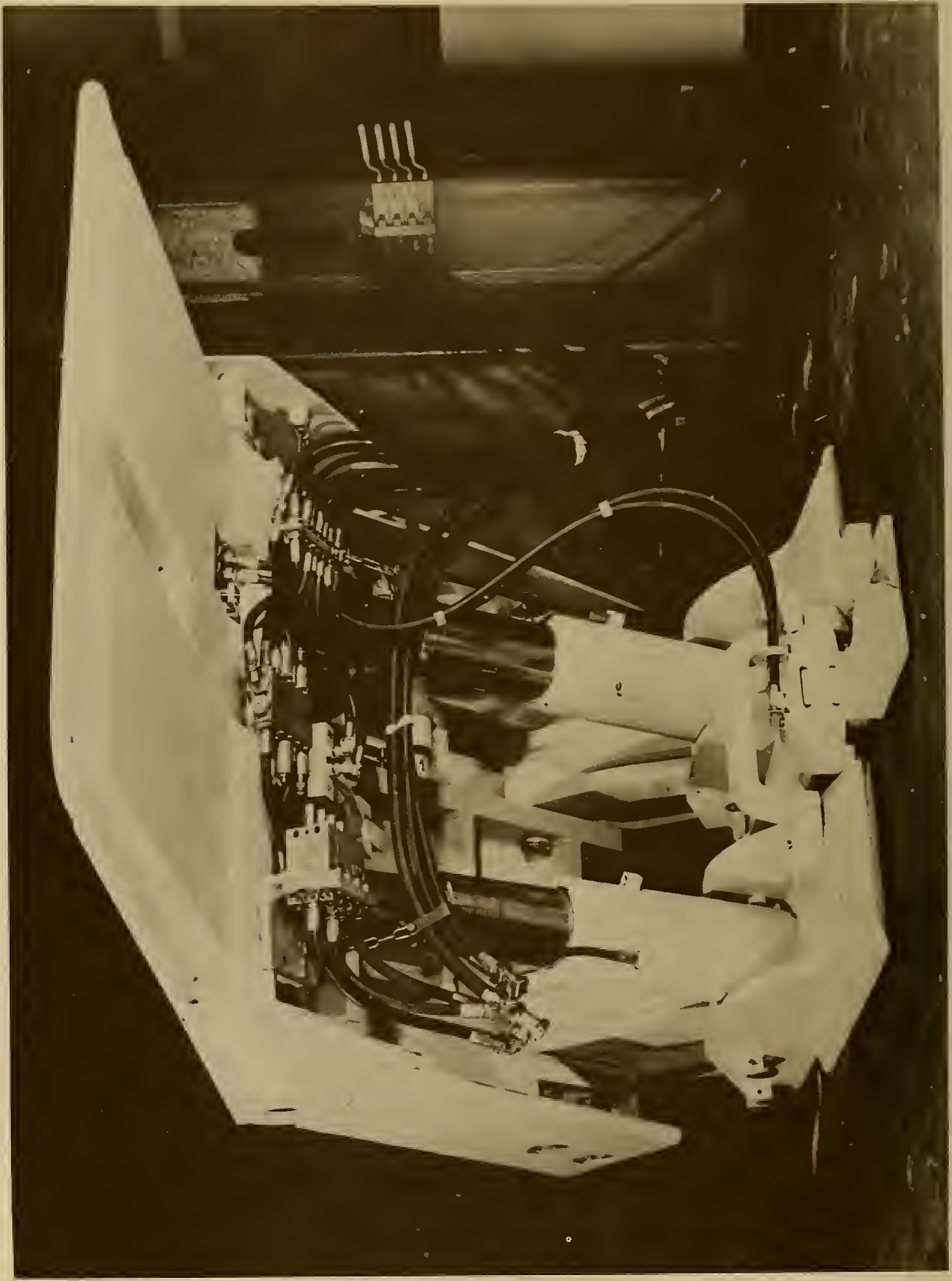


FIGURE 32. - Hemscheidt G-type shield support. *(Courtesy Hemscheidt America Corporation.)*

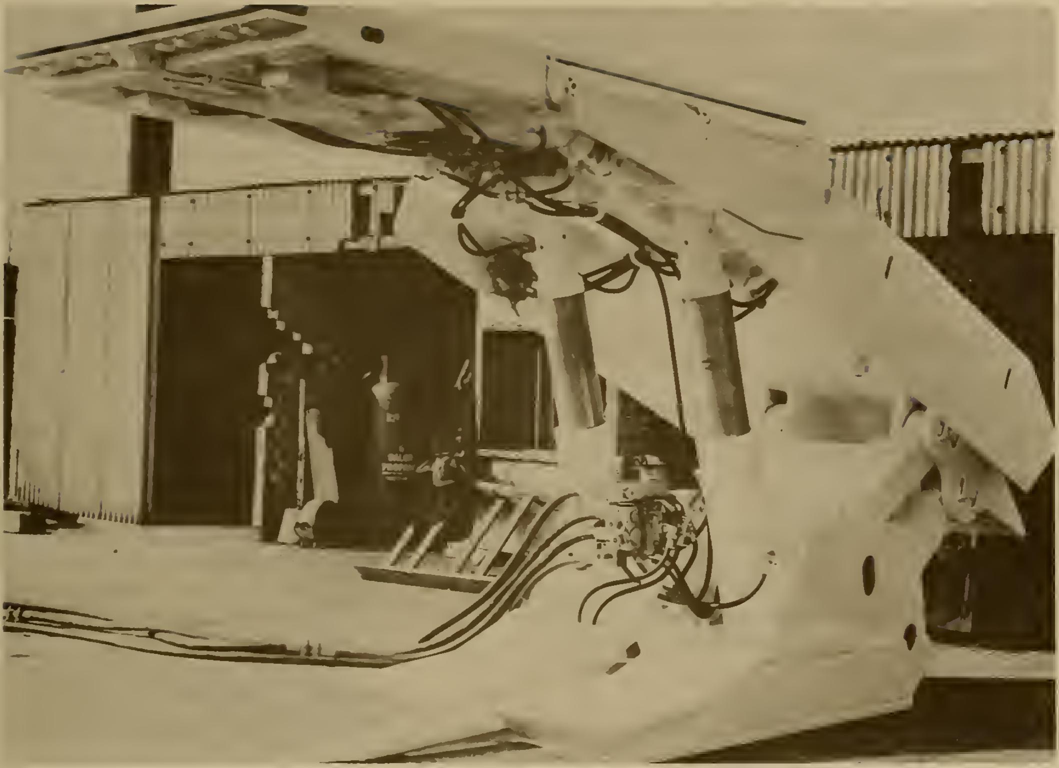


FIGURE 33. - Dowty 2-leg 350-ton shield support. *(Courtesy Dowty Corporation.)*

Shield supports can be operated with either plow or shearer. In plow faces, the support stands behind the face conveyor. After the conveyor and the plow have advanced a certain distance, the shield unit is moved forward to the face. For shearer faces, the shield units initially stand one web back before cutting. After the upper part of the seam has been cut, the support can be moved forward immediately to support the exposed roof (78-79, 96). Figure 34 shows the mode of operation of the shield supports with the two methods of coal winning.

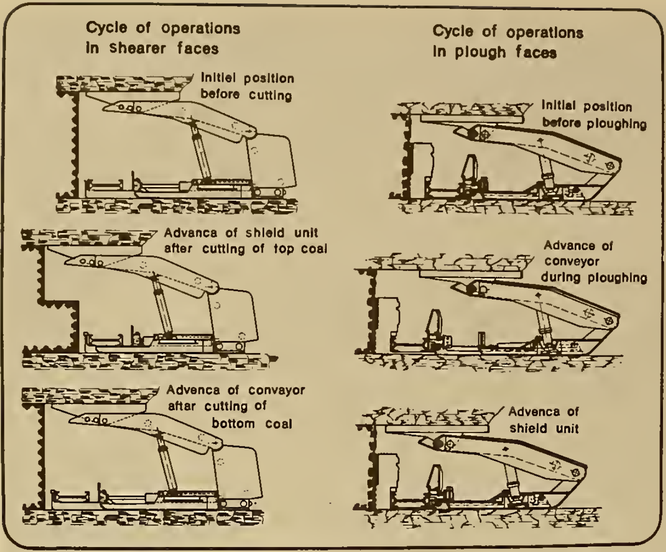


FIGURE 34. - Mode of operation of shield supports with shearer- and plow-equipped faces. *(Courtesy NMS Longwall Company.)*

Factors Influencing Design, Selection, and Utilization of Conventional, Powered Face Supports

Increasing knowledge about strata behavior and field experience motivate continuing programs in powered-support development and improvement by manufacturers. Serviceability and safety are the two main concerns of support design. Serviceability means that the support will facilitate high production. Structurally, the supports must not allow excessive deformation or go "solid" (to reach the point beyond which no hydraulic yield is possible). Safety is the ultimate concern in design against technical judgments which include hydraulic systems, structural members, stabilization techniques, load-bearing capacity calculations, and the cost of these features. The ultimate goal is to match the characteristics of the particular powered support with the mine's geological and operational setting.

Hydraulic System Requirements

Powered supports are operated by hydraulic power generated by a power pack (a pump unit and a sealed tank). The electric pump supplies the high- and low-pressure requirements of the hydraulic circuits. The high-pressure circuit directs the oil-water emulsion fluid into the main lines for prop setting while the lower pressure circuit operates the conveyor rows and the double action jacks of the roof supports.

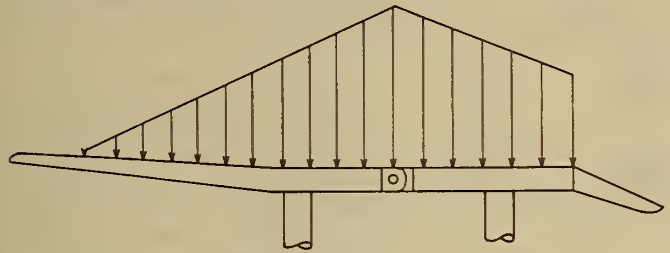
The sealed tank serves as the fluid reservoir. The tank is equipped with fluid level and temperature control devices, emulsifier, breather, filtering systems, and an electric control system. A 1 to 5 percent oil-water emulsion serves as the hydraulic fluid.

To keep pressure gradients within acceptable limits in the high pressure lines and to give maximum flow for rapid chock operation, the specifications on supply and return lines and the pressure drops in the hydraulic system must be carefully controlled. Hoses and fittings are connected up by self-sealing units rather than screw connections and interunit connections are reduced to a minimum (78).

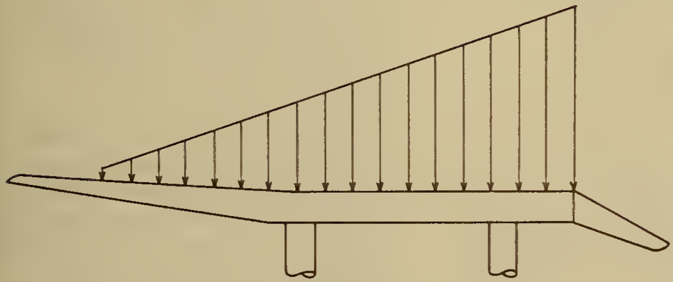
Structural Members

In addition to the hydraulic legs, the important structural members of conventional powered supports are roof-bars, roof-bar extension pieces, base and foot plates, a ram and a flushing shield.

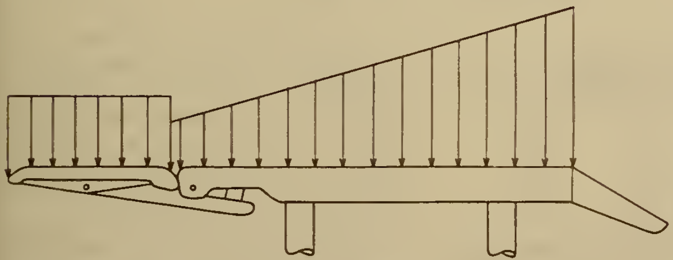
The roof-bars are either rigid or articulated. Rigid roof-bars are well suited to supporting large areas of roof rock and are easy to handle but do not work well when irregular roof conditions are encountered. Although articulated roof-bars can usually maintain better contact with an irregular roof, they tend to "jack-knife" into the deeper roof cavities unless the bar tips can be swiveled toward the roof through the pin joint. The idealized load distribution curves for both the rigid and articulated bars (fig. 35) indicate that, because the load applied by the roof-bar close to the tip is very small, the formation of cavities is difficult to avoid with either type of bar. The problem of roof cavity generation, to a large extent, has been solved by using a pivoted fore-pole bar which provides more uniform load distribution near the face (fig. 35). The same distribution principle is used in shield supports.



A Articulated roof bar



B Rigid roof bar



C Hydraulic forepoled bar

FIGURE 35. - Load distribution curves for three types of roof bars (after 78).

The load on the support is transmitted to the floor by floor plates in the case of frame-type supports or the one-piece base in the case of the chock-type support. Floor plates are connected by leaf springs to provide flexibility under load and to let the set support adapt itself to floor undulations. The one-piece bases of the chock-type provide rigidity and a large coverage area for stability. A ram is installed within the base of the floor beams and connected to the conveyor to advance and aline the chock and conveyor. Soft floor, variance in cutting horizon, and conveyor creep can damage the ram and ram attachments. Improvements have been made to reduce the damage by eliminating the transverse loads exerted on the ram by chock movement. The flushing shield prevents caved material from interfering with operation of the supports. These flushing devices come in such forms as a deflector which is extended from the roof bar and bent downward on the goaf side, pendulum plates suspended from the roof bars, or even a box shield.

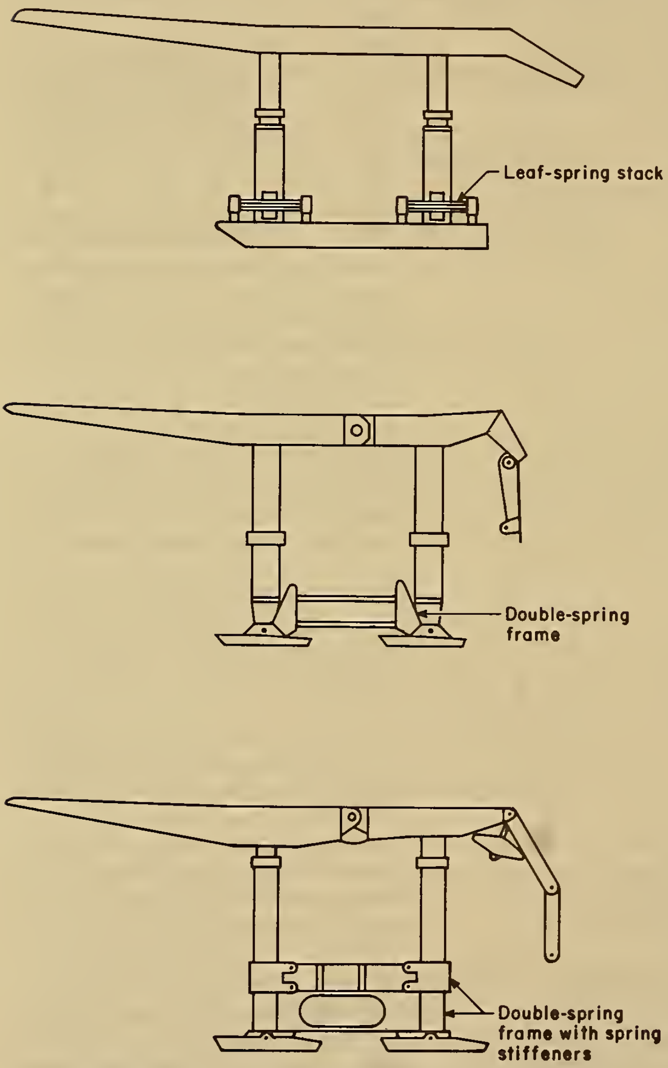


FIGURE 36. - Spring steel stabilizers (after 78).

Stabilization of Powered Supports

Because powered supports are subjected to external loads which may be applied both normally and eccentrically to the structural members, the unit may be damaged or even upset. To help compensate for the eccentric loading caused by by roof movements from face to goaf, the legs of conventional powered supports are usually inclined slightly forward in the vertical plane (about 3°). In inclined workings, the legs are usually inclined toward the face at one half the dip angle of the seam instead of being set normal in the seam. As a practical criterion, however, the forward inclination must not be more than 9°.

To provide further insurance against damage caused by eccentric loading, the legs are attached to the base and canopy by a stabilizer which helps the support accommodate differential movements of roof and floor, irregularities of the strata being supported, and inclination of the workings. The stabilizer must be resilient enough to accommodate small movements of the support legs caused by eccentric loading, but be able to restore the legs to their original position when the eccentric load is removed. The practice in Great Britain has been to have the legs accommodate a 75-mm (3-inch) movement of the roof member relative to the floor in a face-waste direction for seam heights of 1 m (3 feet) (8). Half as much movement is allowed in other directions. These allowances are proportionally increased for greater seam heights.

German longwall research effort has focused on more reliable powered supports, especially at the Supports and Rock Mechanics Laboratory of Bergbauforschung G.m.b.H. (78). Figure 36 shows a typical German design with

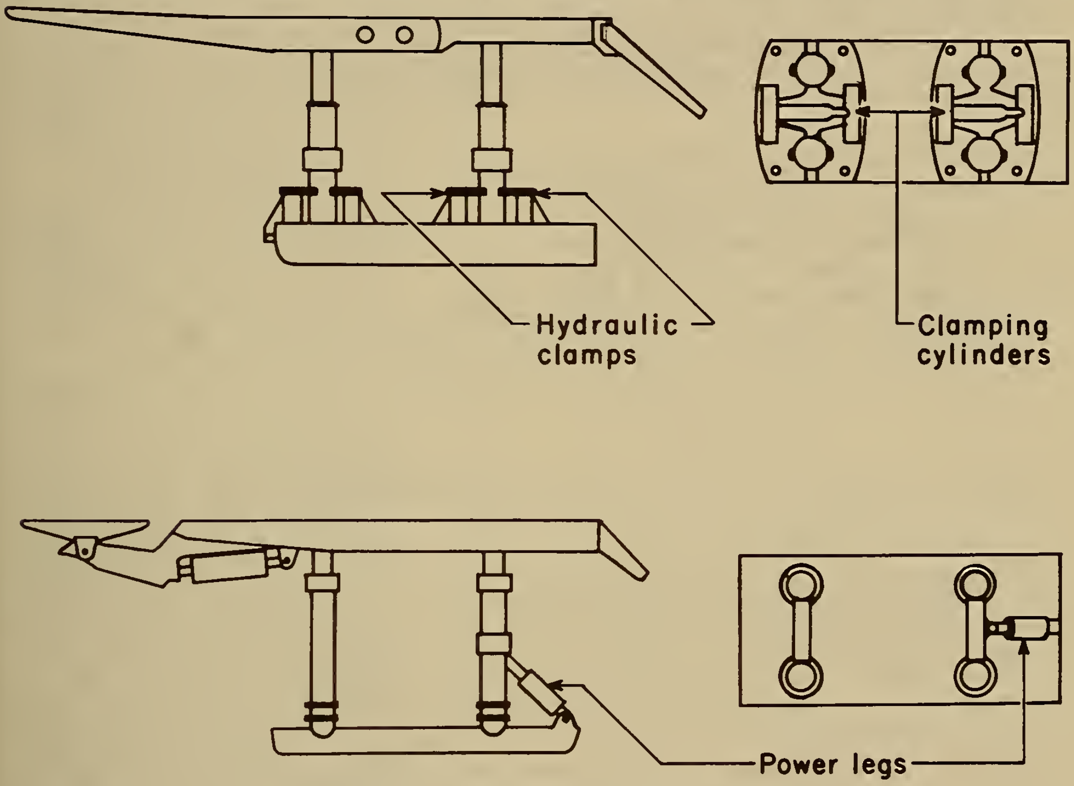


FIGURE 37. - Hydraulic stabilizers (after 78).

spring stabilizers for mounting and alining the support legs. Hydraulic stabilizers have also been used when the system operates under rugged conditions beyond the capabilities of spring stabilizers (fig. 37). Flexibility of the leg mountings is achieved by the clamping cylinders, or by the hydraulic stabilizer mounted at an angle of 40° between the floor plate and the cross bar link. Powered roof beams have also been developed for two- and three-frame units to make the supports more adaptable to changes of thickness and gradients under the working conditions in German coalfields (fig. 38).

Load-Carrying Characteristics

A support exerts a load to counteract the potentially damaging movement of the roof which could produce large-scale caves or roof cavities. The setting and the yield loads are important in support selection and use. The setting load is initially applied to the roof through a prop, and the yield load is eventually carried by the individual prop in the support assemblage. Higher setting loads in general tend to improve roof conditions, while reduction in the yield load reduces the chances of structural damage to the props.

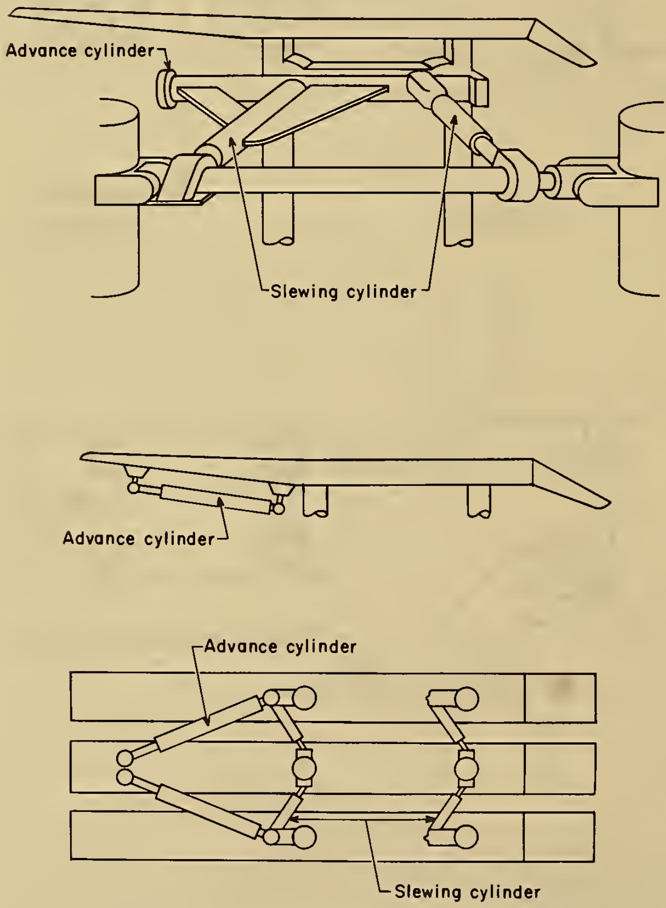


FIGURE 38. - Powered roof members (after 78).

The determination of setting load is based on the height of the rock in the immediate roof. The weight per unit length exerted by the roof on the support is a function of the thickness of the caving roof which can be estimated from the thickness of extraction and the dilatancy of broken rock. Because the increase in volume of the roof after breakdown in the waste is about 50 percent, the limit of thickness of the immediate roof in terms of the thickness of extraction is approximately twice the seam height (8). The load that the support has to counteract is simply the weight of the rock that forms the waste pile. Assuming a relative density of 2.3 for rock, this load amounts to

0.125 times the height of extraction measured in feet. In SI (International System of Units) the load estimation becomes 0.041 MN/m^2 for each meter of seam height. In the load calculation, British practice has been to use a safety factor of 2 which provides a comfortable margin for unusual circumstances. This leads to a recommended setting-load density in tons per square foot of 0.25 times the extraction height in feet, or 0.082 MN/m^2 for each meter of seam height. Similar arguments are used by the German Mines Inspectorate to recommend their setting-load densities of 0.072 MN/m^2 for each meter of seam height (0.22 ton/ft^2 for each foot of seam height).

To have an adequate setting-load density for each prop, allowances are made for imperfections in the hydraulic systems. Nominal setting loads are usually 30 percent higher than the calculated loads. Because yield valves may malfunction, the design yield load of the support is usually 25 percent greater than the nominal setting load.

British engineers have investigated the mean load densities, average load taken by the props in each set of supports, over a wide range of field conditions (8, 14). Variations in load for individual legs with time and variations in roof area exposed in the working cycles were accounted for in the measurements of the MLD's. Most of the measured MLD's were between 0.1-0.2 MN/m^2 (1-2 tons/ft^2). Compared with the mean load densities resulting from the setting load calculations (approximately 0.35 MN/m^2, 3.5 tons/ft^2) for a typical coal seam, the measured MLD's indicate that the powered face supports in British Coal Mines have been operated with a substantial safety factor.

Two additional important factors influencing the load-carrying characteristics of powered face supports are the ability of the support to maintain close contact with the roof and floor through the roof-bars and floor bases, and the ability of the support legs to accommodate any likely convergence or restriction of height on the face without going "solid." In choosing the support the engineer must be sure that the legs have sufficient travel to deal with expected convergence and with any irregularities likely to be encountered in the seam. Two parameters, the minimum extended height and the vertical hydraulic travel, should be evaluated when selecting a support for a particular face. The minimum extended height defines the support's ability to be set at a given height of extraction. The vertical hydraulic travel is the distance required below the minimum height to let the support be continually lowered and advanced to new positions under all likely geological conditions. The minimum extended height is simply the nominal height of extraction less the convergence of the roof at the point where the leg is standing. Allowances must be made for varied seam thickness expected during the life of the face.

Maximum convergence in British coal mines was found to be a function of the nominal height of extraction. Ashwin (8) provides the following empirical relationship between C, the maximum convergence, and H, the nominal height of extraction:

$$C = 0.037\ H + 0.093,$$

where both C and H are in meters.

In U.S. customary units the equation becomes

$$C = 0.037\ H + 0.283,$$

where C and H are in feet.

The vertical hydraulic travel can be calculated from the following relationship:

$$V = 0.076 + 2a + (0.037H + 0.093),$$

where V is the vertical hydraulic travel,

a is the seam thickness variation,

and H is the nominal height of extraction, all in meters.

In U.S. customary units, this relationship becomes

$$V \doteq 0.5 + (2a + 0.037H),$$

where a and H are in feet.

Suggested magnitudes for a are given for three different extraction height ranges as follows:

$a = 0.10$ m (4 in) for $1.14 < H \leq 1.52$ m (60 in),

$a = 0.15$ m (6 in) for $1.52 < H \leq 2.00$ m (79 in),

and $a = 0.20$ m (8 in) for $2.00 < H \leq 3.00$ m (118 in).

Vertical hydraulic travel can be achieved by single or double telescopic legs. In thin seams, double legs are becoming popular. Recent developments incorporate mechanical extension facilities with the hydraulic legs. The hydraulic stroke is extended, by a mechanical assist, to let the prop be readily adjusted under a wide range of seam thicknesses (78).

Immediate Forward Support

Face advance speed is affected by the rates of such activities as coal getting, conveying, advancing the face ends, and the movement of supports. Under ideal conditions most support systems can be advanced along the face at a rate of 15 m/min (50 ft/min). However, three factors usually retard the support movement and prevent realization of the ideal rate even under good roof conditions. The limiting factors are delays in (1) the movement of the face conveyor; (2) lowering the support from the roof; and (3) the advance and set up of a given support caused by the loss of fluid pressure supply to the conveyor push-over rams and other circuits. The last two factors are related to inadequacy of the power pack capacity and the buildup of back pressure in the return line. Both can be alleviated by augmenting the hydraulic supply system. The first factor has led to the development of a technique known as immediate forward support (IFS) which will be discussed in some detail here.

Under the normal sequence of operations (cut, snake, and support) newly exposed roof could not be supported until a certain length of the face has been sheared or plowed and the conveyor snaked into a new position. Delay in supporting the roof often allowed cavities to be formed in the roof between the face and the tip of the roof beam. To preclude the roof deterioration caused by this delay IFS systems were developed for a longwall mining technique known as the one-web-back method. This method changes the sequence of operation from cut-snake-support to cut-support-snake. As the cutting head of the plow or shearer passes a particular point, the support is immediately advanced before the conveyor is pushed to the coal face. This can be done because the IFS chocks have an extended cantilever roof beam which has a length of one cutting web or have a longer roof beam than conventional chocks. The one-web-back method improves roof control and creates more travel space between the conveyor and the chocks (fig. 39). Because of the advantages of this method U.S. operators are adopting it (93).

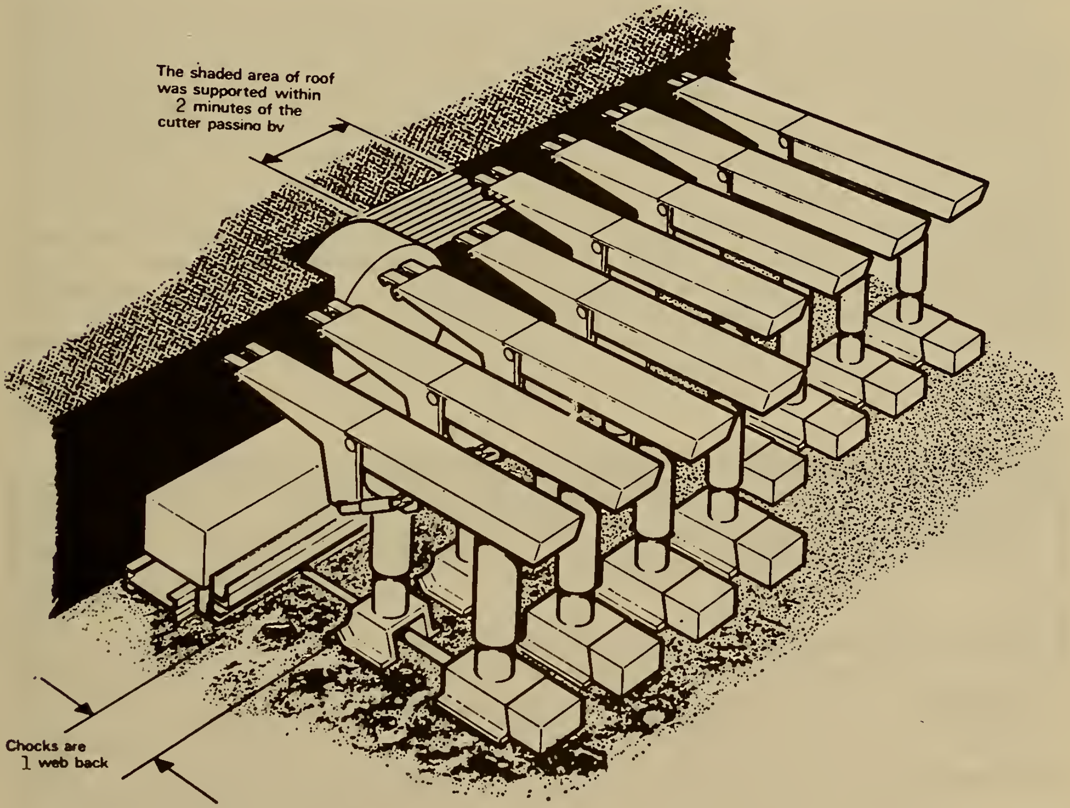


FIGURE 39. - An early, immediate forward support system (after 37).

Three important aspects of the IFS systems deserve further mention (37). First, IFS faces must be equipped with chain-restraining devices to minimize the risk to workers if haulage chain breaks. Second, the extended rams of the powered support could be bent by heaving floor conditions if the supports stand for an extended period. Finally, because the articulation of the powered cantilever might obstruct the movement of the power loader, operation of IFS systems with powered cantilevers is not possible in seams thinner than 4 feet. Thin seam operation of IFS systems, however, is possible when the powered cantilevers are not used.

Face-End and Roadhead Supports

Extensive application of the advance heading methods in Great Britain together with the requirements for increased mechanization of face-end operations have led to development of special types of powered supports for control of the roof strata around the face ends. Three of these special support types (anchor, packhole, and buttress) are shown in the advancing longwall layout of figure 40.

Anchor supports fix the armored face conveyor at the face end and support the roof in this area. In addition to the anchor supports a special support protects the gear-head machinery of the face conveyor. Packhole supports are set between the standard chocks and the packs to facilitate the packhole operations in the advance system. They are conventional units fitted with rearward-facing hydraulic cantilevers to support the roof over the packhole area. The rear cantilever is extended when the main support is advanced and retracted after the pack is built. Buttress supports were developed to supplement wood chocks used to control waste collapse at the junction of the waste edge and the corner of roadside packs. Buttress supports have eliminated most hazards of wood chock installation at face ends. Basically, they are another modification of the standard chocks where antiflushing arrangements or rear cantilever roof beams give positive break-off to the goaf.

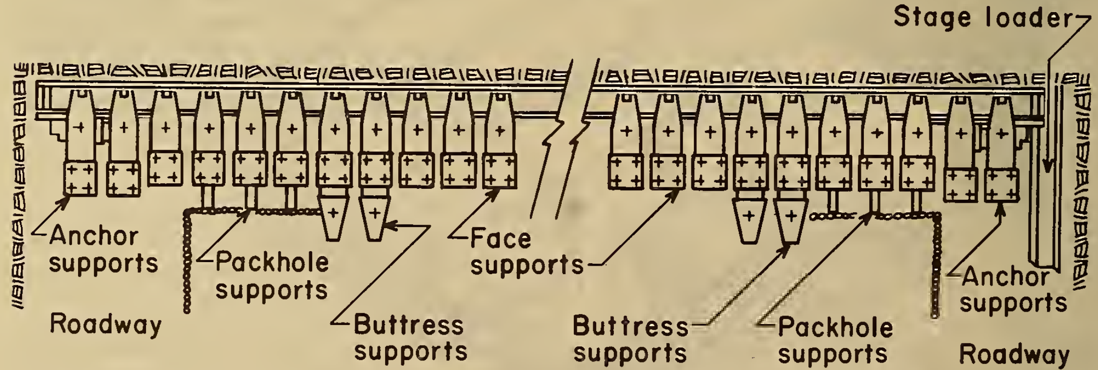


FIGURE 40. - Advancing longwall face layout showing anchor, packhole, and buttress supports. *(Courtesy Joy Manufacturing Company.)*

Standard chocks modified with front and rear cantilevers, provide continuous support throughout the roadhead area. The base of the roadhead support can be modified into a tunnel shape when the support is installed over the stage loaders at the main gate end of the face.

Coal-Winning Systems

Coal winning in fully mechanized longwall faces is achieved by plows or power loaders. Before choosing a system the engineer must evaluate factors such as the workability of coal, seam thickness, seam conditions, face layout, the desired size of the fragmented coal, and other production requirements. Ideally, the selected system would continuously cut and load the coal at a rate commensurate with the capacity of the face conveyor. Other relevant parameters of the winning and conveying systems that affect output have been analyzed by Teale (182) and by Guppy and Whittaker (70).

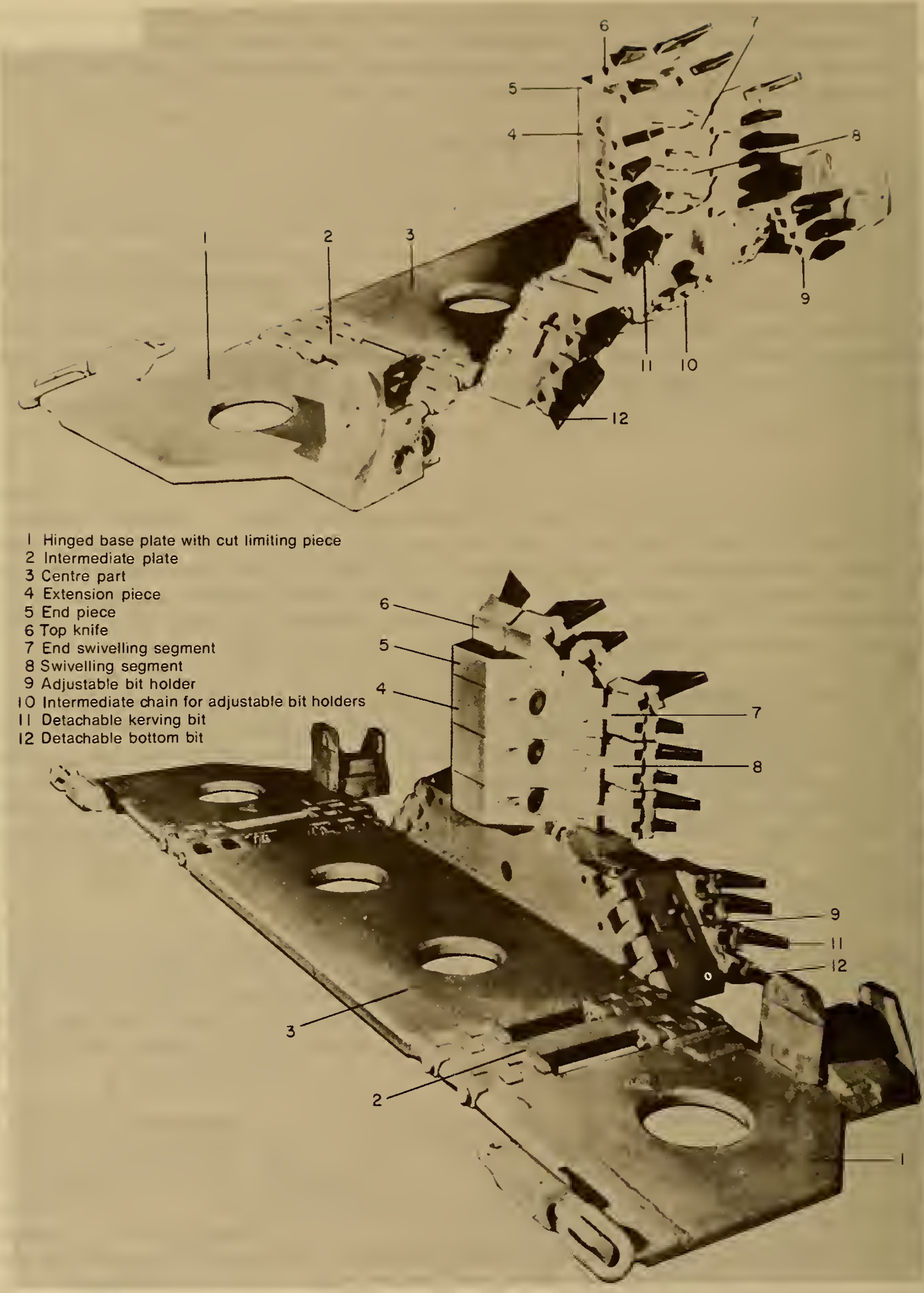
Plows

Coal plows were originally developed for winning friable coals in West Germany in seams less than 1.3 m (4.3 feet) in thickness. The advantages of plow systems include simplicity, robustness, high output, acceptable product size, and low dust production. Singhal (173) has described the various plow systems such as the universal, the ramp, and the hook which are used in Western Europe. Figure 41 shows a hook plow, the Reisshaken, which is suitable for high-speed plowing up to 400 ft/min (120 m/min).

The cutting elements of the plow are attached to the central part of the articulated base plate which slides under the face conveyor. The extension piece carries the swivel segments and the attached drag bits or cutting blades. The swivel segments are stacked to attain the height required to cut the seam. A vertical-ranging top knife is mounted over the end piece for rapid cutting height adjustment. The bottom part of the plow body, the central plow base, contains adjustable bit holders, detachable kerfing bits, and bottom bits for floor dinting. Because the blade arrangement is symmetrical on both sides, the system can cut and load in two directions.

Although the plow is attached to the face conveyor, it rides on heavy-duty plow guides. Trough and spill plates are also used in most plow installations. Dust suppression is achieved by water sprayed from a hose under the trough. The plow is hauled along the face by a heavy-duty chain driven by a high-performance motor.

Removal of the coal by plow systems is achieved by the shearing of the cutting blades. The cutting force depends on the depth of cut, blade geometry, and strength of the coal. The extraction rate per unit depth of cut is the product of the width of the plowed strip times the plow speed. The haulage force is the sum of the frictional force in the system and the total cutting force of the blades. To increase the depth of cut and hence the coal output, the haulage force and sizes of chain and shear pins must be increased. Increases in plow speed can result in greater volumes of coal produced per unit time with no increase in haulage force. To achieve these results, the



1 Hinged base plate with cut limiting piece
2 Intermediate plate
3 Centre part
4 Extension piece
5 End piece
6 Top knife
7 End swivelling segment
8 Swivelling segment
9 Adjustable bit holder
10 Intermediate chain for adjustable bit holders
11 Detachable kerving bit
12 Detachable bottom bit

FIGURE 41. - Westfalia Reisshaken hook plow. *(Courtesy Mining Progress, Inc.)*

depth of cut must be held constant and the power levels for the plow drives must be boosted. European experience has shown that output can be increased more effectively and at less cost by raising the plow speed than by increasing the depth of cut.

Plow systems, although still widely used, have some serious shortcomings, such as difficulties in cutting hard coal, achieving horizontal control, regulating depth of cut, and regulating the output to the face conveyor. In addition the face end equipment for plow systems needs stables at the face ends or an advanced heading layout.

During the past decade, European researchers have improved techniques of plowing, and optimized the design of existing plows, to come up with more efficient systems (68-69, 151, 158, 163, 190, 192). In summary, plow systems continue to keep their foothold, as the effective machine for the range of thin soft coal seams where shearers are inefficient.

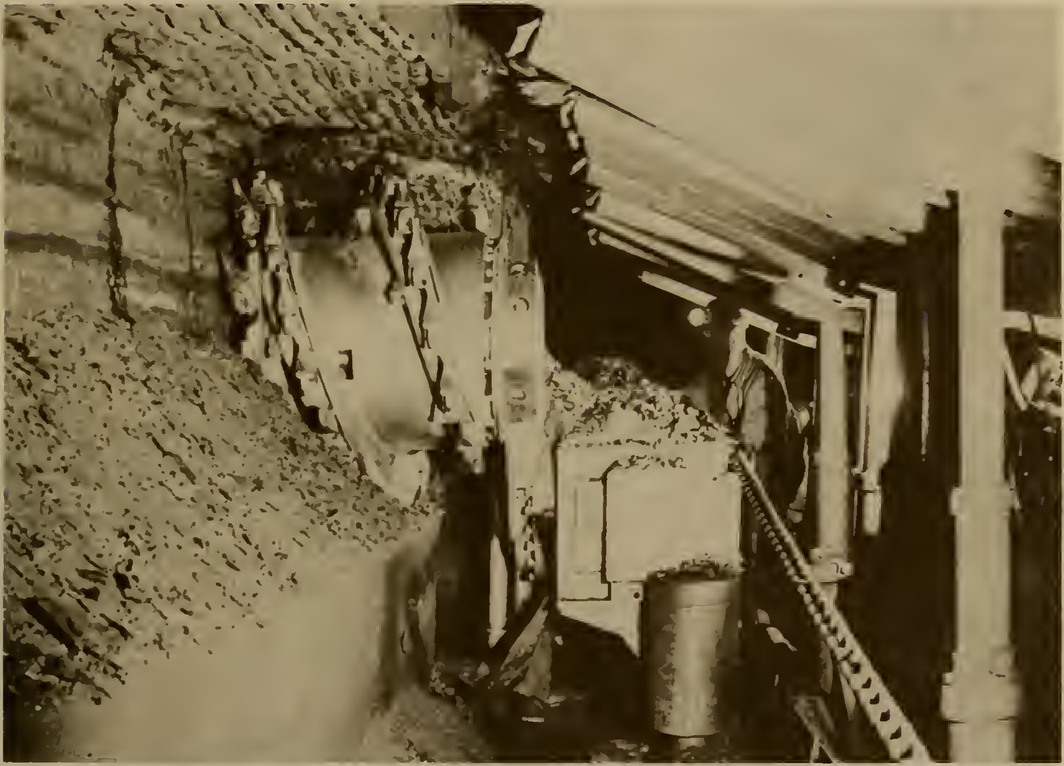


FIGURE 42. - Shearer loader making roof cut. *(Courtesy Eickhoff-National Mine Company.)*

Power Loaders

Power loaders have a rotating head (usually a drum or drums) armed with picks or some form of cutter bits; the two types are shearer loaders and trepanners.

Shearer Loaders

Until recently, shearer loaders were exclusively conveyor-mounted cutting/winning machines equipped with an electric motor, shearing drum(s), gearhead, and haulage units. Cutting is achieved by picks mounted on the periphery of the rotating drum, offset into the face (fig. 42). As the cutting proceeds, the machine pulls itself along the face by wire rope (rarely) or haulage chains. Most of the coal cut by the shearer falls on a conveyor and is removed from the working face. Much shearer loader development has involved the operational capability of the shearing drum(s) and the geometric arrangements of the drums with relation to the coal face. Some of the more commonly used shearer loaders include unidirectional and bidirectional (fig. 43) units, machines with a ranging floor drum, single-ended ranging drum shearers (SERDS) (fig. 44) and double-ended ranging drum shearers (DERDS) (figs. 45-46). Further details of past shearer system developments are available in the literature (21, 62, 108).

Shearer loaders can win entire seams of variable heights even when the cutting-drum diameter is smaller than the seam thickness and can cut hard coal and seams containing hard dirt bands which are difficult to win by plow systems. The single-ended shearer, working unidirectionally, cuts the coal in one direction and scrapes and loads loose coal from the freshly cut face during the return or flitting run (returns without cutting). Bidirectional units cut on both passes. During the flitting run, the conveyor is snaked forward and the supports are advanced. If working bidirectionally, the AFC

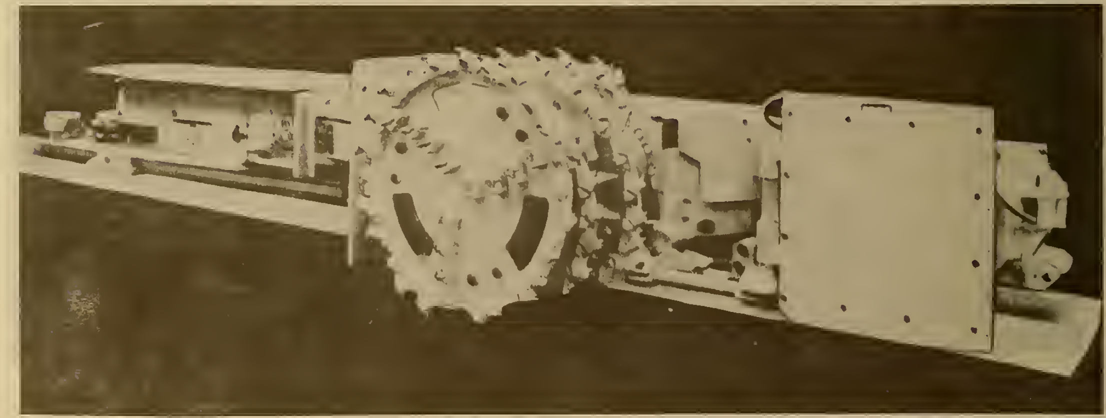


FIGURE 43. - The Anderson Mavor AB 16 bidirectional shearer loader.
(Courtesy Anderson Mavor (USA), Ltd.)

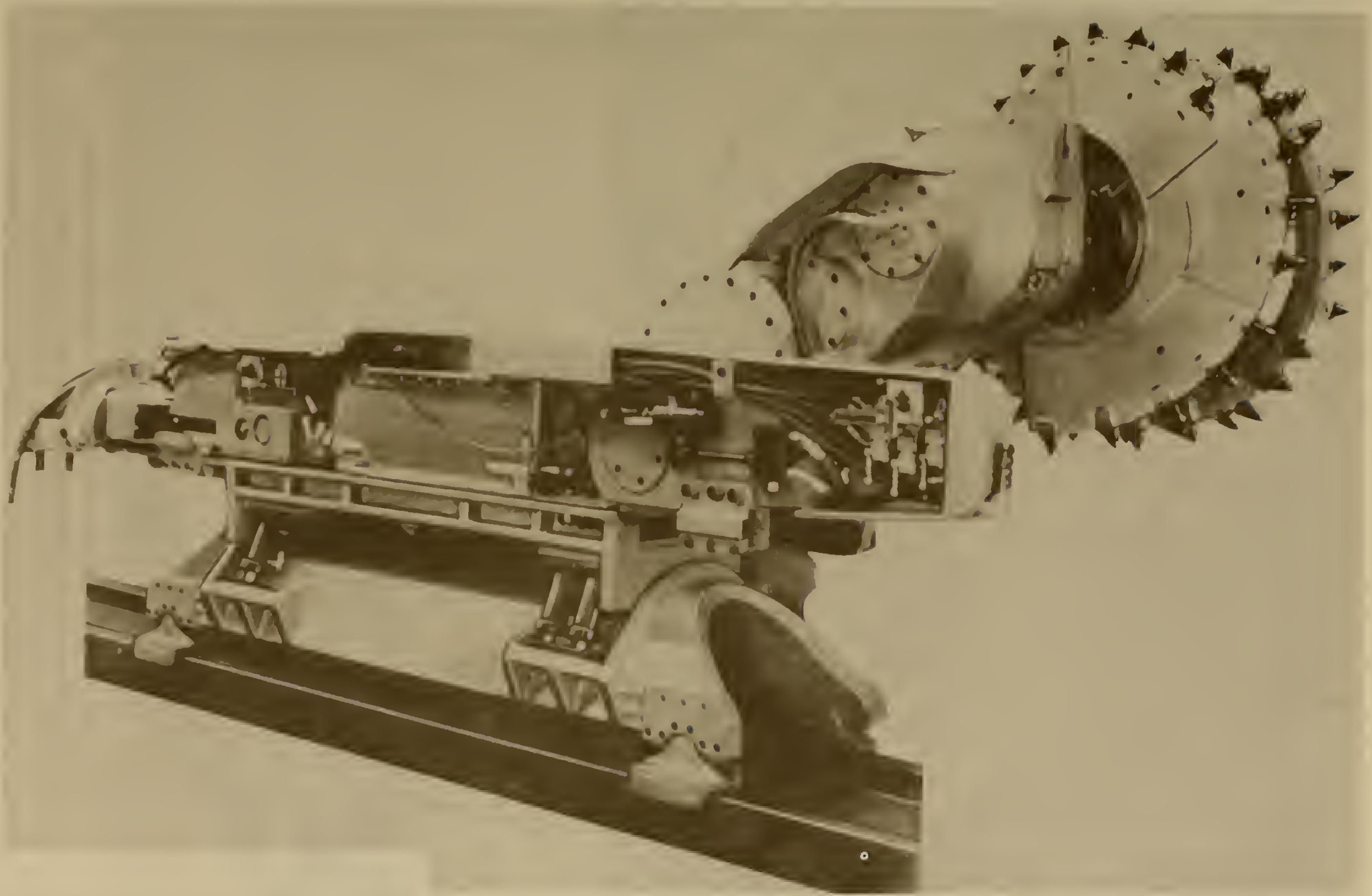


FIGURE 44. - Anderson Mavor single-ended ranging drum shearer. *(Courtesy Anderson Mavor (USA), Ltd.)*

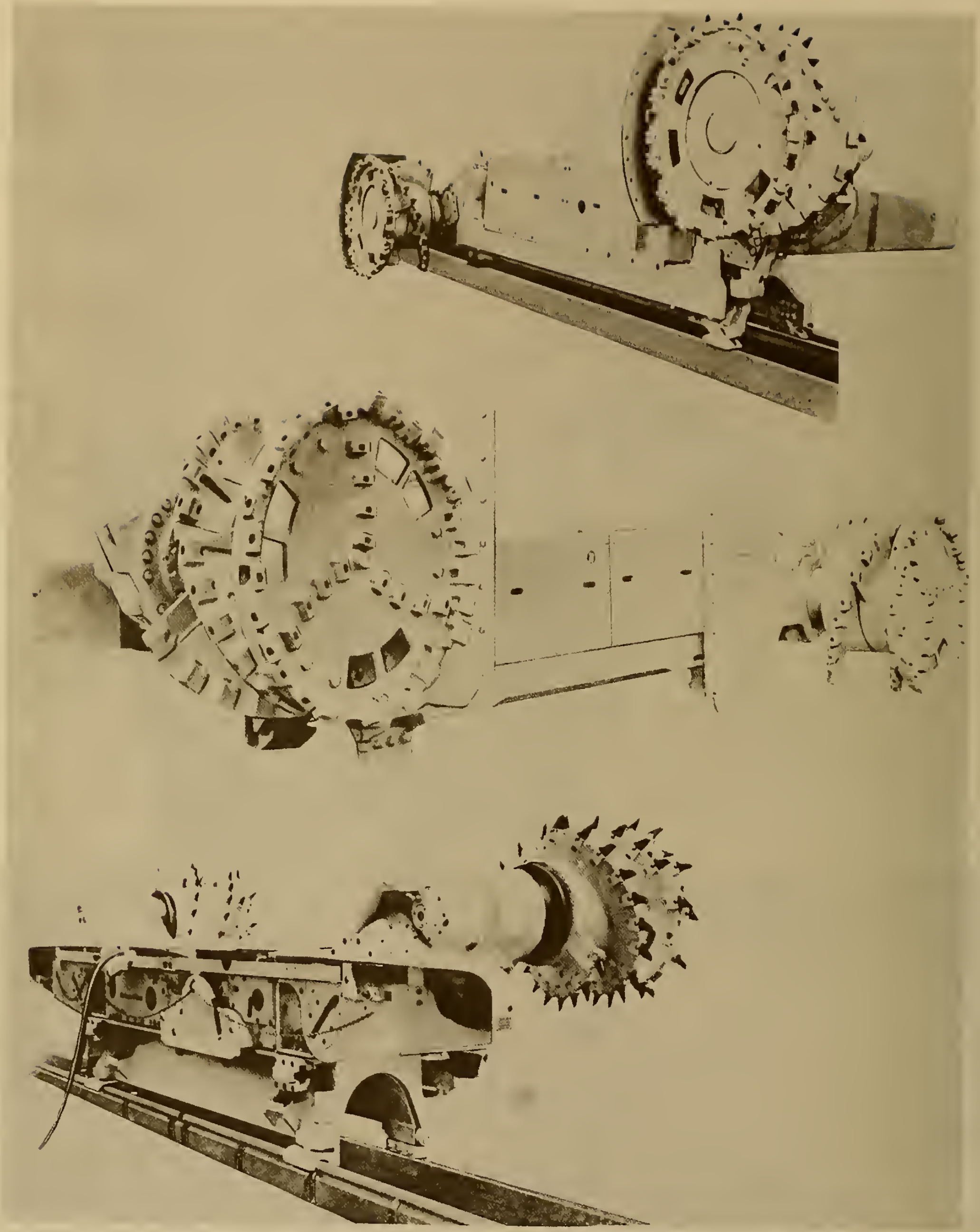


FIGURE 45. - Anderson Mavor double-ended ranging drum shearer.
(Courtesy Anderson Mavor (USA), Ltd.)

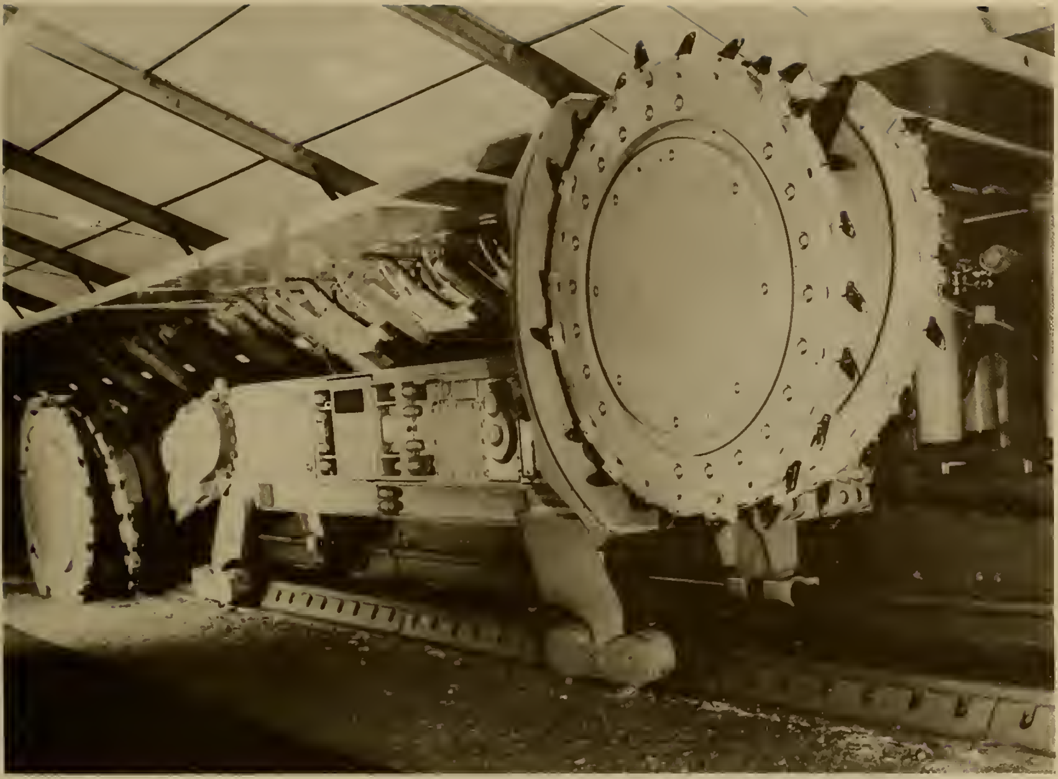


FIGURE 46. - Eickhoff EDW-300-L double drum ranging arm shearer.
(Courtesy Eickhoff-National Mine Company.)

and supports are advanced behind the machine. Shearer loaders equipped with double-ended ranging drums (DERDS) are bidirectional in operation. Normally, the machine travels along the coal face with the leading drum cutting the top coal and the trailing drum cutting the bottom. The whole seam is thus extracted in one pass. The conveyor and supports may be immediately advanced behind the machine to control the roof. DERDS can also rip and dint (to cut into the floor of a roadway to obtain more headroom) at the gate ends and eliminate the need for stables in advancing longwall layouts (72).

Trepanners

Trepanning type cutter-loader systems were developed in Great Britain to produce large-size coal from mechanized thin-seam longwall faces. Since the inception of the single-ended and double-ended floor mounted trepanners in 1951-54, and the trepan-shearer in 1959, developments have led to the single-ended and double-ended conveyor-mounted trepanners in the 1960's. The floor mounted trepanners utilized a trepan-wheel for cutting and discharging the coal onto the armored face conveyor. The trepan-shearer is a conveyor-mounted shearer-loader that has a trepan-wheel for removing the coal and a shearer drum following the trepan-wheel for trimming the roof and floor.

Several other longwall machines such as the Midget Miner, Buttock Miner, and Vertical Drum Shearer, employ the trepan-wheel as the main cutting element. These units have been used from time to time, but they have not attained wide application (60, 124, 172).

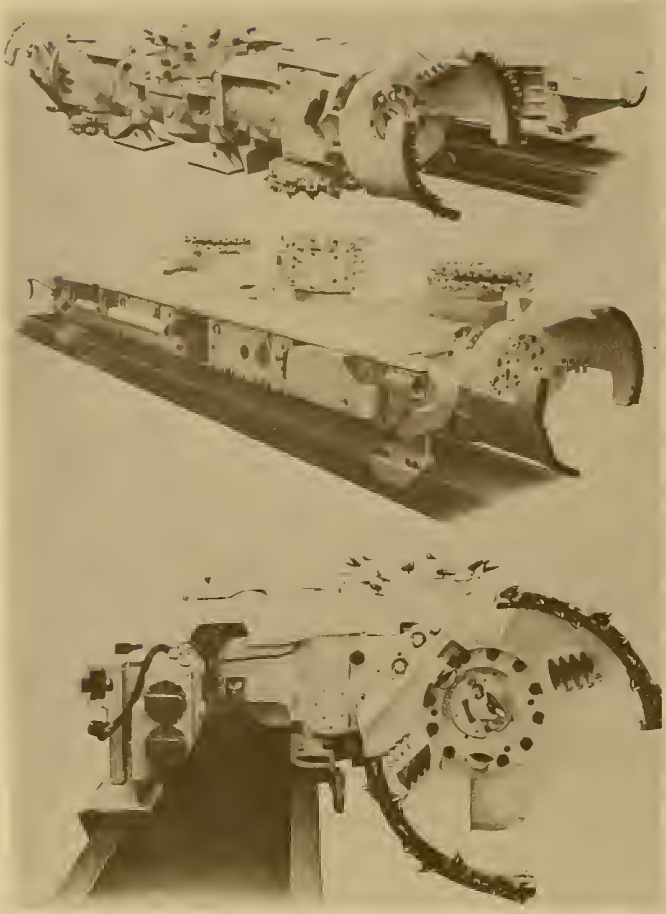


FIGURE 47. - Anderson Mavor double-ended conveyor mounted trepanner. *(Courtesy Anderson Mavor (USA), Ltd.)*

The double-ended, conveyor-mounted trepanner (fig. 47) has two main assemblies side by side. One assembly, mounted on the top of the face conveyors, powers the cutting units and has haulage and steering components for moving the machine along the face. The other assembly, the cutting gearboxes which carry the trepan wheels, is mounted alongside the conveyor-mounted unit and is offset to the face. Elements are mounted in the trepan wheels to cut the coal and load it on the conveyor. Floor-cutting disks beneath each trepan gearbox square out the base of the seam down to the floor level. A roof-cutting turret, which may be raised or lowered, is mounted between the trepan gearboxes to cut to the required roof level. A scraper plow mounted behind the trailing trepan wheel clears any spillage left by the machine and loads the material on the conveyor.

Recent equipment developments in France (198) have resulted in a trepan type of shearer loader which attacks the face at right angles to it rather than in line as with conventional shearer loaders. This type of cutting action eliminates the need for stable holes and is well suited to extracting seams having roof problems and friable top coal.

Chainless Haulage for Shearer Loaders

Early power loaders were hauled by wire ropes. As the weight and horsepower of the power loaders increased, the wire ropes were replaced by chains. Although the chains were much stronger, they still broke and caused accidents and lost production. Accidents attributed to power loader haulage chain, however, are not only caused by breakage, but are also caused by chain whip. One solution to the whipping problem has been to use chain restrainers. The risks of chain accidents are reduced by the use of chain guards provided at the driving and idler sprockets to contain the flying chain (18, 129, 131).

Several systems of chainless haulage have recently been developed by the National Coal Board (NCB) of Great Britain, Centre d' Etudes et Recherches des Charbonnages de France (CERCHAR), and several European manufacturers to eliminate the production and safety problems associated with whipping and broken chains.

Among the innovations of the chainless haulage power loader, the NCB introduced the tract-reactive haulage and the "Rack-A-Track" system which applies the rack-and-pinion principle for the shearer to pull itself. The "Rack-A-Track" system (fig. 48) propels the loader by a short, endless roller link chain, geared to the drive motor of the loader, which meshes with the retractable steel pegs of the rack located on the goaf side of the armored face conveyor. The pegs, level with the upper surface of the rack when they are not engaged with the chain, are lifted into an exposed position by a sliding wedge, which is attached to the loader and fitted to the underside of the track. Field tests have indicated that rack-a-track can be developed into a safe and reliable method of power loader haulage (109, 132).

Although most chainless haulage systems use the rack and pinion principle, power loaders also can be propelled with alternating hydraulic rams (117). Additional details on the Rack-A-Track system, the ram propulsion method, and other techniques of chainless haulage for power loaders are available from several references (45, 110-111, and 194). Some publications describing recent advances in chainless haulage systems are also included in the section of the bibliography on research and development for longwall cutting equipment.

Face Transport Systems

Face Conveyors (panzerforderer) originally developed in Germany during the Second World War for plow-equipped faces were a new concept of coal transport. Further development of face conveyors, in conjunction with improvements in early winning and support systems, was the needed link for the continuous face operations found in modern longwall mines.

Armored Flexible Conveyors (AFC)

Two of the most outstanding features of current armored face conveyors or armored flexible conveyor (AFC) are adaptability and robustness. The AFC can negotiate limited curves and vertical undulations, yet is strong enough to carry heavy winning machines. In addition, the AFC can resist the high thrusts exerted by the rams connected to powered supports.

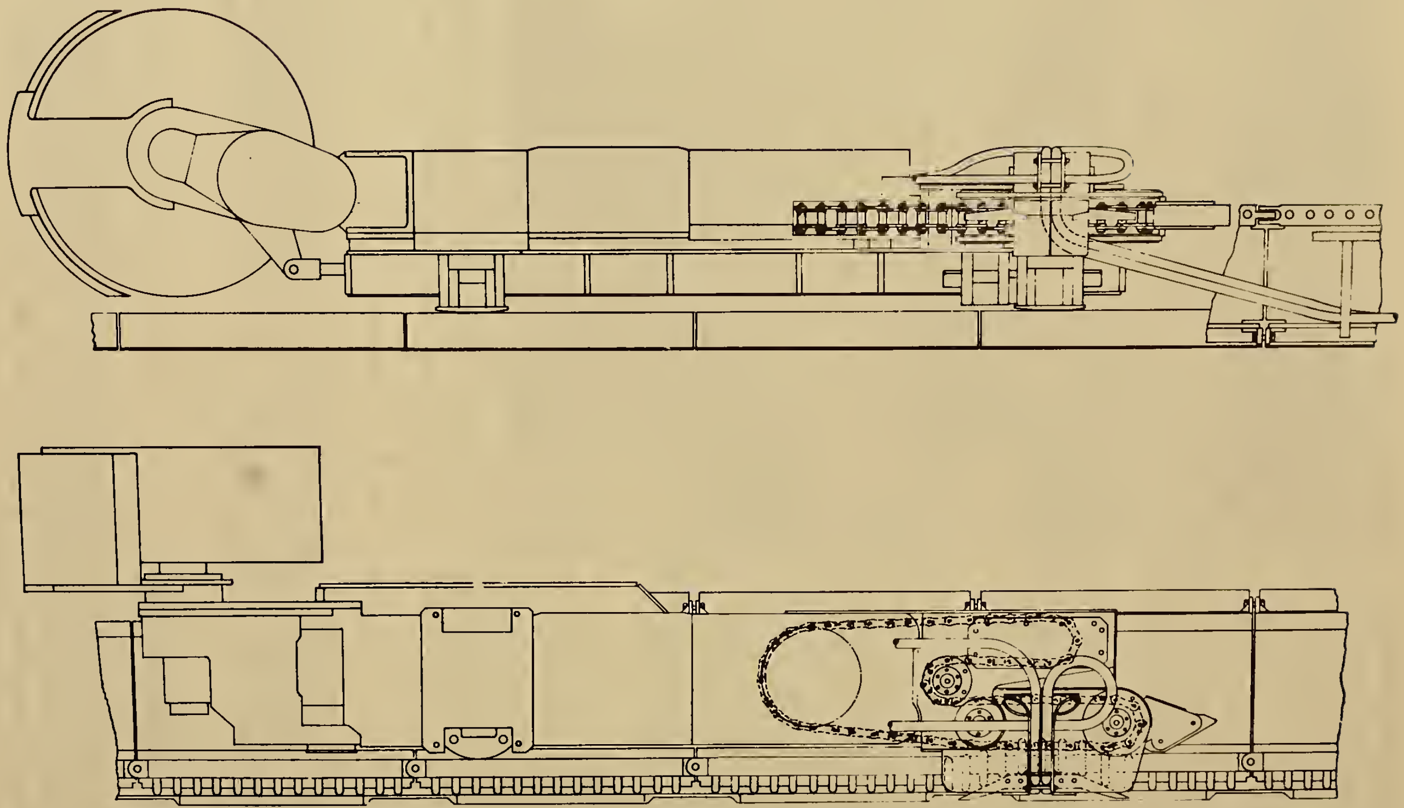


FIGURE 48. - Plan and side views of a single-ended ranging drum shearer equipped with Rack-A-Track haulage (after 109).

FIGURE 49

A high production rate requires that the conveyors have enough power, strength, and reliability to convey large tonnages of coal from each face. The capacity, width, and conveying speed of the AFC are influenced by the methods of winning and by total face output. To keep the overall operation at full capacity, the rate of output from a face should not exceed the rate at which the AFC can transport the coal onto the stage loader at the main gate. To enable operators to optimize mining rates, European engineers have computed the relationships among the factors which control the output of coal winning machines such as web width, depth of cut, machine speed, and seam heights, and the coal carrying capacities of face conveyors (70, 182).

The components of the AFC include line pans, chains, flight bars, a chain tensioner or "compensator" (not always used), drivehead, gearboxes, and accessories. Designs of the AFC components are varied slightly according to the individual specifications of the mining system, length of face, and seam characteristics such as gradient and height. Figure 49 shows the main parts of an AFC and its installation.

Line Pans

Line pans, the basic structural element of the AFC, are fabricated in sections from rolled-steel side members welded to a thick deckplate which forms the surface on which the conveyor chain and flight bars move the coal. Although sections of line pan can range from 1.5 to 2.0 m (5.0 to 6.6 ft) in length, the 1.5-m length is almost standard. The height of the side member and width of the pan vary according to the conveyor capacity and manufacturer's design. Some basic differences between British and German AFC line pan profiles are shown in figure 50.

Line pans are connected by strong cam screws or connectors that provide the flexibility between the adjacent sections for the snaking action needed to advance with the face. Most line pans are open bottom, but some have a

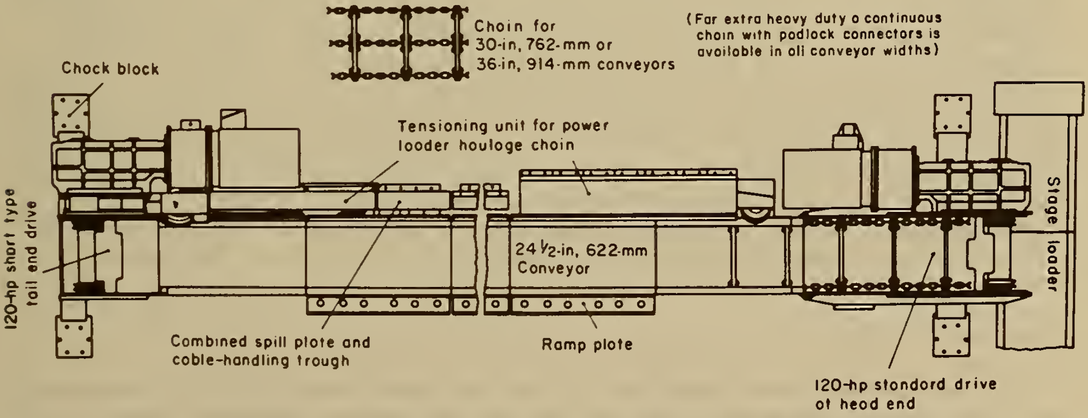
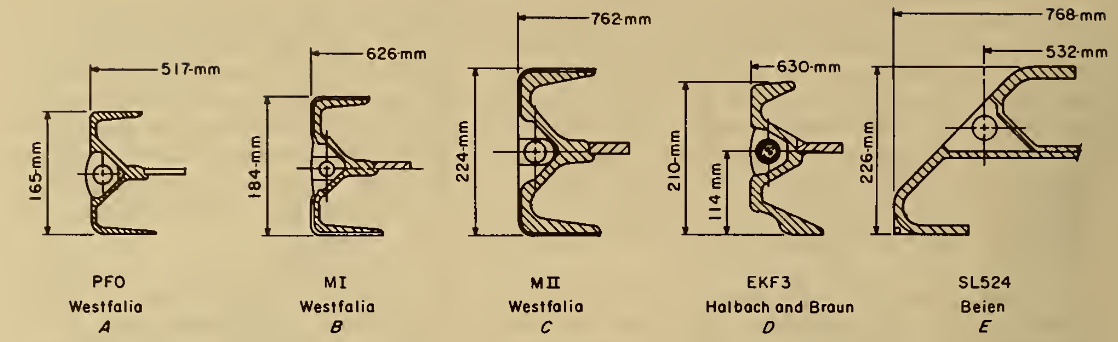


FIGURE 49. - The main parts of an armored face conveyor (AFC).

(Courtesy Anderson Mavor (USA), Ltd.)

Profiles of current German armored flexible conveyors



Profiles of current United Kingdom armored flexible conveyors

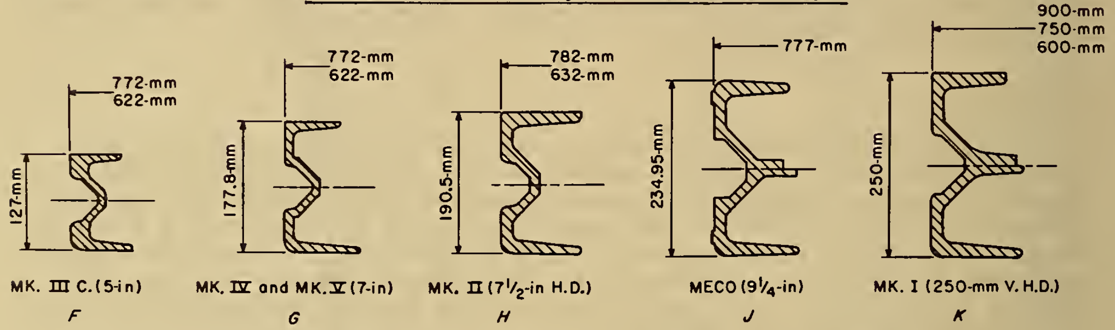
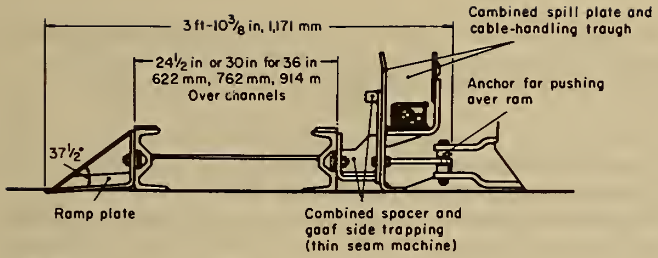


FIGURE 50. - Profiles of British and German armored face conveyor line pans (after 20). NOTE.—H.D. indicates heavy duty; V.H.D. indicates very heavy duty.

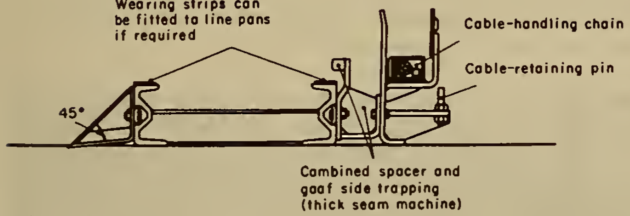
bottom plate welded to the lower flanges of the sides. Covered-bottom pans are widely used in British mines because the soft mine floors cause numerous fouling problems. Underplated pans reduce the amount of fine coal and soft floor scraped back along the bottom race, increase the strength of the AFC, and help to prevent the chain from coming out of the race. However, designs that solve some problems often cause other difficulties; for example, the bottom of the underplated pans can cause the chain to stall when fines are carried back on to the bottom race (181). Similar chain stalling and breakage problems were encountered in early attempts to match new shield support designs with existing AFC units having conveyor carrying frames. To solve these problems, German equipment manufacturers developed a tiltable-conveyor carrying system, which could provide clearance for the chain and prevent blockage (96).

Line Pan Fittings

Prior to 1970-71 the practice in British mines had been to use hand labor to clear the coal from the track of the cutting machine and allow good, full pushovers of the AFC by the rams attached to the power supports. Because of an NCB safety instruction, the hand-cleaning practice had to be discontinued and mechanical means have been developed for this task.



Thin seams



Thick seams

FIGURE 51. - Cross sections of thin and thick seam AFC line pans showing typical locations of fittings.

(Courtesy Anderson Mavor (USA), Ltd.)

Line pans are now fitted with ramp plates on the face side to assist in clearing the coal left in the track of the cutting machine. The ramp plates are usually inclined to the horizontal (fig. 51). Ramp shapes, dimensions, and angles can vary considerably. Some units manufactured by Eickhoff and Westfalia constitute activated ramp plates that are really small "cleanup" plows. Although the ramp plates do facilitate pushover of the AFC, careful attention must be given to the distance between the coal face and the front edge of the ramp plate (136). If the AFC is not properly positioned, the web depths will be reduced and production losses range from 5 to 10 percent. Recent dimensional analysis and scale model research, sponsored by the National Coal Board, has demonstrated that for any specified operating condition, there is an optimum value of ramp plate toe angle which will bring the AFC closest to the face (167). Ramp toe angles of less than 45° were suggested when large lumps of coal and rock are present.

Other accessory fittings attached to the line pans include such elements as the spacer, trapping, spill plates, cable handling trough, and the coupling for the ramming bar. The spacer provides room for the machine haulage chains (if used) and the machine overhand to pass between the face side of the spacer and the cable handling trough. The trapping (a square or round bar) helps to guide the coal cutting machine along the AFC and hold the machine on the pan line. The spill plate and the cable handling trough are normally bolted to the spacer. Spill plates help to increase loading capacity of the conveyor, especially at the face where larger lumps of coal may be produced.

AFC Chain Assemblies

The moving parts in the AFC include the chain, chain connectors, and flight bars. Chain arrangement for the AFC are either single-, double-, or triple-strand assemblies of round link chain. The chains are connected together by either padlock connectors or D-links. The flight bars which convey the coal also guide the chain over the sprockets at the drivehead and tail end and assure that the chain centers pass safely through the bottom race. The chain can be outboard, triple-strand, single and double center strand and can range in size from 18 to 30 mm in diameter (approximately 0.7 to 1.2 inches).

The nominal chain speed, by NCB standards, is 65 m/min (214 ft/min). This speed provides a capacity of 6.2 tons/min of coal for the 0.62 m (2 ft) AFC commonly used in the British mines. Power requirements are approximately 4 kw/ton of coal, plus 0.2 kw/m for the conveyor (20).

The major operational problems of the AFC are associated with the chain. Examples include the chain being out of the race, broken chains, and chain stalling. The common cause of these problems is the friction developed between the chain and the frames of line pans. The use of a single-strand (fig. 52) or a twin center chain has some advantages, but the single-strand chains must have a larger size chain, large sprockets, and more effective chain tensioners, all of which are difficult to use in thin seams.

FIGURE 52. - Single-chain assembly for AFC. *(Courtesy Hemscheidt America Corporation.)*

Stage Loaders

Stage loaders are short, chain conveyors similar to the AFC in construction. The principal differences are that the flight bar spacings are shorter, 0.5 m (1.65 ft), and the line pans are sometimes wider than the AFC. The stage loader is usually operated at higher speeds than the AFC, approximately 75 to 97 m/min (250 to 300 ft/min); it connects the delivery end of the AFC and the panel belt conveyor. For maximum operating efficiency, improved face management and better reliability of the entire coal transport system, the AFC needs to be mechanically secured to the stage loader and electrically interlocked (116).

DISCUSSION

U.S. coal mines use a variety of surface and underground methods, the selection of which depends, in part, on the depth of coal and the thickness of the seam. Other factors include production requirements, character of the coal, ground conditions, environmental constraints, availability of skilled labor, capital costs, and equipment delivery schedules. Because early underground coal mines in the United States were located in thick, flat-lying seams, heavy equipment could be used. Almost 95 percent of current U.S. underground coal mines use the room-and-pillar method with a continuous miner to cut the coal. Strong roof and floor strata have permitted simple methods of ground control such as roof bolting, a technique well suited to room-and-pillar mining. The room-and-pillar method, however, has several disadvantages including a low recovery percentage which grows worse as the mine reaches greater depths. In addition, the room-and-pillar technique is not particularly well suited to some types of thin seams, to multiple seams, or to exceptionally thick seams.

During the last several years the productivity of underground mines has fallen sharply and the percentage of the nation's coal mined underground has declined. Underground mining historically accounted for approximately two-thirds of the coal produced by U.S. companies. In 1973, however, surface mines, not including auger operations, produced 276,645,000 short tons of bituminous coal and lignite, almost half of the Nation's total output of 591,738,000 short tons (188).

The U.S. coal production figures for 1974 show a further decline in underground production (44). Although the total coal produced in 1974 increased to 603,406,000 tons, a 2-percent hike over the total for 1973, the percentage contributed by underground mines (46 percent) dropped 7.4 percent compared with 1973 totals.

In addition to the requirements for more coal to be produced from underground mines, factors such as a growing concern for preservation of environmental quality, resource conservation, and safer working conditions emphasize the need for improved techniques of mining coal underground. Two of the most significant advantages of the longwall method over room-and-pillar mining, increased recovery percentages, and better performance in deep seams support increased consideration of the longwall method for U.S. mines having favorable geologic conditions (40, pp. 95-96). Both the mining industry and the Bureau have stepped up efforts to evaluate longwall techniques in a wide range of field demonstrations.

This report reviews longwall mining literature, emphasizing articles describing European equipment and methodology developed during the past decade. The longwall systems and techniques for each country differed due to a variety of natural and human factors. All developments, however, were directed toward a common objective--cost reduction by increased productivity. European engineers have increased face productivity by eliminating bottlenecks through careful operational planning, concentration of workings, and full-face mechanization. Reliable and powerful equipment has been developed for roadway drivage, ground control, and materials handling. Much of this foreign technology can be applied in U.S. mines. Although the longwall method is not the ultimate solution to all underground mining problems, the technology offers significant advantages for mines having favorable geologic conditions.

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APPENDIX A

TABLE A-1. - Examples of Bureau of Mines in-house research seeking to apply longwall, shortwall, or related technologies to improve productivity and safety of U.S. underground coal mines

Project title	Bureau research center performing research	Objectives or conclusions
Shortwall Mining....	PMSRC	Demonstrate, in cooperation with Beth Elkhorn Corp. that the shortwall mining method can reduce roof fall accidents and offer significant economic advantages because of high productivity. The tests are being conducted in the Hendrix No. 22 mine, Jenkins, Ky. (142-144).
Coal Mine Single Entry Study.	SMRC	Test the hypothesis that the single entry system in the Sunnyside mine, Utah, is equivalent to or better than a two-entry system (146-147, 156).
Comprehensive Ground Control Study of a Mechanized Longwall Operation.	DMRC	Perform statistical analysis of ground control data obtained by Harza Engineering under BuMines contract H0230012. Determine optimum face support setting load as a function of pressure.
Delineation of Longwall Mining Ground Control Problems.	PMSRC	Part of research involves development of mine roof simulator. Conduct underground investigations to identify longwall roof control problems of major importance to U.S. mining applications.

APPENDIX B

TABLE B-1. - Examples of Bureau of Mines contract research seeking to apply longwall, shortwall, or related technologies to improve productivity and safety of U.S. underground coal mines

Contract number, title, and contractor	Bureau research center monitoring progress	Objectives or conclusions
H0155092--Development of an Automated Longwall Shearer (NASA-Marshall Space Flight Center, Huntsville, Ala.).	PMSRC	Develop sensors and control mechanisms for a ranging double drum shearer loader.
H0232064--Excavation of Coal Using a High Pressure Water Jet System (University of Missouri--Rolla, Rolla, Mo.).	TCMRC	Establish initial design parameters for a water jet coal cutting head that can be used in a hydraulic jet longwall coal mining system (178).
H0122067--Development of Mine Roof Simulator (Wyle Laboratories, Huntsville, Ala.).	PMSRC	Develop a detailed cost estimate for the construction of a mine roof simulator which could be used as a research tool to investigate artificial roof support methods.
H0252037--Development of a Longwall Water Jet Cutting Machine (University of Missouri--Rolla, Rolla, Mo.).	TCMRC	A followup of the research conducted under contract H0232064. The contractor will develop and field test a longwall water-jet mining machine.
H0242045--Study of Continuous Face Haulage Systems (Joy Manufacturing Co., Pittsburgh, Pa.).	PMSRC	Evaluate concepts such as bridge-conveyor bridge carrier systems, extensible belt conveyor systems, flexible conveyor belt systems, and longwall conveyor systems that have been proposed for continuous face haulage.
S0144074--Demonstration of Tunnel Boring Machines for Coal Mine Development (Eastern Association Coal Corp., Pittsburgh, Pa.).	SMRC	Show that TBM's can be an effective tool for rapid development for longwall mining (53-54, 99).
S0155049--Demonstration of an In Seam Heading Machine (Dosco Corp.).	SMRC	Demonstrate that the Dosco In Seam Miner can facilitate faster, safer entry development for longwall mining (53).

TABLE B-1. - Examples of Bureau of Mines contract research seeking to apply longwall, shortwall, or related technologies to improve productivity and safety of U.S. underground coal mines--Continued

Contract number, title, and contractor	Bureau research center monitoring progress	Objectives or conclusions
H0232053--Wedge Longwall Cutterhead Development--Phase I (Rapidex, Inc.).	TCMRC	Demonstrated that the wedge cutter principle could cut the White Pine siltstone (comp. strength 20,000-28,000 psi) at force levels obtainable from longwall supports (145).
H035700--Evaluation of Coal Thickness Sensors (Foster-Miller Assoc., Waltham, Mass.).	PMSRC	Evaluate existing technology for sensing thickness of coal left on roof after seam has been mined. Adaptability of the techniques to U.S. operations will be assessed.
H0230012--Comprehensive Ground Control Study of a Mechanized Longwall Operation (Harza Eng. Co., Chicago, Ill.).	DMRC	Gather rock mechanics data on operating longwall panels. Analyze bearing capacity of roof and floor rocks.
S0241051--Conceptual Design of an Automated Longwall Mining System (Cominec--Joint venture between Fenix and Scisson, Tulsa, Okla., and Thyssen Schachtbau (GMBH).	DMRC	The design shall resolve questions on the extent and nature of automation and ground control, control and feedback mechanisms, and configuration of the face equipment.
H0133039--Rock Mechanics Study of Shortwall Mining (University of Kentucky, Lexington, Ky.).	PMSRC	Measure subsidence from shortwall mining operations. Relate ground movements and pressures to the physical properties and geologic characteristics of the coalbed and strata at Beth Elkhorn's Hendrix No. 22 mine at Jenkins, Ky.
S0144128--Study of Current Practices in Hydraulic Supply Systems for Longwall and Shortwall Mining Equipment (Dept. of the Navy, Naval Weapons Laboratory, Dahlgren, Va.).	PMSRC	List all known past, present, and proposed longwall and shortwall installations in the United States. Categorize these operations by types of longwall equipment used. Review state-of-the-art of longwall hydraulic supply systems (104).
J0155091--A Demonstration of Longwall Mining (Old Ben Coal Co., Chicago, Ill.).	PMSRC	Demonstrate that longwall methods can be used to successfully extract coal from southern Illinois seams despite previous failures encountered by industry.

U.S. GOVERNMENT PRINTING OFFICE : 1977 O—242-974