PB97-120620

ARTIFICIAL SUPPORTS FOR COAL MINE GROUND CONTROL

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

REPRODUCED BY: NTIS
U.S. Department of Commerce
National Technical Information Service
Springfield, Virginia 22161

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ARTIFICIAL SUPPORTS FOR COAL MINE GROUND CONTROL

INTRODUCTION

Ground control in underground coal mines is accomplished by several means, including basic mine design, excavation sequencing, entry sizing and pillar design, and installation of artificial supports. Support systems must address the basic problem of reducing injuries and fatalities caused by falls of roof during the development of main and gate entries and, later in the mining process, during extraction. The following is a discussion of four types of support systems developed by the U.S. Bureau of Mines for use in both room-and-pillar retreat and longwall mining systems.

- Mobile Roof Support System
- Steel-Fiber-Reinforced Concrete Cribbing
- Yielding Steel Posts
- Lightweight Hydraulic Supports

MOBILE ROOF SUPPORT SYSTEM

BACKGROUND

Retreat pillar mining is highly productive, but dangerous. The primary danger during pillar removal is premature caving of the roof. The roof must cave in a predictable and dependable manner to prevent excessive abutment loads in adjacent pillars, which can result in rib bursts, floor heave, or crushed pillars.

The safety of the miners depends on successful control of the roof. Roof support during retreat is usually obtained by setting posts, cribs, hydraulic props, roof bolts, or a combination of these devices. Because these temporary support devices must be set manually by a miner working in a hazardous area, a system to set and retrieve these roof supports safely was needed.

SYSTEM DEVELOPMENT

The Bureau embarked on a project to develop a system to place and retrieve temporary roof supports without danger to the operator. In conjunction with a contractor, a mobile roof support unit was designed, built, and field tested underground in an Illinois coal mine. The unit was remotely operated, battery powered, and rubber tired. It carried four jacks, two on the body of the unit and two at the end of hinged arms. The jacks extended to form columns between the floor and roof, each with 30 tons of potential support. The jacks could be hydraulically locked and the load distributed to three points on each jack without loading the unit chassis.

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As a result of prototype field testing and concept acceptance, the Bureau decided to build a second-generation unit (fig. 1) that incorporated solutions to problems encountered in the field tests.

A Utah coal mining company offered its mine as a test site. The company was removing 12 feet of a 15-foot coal seam and had a four-member support crew setting posts. At times, this time-consuming and hazardous task occurred under unsupported roof. A mining equipment company offered to supply some of the parts and to assist during design and fabrication of the unit.

During the preliminary design phase, all participants agreed that, in the tram mode, the unit should be 8 feet wide and up to 10 feet long, with at least a 12-inch ground clearance. It should be of rugged construction and have towing hooks on both ends. It should be mounted on independently controlled crawlers that exerted 20 psi or less ground pressure. The unit should be powered by a 40-hp, 460-V alternating current permissible motor from a 260-foot, reeled, trailing cable and transmitter-remote controls. A tramming speed of at least 80 ft/min on 20-pct grade should be achievable and the unit should be reversible and have variable speed. Freewheeling for emergency towing was to be included. Front and back dozer blades having a 12-inch range were required.

The unit was to carry two chassis-mounted jacks and two swing-arm jacks having a working height of 7 to 15 feet. The jacks were to have a 50-ton maximum loading capacity. The swing jacks were to form a breaker row with a 6-foot separation between the chassis jacks and would have a visual load indicator. To deal with heavy ground, the ability to remotely jettison either or both swing jacks was incorporated. The jacks were to be capable of being retracted within 30 seconds to allow the unit to be removed quickly. The mine requested that the unit be remotely controlled by radio.

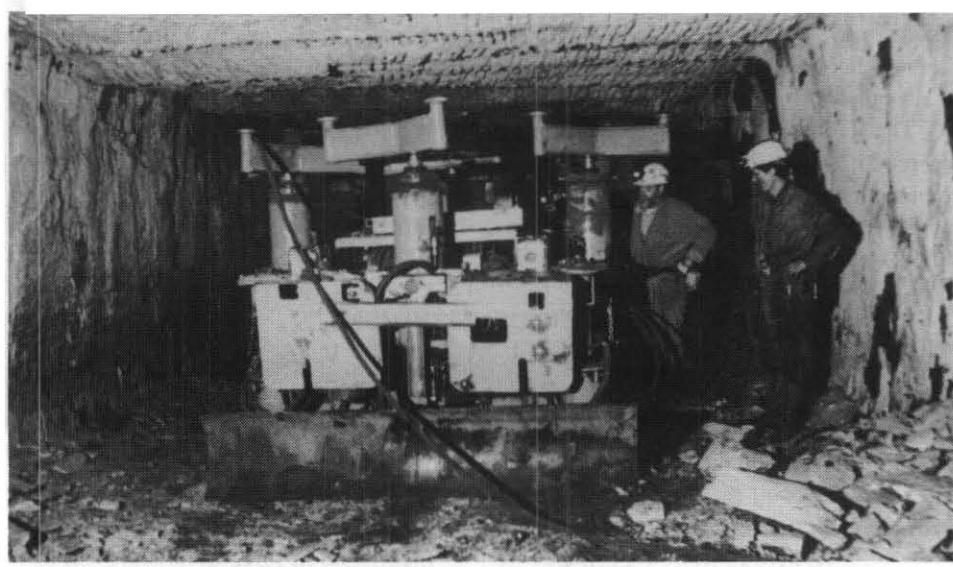

Figure 1.—Second-generation mobile roof support.

UNDERGROUND TESTS

Two second-generation units were shipped to the Utah mine and tested underground for over 3 years. Figure 2 shows the test mine's ground control plan during full-pillar extraction. The plan requires setting 24 posts for pulling each fender. Figure 3 shows the planned sequence of operation using the mobile roof support unit. The unit can be moved and set remotely, thus eliminating miner exposure to unsupported roof when setting the posts.

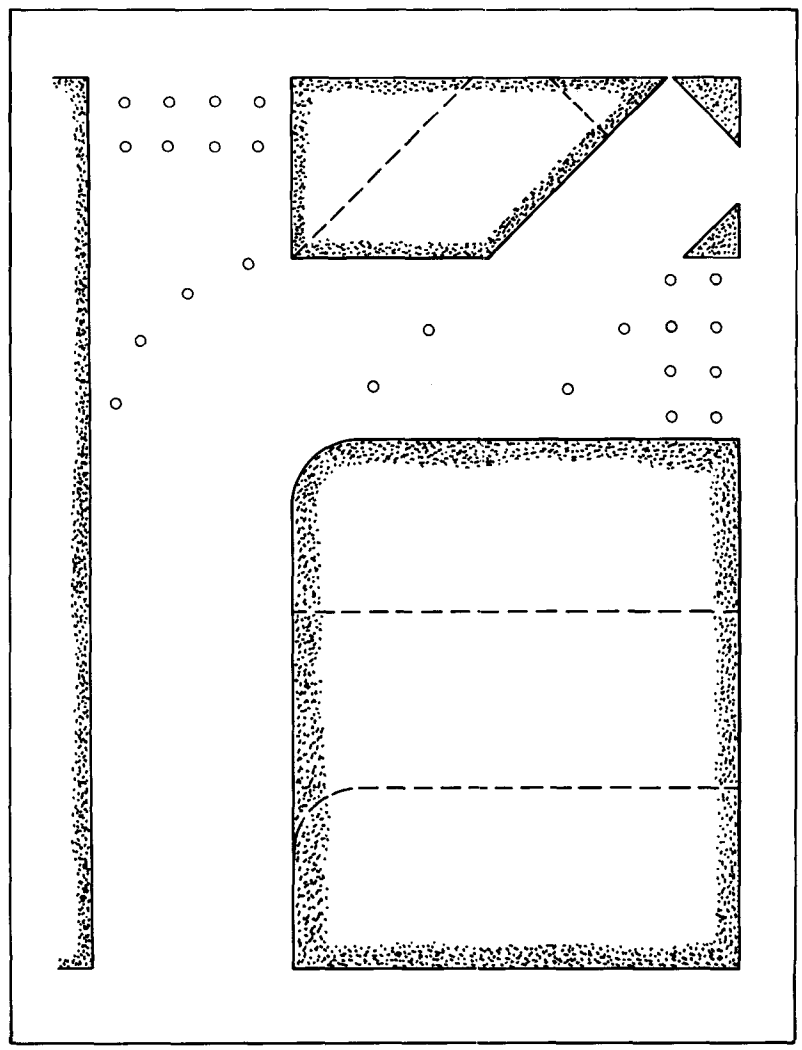

Figure 2.—Ground control plan during full pillar extraction using wood posts and hydraulic jacks. Pillar being extracted is at left. Small circles indicate posts.

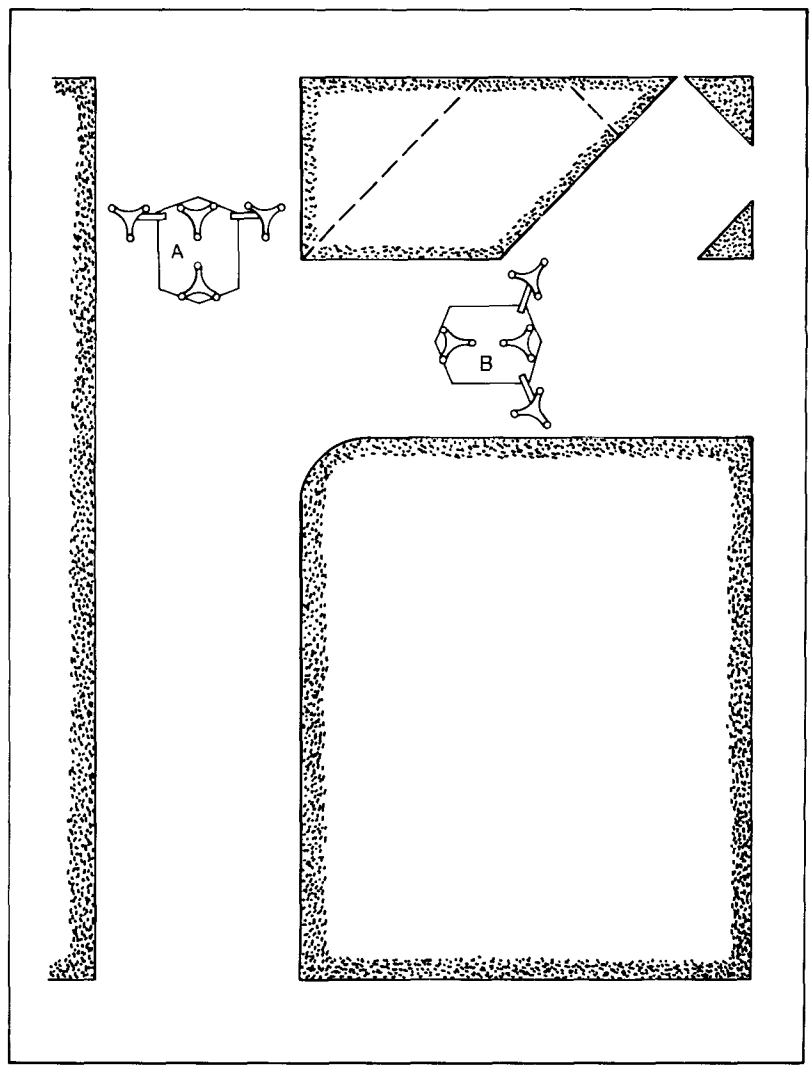

Figure 3.—Sequential operation using two mobile roof support units, A and B (without posts).

SUMMARY

The Bureau designed and built a support system for retreat mining that can be set and retrieved remotely. The system has been tested underground for over 3 years in a Utah coal mine and tests are continuing. This system provides added safety for miners by eliminating the need to set posts, cribs, or hydraulic props in hazardous areas. The unit will also increase productivity, because the number of manual support-setting operations has been decreased.

STEEL-FIBER-REINFORCED CONCRETE CRIBBING

BACKGROUND

Through the combined efforts of the Bureau and private industry, steel-fiber-reinforced concrete (SFC) crib blocks have been developed and are in commercial use to improve coal mine safety in the area of roof control. The development objective was to improve safety conditions with a stiffer, stronger, nonflammable roof support at a competitive cost. During the time this method of roof control has been in use in the mining industry, it has proven to have definite functional and economic advantages.

RESEARCH AND DEVELOPMENT

Most artifical roof support in coal mines consists of roof bolts, wooden posts, and/or wooden cribs. Because wood has many disadvantages, the Bureau initiated developmental research on fiber-reinforced concrete crib blocks as an alternative to wood cribs. Concrete offers a low-cost support and appeared to be the best choice for replacing wood supports if a solution could be found to the problem of poor failure characteristics. It was thought that the addition of fibers to concrete would greatly improve its safety factor by eliminating the possibility of sudden, brittle failure.

Many types of fibers were considered for the initial tests, including glass, asbestos, aramid, nylon, carbon, polypropolene, and steel. Except for steel, all fiber types were eliminated because each had a problem; their mixing characteristics were poor, they were too expensive, they constituted a health hazard, their strength was too low, etc. The steel fibers considered included straight-round, straight-flat, crimped full-length, melt-extracted, deformed full-length, and bent-end types. The bent-end type fiber was selected on the basis of its performance and low cost.

The next step was to select a concrete mix design and determine the quantity of fibers needed for a given mix. The resulting support members offered a significant improvement in stiffness and strength in compression compared with wooden cribs, yet they avoided the brittle or catastrophic compressive failures associated with unreinforced concrete. Full-scale compression tests showed the ultimate compressive strength of SFC blocks to be 4,000 psi, compared with 500 psi for wood. Because eight times more wood is necessary to equal the strength of an SFC crib block, the use of SFC greatly increases the cross sectional area of an opening, allowing personnel, equipment, and air to move more freely. The 4,000-psi concrete was selected as optimum strength because it most closely approximated the strength of a typical roof and floor structure in a coal mine. SFC cribs were successfully installed in a Utah mine and were made part of a single-entry longwall demonstration at that mine. The wood cribs that were being used to support the single entry were not stiff enough to hold the tailgate section of the entry open after passage of the first longwall face.

The prototype blocks made by the Bureau in the research and testing phase were manufactured on a limited, low-volume production basis at a cost of approximately $7 per block. This cost was prohibitive, and a method of mass-producing the SFC blocks was developed in cooperation with private industry. The resulting commercial production technique reduced the cost to about $2.30 per block.

UNDERGROUND TESTS

The Bureau has been involved in cooperative underground evaluations of SFC supports at numerous major mines in all coal-producing areas of the United States. In most cases, the cribs were used in the tailgate section of the entries on longwall panels (fig. 4). Because these installations were very successful, some companies expanded the use of SFC to areas where permanent support systems were required, such as ventilation entries and the bases of ventilation shafts.

In almost all applications, SFC has not only provided added safety, better airflow, and more area for movement, but has also proven cost effective. For example, in a mine using a single row of wood cribs set on 9-foot centers, SFC cribs were installed in a single row on 15-foot centers.

Many of these mines have also found SFC cribs to be efficient in areas where longevity is a factor and, although the cost may be initially higher in some cases, the longer life of SFC cribbing makes it more economical in the long run. The industry has found that where the entries will be maintained for a long time, SFC cribbing is an advantage because of its inherent qualities of stiffness, strength, nonshrinkage, resistance to rot, and nonflammability. Replacement costs of wood cribbing have proven to be very high. In any area

Figure 4.—Concrete cribs supporting tailgate after passage of longwall face in Western U.S. coal mine.

where a wood crib would need to be replaced because of rot and/or failure, the SFC block would eventually prove to be more economical. Figure 5 shows an example of a main haulage entry support.

To date, a combined total of about 300 miles of longwall tailgate, main, and bleeder entries are being supported with SFC cribbing. SFC cribbing has also been used to build stoppings and overcasts where normal cinder blocks have proved ineffective because of crushing. An SFC block is approximately 2.5 times stronger than a typical cinder block and is not subject to brittle failure.

SUMMARY

There is no question of the strength and longevity of SFC cribbing blocks and their success in present installations. Although wood has been the traditional material to use for roof support in the mining industry, the problems of wood supply and cost are increasing to the point where an economic alternative must be found. Concrete products are readily available in all parts of the country. The SFC cribs are proving to be the answer to many roof control problems and are the most economical alternative to wood.

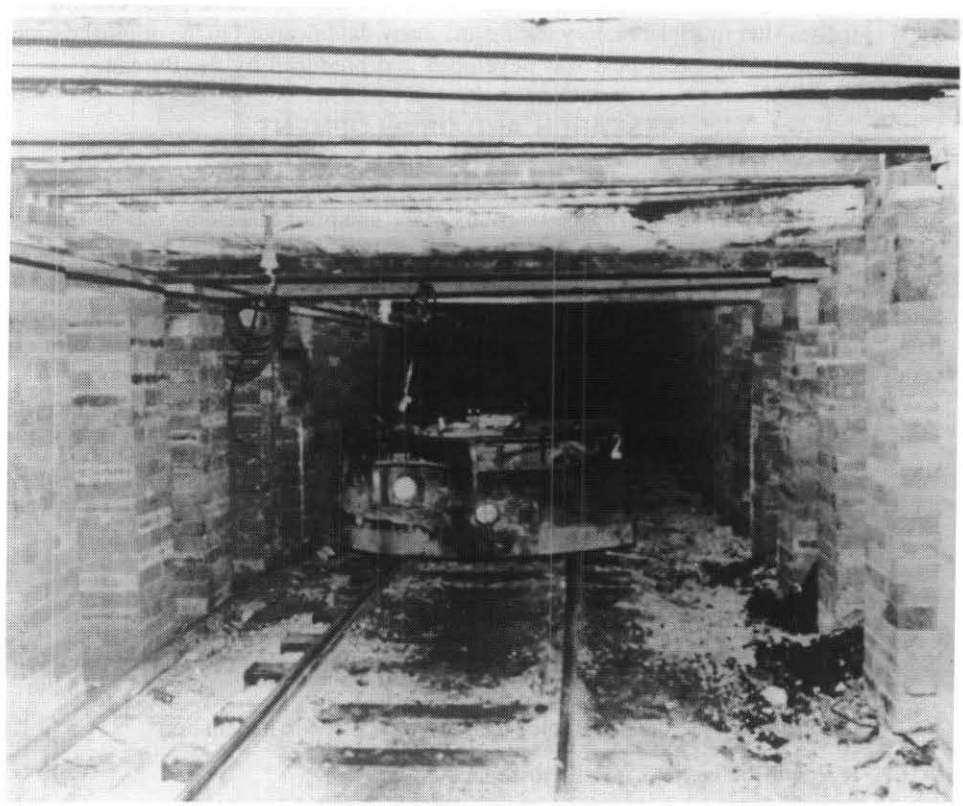

Figure 5.—Solid concrete cribs supporting long-life haulage entry in a coal mine in Pennsylvania.

YIELDING STEEL POSTS

BACKGROUND

Stabilizing excavations in highly yielding rock masses is a problem in underground mining. After an excavation is made, the surrounding strata squeeze into the entry, causing rib slough, roof sag, and floor heave. The squeeze reduces the area available for ventilation and creates a narrower and more cluttered escape path. Most artificial roof support in coal mines consists of roof bolts, wooden posts, and/or wooden cribs, but wood has many disadvantages.

Many underground support problems could be reduced if a simple support post could be designed. Such a support would need to have an equal or greater load capacity than wood, a consistent yield mechanism, and a substantial yield length. It should be easily installed and relatively inexpensive.

Several design approaches were pursued by the Bureau to develop a stiff support member capable of supporting high loads and yet having the ability to yield in a controlled manner before failure. The most successful was based on tube expansion theory where an oversized ring is forced into the inside diameter of a thick-walled pipe, causing it to yield radially. After much laboratory testing and many modifications to the original designs, a three-piece yielding steel post was developed and produced by the Bureau.

RESEARCH AND DEVELOPMENT

The design was determined from a combination of performance, handling, fabricating, and economic considerations. The load capacity of the unit prior to yielding was also studied. To meet the preliminary design requirements, the sizes and properties of the wood and steel column-type supports currently being used in coal mines had to be studied. Factors such as typical mine roof and floor compressive strengths, the average longwall mining height for Western U.S. coal mines, and the range of overburden pressures were also taken into account.

Ease of handling was also important, so the weight of the post was restricted to what a single miner could physically lift and place in an underground environment. Special installation equipment was to be avoided because of economic restraints and the lack of working space in an entry. Both the fabrication and material cost of the post were evaluated at the same time. Other design requirements for the unit were—

1. It must have at least a 50-ton capacity.
2. It must maintain a controlled load over a closure of up to 6 inches.
3. It should be easy to manufacture, ideally in a mine shop.
4. Its operation should be simple, to help prevent poor installation.
5. It should be easy to install, to reduce cost.
6. It should cost less than $200 to manufacture.

After the design requirements were established, appropriate materials were selected and the yield mechanism was developed. Following the evaluation of wood, steel, concrete, and composite materials, steel was selected. It is readily available, has high strength characteristics, is nonflammable, and is relatively inexpensive.

The most successful design consisted of an expansion (interference) ring welded to the outside surface of a smaller pipe. The two pipes are forced together until the ring causes the larger pipe to deform radially (fig. 6).

During initial prototype testing, it was found that a large number of variables affected the performance of the post, including pipe wall thickness, angle of the expansion ring bevel, angle of the flaring mandrel, and the amount of interference between the expansion ring and the yield leg.

Many of these variables and design problems had been recognized at the outset of research. However, as the prototype came closer to meeting original support design specifications, the material and mechanical limits of the post became more critical. Ultimately, the test results led to the development of a functional post design that could be used in highly yielding ground.

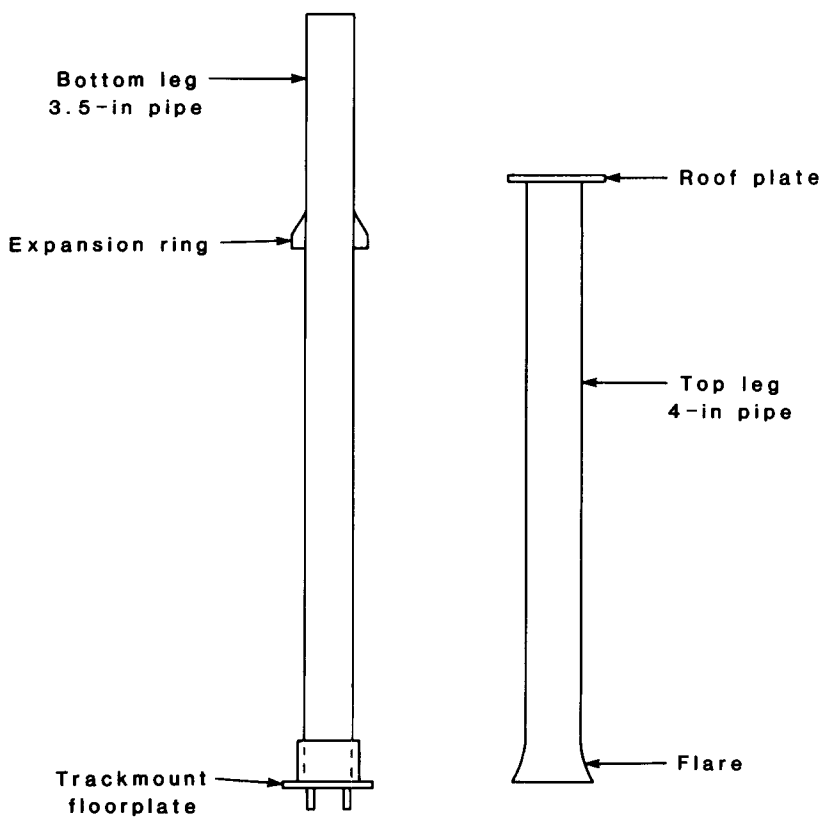

Figure 6.—Components of prototype yielding post.

FIELD TESTS

The field test criteria required that the test mine have high loads and a large amount of roof-to-floor closure. The mine chosen to meet these specifications had 1,500 to 2,500 feet of overburden and used the retreat longwall method of mining. The gate roads are used twice during their lifetime: first as the headgate and then as the tailgate for the adjacent panel. To reduce entry closure, the operator must install double and triple rows of cribs. Even with massive cribbing, there is still a great deal of floor heave between the cribs.

The mine management cooperated with the Bureau by providing advance information concerning the test site, as well as by providing a mine crew to install the posts and to monitor the site visually when Bureau personnel were not present. The mine also obtained the Mine Safety and Health Administration permit required for an experimental support system. Bureau personnel provided the yielding posts, mapped and measured the site, coordinated the installation, and retrieved test site data after the posts were installed.

The yielding posts were placed in two test sections. In the first section, 10 posts were installed alongside the wooden crib line. The success of this test and discussions with mine management led to a larger scale test, where 84 yielding steel posts were placed in two different configurations along 187 feet of headgate entry (fig. 7).

Figure 7.—Field test of yielding posts in coal mine headgate entry.

SUMMARY

Laboratory and field tests have shown that the yielding steel post is a workable mechanism for supporting ground. Data from the tests support the following conclusions and recommendations:

1. When the posts are used in a floor-beam system adjacent to a crib line, middle-floor heave is reduced.

2. A two-rail system is better than a one-rail system in that it eliminates the need for cribs on the coal rib side of the next longwall panel. However, support is still needed on the chain pillar side.

3. To control column buckling and roof punching, a 45-ton load capacity is a reasonable upper limit for a yielding steel post in the 6- to 7-foot range.

4. Pipe specifications must be rigidly controlled when ordering materials to build the units. Wall thicknesses must be in excess of 0.226 inch and A-120 pipe must be used.

Use of the posts with rails to form floor beams appears to be a very promising procedure. Aside from metallurgical problems with some pipe welds and thin walls of the foreign-made pipe, the system functioned well. The field test showed that the two-rail system was superior to the one-rail system in that it provided more floor-bearing area.

LIGHTWEIGHT HYDRAULIC SUPPORTS

BACKGROUND

Placing temporary roof support is an integral part of underground coal mining. Historically, wooden posts, metal screw jacks, and, more recently, telescoping hydraulic supports are used for this purpose. Wooden posts are time-consuming and cumbersome to install, they are not consistent in size and strength, and they also represent a sizable cost. Screw jacks, while easier to install, have no yield capability and are prohibitively heavy where high-strength supports are required. The all-hydraulic, telescoping cylinder support remains the best choice for reusable temporary support.

There are now on the market various hydraulic supports made of steel tubing and steel components that perform very well as temporary support. Unfortunately, because of increasing support-load requirements and the thicker coal seams found in the West, these steel supports are becoming extremely heavy and cumbersome to use. A support rated at 22 tons and used in a 6- to 8-foot coal seam weighs over 110 pounds. The same type of support designed for use in a 12-foot seam weighs approximately 300 pounds.

To eliminate these constraints, the Bureau funded a contract to review state-of-the-art technology in lightweight hydraulic cylinder design in an effort to construct a high strength-to-weight ratio, yielding, temporary roof support.

RESEARCH AND DEVELOPMENT

A review of previous work in the area of lightweight supports as well as existing commercially available materials and products identified the following major desirable design features:

1. A 22-ton capacity.
2. A goal weight of 50 pounds.
3. Controlled yielding at overload.
4. Fully self-contained; i.e., integral reservoir and pressurization.
5. Remotely recoverable.
6. Easily and quickly installed.

Of the two concepts considered, one totally hydraulic and the other hydromechanical, the all-hydraulic version (fig. 8) was selected for prototype production and testing. Although the hydromechanical support was lighter in weight, it was rejected because of its mechanical complexity, cost, and complexity of installation in a mining situation.

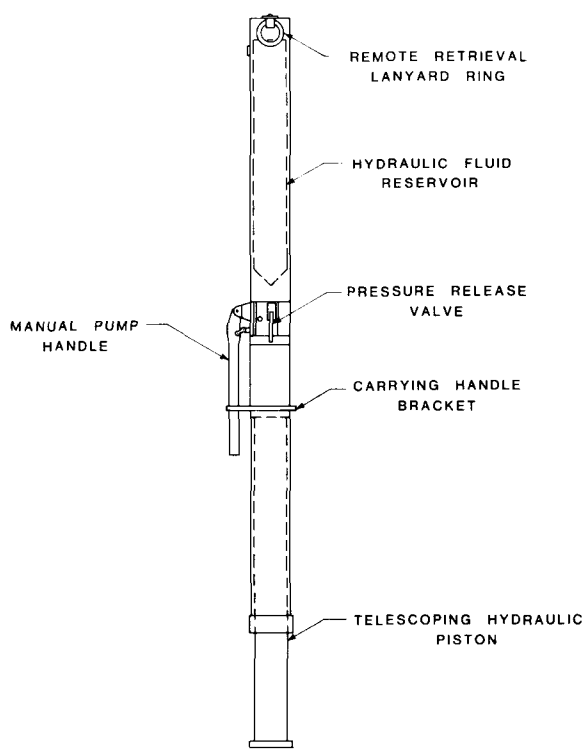

Figure 8.—Components of lightweight hydraulic support.

Four prototype models of the all-hydraulic lightweight support were fabricated to determine if the design was feasible. Based on value and manufacturing engineering considerations, some design changes were then made. Additional changes were found to be necessary during assembly and testing. Chief among these was modifying the pump block assembly and redesigning the main cylinder. Two supports were tested to ultimate load failure to determine ultimate column strength.

Following the completion of successful tests of the models, a production lot of additional supports was constructed (fig. 9). Ten of these supports were provided to each of four different mines for a 6-month demonstration and evaluation period.

UNDERGROUND TESTS

Three mines, two in Colorado and one in Utah, received the props for underground testing. Each mine was given 10 supports to use under actual mining conditions.

At the test site in eastern Utah the supports were incorporated into a continuous mining development section. The miners used the lightweight supports continuously and felt

Figure 9.—Hydraulic support weighs 55 pounds, can be extended from a 6-foot to an 8-foot length, and has a load capacity of 22 tons.

they were superior to what they had been using as far as handling and setting were concerned. Six of the supports were left, fully loaded, across an entry for 3 months during a strike with no failures.

The site in western Colorado used eight units as part of its longwall tailgate support plan. The only problems encountered were one broken pump handle and one sticking release valve. The supports were also used in various applications such as setting brattice curtain lines, setting chain-link fence at pillar ribs, and in longwall panel development work.

At the third test site, located near Grand Junction, CO, the supports were used in development work. In order to work in the 8.5-foot coal seam, a 2-foot steel extension was added to the support. The supports were used in slow development work for about 8 months, after which most of the units needed some repair. Problem areas were failure of the main seal, a sticking pressure release valve, and failure of a pressure pump piston. These supports were sent back to the Bureau for inspection and rebuilding.

SUMMARY

In the three mines, all comments about the test were positive. In all cases, both miners and management liked the supports and wanted to continue to use them. Although several areas of weakness became evident, they were not major problems. It should be noted that although the duty-cycle was only about 6 months, the problems exhibited were similar to those affecting supports currently on the market.

For more information on these systems, contact.

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