OPTIMIZING SECONDARY TAILGATE SUPPORT SELECTION

by

Cary P. Harwood, Jr.

Thesis submitted to the Faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

IN

MINING AND MINERALS ENGINEERING

APPROVED:

Dr. Christopher Haycocks
(Chairman)

Dr. Michael Karmis
(Head of the Department)

Dr. Gerald Luttrell

12 June 1996

Blacksburg, Virginia

Keywords: Coal Mining, Longwall, Tailgate, Secondary Support, Capacity

OPTIMIZING SECONDARY TAILGATE SUPPORT SELECTION

by

Cary Harwood

Dr. Christopher Haycocks, Chairman

Department of Mining and Minerals Engineering

ABSTRACT

A model was developed to facilitate secondary tailgate support selection based on analysis of a data base of over 100 case studies compiled from two different surveys of operating longwall coal mines in the United States. The ALPS (Analysis of Longwall Pillar Stability) program was used to determine adequacy of pillar design for the successful longwall case histories. A relationship was developed between the secondary support density necessary to maintain a stable tailgate entry during mining and the CMRR (Coal Mine Roof Rating). This relationship defines the lower bound of secondary support density currently used in longwall mines. The model used only successful tailgate case history data with adequate ALPS SF according to the CMRR for each case. This model facilitates mine design by predicting secondary support density required for a tailgate entry depending on the ALPS SF and CMRR, which can result in significant economic benefits.

ACKNOWLEDGMENTS

The author would like to extend his appreciation and gratitude to committee chairman Dr. Christopher Haycocks for his guidance, support, and constant motivation throughout. The valuable review and comments of Dr. Michael Karmis, Head of the Department and committee member, and Dr. Gerald Luttrell, committee member, are also gratefully acknowledged.

Table of Contents

LIST OF FIGURES

List of Tables

CHAPTER 1

Introduction

Maintaining a stable tailgate during mining is a major concern for modern retreating longwalls. Adequate support capacity is needed to ensure that the tailgate remains open in order to prevent the high costs associated with down-time, serious injury or loss of life, and the possible permanent stoppage of the longwall panel. Traditional methods of secondary tailgate support typically involve large quantities of timber installed as cribs while the opening is still a headgate. When the tailgate panel is properly designed for local conditions, the supports are often over-designed and will experience loading far below their capacity, therefore representing a waste of money. When heavy loading does occur, the cribs may be distorted or destroyed to the point where tailgate closure is imminent and continued operation of the longwall panel is in jeopardy. To minimize either of these possibilities, support must be custom-designed to meet the projected strata and loading conditions for each panel. The primary goal of this research is to develop a model to optimize support selection and application while minimizing its cost. Existing systems of secondary tailgate support have been identified and classified according to their support responses. Numerical modeling has identified optimum location for the support, and this research will be aimed at optimizing selection of secondary support systems.

A quantitative selection process for choosing the appropriate amount of wooden cribbing for a particular tailgate entry is not available. Wooden cribs are typically installed in the tailgate based on previous experience and without regard to conditions that may vary along the gateroad. Typical support placement is constant throughout the entire tailgate entry, even though the immediate roof conditions may be diverse. Additionally, secondary support type and layout are influenced by the experience gained from the performance of the panel. In the case of a successful panel, it is not evident whether a lesser quantity of support could have achieved the same results. Where mines have encountered cases of unsuccessful support, it is probable that an excessive amount of support has been added to avoid future failures. Typical support placement does not vary between panels and only changes when differing roof conditions become visually evident. A system, or protocol, for selecting secondary support density could reduce the high costs associated with over-supporting a tail entry and allow for changing density to conform to varying roof conditions.

CHAPTER 2

Review of Literature

2.1 Introduction

Since the introduction of the modern longwall coal mining method into the United States during the early 1960's, little has changed with respect to overall panel layout and longwall equipment. However, fine tuning combined with increased computer control of the longwall mining process has increased production rates, improved efficiency and alleviated the need for numerous operating personnel. The trend today is to increase panel width and length for higher extraction ratios, and to extend the time and production between longwall face moves.

In the Appalachian coalfields of the Eastern United States, retreat longwall mining is the only type of longwall system in use. Advancing longwall mining has been used in the Western United States and is commonly used in Europe. Both have advantages and disadvantages, but retreat longwall mining has proved to be more conducive to the mining experience and geological conditions found in the Appalachians.

Advancing longwall mining requires no pre-development around the perimeter of the longwall panel. Figure 2.1.1 illustrates a typical advancing longwall layout. Because this method does not require development ahead of the working face, the initial investment is much smaller when compared to retreat longwall mining. Additionally, the coal can be

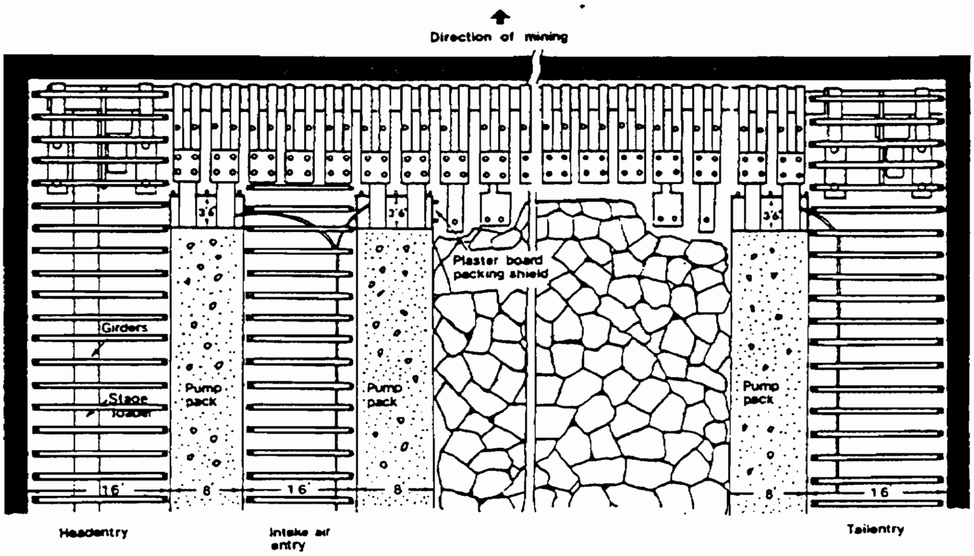


Figure 2.1.1 Illustration of advancing longwall mining method (Peng and Chiang, 1984).

produced for sale much sooner when using advancing longwall mining (Peng and Chiang, 1984).

The retreat longwall mining method requires that entries be driven around the length and width of the panel. Figure 2.1.2 represents the most common layout for a retreat longwall coal mine. This method has been used successfully in the Western United States in seams dipping as much as 27° - 33° (Peng and Chiang, 1984). Initial investment is higher than with the advancing longwall, as the entries must be driven by continuous mining equipment, and the coal in the longwall panel cannot be extracted until the entries are completed. The entry arrangement of the retreat longwall method is somewhat more complex than the advancing method since additional entries must be created for ventilation and transportation purposes.

The retreat longwall mining method does have the advantage of providing first-hand information on geological conditions throughout the entire length and width of the panel. This early information is very important if adverse geological conditions are discovered, such as faults, rolls, or pinch-outs. Entry maintenance is easier in the retreating method than the advancing method since the entries are developed in solid coal. This is in contrast with the artificially supported entries in advancing longwall mining formed from packwalls as the face progresses. Such entries are more costly and, at times, more difficult to maintain. It is therefore easier in the retreating method to maintain entries which meet current laws for transportation of mine personnel, ventilation, and haulage (Peng and Chiang, 1984).

The direction of the working face advance is controlled in the retreat longwall method, since the face always follows the headgate and tailgate pre-developed entries. The direction of an advancing longwall face must be frequently surveyed to ensure that the heading is correct and to control the face width. The advancing longwall method, however, will realize a higher coal recovery than the retreating method since a lesser amount of in-situ coal must be left behind to maintain the gateroads.

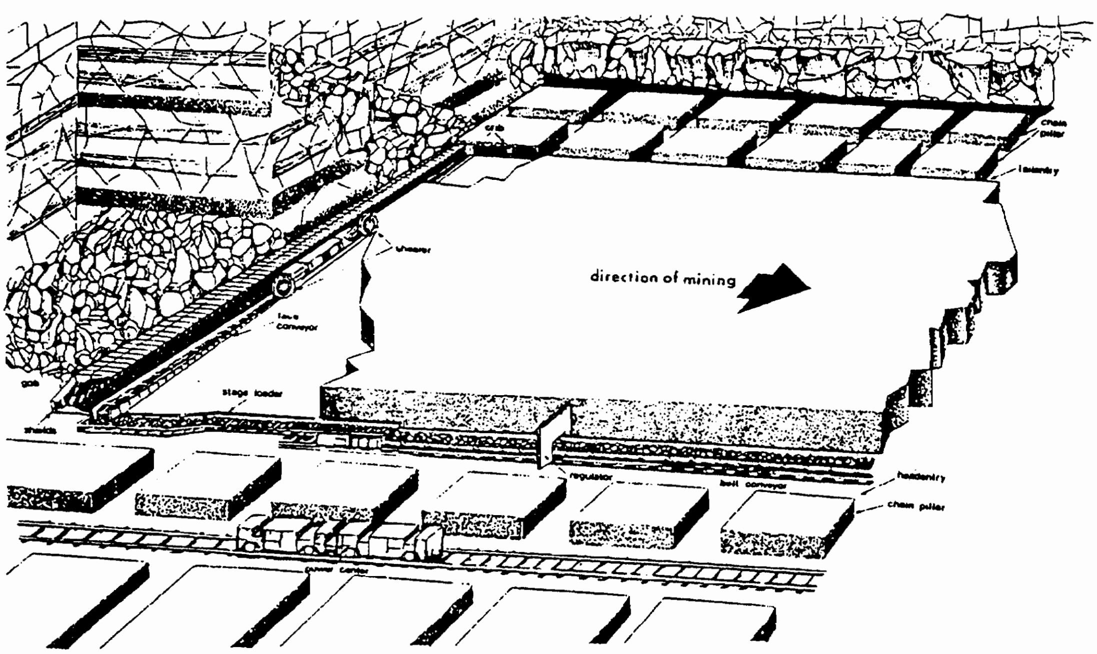


Figure 2.1.2: Cutaway view of a typical longwall panel and gateroads during retreat longwall coal mining (Peng and Chiang, 1984).

The tailgate entry in retreat longwall mining experiences very large loads as the working face of the panel retreats. This is due to overburden loads received from both the current panel and the adjacent, previously mined-out panel area. High stresses on supporting coal pillars and both horizontal and vertical roof movement typically require installation of large quantities of supplemental support in the tailgate entries.

Wooden cribs installed throughout the length of the entry are the most common type of secondary tailgate support. During the summer of 1993, 76 mines and 86 longwall panels were surveyed to determine trends in longwall tailgate support. It was concluded that 86% of the mines surveyed utilized wooden cribs for providing secondary support in the tailgate entry (Peng and Biswas, 1994). The most common configuration was a 4-point crib installed in a two-row parallel arrangement centered throughout the length of the gateroad.

The increasing cost and decreasing supply of hardwood timbers has led to the development of numerous new types of supports incorporating many different materials. Experience, cost, and performance are the driving factors influencing most the selection of secondary support systems. At the current rate of cost increase for wooden crib material, other support materials may be more competitive in the near future.

2.2 Geology

2.2.1 Overburden

The depth of overburden for longwall coal mines in the United States, according to a 1995 U.S. longwall census, ranges from 150 feet up to 2,700 feet (Fiscor and Merritt, 1996). The coal height in seams currently being longwalled in the Eastern United States ranges from 36 inches to 132 inches. Western United States longwall mines encounter seams heights as great as 276 inches.

Considerable effort must be given to determining the characteristics of the rock material above and below a coal seam, as well as of the coal seam itself. Geological information about the rock strata around a coal seam is typically obtained from rock-core samples produced by vertical drilling from the surface. A good understanding of the strata conditions from the surface to the coal seam can be determined from borehole logging. Trends in the rock material and seam thickness can be followed by interpolation between boreholes (Peters, 1992).

Rock strata above the coal seam and mined openings is typically sub-divided into two categories, the immediate roof and the main roof. The immediate roof lies directly above and is in contact with the coal seam. The main roof consists of the rock material from the top of the immediate roof to the surface. Figure 2.2.1 illustrates the location of the immediate roof and main roof with respect to the coal seam and the longwall face. The reaction of the two roof categories to longwall coal extraction is different with respect to caving and subsidence.

The immediate roof-rock material lies directly above the coal seam and will cave into the gob area immediately following the advance of the longwall-powered supports (Peng and Chiang, 1984). The make-up of the immediate roof can range from thin shale layers to massive sandstones and can extend up to approximately fifty feet above the coal seam. Mine entries today range from 16 to 22 feet in width, with the immediate roof entirely exposed. The immediate roof usually will not span the entire width of the entry for long periods of time without some form of artificial support. Primary support, usually in the form of steel roof bolts, is installed in the lower portion of the immediate roof to form a beam from several thin rock stratum. This beam composed of several layers is intended to span the entire width of the entry without failure of the rock material. The primary support installed in mined openings is usually sufficient for supporting competent roof in entries that are not adjacent to caving areas. The headgate and tailgate entries, however, which are directly affected by the longwall caving areas, must be equipped with additional support systems. The weight of the immediate roof must be supported by secondary

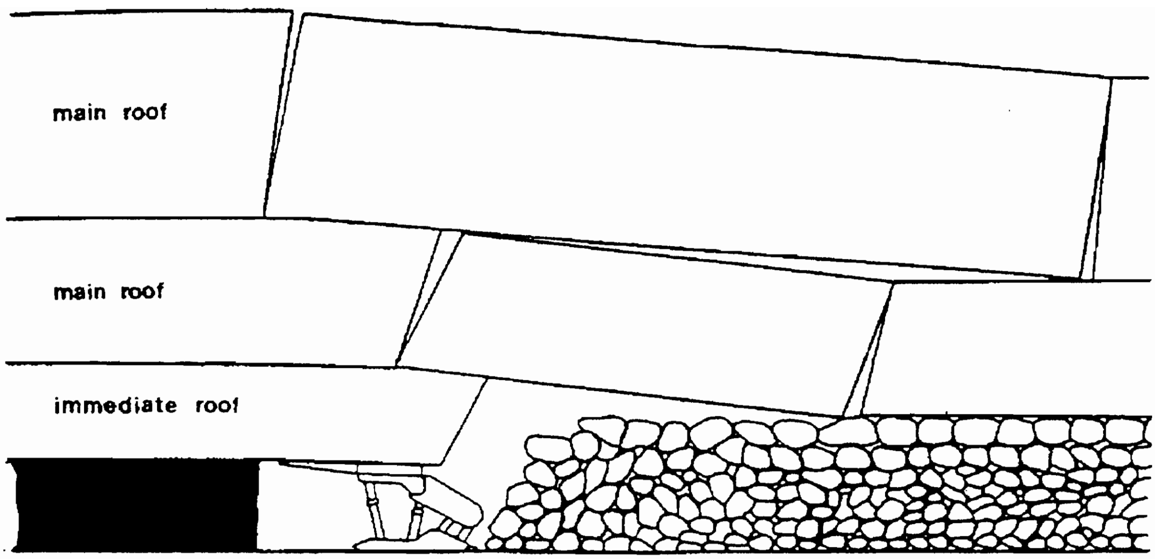


Figure 2.2.1: Location of immediate roof and main roof rock strata with respect to the coal seam and the longwall face (after Peng and Chiang, 1984).

support along the gateroads and by powered supports along the longwall face. The immediate roof in this area will cave immediately following the advance of the powered longwall supports and will load permanent, secondary support along the gate entries slightly ahead of the face. By supporting the immediate roof and keeping it just in contact with the main roof, the integrity of roof material above mined openings can be maintained until the support is removed. Once the material has caved it can no longer transmit any horizontal forces, causing the stresses to redistribute throughout the intact strata.

The entry most affected by the caving gob is the tailgate entry which lies between a panel currently being mined and the gob area of the previously extracted panel. Figure 2.2.2 illustrates the location of the headgate and tailgate entries and the excessive loading in the critical pressure-abutment zone. This zone, which lies in the tailgate entry, receives load from the previously extracted panel as well as from the panel currently being mined. Tailgate entries are typically equipped with large quantities of secondary support for maintaining the immediate roof until the working longwall face has passed. Once the face has passed a support installed in the tailgate entry, the immediate roof caves and the support is buried in the gob area. The relatively short lifespan and the non-recoverable nature of secondary tailgate support requires the cost of support to be as low as possible.

The main roof, which lies directly above the immediate roof and extends to the ground surface, does not cave immediately after the advance of powered supports but tends to subside relatively intact over mined areas. The portion of the main roof which lies directly above the immediate roof will fracture and cave to some extent, as it settles on the gob area of the extracted panel. Figure 2.2.3 represents the respective locations of the three zones of movement encountered during longwall panel extraction.

Coal seams are typically overlain and underlain by differing lithologic units which can directly affect mine planning and layout. Investigation of the floor and roof material is very important prior to extracting a longwall panel. Much data can be collected on the surrounding rock characteristics during the development phase of a panel in retreat longwall mining. Once the development has been carried out, mining dimensions are fixed

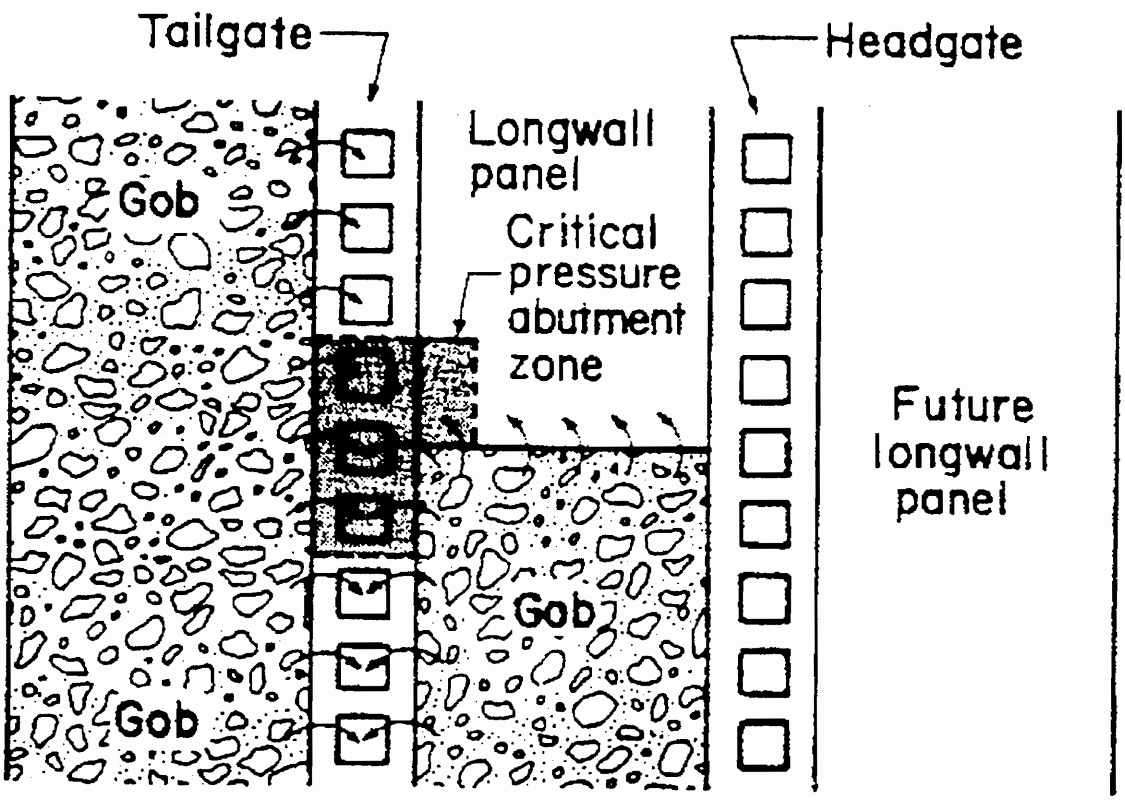


Figure 2.2.2: Location of headgate and tailgate entries and critical pressure abutment zone with respect to the gob area of a previously mined panel and a future longwall panel (Kripakov et al., 1990).

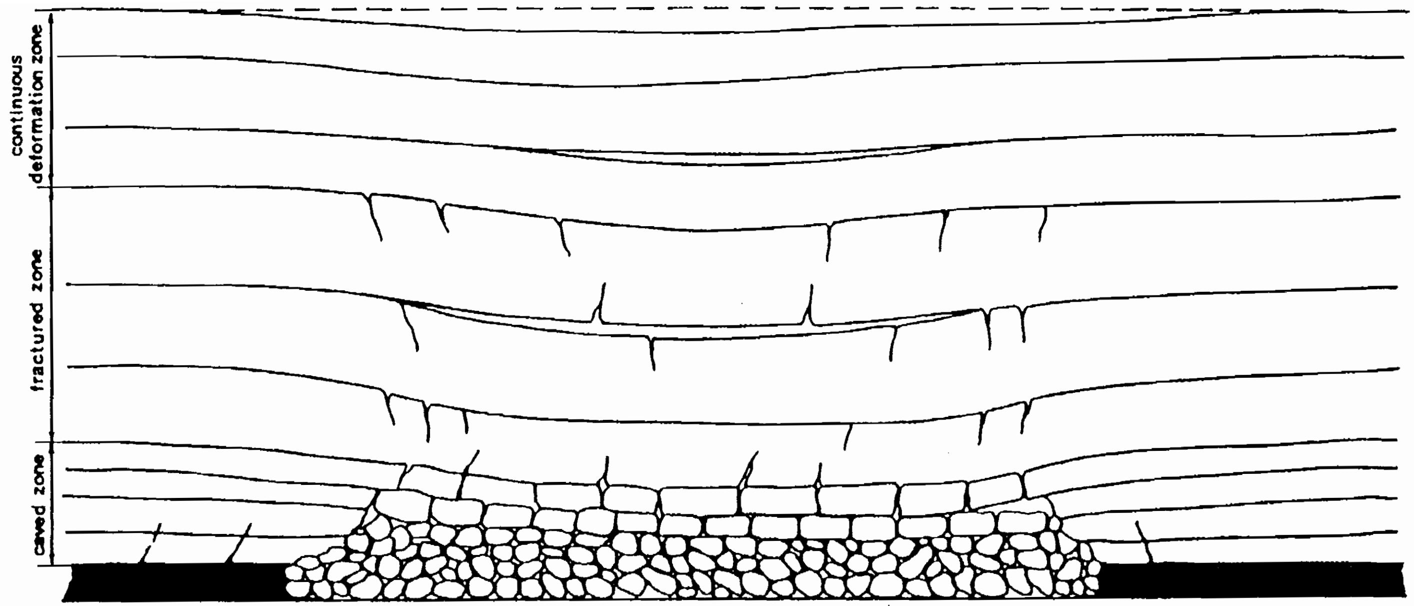


Figure 2.2.3: Three zones in overburden movement as a result of longwall mining (Peng and Chiang, 1984).

and cannot be changed to suit the new information on geology or structure. Instead, the information collected during development can be used to determine other mining factors, such as support density. Figure 2.2.4 is a classification of five different roof types commonly found above coal seams. The characteristics of each roof type will vary depending on the thickness and uniaxial compressive strength of the immediate roof, the ratio of the thickness of the immediate roof to the mining height, and the thickness and tensile strength of the main roof.

2.2.2 Roof Classification

A roof classification system has been developed by the United States Bureau of Mines (USBM) to classify rock masses in coal mine roofs. The CMRR (Coal Mine Roof Rating) is used to assign a strength rating to the immediate roof for the purpose of mine design and roof-support selection. The CMRR determines the structural competence of mine roof rock primarily by investigating the discontinuities that weaken the rock fabric. The CMRR differs from other rock classification systems in that it is unique to coal mine roofs through the following contributions (Molinda and Mark, 1994):

(1) It is specifically designed for bedded coal-measure rocks.

(2) It concentrates on the bolted interval and its ability to form a stable mine structure.

(3) It is applicable to all U.S. coal seams.

(4) It provides a methodology for data collection.

Data for CMRR calculations can be collected from any exposed roof surfaces, such as roof falls, overcast cuts, or highwall exposures. Core logs and borescope test holes are also used for generation of CMRR input data (Mark and Molinda, 1996). From the rock surfaces or logs, information is collected on rock intervals with distinct structural

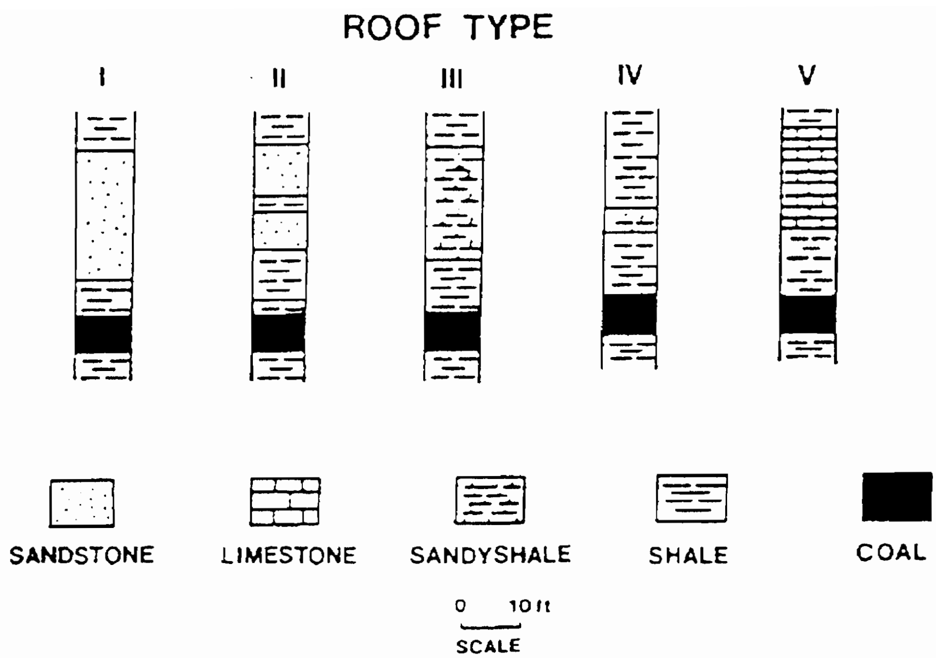


Figure 2.2.4: Five different roof types commonly encountered in underground coal mining (Peng, Hsiung, and Jiang, 1987).

characteristics. Discontinuities are recorded as well as their spacing, roughness, and orientation relative to the heading. Cohesion of the bedding planes or discontinuities are determined and a description is made of the contact surface. The strength of the intact rock is determined and a test is made to determine the sensitivity of the rock with respect to moisture. Appendix A contains field data sheets for determining CMRR.

A computer program for calculating the CMRR has also been developed which allows the user to input raw field data from a geological investigation to calculate the CMRR and provide two graphic displays. From this program, a link can be established between a qualitative geological description of the coal-mine roof and quantitative engineering needs for mine design, roof-support selection, and hazard detection (Riefenberg and Wuest, 1994).

2.3 Roof Loading

During extraction of a longwall panel, the tailgate entry will experience both horizontal and vertical strata movements. Stress redistribution will occur continuously as the immediate roof material caves and the main roof strata deforms. Extremely large abutment pressures are a result in both the coal pillars and the roof material directly above the coal. The load distribution is not uniform across the gate entries, nor is it uniform along the length of the gateroads. Figure 2.3.1 illustrates the idealized state of vertical stress distribution during extraction of a typical longwall panel. Tailgate entries receive stress increases from both the previously mined panel as well as the adjacent panel currently being extracted. The loads experienced by the tailgate entry are generally higher than those experienced by the headgate entry, since the tailgate is nearest the gob of the previously mined panel. The stress transferred from a mined longwall panel extends over the gateroads along the side of the caved zone and into the unmined panel. The extent of

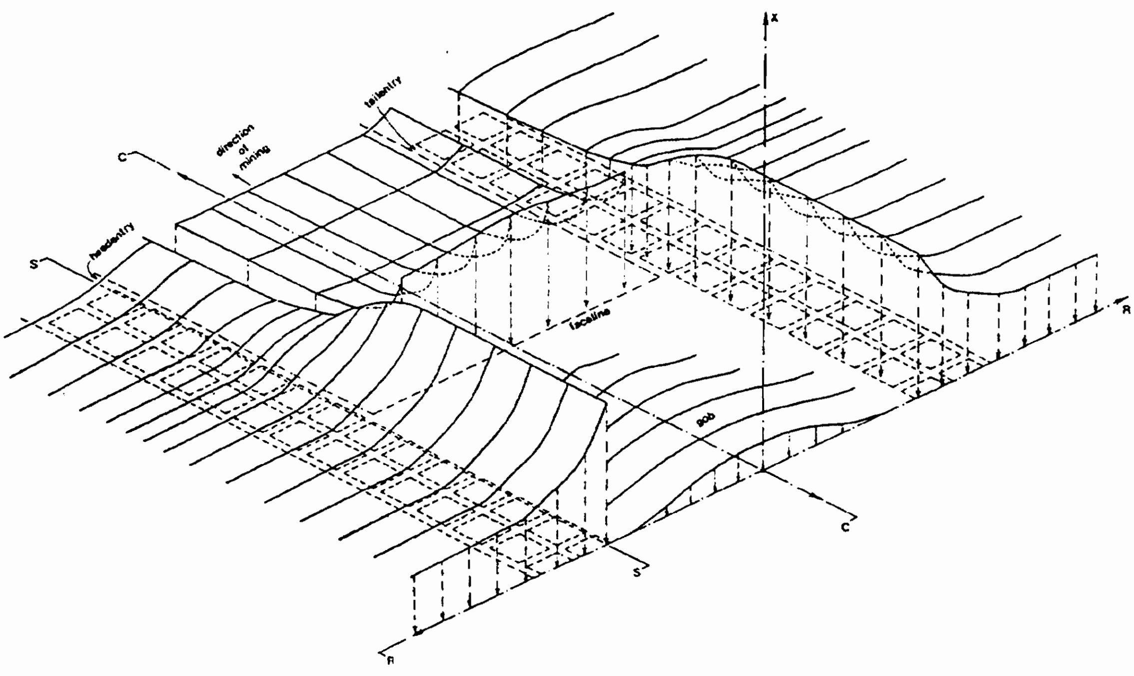


Figure 2.3.1: Idealized state of vertical stress around a longwall panel (Peng and Chiang, 1984).

the influenced zone can be found using equation 2.1: where D is the distance outward from the mined panel and h is the depth of overburden,

$$D = 9.3 \bullet \sqrt{h} \text{ ....(2.1)}$$

where:

D = extent of influenced zone from edge of longwall panel (ft)

h = depth of overburden (ft)

The stress values within the influence zone decrease as the distance from the edge of the longwall panel increases. The stress values in the abutment zone have been found to decay according to the inverse square of the distance from the panel edge (Mark, 1990). Figure 2.3.2 illustrates the decreasing abutment stress values as the distance from the mined longwall panel increases. Outside of the abutment or influenced zone, the state of stress is that of the virgin stresses prior to any influence of mining.

Typical tailgate entries are cut 16 to 20 feet in width and are most commonly supported by two parallel rows of four point wooden cribs. The cribs provide passive support as the degrading roof mass over the gateroad relaxes vertically and horizontally toward the gob area. Ideally, the crib supports will keep the roof material sufficiently intact and in place until the powered supports of the longwall face have passed. The immediate roof material supported by the secondary supports will then be allowed to cave behind the shield supports.

2.4 Current Tailgate Support Systems

Today, many support types and configurations exist, composed of a variety of materials. The goal of each support type and configuration is to provide the most effective tailgate support at the lowest possible cost for material and installation. Many of

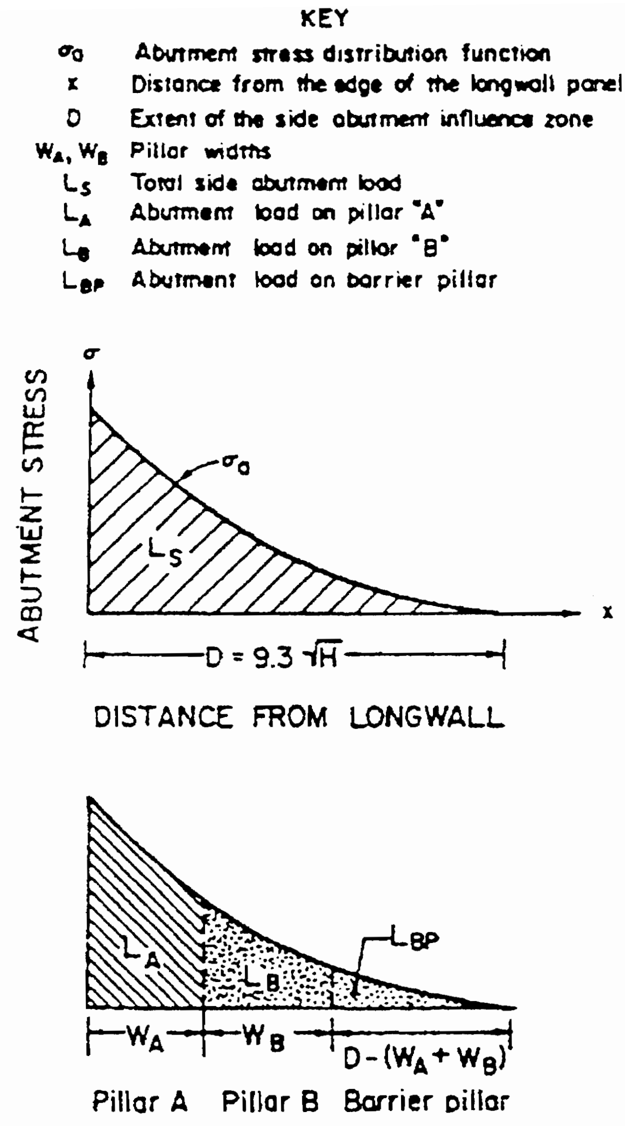


Figure 2.3.2: Side abutment stress decay function (Mark, 1990).

the materials used in the past for support purposes are becoming more difficult to obtain and less economically attractive.

2.4.1 Concrete Support Systems

Concrete support systems for mine-roof support were developed to overcome the relatively low load capacity of wooden support systems and their dramatic displacements under very high stresses. Because concrete has a much higher modulus of elasticity than wood, the support is much stiffer and under compression will deform very little. Concrete supports are generally of a crib or column configuration, constructed of several preformed members or sections. Concrete is also pumped into place underground to form supports. Concrete support members are typically reinforced with small steel fibers imbedded within the concrete to improve their tensile strength. Concrete admixtures and air-entrainment have been used to reduce the stiffness of the support and increase its post-failure load-carrying capability as well as the workability of the material in underground pouring.

Concrete is an excellent building material because it can be formed in a wide variety of shapes and textures for use in an unlimited number of applications. Since concrete is a manmade material, many of its properties and characteristics can be controlled and modified to achieve specific results. By simply controlling the water content added to concrete mixtures, the following advantages can be obtained (Kosmatka and Panarese, 1988):

(1) Increased compressive and flexural strength.

(2) Lower permeability, thus increased watertightness and lower absorption.

(3) Increased resistance to weathering.

(4) Better bond between layers and between concrete and reinforcement.

(5) Less volume change from wetting and drying.

(6) Reduced shrinkage-cracking tendencies.

Other properties can be altered by the use of air-entrainment or various concrete admixtures. Admixtures are commonly added to the concrete mixture to adjust various physical properties such as the setting time and hardening, water demand, and workability. Mechanical properties such as the compressive strength of a concrete mixture can be controlled to cover a large range of applications. General use concrete compressive strengths range from 3000 psi to 5000 psi while high strength concrete mixtures possess a compressive strength of 6000 psi to 20,000 psi. Even greater compressive strengths, up to 25,000 psi, have been achieved for special applications.

Concrete supports in general reach failure at less than 2% strain and essentially lose all load carrying capability beyond 5% strain (Barczak and Gearhart 1994). After failure of a concrete support, very little post-failure load carrying capacity is realized. If premature failure of the support occurs, roof falls could lead to entry closure. Because concrete supports are much stiffer than wooden supports, their usage as secondary tailgate support is limited to mines where main roof movement over the gateroad entries is minimal. The increased stiffness of concrete supports does however have the advantage of providing immediate substantial support to reduce the delamination of the roof strata. Concrete supports also do not shrink after installation, unlike many wooden supports, making the material attractive with respect to labor requirements for retightening supports.

Concrete support systems have four main disadvantages (Barczak and Gearhart 1994):

(1) The tensile strength of concrete is less than 10% of its compressive strength.

(2) Concrete structures fail from tensile stresses in a brittle and sometimes violent manner.

(3) Concrete is susceptible to stress concentrations produced by boundary contact conditions.

(4) The density of concrete provides weight handling limitations for support design.

Additionally, preformed concrete supports are somewhat fragile when compared to wooden supports. While wooden support members can generally be handled roughly, the integrity of concrete members can be harmed easily by the rough handling of underground mining equipment.

In many cases, concrete support systems can become more compatible with roof movement by incorporating wood into the support composition. Wood is typically inserted at the top of the support at the mine-roof interface, and at a thickness of twice the expected distance of roof and floor convergence. This helps to ensure that the support will not fail prematurely during roof and floor convergence. When wood is incorporated into a concrete support as described above, the initial deformation of the support under load will be controlled by the wooden members.

Concrete has been used extensively in conjunction with timber in supporting stopes in deep-level, hard-rock breast stoping operations in South Africa (Wilson, 1975). Testing of wood-concrete composite cribs was carried out during the 1960's in Johannesburg, South Africa. It was concluded that, by using a composite of concrete and wood in alternating layers, the compressive strength and the stability of the crib could be greatly increased (Wilson and Emere 1972). As a result, roof movement in the South African mines could be controlled to a higher degree even at great depths.

Typical concrete support systems are in the shape of square or cylindrical columns. Other systems incorporate the use of cloth bags filled with aerated cement to form a support column, and vertical, concrete-filled steel pipe sections. Most types of concrete support systems incorporate other materials in conjunction with the concrete to achieve increased deformation abilities and greater post-failure load-carrying capabilities.

2.4.1.1 Steel-Fiber-Reinforced Concrete Cribs

Steel-fiber-reinforced-concrete cribs (SFC cribs) resemble the standard wooden crib in appearance and installation procedure. Most SFC cribs exhibit a square geometry in the plan view and can be constructed in a 4-point, 9-point, or greater interlayer-contact point configuration depending on the individual member dimensions. Figure 2.4.1 illustrates a four-point SFC crib. The SFC crib blocks are preformed off-site with consistent block dimensions and a weight of approximately 45 pounds per block. As shown in Figure 2.4.1, the face with the largest surface area is used to gain the largest interblock contact area possible in order to provide the highest load capacity. Each SFC block is reinforced with fine steel fibers to increase the tensile strength of the concrete. Dissimilar to the wooden cribs, SFC cribs do not require the crib members to have overhanging ends on each layer.

Figure 2.4.2 illustrates a nine-point SFC crib. Because the length of the individual crib blocks are insufficient to leave space between the blocks in each layer, the crib can be considered a solid or closed SFC crib. Because of their much larger contact area with the roof and floor, closed SFC cribs are more likely to encounter point loading than the four-point SFC cribs. Tests have shown that if one corner of a four-point or open SFC crib fails from point loading, then the remaining three will still support load. The closed SFC cribs, when subjected to point loading, tend to allow the propagation of failure throughout the entire crib (Tanious, Beckett, and Bollinger, 1984).

Wood is commonly used in conjunction with concrete cribs, usually placed between the top of the crib and the mine roof. The wood serves two main purposes: to tighten the crib against the mine roof and to allow for some vertical deformation of the crib if desired. The wood placed on the support and roof interface will deform under load to more evenly spread loading across the top of the support. This will decrease the chances of point loading due to the irregular surface typical of mine roofs.

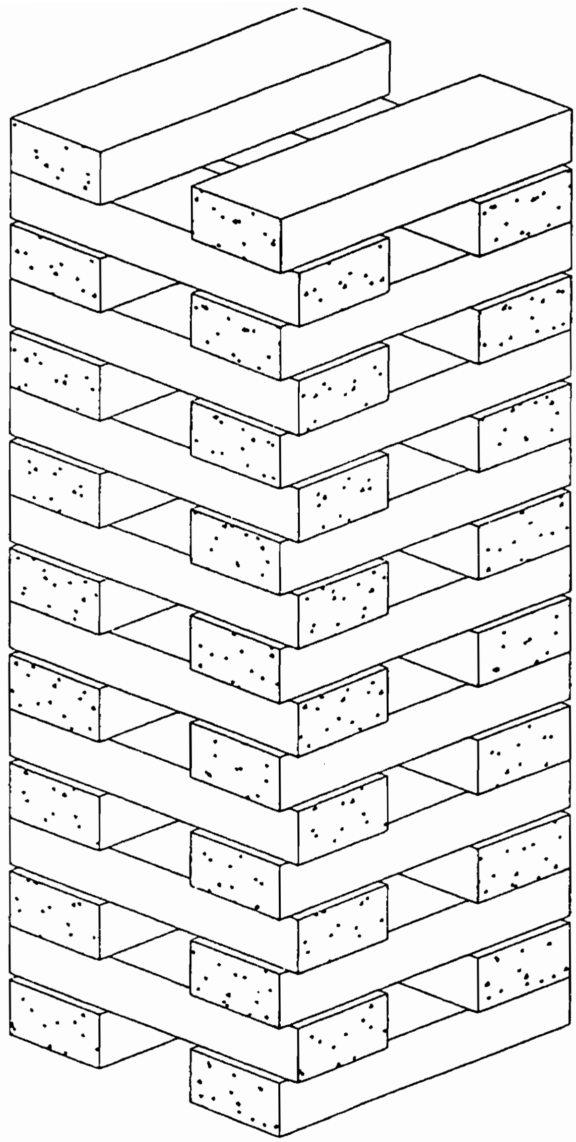


Figure 2.4.1: Four-point steel-fiber-reinforced-concrete crib.

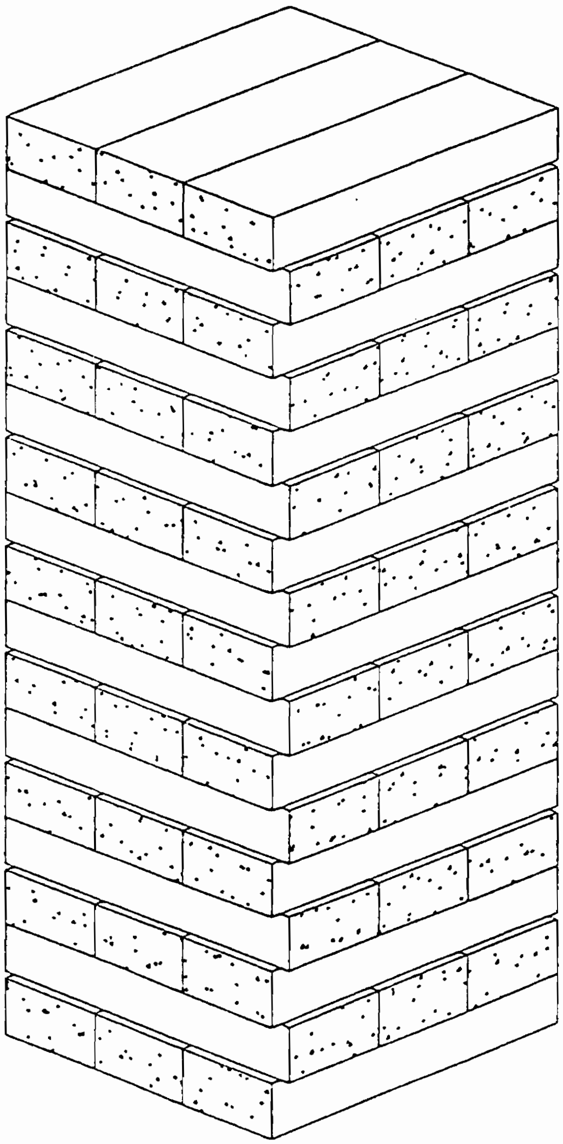


Figure 2.4.2: Nine-point or 'solid' steel-fiber-reinforced concrete crib.

Crib compressive strengths cannot be accurately measured simply by surface contact area and the compressive strength of the concrete mixture. The actual load-carrying capacity of SFC cribs must be determined through the testing of each different crib geometry and the different concrete mixtures used. Testing of SFC cribs requires that the support material be tested in the same fashion as it would receive load once installed underground. ASTM testing standards used a cylindrical test specimen to determine the compressive strength of the concrete used to form the individual crib blocks. An extreme variance in actual crib-test compressive strength and ASTM concrete-cylindrical-specimen compressive strength was realized. The crib compressive strength as determined during testing proved much closer to actual installed crib compressive strengths due to the irregular contact surfaces between the roof and crib. The surface irregularities of the roof and floor caused high stress concentration points on the crib, leading to premature failure and reduced load-carrying capacity. A typical range of values for a SFC crib load capacity would be approximately 440 kips to 1040 kips, with a displacement at yield of only 0.8 to 1.4 inches (Barczak and Gearhart, 1994).

During the summer of 1993, a survey of 86 longwall panels was conducted in the United States to determine general use of primary and secondary support systems. It was concluded that less than 2% of the mines surveyed utilized SFC concrete cribs for providing secondary support in the tailgate entry (Peng and Biswas, 1994).

2.4.1.2 Donut Cribbing™ and Disc Cribbing™

Other types of reinforced concrete cribbing are the Donut Cribbing™ and Disc Cribbing™ manufactured by Commercial Pantex Sika, Inc. These forms of cribbing offer support advantages similar to the SFC concrete cribs with respect to capacity and vertical displacements. These cribs, form a cylindrical column as three-inch thick discs are stacked on top of one another from the mine floor to roof. A 22-inch diameter column is the result, usually tightened by wood wedging at the crib and roof interface.

Similar to the SFC cribs, wood blocking is placed at the top of the support to allow for vertical convergence of the mine roof and floor. Commercial Pantex Sika, Inc. recommends using one inch of wood blocking for every foot of crib height. Additionally, the concrete donuts and discs require load-transfer discs to be placed in the crib between every three or four courses that are laid. The load-transfer discs are 1/8 inch-thick fiber shims that allow equal distribution of load throughout the interlayer contact area. Figure 2.4.3 shows the location of the load-transfer discs with respect to the donut crib layers.

Disc cribbing comes in the form of solid discs, to provide 40% more bearing area than the Donut Cribbing for use in areas of extremely high loading. Donut Cribbing weighs 56 pounds per unit and Disc Cribbing weighs 84 pounds per unit. Similar to the SFC cribs, the donuts and discs are pre-cast off-site with reinforcement added to them for improved tensile strength. The dimensions of the disks are strictly controlled to assure consistent thickness of each unit in order to reduce the possibility of point loading.

The cylindrical shape of the cribbing is beneficial for ventilation air flow when compared to a support of square geometry, as the smooth, round, regular outside surface of the crib reduces the frictional drag associated with square crib supports. The flat top and bottom surfaces of the cribbing also help to eliminate the point loading between crib members which can occur in SFC crib loading.

2.4.1.3 Other Concrete Support Systems

Many other concrete support systems have been designed to meet requirements for secondary tailgate support. Such systems are, for the most part, composed of a composite of both steel and concrete elements. Typically, a steel casing or pipe is filled with hydraulic cement to form a vertical column. This design has met some success with controlled failure through several inches of vertical displacement. Other methods have included the use of used automobile tires for the confinement of a vertical concrete column (Barczak and Gearhart, 1994).

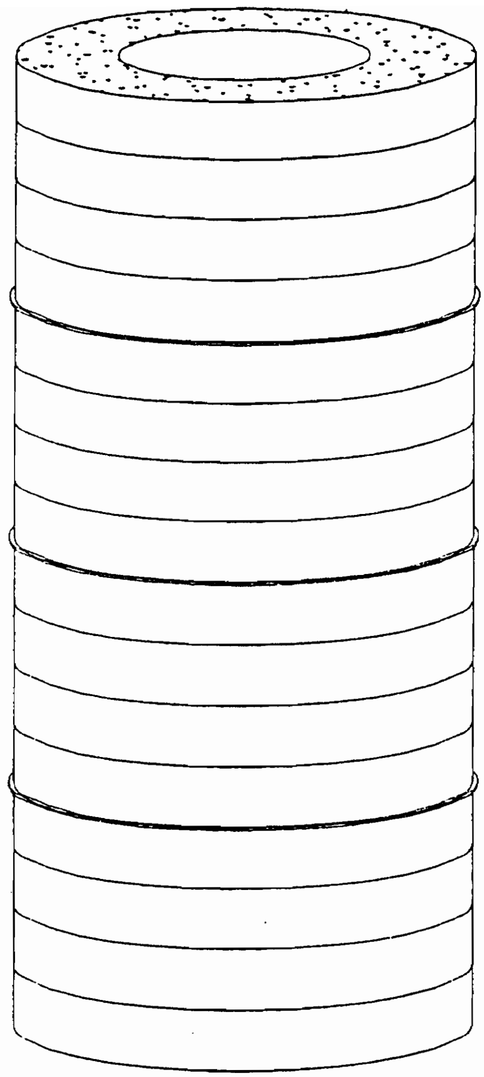


Figure 2.4.3: Donut Crib™ constructed of concrete rings and load transfer disks placed between every four layers.

2.4.2 Wooden Support Systems

Wooden support systems are by far the most frequently used type of secondary tailgate support. In 1994, 93% of longwall coal mines surveyed in the United States utilized wooden secondary support systems in tailgate entries. The external wooden supports, when properly designed, offer adequate support from immediate roof dilation as well as floor heave in the tailgate opening. Although these are among the most common support types, the increasing price of timber is driving the industry to design supports which require a lesser quantity of wooden materials. High costs are also sparking renewed interest in other materials for the replacement of wood in secondary support systems.

A large variety of wooden support configurations are available for secondary tailgate-support purposes. The supports can be of the standard wooden crib type and configuration or one of many various prefabricated systems. Additionally, the quantity and orientation of timber incorporated into the support can be varied to achieve specific results.

Wooden cribs are typically constructed of hardwood or a mixture of hardwoods (deciduous trees) because of their higher compressive strengths when compared to softwoods (coniferous trees). It is worth noting that some softwoods actually possess higher compressive strengths than do some hardwoods, but softwoods are much more valuable as a residential and commercial construction material than as a cribbing material. Table 2.4.1 lists some mechanical properties of commercially important hardwoods commonly grown in the eastern United States and used in crib construction. Table 2.4.2 lists the same properties for softwoods grown in the eastern United States. For posts, timbers, and crib members which are used to support load in a vertical orientation, the compressive strength parallel to grain (F_c) should be considered. Timber which is loaded perpendicular to grain, as it is in standard wooden cribs, should use the perpendicular-to-grain compressive strength ($F_{c\perp}$) for design loads. Values are given for dry service conditions and do not account for defects in the wooden members such as checks, knots,

Table 2.4.1: Mechanical properties of some commercially important hardwoods commonly grown in the Eastern United States (Forest Products Laboratory, 1989).

Wood Species	Compressive Strength parallel to grain F_c (psi)	Compressive Strength perpendicular to grain $F_{c\perp}$ (psi)	Specific Gravity G
Ash, Black	2300	350	.45
Ash, Green	4200	730	.53
Ash, White	3990	670	.60
Aspen, Bigtooth	2500	210	.36
Aspen, Quaking	2140	180	.35
Basswood, American	2220	170	.32
Beech, American	3550	540	.56
Birch, Sweet	3740	470	.60
Birch, Yellow	3380	430	.55
Butternut	2420	220	.36
Cherry, Black	3540	360	.47
Cottonwood, Eastern	2280	200	.37
Elm, American	2910	360	.46
Elm, Rock	3780	610	.57
Elm, Slippery	3320	420	.48
Hackberry	2650	400	.49
Hickory-Pecan, Bitternut	4570	800	.60
Hickory-true, Mockernut	4480	810	.64
Hickory-true, Shagbark	4580	840	.64
Honeylocust	4420	1150	.60
Locust, Black	6800	1160	.66
Maple, Black	3270	600	.52
Maple, Red	3280	400	.49
Maple, Silver	2490	370	.44
Maple, Sugar	4020	640	.56
Oak-Red, Black	3470	710	.56
Oak-Red, Northern Red	3440	610	.56
Oak-Red, Pin	3680	720	.58
Oak-Red, Scarlet	4090	830	.60
Oak-Red, Southern Red	3030	550	.52
Oak-White, Bur	3290	680	.58
Oak-White, Chestnut	3520	530	.57
Oak-White, Overcup	3370	540	.57
Oak-White, Post	3480	860	.60
Oak-White, Swamp White	4360	760	.64
Sweetgum	3040	370	.46
Sycamore, American	2920	360	.46
Tupelo, Black	3040	480	.46
Walnut, Black	4300	490	.51
Willow, Black	2040	180	.36
Yellow-Poplar	2660	270	.40

Table 2.4.2: Mechanical properties of some commercially important softwoods commonly grown in the Eastern United States (Forest Products Laboratory, 1989).

Wood Species	Compressive Strength parallel to grain F_c (psi)	Compressive Strength perpendicular to grain $F_{c\perp}$ (psi)	Specific Gravity G
Baldcypress	3580	400	.42
Eastern Redcedar	3570	700	.44
Hemlock, Eastern	3080	360	.38
Pine, Eastern White	2440	220	.34
Pine, Pitch	2950	360	.47
Pine, Virginia	3420	390	.45
Spruce, Black	2840	240	.38
Spruce, Red	2720	260	.37
Spruce. White	2350	210	.33

splits, and shakes. The values listed for compression perpendicular to grain are actually the stress at the proportional limit because there is no clearly defined ultimate stress for this property.

The strength values can also be affected by the duration of applied load. Wood is unique in that it can support higher stresses when loads are applied for short periods of time. Permanent loads applied for long periods of time tend to reduce the load-resisting capability of wooden structures. Figure 2.4.4, the Madison Curve, shows a correction factor that is used in wooden-structure design for sustained loading on wooden members. The graph simply shows that wooden members can withstand higher loads for very short periods of time as opposed to loads that are applied long-term. For this reason, cribs may resist higher applied loads immediately after roof dilation, but will continue to creep as the load remains on the cribs for a long period of time. Tests of how the load rate effects the support capacity of wooden cribs have been conducted by the U.S. Bureau of Mines (Barczak, and Schwemmer, 1988). Figure 2.4.5 shows the impact of load rate on stiffness characteristics of wooden crib specimens. The tests concluded that the load-carrying capacity of a wooden crib was indeed time-dependent. Laboratory load testing of cribs was conducted at a much faster rate than actual conditions underground, therefore wooden cribs would have less load-carrying capacity when loading occurs in the tailgate entry (Barczak, and Schwemmer, 1988).

Wooden supports have many advantages and disadvantages when compared to other commercially available support systems. Wood has the advantage of being able to deform both vertically and horizontally, and still remain stable. Wood is also a material that can be readily handled by workers for long periods of time, since it typically weighs less per unit than many other support systems. It has been easily obtainable for many years but is becoming increasingly higher in price especially, the species that possess higher compressive strengths. Wooden support systems provide both visual and audible signs of loading, which is a much desired characteristic in a secondary support system.

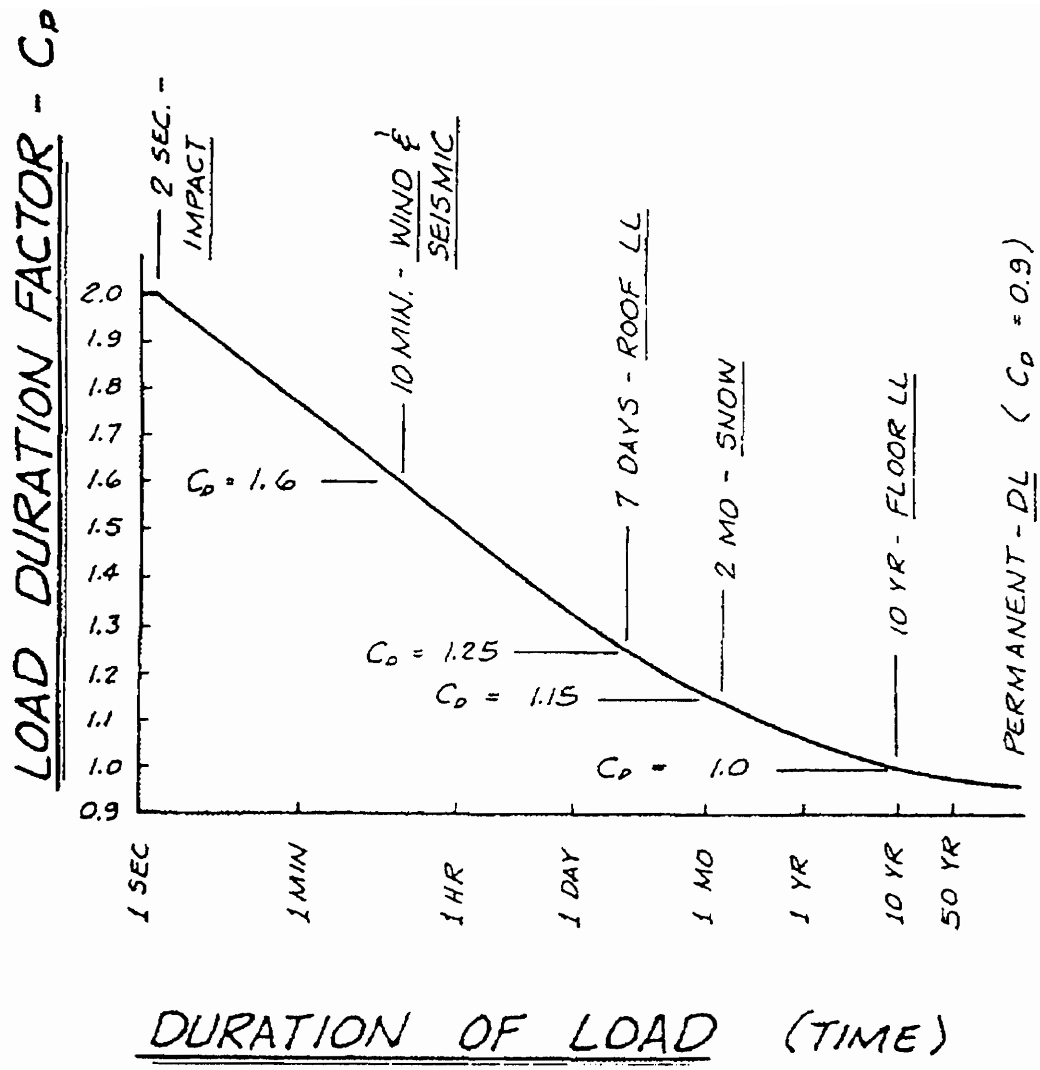


Figure 2.4.4: Madison Curve showing correction factors (C_D) used in wood structure design depending on the duration of the applied load (Breyer, 1993).

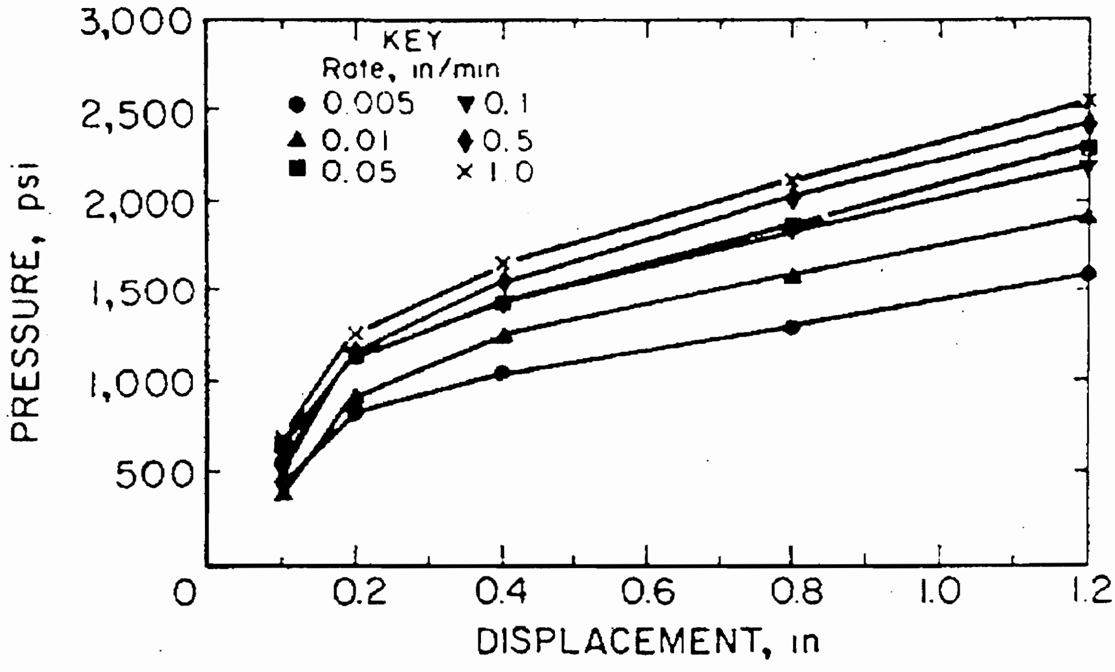


Figure 2.4.5: Impact of load rate on stiffness characteristics of wooden crib specimens (Barczak and Schwemmer, 1988)

Additionally, wooden support materials are not fragile and can be roughly handled by underground equipment to a great extent without harming the integrity of the material.

The disadvantages of wood, however, are as numerous as the advantages. Shrinkage, a problem unique to wooden supports, must be dealt with often to ensure that the support will resist load early during the movement of the immediate roof and mine floor. After wooden supports are installed, they are usually tightened by using wooden wedges or groutable bladders placed between the top of the support and the mine roof. Tightening of the support allows the support to take some initial loading and stabilizes the support. If the wood is unseasoned or "green" when installed, noticeable amounts of shrinkage will usually take place as the wood dries out. The supports must then be tightened again to account for the vertical relaxation of the support from the mine roof. If re-tightening does not occur before roof or floor movement is realized, the rock will be allowed to dilate to a greater extent and roof falls or floor heave could result. Even after re-tightening of the support, wood still provides a very low early resistance to roof sag and floor heave until the support has undergone substantial deformation. Wood tends to shrink less than 1% parallel to grain, while the shrinkage perpendicular to grain can be as much as 12%.

Wood also has the disadvantages of being both flammable and biodegradable. Flammability does not present a problem with support performance, unless of course it is exposed to heat or flame. This characteristic can be dismissed unless one is considering support performance under unusual circumstances, where mine fire is a possibility. Biodegradability can, however, present a significant a problem in wooden support performance. Decomposition of the wood material will often take place before the support is installed, occurring before the tree is timbered or while the support material waits for long periods, exposed to the elements, before shipment or installation. Once installed wooden supports usually begin to dry or season as large amounts of ventilating air pass through and around the support. If this decomposition has occurred, the support can often be expected to perform in a sub-standard manner, depending upon the extent and location of the decay. In many instances, lack of quality control on the part of the manufacturer can be blamed for poor-quality or defective wood being shipped for support use. Excessive defects in cribbing material will naturally lower the performance and load-resisting capabilities of the support.

Cribbing materials used as secondary tailgate supports are usually comprised of a mixture of hardwoods that are native to and common in the areas surrounding the coalfields. In the Eastern United States, there are over 40 different types of hardwoods that can be timbered to produce cribbing material. Each species of tree possesses different mechanical properties, as shown in Table 2.4.1, and cribs are often constructed of several different species of timber. When this occurs, the capacity and performance of the crib is usually based on the member with the lowest compressive strength as a conservative estimate. Performance and capacity of the crib are also dependent on the interlayer contact between the members of the support. If the member dimensions are not equal, then the smallest interlayer contact area must be considered for support capacity. Unequally dimensioned cribbing material can be a result of using batches obtained from different manufacturers or even different batches obtained from the same manufacturer at different times. Blocks of equal dimensions should be used in the same layer, and the dimension permitting the largest interblock contact area should be used to maximize load capacity.

Wooden supports must remain in a certain height-to-width-ratio range to ensure that the support remains stable when loading occurs. The aspect ratio should remain in a range of approximately 2.5 to 5.0 to provide predictable performance (Barczak and Gearhart, 1993). Additionally, cribs should be constructed with overhanging ends to reduce the possibility of shear failure of the crib members. An overhang of one-half to one times the member thickness is a generally accepted range of values for incorporation into crib design.

The geometry of wooden cribs is also of importance when considering stability. The most stable design (as determined through testing) is one which exhibits a square geometry in the plan view. Altering the geometry will inevitably change the moment of inertia of the crib. Since crib-load carrying capacity is estimated from the minimum moment of inertia, a rectangular crib and a square crib with the same minimum moment of inertia will have the same load capacity. The square crib will consume less material than will the rectangular crib, so the square crib is a more efficient configuration for the same support potential.

A crib of a rectangular geometry can be incorporated within the mine entry if poor roof quality requires a larger contact area between the crib and the mine roof. The long axis of the rectangular crib should be placed across the entry and centered to provide symmetrical support of the opening. The rectangular crib will increase the roof area coverage but can only be expected to perform as well as a square crib of the same smallest dimension (Barczak, Schwemmer, and Tasillo, 1989).

2.4.2.1 Standard Wooden Cribs

The most common types of cribs used as secondary tailgate support are the standard wooden cribs, constructed in a four-point, nine-point, or 16-point configuration, depending on the required load capacity. The cribs are constructed of two or more parallel timbers applied in layers. As layers are applied on top of one another, the timbers are placed perpendicular to the previous layer to form one or more square openings in the center of the crib. Figures 2.4.6 illustrates a four-point standard wooden crib constructed with two parallel crib blocks per layer.

By placing additional timbers in each layer, the support capacity of a wooden crib can be significantly increased. The interblock contact area can be increased by 125% simply by adding one additional timber to the two-by-two configuration. This will make each layer consist of three timbers and as successive layers are added, nine contact points are produced. The three-timber-by-three-timber crib matrix is called a nine-point crib. Figure 2.4.7 illustrates a nine-point standard wooden crib. By adding one more timber per

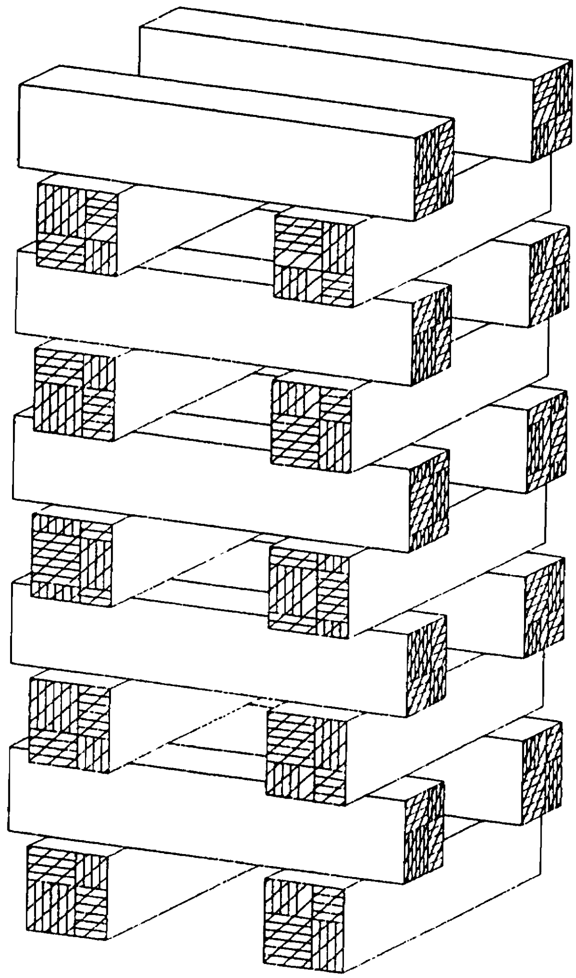


Figure 2.4.6: Four-point standard wooden crib formed from a two-timber-per-layer square configuration.

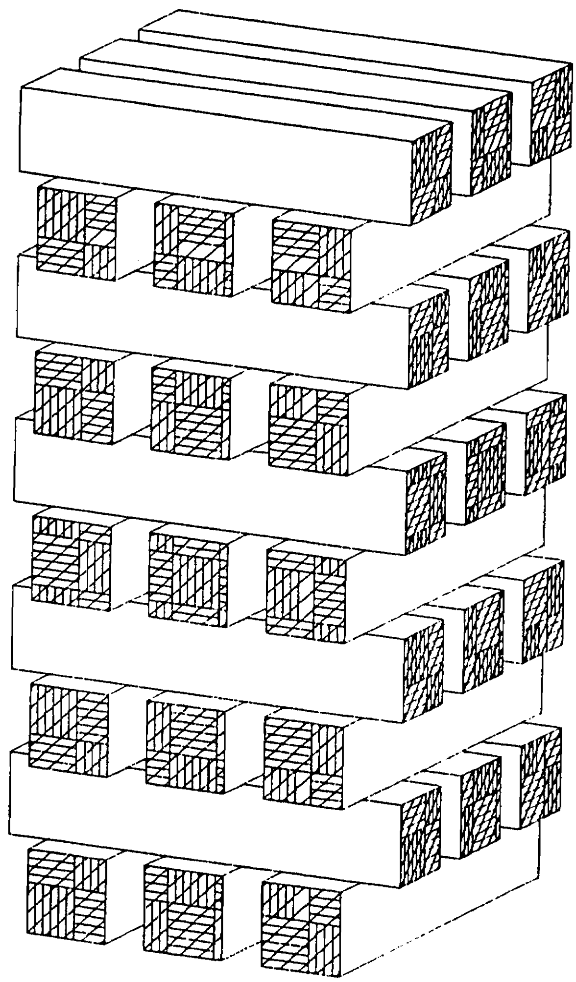


Figure 2.4.7: Nine-point standard wooden crib formed from a three timber-per-layer square configuration.

layer, the interblock contact area can be increased another 178%. The additional timber would form a four-by-four matrix, or a 16-point crib. Figure 2.4.8 shows a 16-point standard wooden crib constructed with four timbers per layer. It is therefore reasonable to assume that adding additional members per layer is a more efficient method of achieving increased load capacity as opposed to constructing additional cribs as long as contact area on the roof and floor is not an issue. Figure 2.4.9 supports this idea by showing a comparison of performance of the two-by-two, three-by-three, and four-by-four matrix crib configurations.

The support capacity for standard wooden cribs varies greatly depending on the wood species, interlayer contact area, and overall crib dimensions. Typical expected load capacities for standard wooden cribs are in the range of 100 to 500 kips at the elastic material strength limit. Ultimate load-carrying capacity may be considerably higher, but at the above loads a reduction of support stiffness was realized during testing of the support. Figure 2.4.10 shows typical performances of a two-by-two standard wooden crib constructed of five different wood species. The mechanical properties of the four eastern hardwood species can be found in table 2.4.1, but the Lodgepole Pine is a softwood typically found in the western United States.

2.4.2.2 Confined-Core Wooden Cribs

A variation of the standard wooden crib which incorporates loading of wooden members parallel to grain is the confined-core wooden crib. Here the nine-point and 16-point standard wooden cribs are constructed around vertical members, which are placed within the crib near the center in the voids formed by placing timbers horizontally in layers. Figure 2.4.11 depicts a common confined-core wooden crib with four vertical members enclosed by a horizontal three-by-three matrix of timber. Typically, the vertical members are shorter than the completed crib of horizontal members, to allow for vertical deformation of the crib before the vertical members take any load. Once the vertical

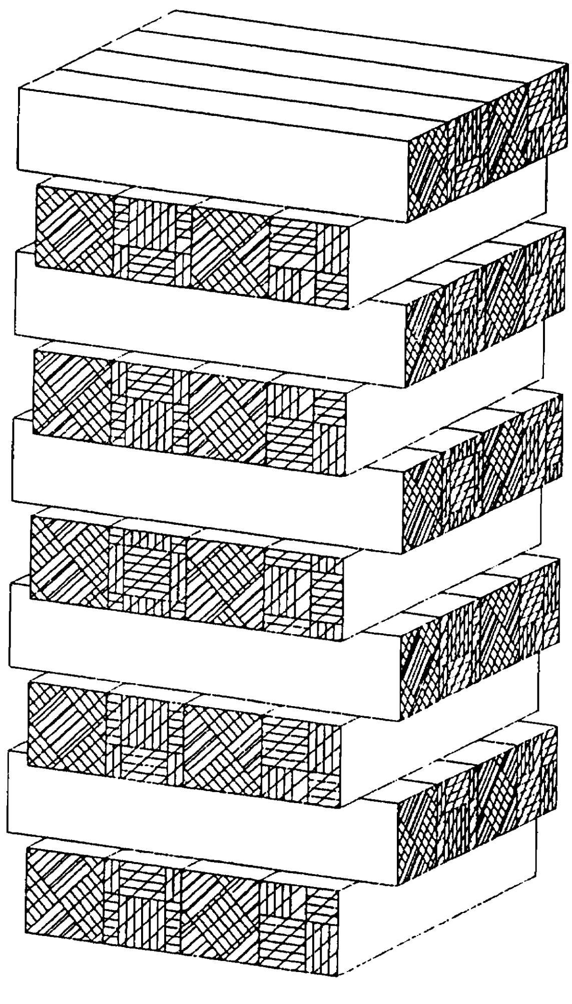


Figure 2.4.8: Sixteen-point standard wooden crib formed from a four-timber-per-layer square configuration.

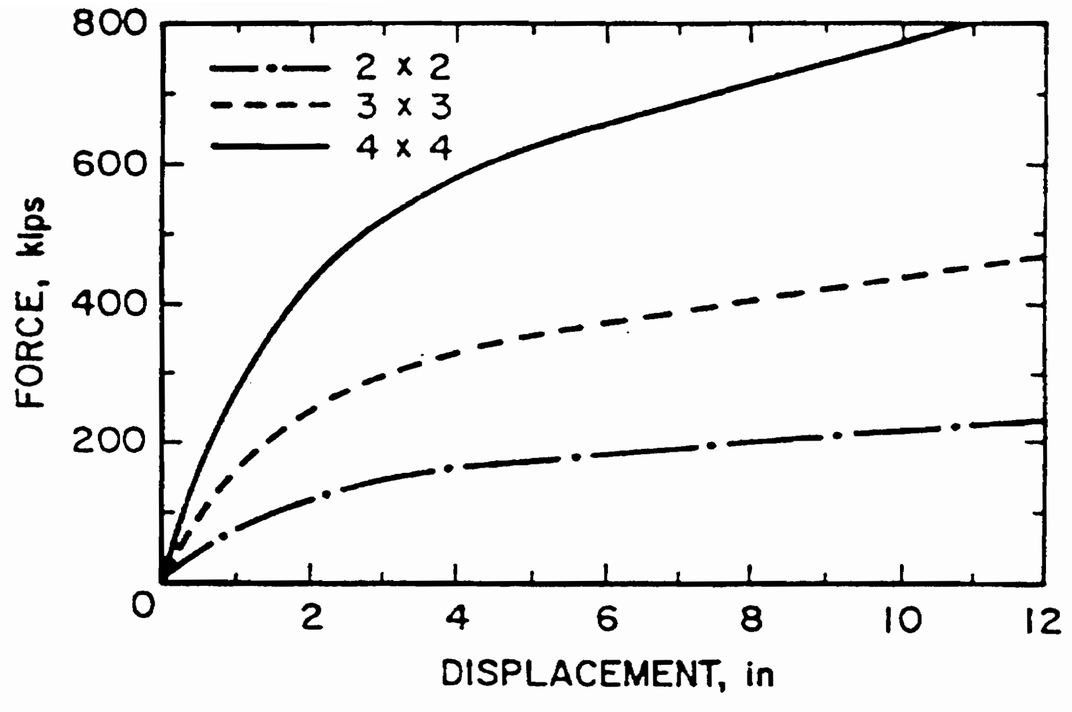


Figure 2.4.9: Comparison of standard wooden crib performance (Barczak and Gearhart, 1993).

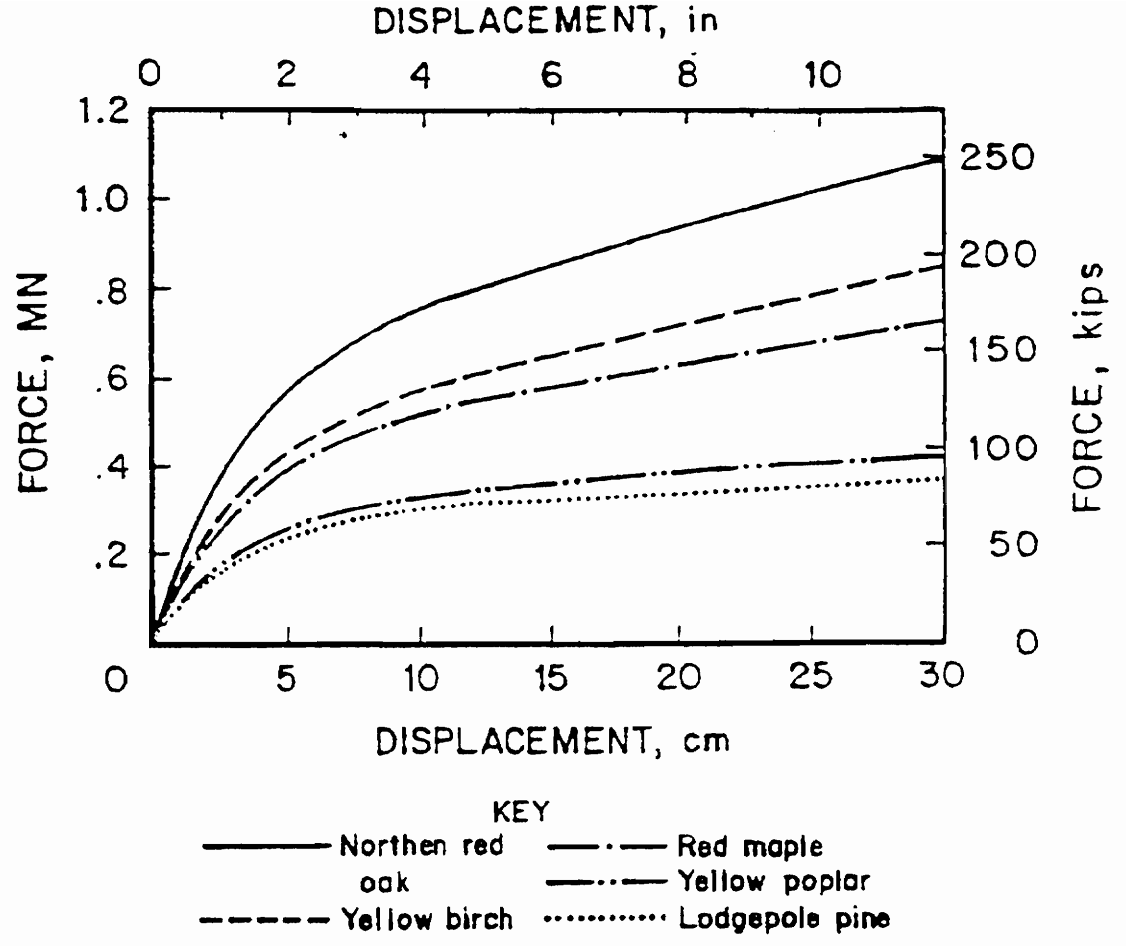


Figure 2.4.10: Performance of two-by-two standard wooden crib constructed from five different species of wood (Barczak and Gearhart, 1994).

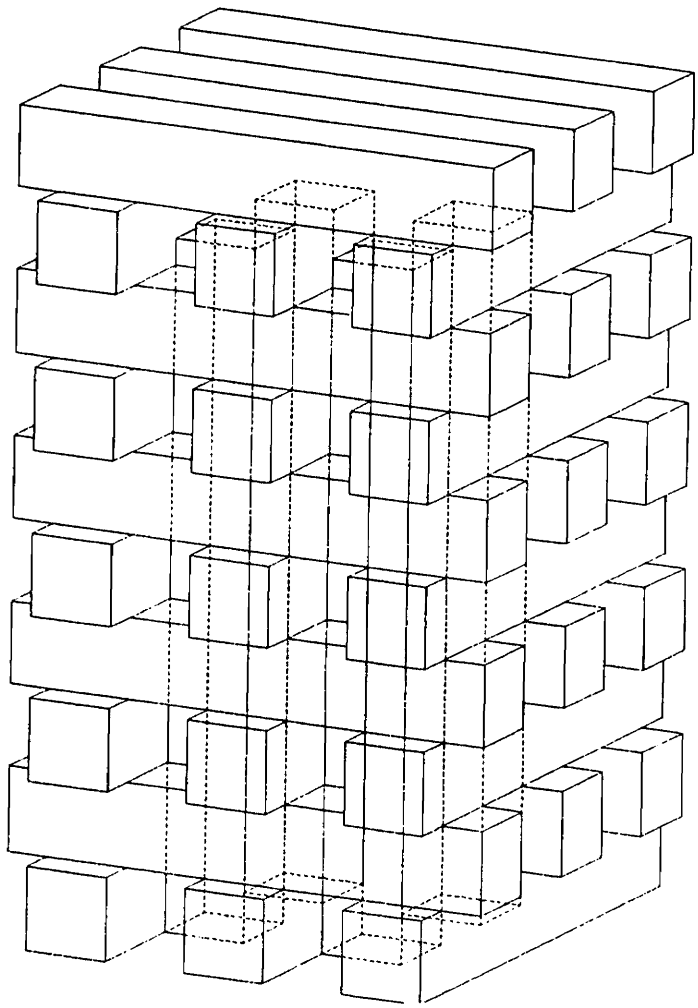


Figure 2.4.11: Confined-core nine-point wooden crib with four vertical members for parallel to grain loading.

deformation of the horizontal crib members has reached the vertical members, a drastic increase in load capacity is realized and maintained throughout further vertical deformation of the crib. Because the vertical members are confined by the surrounding horizontal members, the unbraced length of the vertical members is greatly reduced. By reducing the unbraced or effective length of a vertical member, the stiffness can be controlled for a higher compressive strength (Segui, 1994).

Confined-core wooden cribs are used in situations that require a greater load capacity than that offered by standard wooden cribs. The intent is to obtain very similar deformation characteristics to the standard wooden cribs but with a higher load carrying capacity. There are additional costs associated with including these vertical timbers, both in material costs and in the labor required to cut the timbers to length and place them within the crib. The support-capacity benefits outweigh the cost of constructing additional cribs, however, when additional load capacity is required. The confined-core crib exceeds the yield-load capacity of the standard nine-point wooden crib by 200 kips, and the 16-point wooden crib by 25 kips. Figure 2.4.12 illustrates a test comparison of three different commonly used wooden crib configurations. It is evident in this comparison that the confined-core wooden crib has a much higher load capacity than either the Strata Products, Inc. Hercules™ crib or a standard wooden two-by-two crib constructed of mixed hardwoods.

Laboratory testing of confined-core wooden cribs have proven the yield load capacity of the support to be approximately 250 tons at a displacement of 5 inches (Barczak and Gearhart, 1994). The high load capacity of the confined-core crib is a result of loading the wooden members parallel to grain. By loading the wood parallel to grain, the compressive strength is much higher when compared to loading wood perpendicular to grain.

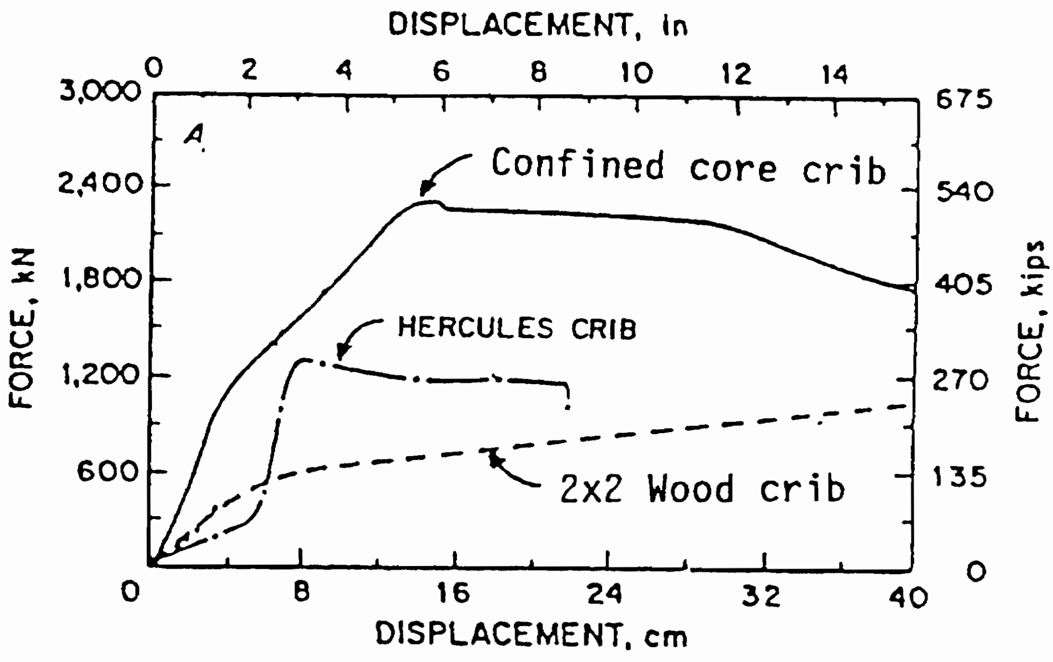


Figure 2.4.12: Performance comparison of a confined-core wooden crib, a pre-fabricated wooden crib, and a standard two-by-two wooden crib (Barczak and Gearhart, 1994).

2.4.2.3 Prop Supports

Because of the ever-increasing cost and decreasing availability of mine timber, prop supports are becoming more popular. The prop supports consume much less wood material than the four-point cribs they are designed to replace, and require less installation time. In addition, the prop supports provide less frictional resistance to ventilation air flow than wooden cribs. Wooden props of many forms have been used throughout mining history because of the desirable yield capability they possess. The props are not, however, without their disadvantages.

Wooden props consist of a single wooden post placed between a footboard and a headboard. The footboard is placed against the mine floor and the headboard near the mine roof. A groutable bladder is placed between the headboard and the mine roof. The grout bag is then pumped full of grout, which stabilizes the prop and allows the support to take active loading. The wooden posts can be cut to length for installation at any mining height. A fully assembled prop support, the Propsetter™ by Strata Products, Inc., is illustrated in Figure 2.4.13. The prop itself is usually cut or tapered on the bottom to provide a section of the post that will deform and displace as the prop receives load. This allows the prop to yield with movement of the main roof, a very desirable trait for gateroad supports.

Wooden props are an appropriate support system for use in longwall gateroads as long as the load capacity requirement is relatively low. In cases where the wooden prop-load carrying capacity is insufficient, additional props must be used. As additional props are installed, a point is reached where the cost of wooden prop supports will exceed the cost of standard wooden crib supports under the same conditions. At this point, wooden cribs or other support systems must be incorporated to resist the large vertical loading and will achieve similar deformation characteristics.

Under the right circumstances, where the vertical loading is relatively low and vertical deformation of the support is expected, wooden props provide adequate support

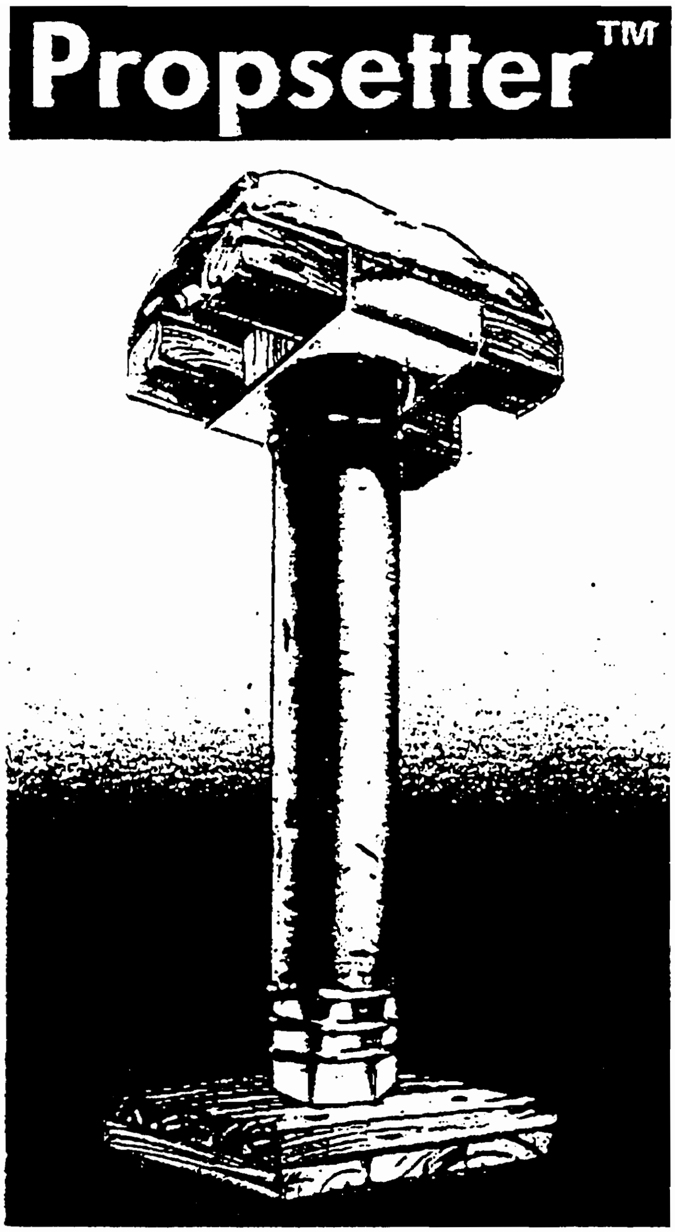


Figure 2.4.13: Strata Products Propsetter™ Yieldable Support System, an example of a wooden prop support.

at costs much lower than wooden cribs and various other tailgate support systems. Figure 2.4.14 illustrates the support capacity and the corresponding displacement of the Strata Propsetter™ support system versus a four-point mixed hardwood crib.

2.4.2.4 Pre-fabricated Wooden Cribs

In an attempt to maximize support capacity and rid underground crib construction of many defects that cause insufficient load capacity or premature failure, prefabricated wooden cribs are becoming increasingly popular. The prefabricated cribs are manufactured and shipped to mines in mats that resemble of single layer of a standard wooden crib; see Figure 2.4.15. The mats of wood are wired together so that each mat is identical to other mats of the same support system.

Similar to the confined-core wooden cribs, the prefabricated wooden cribs combine the horizontal and vertical orientation of wooden members to achieve a high load capacity. By loading the members of the crib both perpendicular and parallel to grain, high load resistance can be achieved without reducing the ability to displace vertically. The vertical members in each mat are located between the horizontal members and rest directly on the vertical members of the previously placed mat.

By manufacturing the individual mats prior to installation, a high degree of quality control can be established for the product. Timbers of equal dimensions are used to provide a constant interlayer contact area and to insure crib stability under load. Timber of a single wood species can be used in the manufacture of the mats to acquire a much more predictable response to crib loading. Additionally, the mats or layers are produced with adequate overhanging ends to insure maximum performance of each member. Many of the deficiencies associated with standard wooden crib construction can be overcome by using a prefabricated wooden crib system. Figure 2.4.12 shows a force-versus-displacement comparison of a two-by-two standard wooden crib, a confined-core wooden crib, and a prefabricated crib system (Hercules™). The prefabricated system in Figure

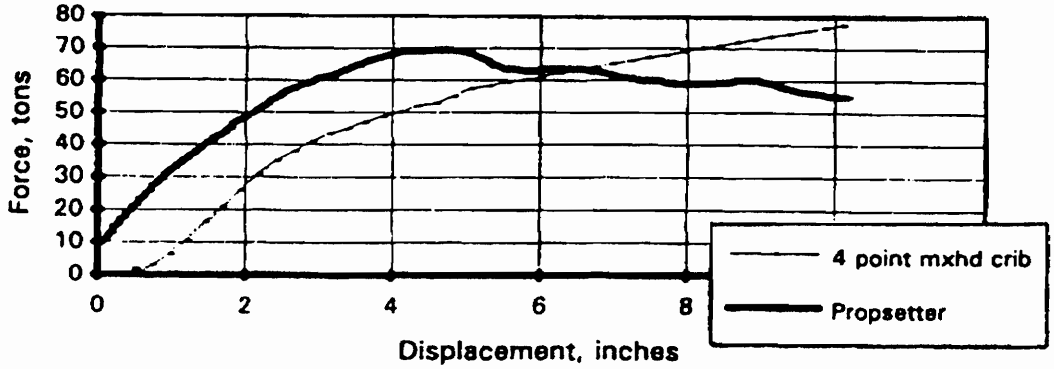


Figure 2.4.14: Force versus displacement test results for the Strata Propsetter™ support system and a four-point standard wooden crib composed of mixed hardwoods (McCartney, Tupper, and Paton-Ash, 1995).

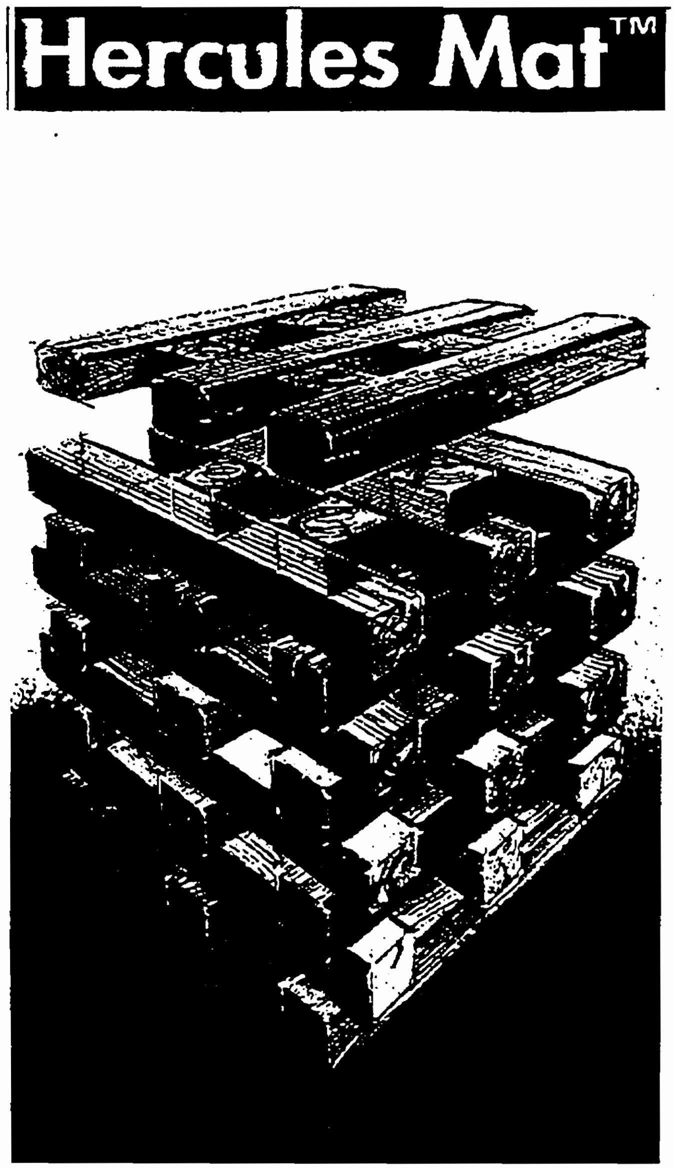


Figure 2.4.15: Strata Products Hercules Mat™ HM9 cribbing system, an example of a prefabricated wooden crib.

2.4.12 has a higher load capacity than the standard two-by-two wooden crib due to the vertical crib members. The load capacity of the prefabricated system is lower than that of the confined-core crib due to the species of wood used in crib construction.

2.4.3 Steel Support Systems

Secondary support systems fabricated from steel or various other metals differ from concrete and wooden supports in their capability of being installed both internally or externally within the mine entry. External steel support systems consist of steel arches, yieldable steel props, and steel posts. The internal steel support systems gaining popularity for their advantages over external support systems are cable bolts and steel roof trusses. A survey conducted during 1994 revealed that only 1.3% of longwall mines in the U.S. used external steel supports, and no information was available for internal steel support systems (Peng and Biswas, 1994).

2.4.3.1 External Support Systems

External steel support systems have various material properties which give this type of support advantages over those constructed of wood and concrete. Steel supports share with concrete supports the trait of accepting great loads immediately without the large deformation of wooden supports. This is very advantageous when attempting to keep the immediate roof beam intact by preventing downward roof movement ahead of the longwall face. Additionally, there is no shrinkage of the support to allow roof strata dilation, common with wooden support systems which do not apply load parallel to grain. The load resistance of steel supports is also more controllable than that of wooden or concrete supports because the material is homogeneous.

supports is a much greater stiffness. However, this system has a much smaller cross-sectional area than that of an equivalent wooden support, so to prevent floor and roof punching they are used in conjunction with wooden headers and foot-boards. When wood is used to increase the contact area at the support, roof, and floor interface, the stiffness of the system is greatly reduced. Most of the deformation of the support will occur in the wooden sections of the support system, and the system as a whole will perform similar to a wooden support.

Steel posts and yieldable steel props are good examples of beam and column-type supports. These supports allow for controlled displacement under load using either friction between sections or a plunger system. Dwidag Systems International, Inc. has developed a plunger type steel support named the Coal Post™, which resists load and controls displacement by forcing the upper section of the support into the lower section like a piston. The resistance, provided by expanding the steel tube, is capable of supporting approximately 45 tons (Barczak and Gearhart, 1994). A similar concept is incorporated into the YIPPI™ steel support developed by Western Support Systems, which demonstrates a very similar support capacity. These steel systems require less labor to transport and install than conventional cribbing and create less air restriction.

Steel arches represent a non-typical secondary support system for tailgate entries. This system is used mainly for openings that require secondary support but must be kept open for the movement of equipment and personnel. The arch support system consists of large steel arches which span the entire width of the entry and are connected using steel sag rods and wooden blocking. This system is not conducive to tailgate entry support since the longwall would not be able to cut into the support without damaging the shearer. Additionally, the yielding characteristics of the arch are not compatible with the roof movement realized in the tailgate entry once the longwall face has passed.

2.4.3.2 Internal Support Systems

In practice, selection of secondary support is greatly influenced by the costs of the support material and, very significantly, the installation costs of the system. More recent support-system designs have various economic advantages over wooden cribs. Roof trusses and cable bolting are two such alternatives. Both systems reduce the labor intensiveness of transporting and handling bulky crib blocks, due to the capability of a much smaller volume of material to provide support equivalent to that of wooden cribs. This means that the material can be transported and installed with up to 40% reduction in cost over wooden cribbing (Mucho, 1996). Additionally, these systems are internal support types, which allow the tailgate entry to remain open for equipment passage prior to panel extraction and decrease ventilation resistance up to 25% (Mucho, 1996).

Roof trusses utilized as a secondary support system in mines can effectively control various abutment pressures caused by longwall mining (Stankus et al; 1994). Figure 2.4.16 illustrates the typical layout of an installed roof-truss system. Truss systems are internal supports and can therefore be installed during entry development, an advantage over external supports. After primary support is installed, the truss system is installed to work in conjunction with the primary support for maintaining the roof beam. By installing the primary and secondary support simultaneously, the entry can remain open for equipment travel and no further secondary support installation is needed after the development for the panel is complete. Actual field installation of truss systems indicates that the system is adequate for tailgate-entry support with a significant cost reduction over wooden cribbing (Stankus et al; 1994).

Several manufacturers are producing roof trusses as a secondary support system for tailgate entries. The capacities of each system vary depending on the size and length of the bolts, the grouted length, the strength of the steel, and orientation in which they are installed. Some truss systems have been tested to provide approximately 50 tons of

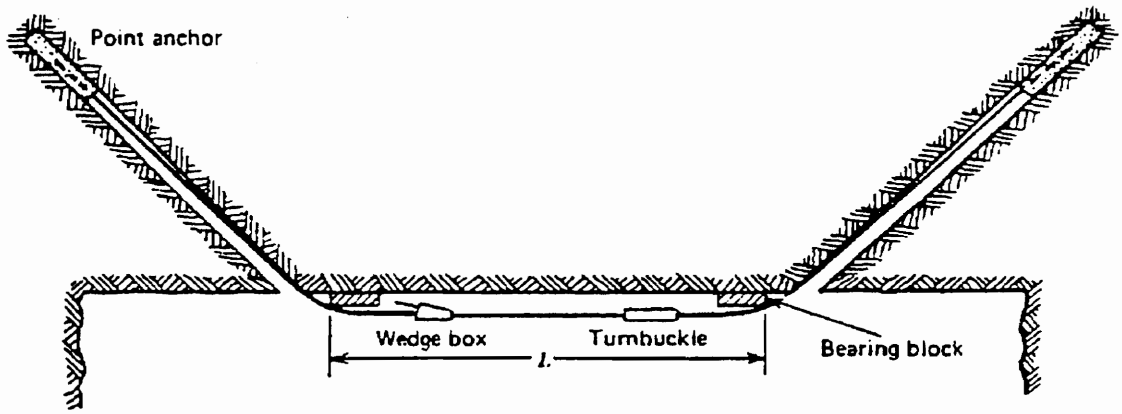


Figure 2.4.16: Typical layout of an installed roof truss system (Biron and Arioglu, 1982).

vertical load capacity (Krupa and Long, 1994). Truss capacities can be compatible with most tailgate entry conditions and can offer significant cost reductions over cribbing.

Cable bolts are also gaining popularity as a secondary support system in longwall tailgate entries. Figure 2.4.17 illustrates an installed cable-bolt support system in a coal-mine entry. Several western mines have replaced wooden cribbing with cable bolts to reduce the support costs associated with the high cost of timber. As with trusses, the labor and material costs of cable bolting are less than the equivalent costs of installing wooden cribs (Mucho, 1996). Cable bolts have been shown through testing, to support loads up to 28 tons with yielding controlled by the quantity and type of resin used during installation. High-strength cable bolts for special applications have a tensile strength of up to 60 tons (Fuller and O'Grady, 1993). Cable bolts also have performed well in field tests by completely caving behind the shield supports, unlike external supports, which frequently do not allow immediate caving along the pillar line (Mucho, 1996).

Cable bolts provide unique internal secondary support, since the length of the bolt can be readily varied to conform to varying roof conditions in the tailgate. As the height of the immediate roof increases, the length of the cable bolt can be increased to anchor into competent strata of the main roof. Pre-tensioning of both the cable bolts and roof trusses allows the systems to provide active support against roof sag and prevent cutter failure. Cable bolts are also constructed of fiberglass for application as secondary tailgate supports.

2.4.4 Composite Support Systems

Secondary support systems constructed of steel, concrete, wood, and various other materials have been developed for tailgate entries. The primary reasons for the development of composite systems is to reduce support material and installation costs, reduce material handling, and achieve support performance appropriate to the varying conditions encountered underground. By using two or more materials in a support

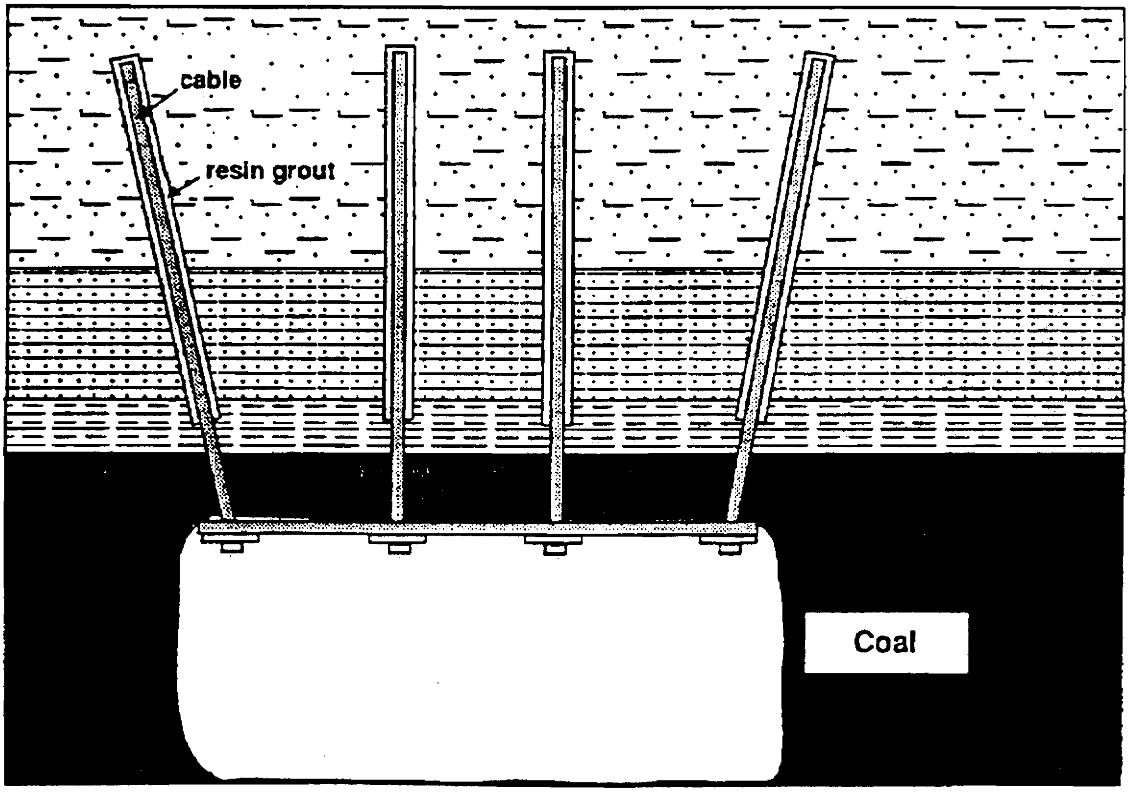


Figure 2.4.17: Typical layout of an installed cable bolt secondary support system (after McDonnell, Tadolini, and DiGrado, 1995).

system, it is possible to maximize the support potential offered by each of the materials. An example is the placement of granular fill in a steel tube, which in turn exerts a horizontal force on the material and thus retains it in a column as it takes load from roof deflection. The deformation characteristics of the support can be controlled by the selection of the fill material used. When the two materials are combined, they create an effective support from otherwise non-load-bearing separate components. Some supports have even used mine waste and pumice as the load-bearing material in an effort to reduce costs and match support deformation with main-roof movement.

CHAPTER 3

Tailgate Design

3.1 Gateroad Dimensions

In the eastern United States, coal-mine entries are currently cut between 15.5 feet to 22 feet in width. The selection of entry width is dependent on the purpose and usage of the opening as well as the characteristics of the immediate roof. Entries that are used as haulage ways and possess competent roof are cut wider than entries not intended for heavy traffic. The tailgate and headgate entry are typically narrower than main-track and belt entries that are not adjacent to longwall panels. The narrow entry exposes less immediate roof and requires less secondary support than a wide entry would, once panel extraction is underway.

Increased vertical stress and roof movement are more pronounced in the tailgate and headgate entries than along interior gateroads. The interior gateroad which is not adjacent to the panels on either side is typically used as a track entry for mines which use rail equipment. This gateroad is somewhat more protected than the headgate and tailgate entry and is also used for intake air and as a neutral entry or escapeway. This entry is usually cut as wide as possible, typically 18 to 20 feet.

If the Analysis of Longwall Pillar Stability Safety Factor (ALPS SF) is sufficient for the various Coal Mine Roof Rating (CMRR) of the immediate roof encountered along the length of the panel, then only a moderate amount of secondary support will be required in the tailgate entry. Figure 3.1.1 was developed from a survey, conducted between 1988 and 1990, of underground longwall coal mines in the United States. The ALPS SF and the CMRR for each active tailgate entry were recorded along with other data, such as the entry width and support densities. This data was compiled and analyzed to determine any mining trends that were related to the composition of the immediate roof and the longwall chain-pillar design. From this survey, safe entry widths can be estimated from the ALPS SF used in the pillar design and the CMRR for the roof along the gateroads.

Entry width is very dependent on the competency of the immediate roof strata. If the immediate roof has a high CMRR, it will usually accommodate a greater width than will a roof with a low CMRR. From Figure 3.1.1 it can be estimated that a weak roof confines the entry width to less than 5.2m (17 ft.) according to past successful cases. In weak-roof conditions this span may require additional primary support for stability. Strong roof can usually span a distance of 6.2m (20 ft.) with less primary support than can a weak roof. During the development stages of the longwall panel, roof quality (if unknown prior to mining,) can be used to alter the entry width and primary support density used in the gateroads. Additionally, the ALPS SF can be adjusted, if needed, to ensure that the tailgate entry, which will be the design element most affected by changing geology, does not receive excessive loads during panel extraction.

3.2 Pillar Design

The proper design of gateroad chain pillars is essential for the continual operational of a longwall system. Chain pillars on both sides of a longwall panel must perform in a manner such that all aspects of longwall mining are satisfied. The behavior of a coal pillar under loading will impact the stability of the gateroad openings and the future

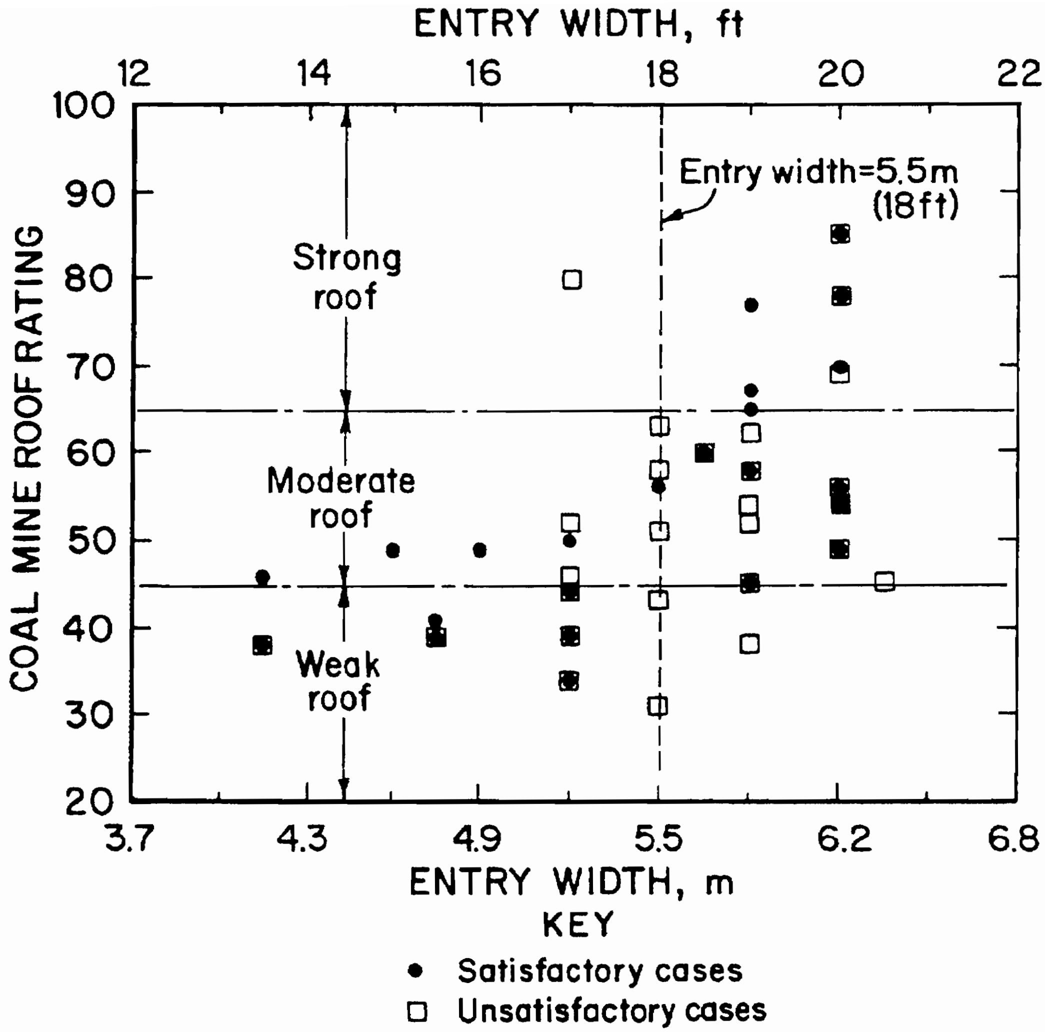


Figure 3.1.1 Tailgate entry width versus CMRR for successful and unsuccessful tailgate case histories (Mark, 1994).

of the coal panel. Additionally, pillar design will ultimately effect the density of secondary support installed to maintain the tailgate entry.

Coal pillars are parts of the coal seam that are left intact, either to provide support for mine openings which must remain open for long periods during the life of the mine or to prevent surface subsidence. Predictable pillar response is necessary for mine roof stability, therefore emphasis should be placed on designing pillars correctly depending on their intended purpose. There are three primary types of coal pillars used in underground coal mining, each with a unique purpose. Protective pillars, support pillars, and yield pillars are all used under different circumstances, depending on support requirements.

Protective pillars are usually large coal pillars left intact to protect either a surface or subsurface structure from ground movement. Protective pillars are employed around mine shafts to ensure that no strata movement will occur in the vicinity of the shaft. Any strata movement near a shaft could hamper the operation of shaft equipment or could even sever the shaft itself. Another example of protective pillars are the barrier pillars which are commonly left near main haulage ways underground, and at the ends of extracted longwall panels (Figure 3.2.1). The barrier pillars along the main entries ensure that mining activity throughout the mine will not effect the power input, ventilating air, haulage ways, railways, and beltlines that commonly traverse these entries. Any roof movement due to mining in surrounding areas will theoretically not effect the entries protected by these barrier pillars. Barrier pillars are also commonly found at the both ends of extracted longwall panels. The purpose here is to protect the bleeder entries and adjacent panel setup room on one end of the panel and the recovery room and adjacent main entries on the other end.

Protective pillars are also commonly used to prevent subsidence near surface structures such as buildings, roadways, and bodies of water. Figure 3.2.2 illustrates a protective pillar used to prohibit ground subsidence below a surface structure. Movement in the vicinity of buildings and other structures can cause damage to foundations and walls, and possibly resulting collapse. Roadways and bridges must be safeguarded by

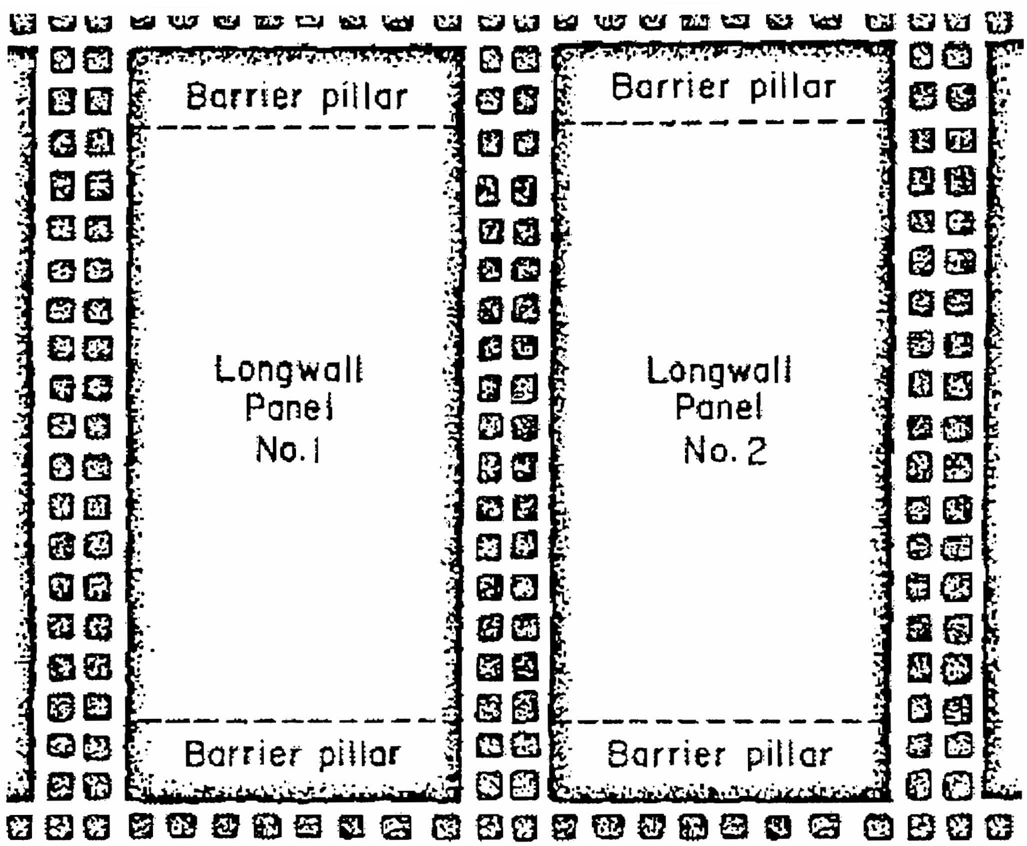


Figure 3.2.1 Barrier pillars left at the ends of an extracted longwall panel to protect the bleeder entries on one end and the main entries at the other end (after Mark, 1987).

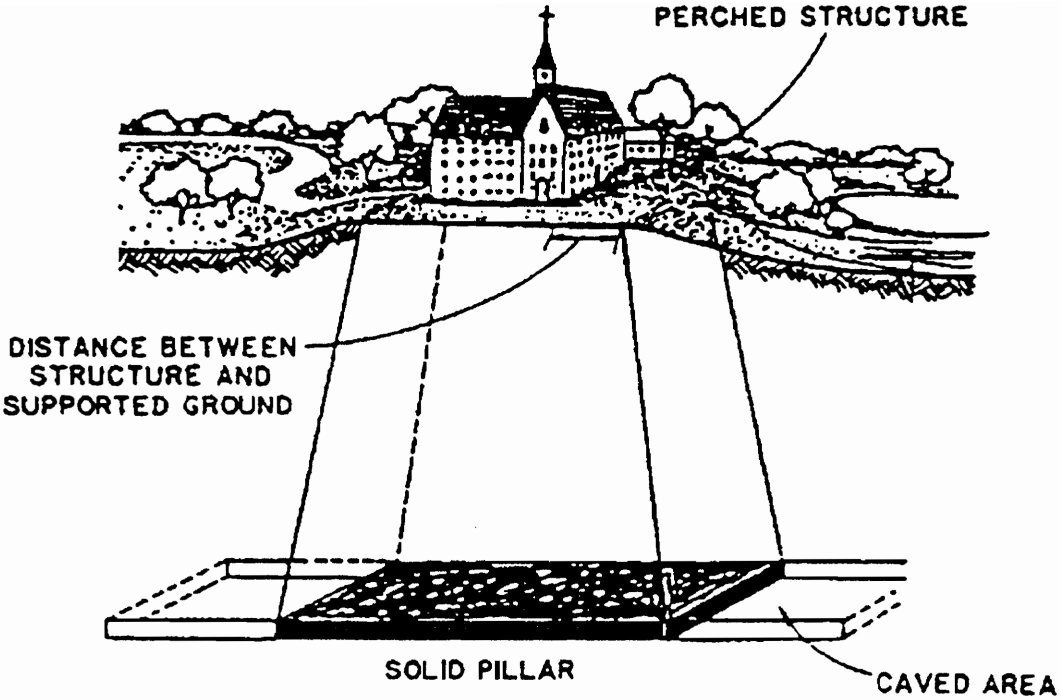


Figure 3.2.2 Protective pillar of coal left intact to prevent surface subsidence near a long-term surface structure (after Singh, 1985).

large protective pillars in order to prevent any long term subsidence from affecting them during or after mining. Bodies of water such as ponds, streams, and creeks are also protected by the use of protective pillars in order to prevent any subsidence which could alter the path of water flow. Safeguarding well-water aquifers is also of importance in some of the deeper seams that are being mined. Subsidence in and around strata that form aquifers, can have adverse effects on wells and lead to legal problems with surface owners.

Support pillars are used to maintain roof strata in areas of mining where maximizing coal extraction is important. Chain pillars are the best example of support pillars that are left in systematic arrangements on both sides of developing entries. They are used along longwall gateroads and bleeder entries, and in all room-and-pillar operations. Figure 3.2.1 illustrates the location of chain pillars with respect to the longwall panels. Their main purpose is to support the roof strata during the mining process, and to maintain mine openings for usage. Some roof movement can be expected over chain pillars, especially near longwall panels where large stresses are transferred to the pillars.

Yield pillars are specially designed blocks of intact coal that can fail progressively and in a predictable manner suitable to the movement of the main roof strata. Yield pillars are commonly found along longwall gateroads adjacent to the panel. They are used in conjunction with chain pillars and are placed in the same systematic way as chain pillars. Yield pillars are designed to fail slowly in order to decrease the risks involved with the sudden or violent pillar failure which is, in turn, due to the very high stress increase generated by the extracted longwall panel. Yield pillars are small in size to insure that a confined core within the pillar does not develop and resist roof movement.

The design and arrangement of chain and barrier pillars in multi-entry retreat longwall mining will greatly affect the stability of the headgate and tailgate entries. If the pillars are not properly designed, the continued mining of a panel and adjacent panels could be in jeopardy. Since most problems associated with longwall mining involve the headgate and, even more frequently, the tailgate entry, special attention should be given in pillar design to prevent adverse problems in these areas.

To cope with problems associated with the tailgate entry in retreat longwall mining, two different design philosophies have been suggested. One approach assumes a stiff-pillar reaction which involves large amounts of in-situ coal. The other involves predictable yielding of coal pillars in response to panel extraction (Dahl 1978, and Choi, et al, 1975). The stiff-pillar approach involves leaving large amounts of mineable coal behind for support, lessening the stress increase on the tailgate entry of the adjacent longwall panel. The yielding-pillar approach, however, involves leaving the least amount of coal possible in each pillar to keep stresses within acceptable limits.

The successful design of chain pillars in retreat longwall mining can be achieved by answering three primary questions (Peng and Chiang 1984):

(1) What is the optimum size of chain pillars ?

(2) Should equal-size or unequal-size pillars be adopted ?

(3) What are the optimum arrangements of the unequal-sized pillars if they are used in a three- or four-entry system ?

The optimum size and arrangement of chain pillars is affected by many parameters, such as panel and entry width, coal strength, depth of overburden, mining height, and roof stratagraphic sequence.

The stiff-pillar approach has been thoroughly investigated, and a relatively new method for stiff longwall chain pillar design was developed by Mark and Bieniawski (1986). The package they developed, Analysis of Longwall Pillar Stability or ALPS, addresses key issues such as time arrival and magnitude of longwall abutment loads applied to chain pillars. The goal of ALPS is to determine the dimensions of longwall pillars based upon the abutment loads to which they will be subjected. ALPS consists of three major elements: estimation of the load applied to the pillar system, estimation of the strength of the pillar system, and application of a safety factor.

When using ALPS to determine the size of pillars, it is necessary to collect mine and coal-strength data. The following parameters are defined in Figure 3.2.3:

(1) Maximum depth of cover (H).

(2) Unit weight of the overburden (γ).

(3) Width of the panel, or face length (P).

(4) Entry width (B).

(5) Pillar length (L).

(6) Height of the coal seam (h).

(7) In-situ strength of the coal seam (σ_1).

(8) Estimate of pillar widths (w).

(9) Estimate of total width of pillar system (W_t).

When using the ALPS program, it is essential that the CMRR of the area under investigation be incorporated into the design. The most recent version of the ALPS program includes a vast database of CMRR values for mineable coal seams in the United States. If the exact CMRR is not available for the mine, a typical value for the seam and location can be used from the database of case histories. The value obtained, however, may not accurately represent the geological conditions encountered. Engineering judgment should be used to determine the similarity between current conditions and those found in the database. Figure 3.2.4 illustrates the scatter plot of both successful and unsuccessful case histories from which the pillar-design equation was developed. The plot lists three different bounds which represent the region of change from the unsuccessful to successful tailgate entry performance. The design equation is based on the right or uppermost bound, which excludes the majority of unsuccessful cases.

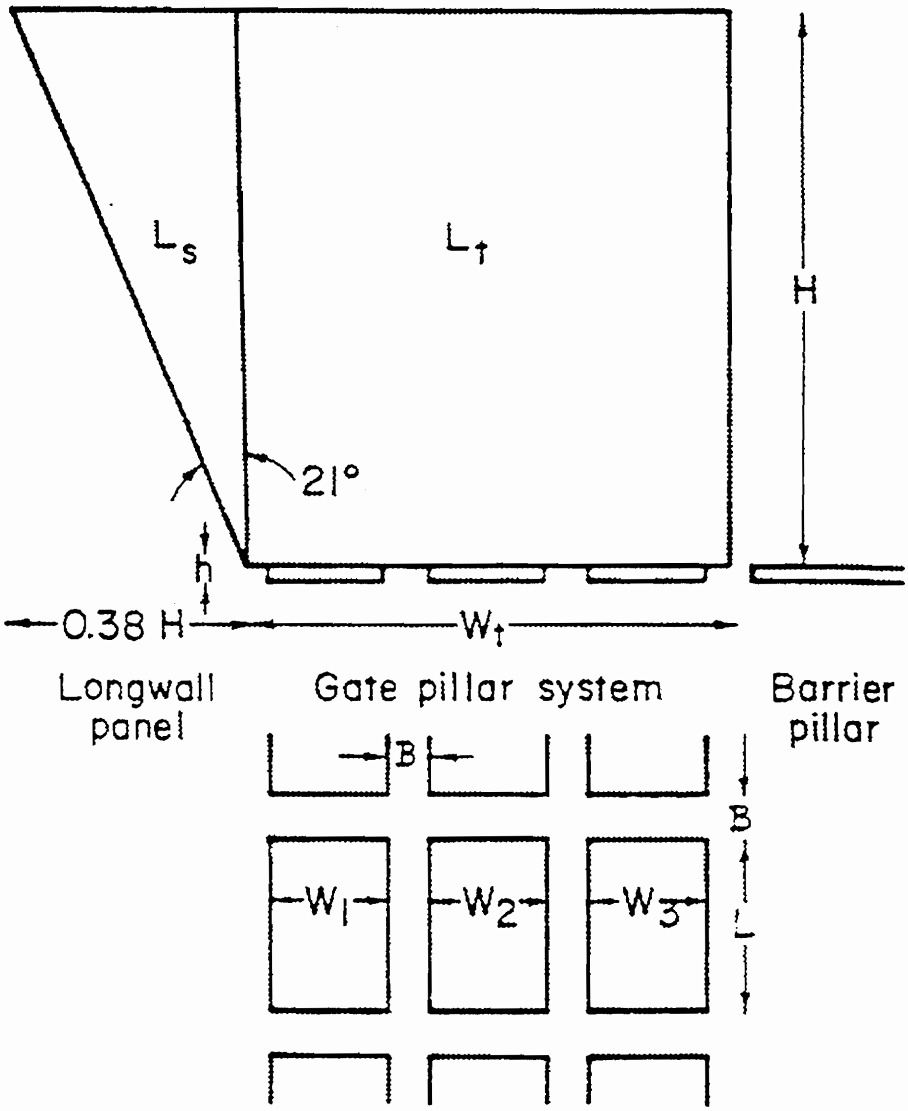


Figure 3.2.3 Definition of geographic parameters for ALPS pillar design program (Mark and Bieniawski, 1986).

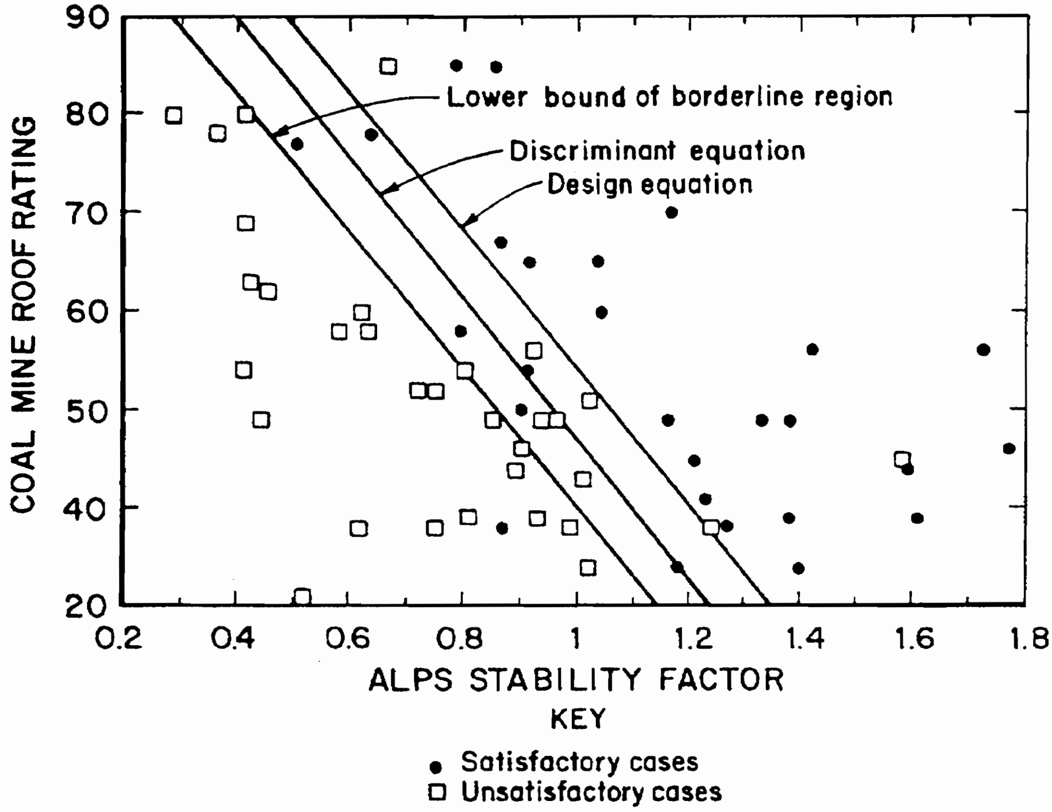


Figure 3.2.4 Scatter plot of successful and unsuccessful tailgate case histories (Mark, 1994).

To determine an adequate ALPS stability factor from the CMRR of the immediate roof, the 'Design equation' line in Figure 3.2.4 should be used. Equation 3.1 represents the design equation line which is the most conservative of the three bounds illustrated in the Figure:

$$\text{ALPS } SF_R = 1.76 - 0.014 \text{ CMRR} \quad \text{............(3.1)}$$

3.3 Mining Equipment

Equipment used in underground coal mining in the eastern United States today has been designed to optimize productivity in a fixed range of entry dimensions. Mine entries developed by continuous mining machinery are typically within the range of 16 to 22 feet in width. These widths have apparently evolved through many years of underground mining without any set reason for the current dimensions. Mining equipment has also evolved to a size and shape that can maneuver effectively and efficiently in the current range of mine-opening dimensions.

Development of a retreat longwall panel is carried out by continuous-miner sections. The continuous-miner sections create the gateroads and chain pillars around the perimeter of a future longwall panel. The main purpose for the development of entries by the miner sections is to create a passage for ventilation, transportation, and the haulage of coal. Since continuous-miner sections produce very little coal when compared to a longwall section, production of coal is not a major factor when developing entries. As the continuous-miner sections outline the longwall panel, geological conditions throughout the panel can be investigated to determine the necessity any modification in design. The most pressing task for the miner sections to accomplish is the creation of stable entries around the panel before the previous panel has been completely extracted. This will allow the longwall mining process to be somewhat continuous with respect to coal production. As soon as one panel is mined out, the longwall section can immediately move to an adjacent panel which has already been completed.

A continuous-miner section typically consists of four types of mobile equipment: a miner to mine the coal, coal-haulage units, bolting machines, and a utility vehicle. The continuous miner is used to mine the coal and load the mined coal into a haulage unit. Haulage units are typically shuttle cars, continuous haulage units, and coal haulers which load from the continuous miner and transport the mined coal to a dumping point, usually a feeder for a conveyer belt. Bolting machines used on the section install primary support as continuous miners advance the entries. The most common type of utility vehicle found on a continuous-miner section is the scoop, which is used for many support tasks on and around the section.

Continuous miners come in many different sizes and configurations in order to accommodate the wide variety of seam thicknesses common in the Appalachian coal fields. The continuous miner pulverizes the in-situ coal with one or more rotating drums, breaking the material into small fragments which can be easily transported to the surface. The pulverized coal is loaded by the miner with the use of gathering arms, which pull the coal from the mine floor first onto a loading deck and then onto a conveyer. The conveyer then transports the coal from the front of the machine to a boom which extends from the rear of the unit. The boom is then positioned over a coal-haulage unit for removal of the coal from the section.

Typical mine entries from 16 feet to 22 feet in width require two adjacent cuts by the miner to achieve the desired width. Each cut can only advance 20 feet at a time before primary roof support must be installed. For equipment that is controlled by a remote unit, where the operator remains under supported top, the miner can advance 40 feet before installing roof support. Once the maximum or desired cut is made, the miner typically leaves the face and moves to the adjacent entry to begin advancing again. Some continuous miners, however, are equipped with a bolting apparatus to install primary support without removal of the unit. In this case, after a cut has been made, bolters are extended from the miner and roof support is installed. If internal secondary support systems are to be used, then it is conceivable that the continuous miner can install both the primary and secondary support without ever vacating the heading. This could improve productivity and save time associated with tramming mobile equipment when rotating to each heading.

Tailgate entries that exhibit a weak roof are typically cut narrow in order to expose less immediate roof. Due to the size and area needed to maneuver a continuous miner, the entry width generally cannot be less than 15.5 ft. This width was also found to be the typical minimum width of tailgates in two surveys conducted in the United States. One mine did drive 13.5 ft. wide tailgate entries using special equipment to combat extremely poor roof conditions which were encountered on a preceding panel.

Coal-haulage units carry the mined coal from the continuous miner at the face to a conveyer belt or other haulage system for transport to the surface. Haulage units are generally rubber-tired shuttle cars or coal haulers, either diesel-powered or electric. Another method of coal haulage from the face is by the use of continuous haulage systems. The continuous-haulage units consist of a series of conveyers which can articulate around pillars and reach from the miner at the working face to the main conveyer or other dumping point.

All of the haulage systems mentioned above must receive the coal from the rear of the miner by maneuvering under the boom. The shuttle cars and coal haulers load from the miner, then tram to the dumping point while a returning unit falls in behind the miner and loads accordingly. Two or three of these units, are required depending on the haul distance, to ensure that loading from the miner does not create a bottleneck at the section. For the continuous haulage systems, only one unit per miner is required to transport all of the coal. This system also ensures that there will be no time lost waiting for coal to be removed from the face area.

The haulage units like the continuous miner have evolved to be more effective in wider entries. Shuttle cars and continuous haulage units cannot operate when the entry width is reduced to less than 15.5 ft. New haulage units, however, can negotiate turns in narrow entries by articulating between the wheelbase for a smaller turning radius. Internal secondary support systems in the tailgate entry will not effect the haulage units if installed on the advance.

For the installation of primary roof support, a roof bolter is required. If a bolting unit does not exist on the miner, then once a cut is made the miner must vacate the face area and allow a bolter to enter and install roof bolts before further mining can continue at that face. The miner will typically move to the adjacent entry that has previously been bolted and continue mining while the bolter is being utilized. The bolter will then follow the same route as the miner and move into the adjacent section to support the roof exposed by the miner.

Roof bolters also come in varying sizes and configurations for use in areas having different mining heights and seam conditions. Typical roof bolters have twin booms near the front of the unit, operated by two mine personnel. The booms allow bolts to be installed in parallel rows along the length of the entry at predetermined intervals. Typical bolt spacing is four feet to five feet on center for both the width and length of the entry. The roof bolter is also used for the installation of internal secondary support systems. The cable bolt and roof truss are installed in a manner similar to the roof bolts in the primary system, but usually after the development headings are completed. New techniques are allowing the bolter to install both the primary and secondary support during the advancement of the tail entry, when internal secondary support systems are used. This can reduce the cost of labor involved with installing secondary support after the gateroads have been completed.

Each continuous miner section usually requires a utility vehicle to accomplish several support tasks at or near the face. A typical support vehicle is the rubber-tired scoop. Scoops are usually battery powered for use in virtually any location in the mine. Typical tasks for scoops are hauling supplies, cleaning up spills, rock-dusting, hauling mine equipment, and basically any other jobs that require equipment with great versatility and mobility. The scoop is also largely used for transporting secondary support systems for installation in the tail entry. Secondary support system components of all types can be transported by scoops into the tailgate entry to reduce manually hauling the materials over great distances. Scoops, like other pieces of underground mobile mining equipment, are designed to function in entries in the range of 16 to 22 feet in width. If internal secondary support systems are used, the scoop can maneuver freely in the supported tailgate entry. If external secondary systems are used then once the support is installed, the tail entry can no longer accommodate mobile equipment.

The aforementioned mobile mining equipment has been designed to operate in a fixed range of entry widths. Therefore it is not usually an option to vary the tailgate entry width to less than 15.5 ft. Instead, the assurance of immediate roof stability in the tailgate should be determined by properly designing the chain pillars for the expected loading conditions and the CMRR. By establishing the CMRR of the immediate roof and using the appropriate ALPS stability factor, further reduction of the tailgate entry width to achieve stability can be avoided.

CHAPTER 4

Ideal Secondary Tailgate Support Characteristics

4.1 Introduction

Based on analysis of current secondary tailgate support systems, each support type exhibits both advantageous and disadvantageous characteristics. The ideal secondary support system would be one consisting of a conglomerate of all the advantageous characteristics of current secondary tailgate support systems. Although each support system currently used has its own advantages depending on site-specific mining conditions, a support system that could be deployed under any conditions would be most beneficial to the mining industry. An ideal support would be one that could be easily and quickly modified to provide the desired performance in any application.

While no secondary support system currently exists which incorporates all of the ideal characteristics, some current systems possess more than others. Each system has unique advantages depending on the conditions encountered underground. Table 4.5.1 is a summary of the ideal support characteristics described above. With each description, the material most commonly at a disadvantage with respect to its material properties is listed.

All of the current secondary tailgate support systems mentioned in Section 2.4 possess some trait which is superior to those found in competing support systems. Cost, material handling, and performance are the predominant factors considered during secondary tailgate support selection. Therefore the lowest-cost support that can be easily

Table 4.5.1: Summary of ideal secondary tailgate support characteristics.

	Ideal Support Characteristic	**Disadvantaged Material**
1.	no shrinkage	wood
2.	non-flammable	wood
3.	non-biodegradable	wood
4.	visual or audible signs of loading	concrete
5.	early support against sag or heave	wood
6.	non-explosive or non-sudden failure	concrete
7.	able to deform horizontally	concrete
8.	non-fragile material	concrete
9.	low ventilation turbulence	external systems
10.	quality control	wood
11.	fast construction	cribs
12.	lightweight	concrete
13.	low cost	cribs
14.	sustained sufficient load capacity	wood
15.	little room for error during construction	cribs
16.	ease of handling	cribs
17.	ability to deform vertically with main roof	concrete
18.	readily re-dimensioned for stability in increased mining heights	external systems
19.	sufficient contact area to prevent roof and floor punching	steel

handled and will provide sufficient capacity, deformation, and stability will likely be chosen.

4.2 Support Performance

During the selection of secondary tailgate support, consideration is given to the effect of the varying geological conditions on prospective support systems. Some of these factors include: the varying height of the immediate roof, differing material composition of the immediate roof, varying floor composition and thickness, varying seam thickness, depth of cover and vertical stresses, and horizontal stresses. Other factors which only become evident as longwall mining continues, such as excessive loading on the tailgate, can also influence support selection.

Although wooden support systems are the most popular type of support used today, they possess many disadvantages, as mentioned in Section 2.4. For a support system to be ideal, shrinkage of the material must not occur. Shrinkage, one of the disadvantages unique to wooden supports, allows dilation of the roof strata before significant resistance is realized. Roof supports need the ability to resist load applied by the immediate roof at the earliest time possible. Passive supports tend to allow some vertical movement of the immediate roof before resistance is applied causing fracture of the roof material. Some advances have been made in the area of early-load resistance by initially loading the wooden support during installation. A common technique is to pressurize groutable bladders and to place these between the top of the support and the mine roof.

Two other factors associated with wooden supports that, if eliminated, would produce a more desirable support system are flammability and biodegradability. It is desirable to have the least amount of combustible material as possible exposed within a mine entry. While this is not a major issue in support selection, it is a characteristic that could reduce the risk of mine fire. Biodegradability is not a problem that typically occurs underground; it is most common prior to timbering and after the manufacture of wooden components. The major problem with the biodegradation of wooden materials is the performance of the affected materials as supports. Once partially decomposed blocks are installed in a support, a reduced load-carrying capacity will be realized, along with associated problems such as decreased stability and the lack of early load resistance. The problem of wood decay can be avoided by the use of non-biodegradable material or by taking quality-control measures when selecting wooden support components.

Wooden supports do possess the very desirable trait of providing both visual and audible signs of loading. Visually, wooden supports will distort and show direction of movement in both the vertical and horizontal directions. Wooden supports also produce audible sounds as the wood takes load and deforms. Concrete supports typically will not provide these signs of loading and can fail in an explosive manner as the compressive strength of the material is surpassed. Steel friction supports and composite supports will provide signs of loading much as wooden supports do.

Pre-stressed supports provide early initial support against roof sag and floor heave, but sustained load resistance depends greatly on the support material. Concrete, steel, and many composite supports, if pre-stressed, will continue to provide support with very little vertical deformation. Wood, however, will continue to deform as more load is applied to the support, allowing continued dilation of the roof strata. In contrast, if expected vertical main-roof movement is greater than the deformation capability of the support, failure of the support or roof and floor punching may result. Under this condition, composite support systems can be designed to offer adequate vertical deformation capability followed by a high load-carrying capacity. Therefore, an ideal support system could be readily designed to conform to a wide array of main-roof movement possibilities while providing sufficient resistance to keep the immediate roof intact and in contact with the main roof.

Roof movement over the tailgate entry is realized in both the vertical and horizontal directions during panel extraction. When horizontal movement of the roof is expected, wooden secondary support systems are typically installed. Both tests and case studies have shown that wooden cribs and prop supports will undergo several inches of horizontal movement and remain stable even under load. This characteristic is not found in current concrete support systems, but can be incorporated into composite systems.

Ventilation must also be taken into consideration when designing a secondary support system. External support systems, by nature, cause to some degree noticeable constrictions in the air flow through the entry. Obviously, the more cross-sectional area a support exhibits, the more the airflow through the entry will be constricted. Consideration should also be given to the shape and texture of the support material. Supports with a smooth, regular surface will cause the least frictional resistance on passing air (McPherson, 1993). Concrete disc cribs, cylindrical columns, and round prop supports are examples of supports which reduce turbulence on ventilating air when compared to wooden and concrete cribs with a square geometry. Additionally, the surface of standard wooden cribs is often very rough, causing more drag than smoother surfaces such as steel. Internal support systems drastically reduce any air turbulence when compared to the external support systems.

Mining heights, which can vary greatly from seam to seam and even within the same seam, can cause stability problems when installing secondary support systems. For wooden cribs, the aspect ratio should remain between 2.5 and five (Barczak, and Gearhart, 1993). Reconfiguration of the wooden crib must occur when the height exceeds the width by more than a factor of five for the support to remain stable. Prop supports have a similar range of stability. Depending on the shape and cross-sectional area of the prop, a limit in member length is reached where premature buckling will occur at smaller loads. Thus, occasionally prop supports must also be altered to remain in a safe range when mining heights increase.

4.3 Cost

Wooden support systems have been predominantly used throughout mining history because of their availability and low cost. In the eastern United States today, however, hardwoods possessing the desired traits suitable for support material are steadily increasing in cost and decreasing in availability. This has led to the design of various other supports composed of steel, concrete, fiberglass, foams, pumice, or combinations of these materials. Each support type has certain advantageous traits when compared to others but also possesses unique disadvantages. No support currently used is "perfect" under all the conditions that can be encountered in the underground mining of coal. Therefore, if a support could be designed which incorporates many or all of the characteristics that provide ideal support performance underground, and which is also cost effective, it would greatly benefit the mining industry.

4.4 Material Handling

The transportation of support material both on the surface and underground is usually undertaken by heavy equipment. The material is subjected to both intentional and accidental rough treatment by loaders, scoops, rail equipment, etc. Components for supports should be able to take some degree of abuse without harm to the integrity of the material. Wood is a good example of a material that can be roughly treated to some extent by both humans and equipment without jeopardizing its strength capability. Concrete, on the other hand, must be treated with more care because of the brittle nature of the material.

Underground geological factors and construction techniques must be considered when designing secondary support systems. Human error in support construction can be minimized by simplifying the installation process of the support. Uneven roof and floor conditions, soft floor, and poor lighting conditions must be taken into account. Common errors in wooden-crib installation which were listed in Section 2.4 include: over-hanging ends of crib blocks being insufficient, unequally dimensioned timber being used in same the layer, and different species of hardwood being used in the same layer. By removing the opportunity for errors such as these to occur, support stability and performance can be greatly improved. With the introduction of the pre-fabricated wooden crib mats, the above deficiencies could be overcome very easily. An ideal support would incorporate similar characteristics by minimizing the risk of human error during construction.

Further characteristics that are desired in a support system deal with the handling of the material and support components. Since all secondary tailgate support systems in use today require manual labor for their construction and installation, support components must be relatively lightweight. Typical mine shifts last eight to ten hours, with support installation consuming about three-quarters of a shift. Miners must be able to handle the support components for several hours a day and for many days at a time. Additionally, numerous supports must be installed as fast as possible to remain well ahead of the retreating longwall face and to reduce labor costs for support installation. The components of a support system should be less than 50 pounds each and able to be easily handled by one miner.

CHAPTER 5

Model of Support Capacity Determination

5.1 Roof Classification

The first stage in determining the approximate secondary support capacity required for a tailgate entry is investigation of the immediate roof. For use in this model, the geological conditions present in the gateroads should be classified using the coal mine roof rating (CMRR). This model and the ALPS SF pillar design program are based on a range of CMRR values. CMRR values for the immediate roof over the gate entries can be determined from visual investigation of the roof material at overcast cuts, of roof falls, and of exploratory drill core. A typical value of the CMRR can also be obtained from the ALPS program Version 4.0.

A new set of procedures have been developed for determining the CMRR of the immediate roof by examining exploratory drill core. This method relies on a large database of point-load tests performed on over 2,000 specimens from the 30 most common coal-measure rock types (Mark and Molinda, 1996). This procedure can be very beneficial for hazard assessment, reinforcement design, and entry design prior to mining.

When a site investigation of the immediate roof in a gateroad is possible, the CMRR value obtained is usually more accurate than the CMRR value provided by the ALPS program. This is due to the constant variations in immediate roof material throughout any coal seam. The CMRR system identifies the structural competence of the roof material within and just above the bolted interval. The system also relies heavily on identifying strong beds in the immediate roof. The quality of the most competent bed within the bolted interval greatly effects the CMRR.

The ALPS Version 4.0 provides a CMRR value for most mineable coal seams in the United States. The CMRR values were obtained from a survey conducted during 1988-1990 of operational longwall coal mines. Similar values were obtained from mines operating in the same coal seam, but in some cases the CMRR varied significantly. For this reason, a geographical location is also given for the varying values in the CMRR database. By using the value obtained from the closest location given in the database, a close approximation of the CMRR can be determined. If, however, geological conditions are dissimilar to the nearest location given in the CMRR database, then a more distant location with similar geological conditions should be considered.

By determining the appropriate CMRR for the immediate roof in a mine, a safe pillar design can be achieved. Through adequate pillar design, tailgate performance can be controlled with only a moderate amount of secondary support. This model was developed to aid in mine planning only when the an accurate CMRR has been determined, and a safe pillar design according to ALPS has been achieved.

5.2 Pillar Design

The second stage of determining the approximate secondary support capacity required for a tailgate entry is proper design of longwall chain pillars. This model assumes that the pillar design used for dimensioning gateroads and chain pillars is above 0.7 ALPS and has an adequate ALPS SF according to the respective CMRR value.

A large database of current and past longwall mines has been compiled to record the trends with varying roof conditions and ALPS SF versus secondary support density.

The initial survey started in 1988 and was completed during 1990, and a second survey was performed during 1993-1994. The data was compiled to determine if the ALPS SF and CMRR could be used to determine safe entry widths, adequate primary support density, and the required secondary support density.

Through multivariate statistical analysis of the survey data, the ALPS SF of each mine showed trends illustrated by the many unsuccessful attempts of longwall mining when pillar design fell below an acceptable level. Since the ALPS SF is dependent on the CMRR, roof-control problems became evident as the CMRR decreased. The poor roof conditions in the unsuccessful cases typically led to the installation of excessive secondary tailgate support. Successful longwall cases revealed that tailgate entries with an adequate ALPS SF according to their respective CMRR values required much less secondary support to maintain the tailgate entry. Through analysis of the successful and unsuccessful longwall cases, it is evident that the density of secondary support is closely related to the ALPS SF and CMRR.

The ALPS program, prior to the development of the CMRR, was designed to dimension longwall pillars without regard to a roof-rating system. The most recent version of the ALPS program incorporates the CMRR in pillar design. ALPS Version 4.0 consists of a pillar-design program and a database of CMRR ratings for various mineable coal seams in the United States. Through visual inspection of the immediate roof in a mine or from rock-core data of the rock layers directly above the coal seam, a CMRR can be established for a current or future tailgate entry. From the CMRR, an adequate pillar design can be established using the ALPS program.

The CMRR was developed for use in coal-mine design and roof-support selection. The CMRR is a roof classification system specifically for quantifying the structural competence of bolted coal-mine roof. The CMRR assigns a value from 1 to 100 to a mine roof, depending on various factors such as discontinuities, strong beds, and groundwater. Mine roofs with a CMRR of 45 or less are classified as weak roofs. Moderate roofs have a CMRR of greater than 45 but less than 65. Strong mine roofs have a CMRR of greater than 65. Through statistical analysis, 84% of the case histories of tailgate performance could be predicted correctly using only ALPS and the CMRR (Mark, Chase, and Molinda, 1994).

From Figure 5.2.1 it is evident that, as the structural competence of the roof increases, the suggested ALPS stability factor (ALPS SF) decreases. Most successful tailgate histories were at or above the suggested ALPS SF according to the CMRR of each mine. Figure 5.2.2 is a plot of the initial survey data that was collected from 1988 through 1990. The points represent successful tailgate histories with an ALPS SF greater than 0.7. This value was recommended as a lowest design stability factor that should be used, regardless of the CMRR. Successful cases which exhibited an ALPS SF of less than 0.7 were omitted from the plot.

It is recommended that mines which exhibit a weak roof should use an ALPS stability factor of 1.3 or greater to ensure that problems do not occur in the tailgate entry once longwalling commences. Mines with moderate roof strength should use an ALPS SF of greater than 1.0, and those with strong roof should use an ALPS SF greater than 0.7. Most of the successful case histories plotted in Figure 5.2.2 fell within the recommended range of ALPS stability factors prior to the development of the CMRR.

5.3 Selecting Secondary Support Systems

The third stage for determining the approximate secondary support capacity required for a tailgate entry is to establish adequate support density. Again, from analysis of previous successful case histories, trends in successful secondary tailgate support density can be identified.

For each case history in the initial survey (Appendix B), the secondary tailgate support type, configuration and arrangement were recorded. Wooden cribs were used in approximately 95% of the tailgate entries surveyed. Since wooden cribs were the

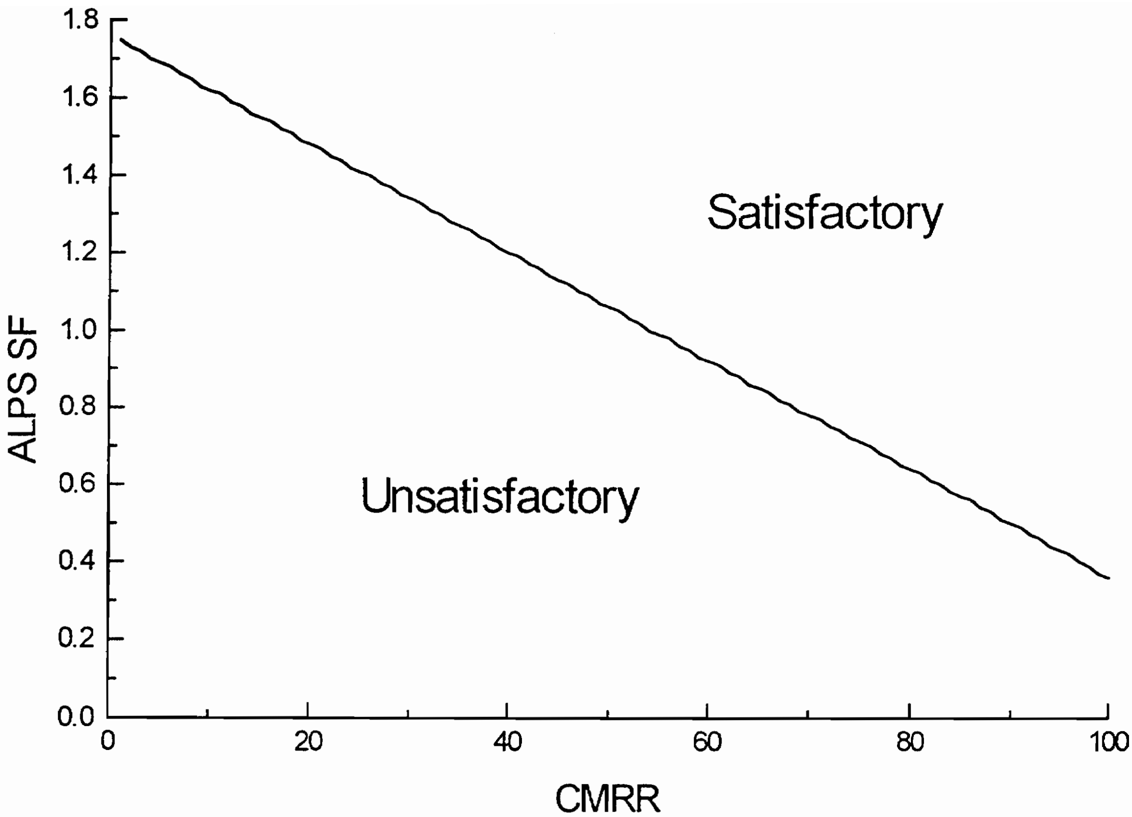


Figure 5.2.1 ALPS-suggested design equation plotted for all possible CMRR values.

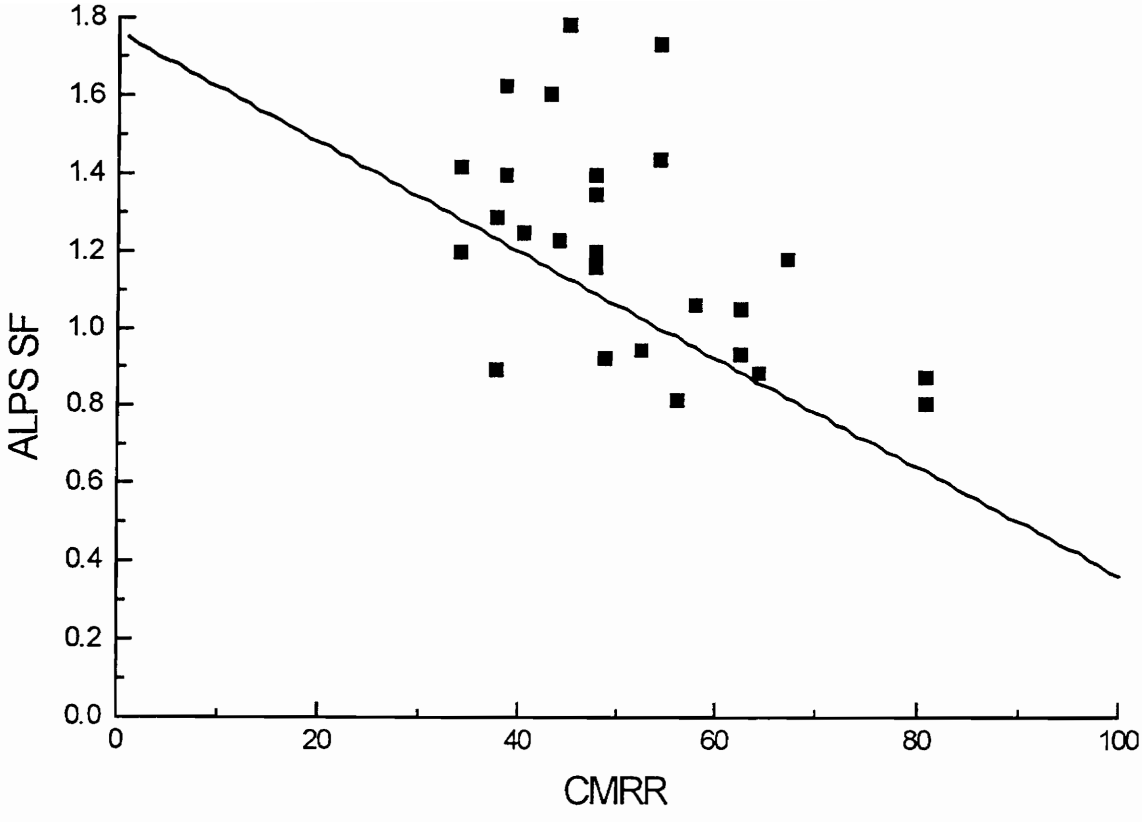


Figure 5.2.2 Successful tailgate case histories with ALPS SF greater than 0.7, plotted with respective CMRR against the ALPS SF-suggested design equation.

predominant support type, a support-density rating was developed to approximate the volume of wood installed per unit length along the tailgate entry. The secondary support rating (SSUP) was developed in search of a relationship with the ALPS SF and CMRR (Mark, Chase, and Molinda, 1994). Figure 5.3.1 illustrates the successful tailgate case histories from the initial survey with respect to their CMRR and SSUP. Equation 5.1 defines the variables associated with determining SSUP.

$$SSUP = \frac{Nc * Lc * Wc}{Sc * 0.3} \qquad (5.1)$$

where:
Nc = number of rows of cribs installed
Lc = length of crib blocks (m)
Wc = width of crib block (m)
Sc = center-to-center distance of cribs (m)

From Figure 5.3.1 it is evident that, as the CMRR increases, the density of support utilized decreases. This plot, however, is only representative of CMRR values between 30 and 70. A somewhat apparent linear lower bound can be established from CMRR 30 and SSUP 0.4 to CMRR 70 and a SSUP of approximately 0.07. The lower bound indicates, from previous experience, adequate secondary support density depending on the CMRR and a satisfactory ALPS SF. The points falling near the line indicate an adequate support density and those falling above the line indicate excessive support density. This lower bound can be used to determine the typical quantity of support utilized in mines under similar conditions.

A second survey conducted from 1993 through 1994 on the same longwall mines reveals that the majority of those still operational and using wooden cribs fall near or above the lower bound in Figure 5.3.1. Figure 5.3.2 illustrates the lower bound established in Figure 5.3.1 but includes data points from the second survey. The two surveys, which took place at least 4 years apart, reveal that this lower bound is

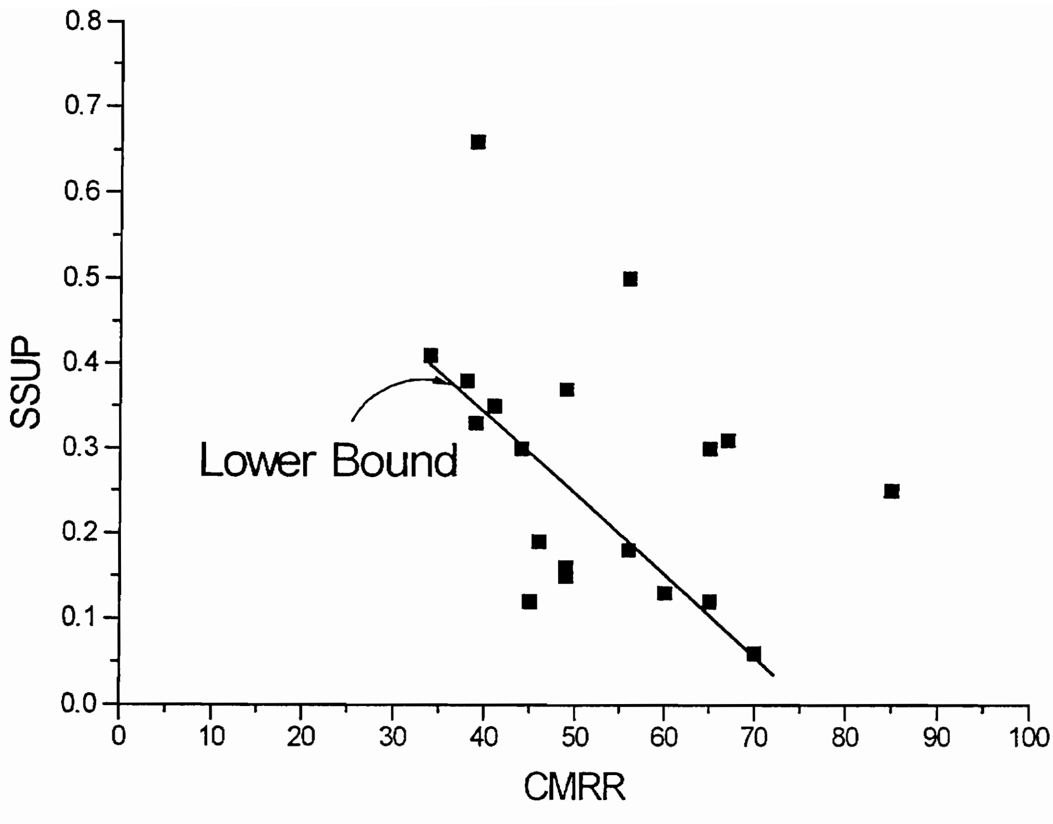


Figure 5.3.1 Successful tailgate case histories from Survey 1 (1988-1990) with respective CMRR and SSUP values.

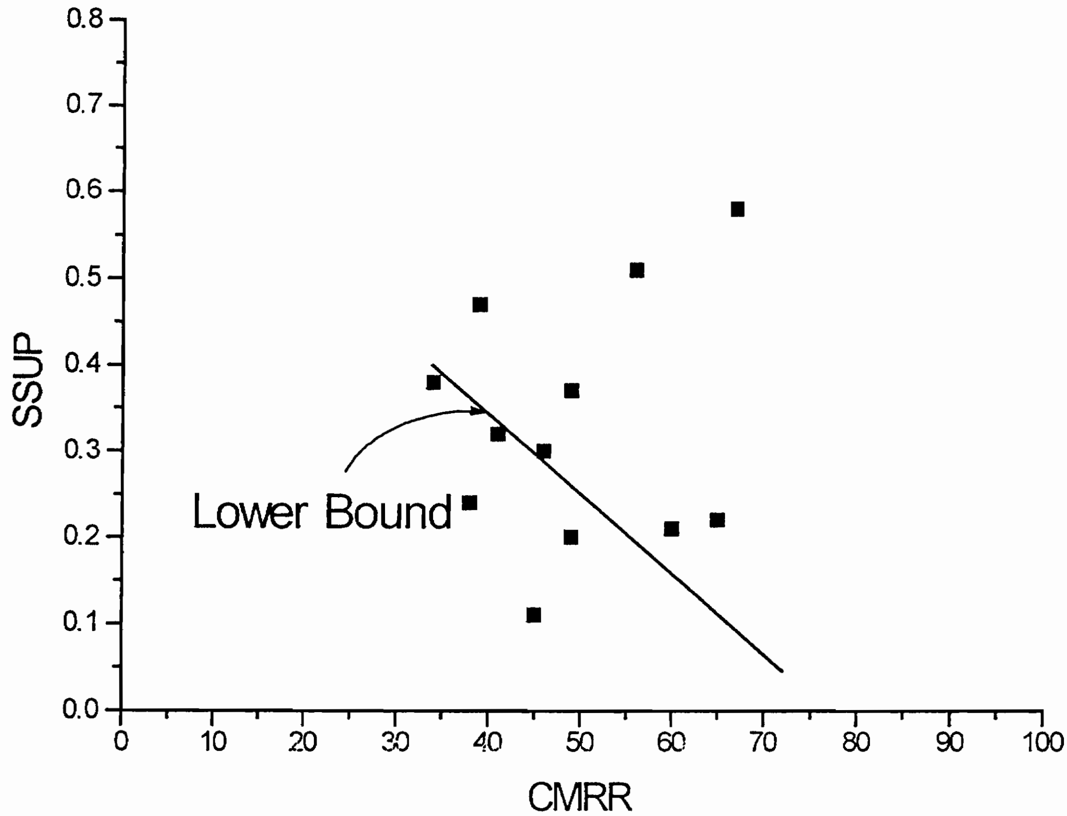


Figure 5.3.2 Second survey data of the same successful case histories represented in Figure 5.3.1, plotted with lower bound established by initial survey data.

representative of the expected secondary support density needed according to the ALPS SF and CMRR.

The second survey (Appendix C) consists of fewer data points, due to changes in secondary support systems utilized at some mines. Additionally, some mines have closed since the initial survey was conducted and data collected did not represent a large enough time lapse to be included in the second survey. From the data that were collected, presented in Figures 5.3.1 and 5.3.2, the apparent linear fit of the lower bound in Figure 5.3.1 has been met or exceeded over a period of at least 4 years as seen in Figure 5.3.2. The points which fall well below the line represent the same mines which appeared below the bound in Figure 5.3.1, with the exception of one point. This point reflects a large decrease in support density from the initial survey to the second survey. The majority of the second survey points do, however, fall near or above the line. The lower bound in Figure 5.3.2 can be used as a guide for the expected secondary support density required according to the mine design and roof conditions.

This can be helpful especially at the conception stage of mining, where initial mine design is taking place and the geological data is being collected from core samples. The CMRR can be established for expected tailgate locations and an approximation of needed secondary-support density can be made. By utilizing this compilation of past successful tailgate histories, the trial-and-error method of choosing secondary-support density can be avoided. By choosing a support density just above the lower bound, adequate support capacity can be expected and stability of the tailgate can be maintained. Figure 5.3.3 shows the lower bound and the equation (Equation 5.1) of the line for estimating the support density appears below. The lower bound can also serve as a guide for panels currently being developed. By comparing the current support density used with this guide, a decrease in support density may be possible without repercussions. Where support costs are high, this tool can minimize costs associated with current support densities where a decrease in support quantity is possible.

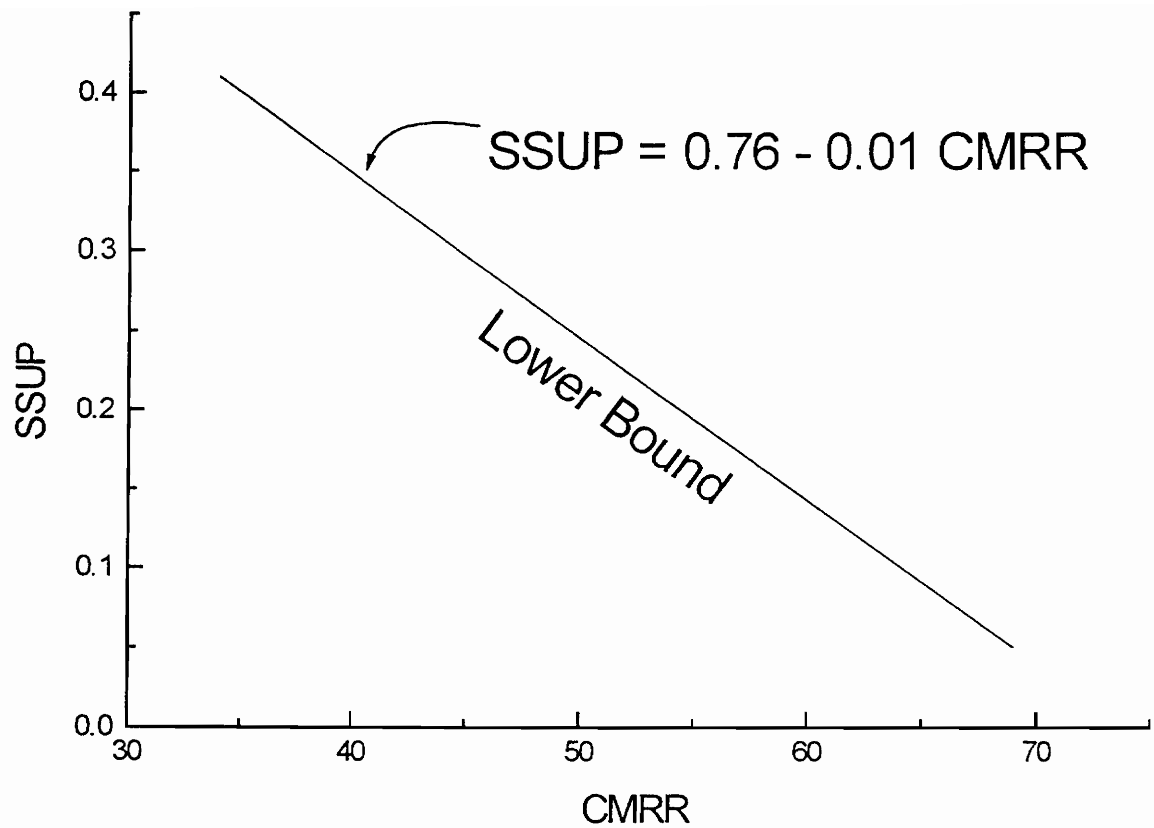


Figure 5.3.3: Lower bound of secondary tailgate support density required.

$$SSUP = 0.76 - 0.01\ CMRR \text{ ....(5.1)}$$

where:

SSUP = secondary support rating of equivalent crib configuration

CMRR = Coal Mine Roof Rating (from 30 to 70 CMRR only)

5.4 Model Input

The lower bound in established in Figure 5.3.1, as stated previously, is only validated by the statistical analysis of data between 30 and 70 CMRR. Additionally, the data used to develop the lower bound came from successful tailgate case histories only, and covers a period of at least four years but not more than six years. The lower bound is only an approximation of the density of secondary support that is required for mining under conditions similar to those found in the survey.

Roof conditions can also vary drastically along a tailgate entry, especially when a sandstone and shale interface is present in the immediate roof. The lower bound developed through this research does not account for varying conditions of the immediate roof. It merely represents the density of support utilized as the CMRR varies. It can serve as a guide for increasing or decreasing the support density according to statistical analysis of past conditions. As roof conditions change underground, the CMRR can be adjusted and different support densities utilized to maintain adequate support capacity.

The CMRR of the area of interest must be calculated to determine the expected support density needed for the immediate roof conditions. If a field investigation to determine the CMRR is not possible, the value obtained from ALPS 4.0 can be used with discretion, as stated previously. Once the CMRR for the mine roof has been established and a satisfactory ALPS pillar design has been incorporated, an approximation of the required secondary-support density can be determined from the lower bound in Figure

5.3.3. Upon determining the SSUP for a tailgate entry, selection of the secondary support system can be made.

Since the SSUP was developed solely for the determination of the volume of wood per unit length of entry, it cannot be used to directly estimate the density of other support types. Under given conditions, Equation 5.2 (below) can be used to determine the support capacity needed for a tailgate. For this scenario a four-point (two-by-two) standard wooden crib constructed of mixed eastern hardwoods with a yield load capacity of 68 tonnes (75 short tons) will be used (Barczak and Gearhart, 1994). The most common crib block dimensions used are 0.15m (six inches) wide x 0.15m (six inches) thick x 0.76m (30 inches) in length. The most common configuration is two parallel rows at a spacing of one to four meters (three to 13 feet) on centers (Peng and Biswas, 1994). By keeping the block dimensions and number of rows constant and varying the crib spacing, an equation for support capacity can be determined from the SSUP. Figure 5.4.1 represents the equivalent, expected support capacity necessary for support systems other than standard wooden cribs.

Capacity = 178.9 SSUP ....(5.2)

where:

capacity = total load capacity of support type (tonnes/meter)

SSUP = secondary support rating of equivalent crib configuration

Equation 5.2 can be simplified by rounding since wood, the material upon which the equation is based, is so variable in capacity. By reducing the equation (Equation 5.3) the capacity required for tailgate support can be easily determined from any SSUP value.

Capacity = 179 SSUP ....(5.3)

where:

capacity = total load capacity of support type (tonnes/meter)

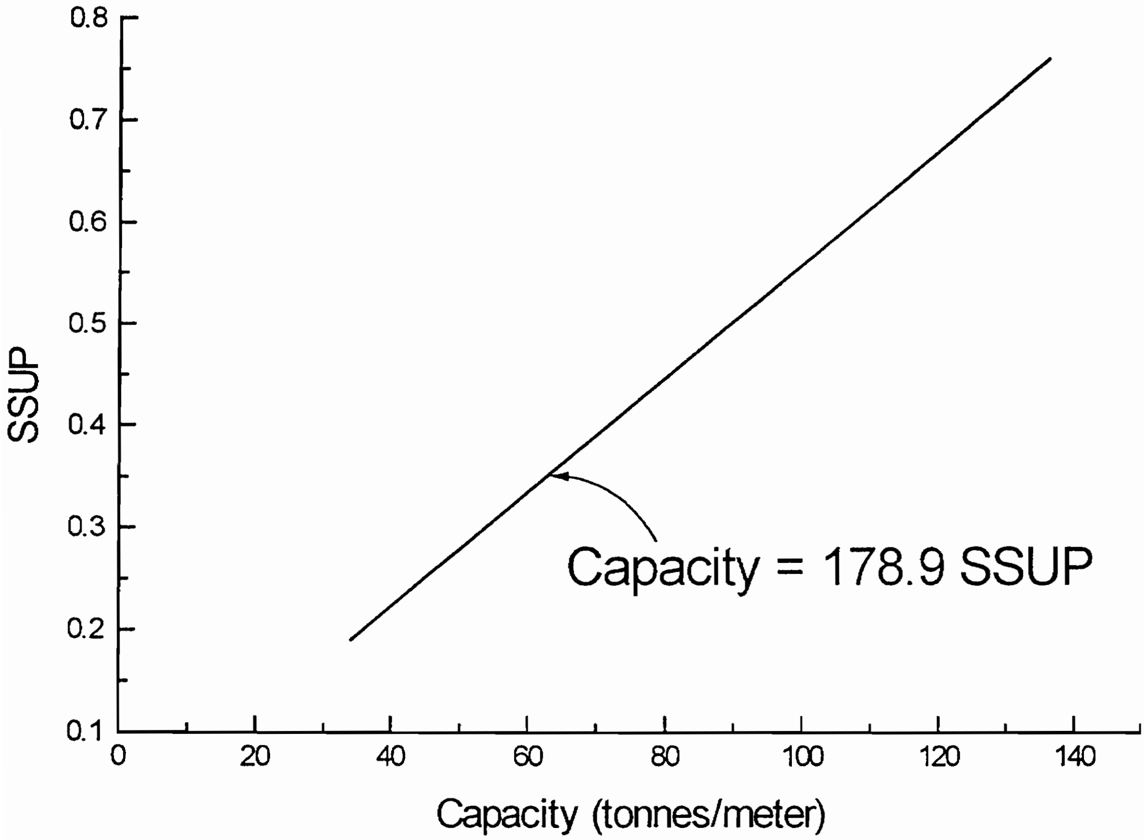


Figure 5.4.1: Secondary support capacity required for tailgate roof control.

SSUP = secondary support rating of equivalent crib configuration

Since the capacity and SSUP have been related through Equation 5.2, it is possible to relate the capacity directly to the CMRR by using Equation 5.1, which was developed for the lower bound in Figure 5.3.3. Equation 5.4 represents the combination of the two equations to solve for capacity in terms of CMRR:

Capacity = 136.0 - 1.8 CMRR ....(5.4)

where: capacity = total load capacity required for tailgate support (tonnes/meter)
CMRR = Coal Mine Roof Rating (from 30 to 70 CMRR only)

Using Figure 5.4.2, it is possible to directly estimate from the CMRR the secondary support capacity required to maintain a stable tailgate entry. Both external and internal secondary support systems can be selected by matching the load capacity of the support and the support spacing needed to achieve the design capacity.

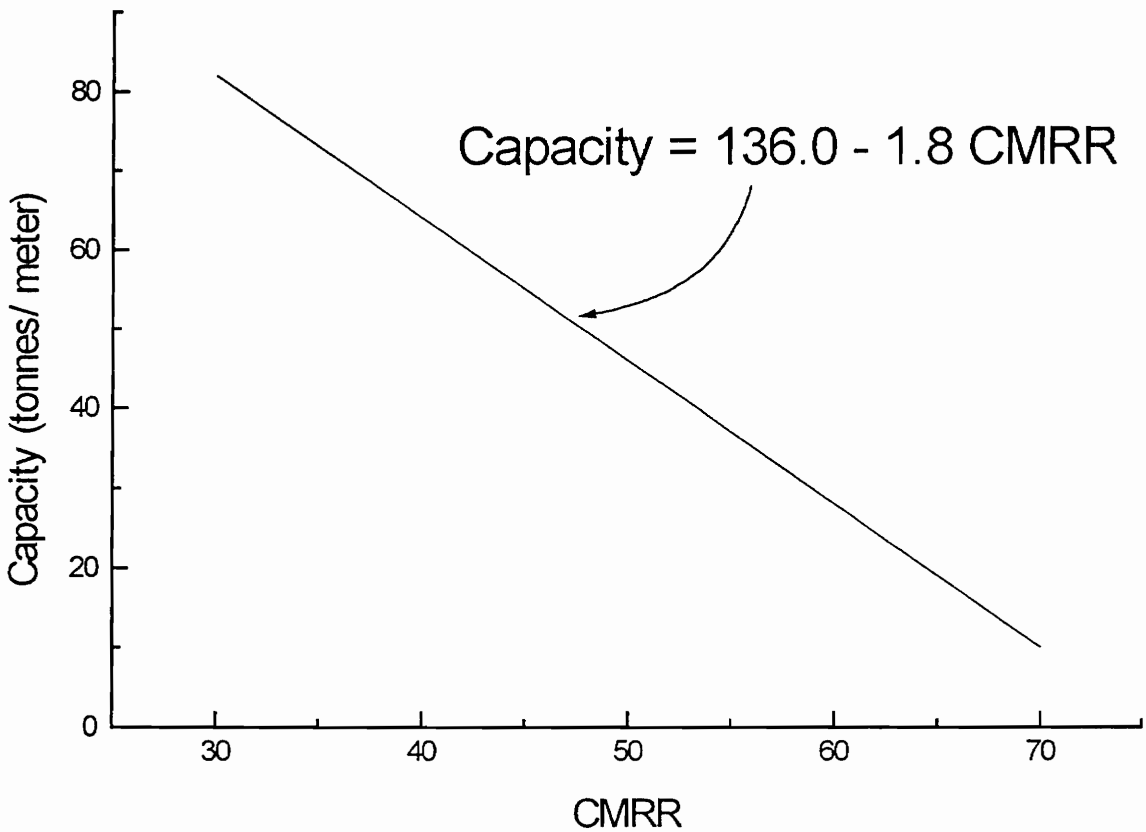


Figure 5.4.2: Secondary tailgate support capacity required for CMRR values of 30 to 70.

CHAPTER 6

Case Studies

6.1 Case Study: Mine #1

6.1.1 Roof Classification

A newly developed longwall coal mine in Raleigh County, West Virginia (Mine #1) lies in the Eagle coal seam, which is overlain by the No. 2 Gas coal seam and some previous longwall workings. The typical CMRR for the Eagle seam in the area is 54, and the immediate roof exhibits highly bedded, lightly slickensided shale. Sandstone is also present in some areas of the mine at the coal and roof interface.

Since Mine #1 lies 180 to 200 feet below the previously mined No. 2 Gas coal seam, proper layout of the longwall panels with respect to the above workings was crucial, during mine design. The mine above contains approximately four million gallons of water, which is constantly being pumped out of the old workings. Once longwall mining commences in the Eagle Seam, fractures in the innerburden will allow the water from above to collect in the newly formed gob area of the first panel. To combat the expected influx of water, the panels have been laid out to move progressively up-dip and away from the lowest point within the new mine. This will allow water to drain to a pumping station located at the end of the first panel. The water will then be pumped, 330 feet vertically to the surface and removed from the area.

6.1.2 Pillar Design

The chain pillars along the gateroads were designed using the Analysis of Longwall Pillar Stability, or ALPS, method. Since the CMRR value for the roof in the seam is 54, any ALPS stability factor over 1.0 will be satisfactory according to the ALPS design equation. The ALPS SF used in chain pillar design was 1.3, in Mine #1 which is more conservative than the ALPS SF design equation.

Chain pillars along the gateroads are of two different dimensions according to the varying depth of cover above the seam. For cover of less than 1,000 feet, the pillar dimensions are 85 by 70 feet. For cover depth of greater than 1,000 feet, the pillar size increases to 95 by 70 feet. This enables the ALP SF to be maintained well above the suggested design equation for improved tailgate performance.

Barrier pillars were omitted from the ends of the longwall panels adjacent to the bleeder entries. Barrier pillars were, however, placed at the panel ends bordering the mains to protect intake air, escapeways, and track and belt entries. Figure 6.3.1 illustrates the location of the first panel with respect to the mains, adjacent panels, and bleeder entries. The figure also shows the removal of the fourth gateroad on each successive panel after the second longwall panel.

All panels in the mine were designed and laid out for 1,000-foot-wide faces. Panel lengths vary throughout the mine from approximately 15,500 feet to 4,000 feet. Longwall panel #1 will utilize a four-entry system for the gateroads on both the headgate and tailgate sides. Longwall panel # 1 is the longest panel in the mine, and requires the additional entries to meet its ventilation requirements across the longwall face. All other panels in the mine are much shorter in length than panel # 1, and are not expected to require the fourth entry in order to maintain adequate ventilation. For each successive panel thereafter, a three-entry system will be used as long as ventilation requirements do not drastically change. The three-entry system will allow development of the gateroads by

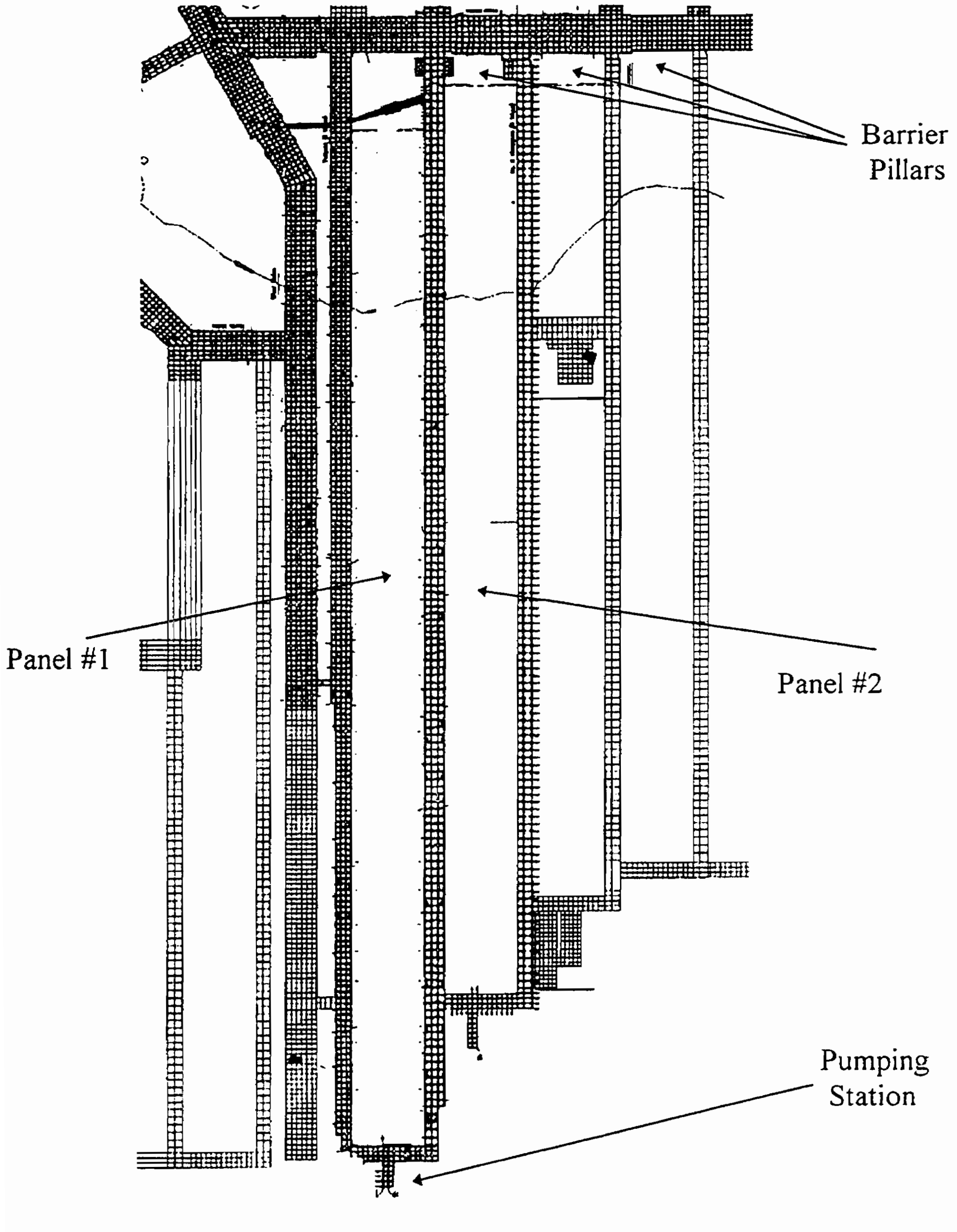


Figure 6.3.1 Design and layout of Mine #1.

a single continuous miner section, at a rate sufficient to develop the new panel prior to the current panel completion.

6.1.3 Selecting Secondary Support Systems

Mine #1 initially utilized four-foot, fully grouted resin bolts on four-foot centers as a primary support system for roof control in the development entries. However, this system eventually proved insufficient for maintaining the roof, as it did not provide active support. The mine had to switch to a system that would provide active support immediately after installation. A combination bolt system developed by Jenmar Corporation was chosen in an attempt to improve roof conditions.

Longwall panel #1 borders a barrier pillar on the tailgate side, running the entire length of the panel. The tailgate entry for panel #1 will be supported by one row of timber supports placed along the center of the gateroad. The timbers will be placed on five-foot centers ahead of the retreating longwall face. The timbers should provide adequate roof support in the tailgate entry since the entry is not adjacent to an extracted panel. This tailgate entry should receive very little, if any, additional load than the headgate for the same panel.

The tailgate entries for the second, and each successive, panel tailgate entry will experience a greater stress increase than the first tailgate entry due to the adjacent extracted panel. For this reason, timber support will not be adequate as a secondary support system. A truss system will be used for tailgate roof support for the second longwall panel. A roof-truss system also developed by Jenmar Corporation will be installed every 1.2 meters along the second panel tailgate entry and at each successive tailgate ahead of the longwall face. An attempt will be made to install the trusses during the development phase in the tailgate concurrently with primary support installation.

Many roof-truss systems are capable of supporting 45 tonnes or greater. With the above secondary support-system design, the truss can be expected to support approximately 38 tonnes of material per meter of entry. From Equation 5.4, it can be determined that the required capacity is 38.8 tonnes. Equation 5.1 indicates that a SSUP of at least 0.22 is required. Equation 5.2 demonstrates that the trusses will produce a SSUP rating of 0.21, which falls slightly below the lower bound illustrated in Figure 5.3.3 according to a CMRR of 54. Since the lower bound is a best-fit line for a trend in support density, a degree of variance can be expected and a SSUP difference of 0.01 is irrelevant. The roof-truss system should therefore provide adequate support capacity for Mine #1, given the conservative ALPS stability factor and the very close correlation with the lower bound.

6.2 Case Study: Mine #2

6.2.1 Roof Classification

A Buchanan County mine, Mine #2 lies in the Pocahontas #3 coal seam without considerable disturbance from other surface workings. The depth of the seam varies from approximately 1,400 feet to a maximum of 2,000 feet. The seam height ranges from 66 to 78 inches throughout the mine. A typical CMRR for the Pocahontas #3 seam from the ALPS SF database of values is 78, with the immediate roof consisting of bedded siltstone and mudstone.

6.2.2 Pillar Design

Mine #2 exhibited a high CMRR, so the ALP SF could be set significantly lower than at Mine #1. From Equation 3.1, it can be seen that an adequate ALPS SF would be only 0.67. However, the minimum recommended ALPS SF is 0.7, even for mines exhibiting strong roofs. Therefore Mine #2 could have designed for an ALP SF of 0.7 and still remain above the suggested design equation. In fact an ALPS SF of 0.92 was used, to insure that loads from adjacent panels would not significantly effect the tailgate entries.

At this Buchanan County mine, barrier pillars remain at both ends of the longwall panels to protect the bleeder entries and the mains from roof movement. It is essential that the bleeder entries remain open in the mine due to the release of methane gas. The chain pillars along the gateroad have consistent dimensions of 110 by 120 feet.

A four-entry gateroad system is utilized for each development section and longwall panel in the mine. There must be at least four entries due to the extremely large generation of methane gas in this particular mine. Each gateroad is cut at 20 feet in width and chain pillars have consistent dimensions for each panel. The relatively high CMRR value for the immediate roof allows the gateroads to be cut at 20 feet even in the tailgate entry.

6.2.3 Selecting Secondary Support Systems

Mine #2 consistently utilizes two parallel rows of four-point cribs constructed from mixed eastern hardwoods. This secondary support system has performed well with respect to the tailgate histories at the mine. The SSUP for this system on eight foot centers is 0.32. According to Figure 5.3.3, the density of secondary support required is less than 0.1. This indicates that an excessive quantity of support is being installed in the tailgate entry. It is possible that a reduction in the support density could adequately support the tailgate and reduce support cost. Since the lower bound in Figure 5.3.3 is only valid for CMRR values of 30 to 70, judgment must be used in determining an acceptable SSUP.

From Equation 5.1 it is evident that the crib spacing can be increased and still maintain adequate support density for the tailgate entry. By increasing the center-to-center distance between cribs to 12 feet, a SSUP of 0.2 can still be achieved. This is more than adequate according to the lower bound in Figure 5.3.3, and could reduce all costs associated with installing secondary tailgate support by 33%.

The expected support capacity required for the tailgate entry can be determined from Equation 5.4. The equation yields a required support capacity of less than 10 tonnes per meter if a value of 70, the lowest valid CMRR for the equation, is used.

CHAPTER 7

Conclusions

The model presented in this paper can be extremely valuable, particularly in preliminary mine design using geological data collected from core samples. The CMRR can be established for expected tailgate locations, and an approximation of secondary support density requirements can thereby be made. By utilizing this compilation of past successful tailgate histories, the trial-and-error method of choosing secondary support density can be avoided. By choosing a support density just above the lower bound, adequate support capacity can be expected and stability of the tailgate can be maintained. The lower bound can also serve as a guide for panels currently being developed. Comparing the current support density used with this guide may lead to a decrease in support density without repercussion. Where support costs are high, this model can be used to minimize the costs of using excessive support. Finally, other support systems can be weighed for economic and performance benefits against wooden cribs by calculating the required support capacity.

While the SSUP rating system was intended for use only on standard wooden cribs, the support capacity of any wooden crib layout can be calculated and used for systems composed of other materials. The model can also serve as a system to determine the density required for internal support systems, such as cable bolts and roof trusses. As demonstrated in the case study performed with the Raleigh County, WV mine (Mine #1), the support capacity of such a truss system can be equated with the equivalent density of wooden cribs.

Economic benefits can be realized by equating the required support density for a tailgate entry, depending on the ALP SF and the CMRR, with the capacity of the various secondary support systems available. Not only can the appropriate density of support be thereby estimated, but the costs of purchasing and installing the various systems can be compared to achieve cost savings. Finally, the case study performed on the Buchanan County mine (Mine #2) indicates that a lesser quantity of support could theoretically be installed to achieve the same tailgate performance but at a reduced cost.

REFERENCES

Anon., "Longwall Census 1995," *Coal*, February 1995, pp. 32-38.

Barczak, T.M., and Gearhart, D.F., 1993, "Engineering Methods for the Design and Employment of Wood Cribs," *Proceedings* of the 12th International Conference on Ground Control in Mining, Morgantown, WV, pp. 47-54.

Barczak, T.M., and Gearhart, D.F., 1994, " Assessment of Wood and Alternative Materials for Supplemental Roof Support Construction," Proceedings of the 13th International Conference on Ground Control in Mining", Morgantown, WV, pp. 190-199

Barczak, T.M., Schwemmer, D.E., and Tasillo, C.L., 1989, "Practical Considerations in Longwall Face and Gate Road Support Selection and Utilization" IC 9217, USBM, pp. 14-21.

Barczak, T.M., and Schwemmer, D.E., 1988, "Effect of Load Rate on Wood Crib Behavior," RI 9161, USBM, pp. 2-11.

Biron, C., and Arioglu, E., 1982, *Design of Support in Mines* John Wiley and Sons, New York, NY, p. 248.

Breyer, D.E., 1993, *Design of Wood Structures* Third Edition, McGraw-Hill, Inc. New York, NY, pp. 129-168.

Choi, D.S., Dahl, H.D., and Von Schonfeldt, H., 1975, "Design of Longwall Development Headings" *SME Transactions*, Vol. 258, December, pp. 358-363.

Dahl, H.D., 1978, "The State of the Art in Underground Coal Mine Design" *Proceedings* of the 1st International Symposium on Stability in Coal Mining, Vancouver, British Columbia, Canada, pp. 125-134.

Fiscor, S., and Merritt, P., 1996, "The 1996 Longwall Census" *Coal Magazine*, Vol. 101, No. 2, February 1996, pp. 32-39.

Forest Products Laboratory, Forest Service, U.S. Department of Agriculture, 1989, *Handbook of Wood and Wood-Based Materials for Engineers, Architects, and Builders* Hemisphere Publishing Corporation, New York, NY, pp. 4.1 - 4.26.

Fuller, P.G., and O'Grady, P., 1993, "FLEXIBOLT Flexible Roof Bolts: A New Concept for Strata Control" *Proceedings* of the 12th International Conference on Ground Control in Mining, Morgantown, WV, pp. 24-34.

Hosca, E., Haycocks, C., and Karmis, M., 1994, "Influence of Support Capacity and Geometry on Tailgate Support" *Proceedings* of the 13th International Conference on Ground Control in Mining, Morgantown, WV, pp. 161-165.

Kosmatka, S.H. and Panarese, W.C, 1988, *Design and Control of Concrete Mixtures* Thirteenth Edition, Portland Cement Association, Skokie, Illinois, pp. 1-10.

Kripakov, N.P., Beckett, L.A., Donato, D.A., and Durr, J.S., 1990, "Computer Assisted Mine Design for Longwall Mining," RI 9172, USBM, p. 38.

Krupa, E., and Long, L., 1994, "Bethenergy supports problem roof with trusses" *Coal Magazine*, Vol. 99, No. 5, pp. 76-78.

Mark, C., and Molinda, G. 1996, "Rating Coal Mine Roof Strength From Exploratory Drill Core" *Proceedings* of the 15th International Conference on Ground Control in Mining, Morgantown, WV

Mark, C., Chase, F., and Molinda, G., 1994, "Design of Longwall Gate Entry Systems Using Roof Classification," New Technology For Ground Control, *Proceedings*: USBM Technology Transfer Seminar, Washington D.C., pp. 5-17.

Mark, C., and Bieniawski, Z.T., 1986, "An Empirical Method for the Design of Chain Pillars for Longwall Mining" *Proceedings* of the 27th US Symposium on Rock Mechanics, AIME, New York, NY, pp. 415-422.

Mark, C., 1987, "Analysis of Longwall Pillar Stability," Ph.D. thesis, Pennsylvania State University, University Park, PA, p. 414.

McCartney, C., Tupper, L., and Paton-Ash, G.R., 1995, "The Design and Application of Propsetter™ in Underground Coal Mines" *Proceedings* of the 14th International Conference on Ground Control in Mining, Morgantown, WV, pp. 144-148.

McDonnell, J.P., Tadolini, S.C., and DiGrado, P.E., 1995, "Field Evaluation of Cable Bolts for Coal Mine Roof Support" Report of Investigations 9533, USBM, p. 19.

McPherson, M.J., 1993, "Subsurface Ventilation and Environmental Engineering" Chapman and Hall, New York, NY, pp. 136-159.

Molinda, G.M., and Mark, C., 1994, *Coal Mine Roof Rating (CMRR): A Practical Rock Mass Classification For Coal Mines* Information Circular 9387, Pittsburgh Research Center, U.S. Bureau of Mines, Pittsburgh, PA. pp. 1-33.

Mucho, T.P., 1996, " Cable Bolts: A 'New' Support" *Ground Control, Mining Health and Safety Update*, Department of Energy, March, pp. 2-3.

Peng, S.S., and Biswas, K., 1994, "Tailgate Support Practice in U.S. Longwall Mines - A Survey" *Proceedings* of the 13th International Conference on Ground Control in Mining, Morgantown, WV, pp. 157-160.

Peng, S.S., Hsiung, S.M., and Jiang, Y.M., 1987, "Method of Determining the Rational Load Capacity of Shield Supports at Longwall Faces" *Mining Engineer*, Vol. 147, No. 313, pp. 161-167.

Peng, S.S., and Chiang, H.S., 1984, *Longwall Mining* John Wiley & Sons, Inc., New York, N.Y., pp. 2-141.

Peters, W.C., 1992, "Geologic Prospecting and Exploration" *SME Mining Engineering Handbook, Vol. 1*, Port City Press Inc., Baltimore, Maryland, pp. 221-242.

Riefenberg, J., and Wuest, W.J., 1994, *A personal Computer Program and Spreadsheet for Calculating the Coal Mine Roof Rating (CMRR)* Information Circular 9386, Pittsburgh Research Center, USBM, Pittsburgh, PA. pp. 2-23.

Segui, W.T., 1994, *LRFD Steel Design* PWS Publishing Company, Boston, Massachusetts, pp. 90-101.

Singh, M.M., 1985, "Review of Coal Mine Subsidence Control Measures" *SME-AIME Transactions*, Vol. 278, Littleton, CO, pp. 1988-1992.

Stankus, J.C., Song, G., McCaffrey, J.J., and Peng, S.S., 1994, "Innovative Concept in Tailgate Entry Support: Elimination of Crib Blocks Through Utilization of New High Capacity Roof Truss Systems" *Proceedings* of the 13th International Conference on Ground Control in Mining, Morgantown, WV, pp. 166-174.

Tanius, N.S., Beckett, R.D., and Bollinger, E.R., 1984, "Development of Steel-Fiber-Reinforced Concrete Cribs to Replace Wood Cribs in Underground Coal Mines" *SME-AIME Transactions*, Vol. 280, pp. 1928-1935.

Wilson, J.W., 1975, "Support of Underground Excavations in Deep-Level, Hard-Rock Mines," Institute of Mining and Metallurgy. Jan.

Wilson, J.W., and Emere, G.T.G., 1972, "The Laboratory Testing of Stope Support" *Symposium on Strata Control and Rockburst Problems on the South African Goldfields*, Papers and Discussions, The Chamber of Mines of South Africa, Cape Town, South Africa pp. 55-105.

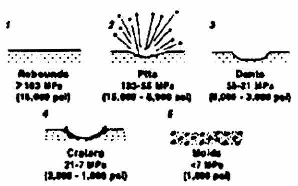
APPENDICES

APPENDIX A

DATE______MINE________________LOCATION__________________________PAGE______OF________ CMRR______

TYPE OF EXPOSURE____________________________________ NAME______________________________

UNIT						UNIT DISCONTINUITIES						Orientation	
Unit No.	Unit Thickness	Strip Log	Description	Strength	Moisture Sensitivity	Disco. I.D.	Description	Cohesion	Roughness	Spacing	Persistence Lateral/Vert	Strike	Dip
3						A.							
						B.							
						C.							
	CONTACT												
2						A.							
						B.							
						C.							
	CONTACT												
1						A.							
						B.							
						C.							
			1	Rebounds	Not Sensitive		1	Strong (>7)**	Jagged	>1.8 m (6 ft)	0-0.9 m (0-3 ft)	N.	Horiz.
			2	Pits	Slightly Sensitive		2	Moderate (4-7)	Wavy	0.6-1.8 m (2-6 ft)	0.9-3 m (3-10 ft)	NE.	Subhoriz.
			3	Dents	Moderately Sensitive		3	Weak (1-3)	Planar	20-60 cm (8-24 in)	3-9 m (10-30 ft)	E.	45°
			4	Craters	Severely Sensitive		4	Slicken-sided (0)		6-20 cm (2.5-8 in)	>9 m (30 ft)	SE.	Subvert.
			5	Molds			5			<6 cm (2.5 in)		S.	Vert.



Groundwater (inflow/10 m (33 ft) of entry length) (Circle)

L/min (gal/min)

Dry 0	1	Heavy Drip 10-50 (2.7-12.2)	4
Damp 0-5 (0-1.3)	2	Flowing >50 (13.2)	5
Light Drip 5-10 (1.3-2.7)	3		

Describe condition in vicinity of fall (circle one)

1. Good 3. Heavy

2. Scaly 4. Failed

** Hammer blows necessary to split bedding with 9-cm (3.5-in) chisel.

COMMENTS: (Roof Support, etc.)

CMRR field data sheet (Molinda and Mark, 1994).

IMMERSION TEST

Mine ______________________ *Date* ______________________

Unit No. ______________________ *Tester* ______________________

Sample Description (lithology, bedding, etc.)

Immersion		*Breakability*	
Observation	***Rating***	***Observation***	***Rating***
Appearance of Water			
Clear = 0	_____	*No Change = 0*	
Misty = -2		*Small Change = -3*	
Cloudy = -5		*Large Change = -10*	
Talus Formation		*Total*	_____
None = 0			
Minor = -2	_____		
Major = -5			
Cracking of Sample			
None = 0			
Minor-Random = -2			
Major-Preferred Orientation = -5	_____		
Specimen Breakdown = -15			
Total	_____		

IMMERSION TEST

Procedure for Immersion Test

1. *Select sample(s) ≈ hand-sized.*
2. *Test for hand breakability.*
3. *Rinse specimen (to remove surface dirt, dust, etc.).*
4. *Immerse in water for 24 h.*
5. *Observe and rate water appearance, talus formation, and cracking of sample.*

   Sum Rating for Immersion Test Index.
6. *Retest for hand breakability.*

   Determine Breakability Index.
7. *Use the larger negative value of the Immersion Test Index or the Breakability Index as the Weatherability Rating.*

Immersion test data sheet for determining CMRR (Molinda and Mark, 1994).

APPENDIX B

State and seam	ALPS Stability Factor	Coal Mine Roof Rating	Entry width, m	Primary Support Rating	Secondary Support Rating
Alabama:					
Blue Creek	0.96	49	6.2	0.50	0.16
Do	0.94	49	6.2	0.28	0.75
Do	0.85	49	6.2	0.15	0.27
Do	0.44	49	6.2	0.18	0.16
Colorado:					
D Seam	1.02	51	5.5	0.31	0.44
Wadge	0.45	62	5.8	0.15	0.50
Kentucky:					
Harlan	0.42	63	5.5	0.26	1.14
Lower Elkhorn	0.66	85	6.2	0.19	0
Taggart	0.41	54	6.2	0.15	0.53
Warfield	0.92	56	6.2	0.12	0.27
New Mexico:					
Left Fork	0.52	31	5.5	0.25	0.88
Pennsylvania:					
Pittsburgh	0.81	39	5.2	0.30	0.66
Pittsburgh	0.90	46	5.2	0.22	0.38
Pittsburgh	1.02	34	5.2	0.26	0.41
Utah:					
Castlegate	0.28	80	5.2	0.21	0.67
Castlegate	0.41	80	5.2	0.21	0.67
Wattis	0.41	69	6.2	0.15	0.66
Virginia:					
Jawbone	0.80	54	5.8	0.23	0.15
Lower Banner	1.58	45	6.3	0.21	0.21
Pocahontas No. 3	0.36	78	6.2	0.15	0.25
Taggart	0.63	58	5.5	0.30	0.38
West Virginia:					
Campbell Creek	0.75	38	5.8	0.19	0.33
Do	0.75	52	5.8	0.21	0.25
Do	0.62	38	5.8	0.19	0.25
Do	0.58	58	5.8	0.15	0.31
Do	0.72	52	5.2	0.23	0.25
Eagle	0.62	60	5.7	0.20	0.13
Pittsburgh	0.93	39	4.8	0.20	0.33
Pittsburgh	0.99	38	4.2	0.09	0.24
Pittsburgh	1.24	38	4.2	0.09	0.24
Upper Freeport	0.89	44	5.2	0.26	0.25
Wyoming:					
Hanna	1.01	43	5.5	0.29	0

Do. Same as above.

First survey data for unsuccessful tailgate case histories (Mark, Chase, and Molinda, 1994).

IMMERSION TEST

Mine ____________________ *Date* ____________________

Unit No. ____________________ *Tester* ____________________

Sample Description (lithology, bedding, etc.)

Immersion		*Breakability*	
Observation	***Rating***	***Observation***	***Rating***
Appearance of Water *Clear = 0* *Misty = -2* *Cloudy = -5*	____	*No Change = 0* *Small Change = -3* *Large Change = -10*	
Talus Formation *None = 0* *Minor = -2* *Major = -5*	____	*Total*	____
Cracking of Sample *None = 0* *Minor-Random = -2* *Major-Preferred Orientation = -5* *Specimen Breakdown = -15*	____		
Total	____		

IMMERSION TEST

Procedure for Immersion Test

1. *Select sample(s) ≈ hand-sized.*
2. *Test for hand breakability.*
3. *Rinse specimen (to remove surface dirt, dust, etc.).*
4. *Immerse in water for 24 h.*
5. *Observe and rate water appearance, talus formation, and cracking of sample.*

   Sum Rating for Immersion Test Index.
6. *Retest for hand breakability.*

   Determine Breakability Index.
7. *Use the larger negative value of the Immersion Test Index or the Breakability Index as the Weatherability Rating.*

Immersion test data sheet for determining CMRR (Molinda and Mark, 1994).

APPENDIX C

Seam	ALPS Stability Factor	Coal Mine Roof Rating	Entry Width (ft)	Primary Support Rating	Secondary Support Rating
Herrin #6	1.38	49	16.0	0.26	0.37
Upper Alma	1.42	56	20.0	0.12	0.51
Pittsburgh	1.4	34	17.0	0.26	0.38
Pittsburgh	1.38	39	16.0	0.2	0.47
Pittsburgh	1.77	46	14.0	0.2	0.3
Blue Creek	1.16	49	20.0	0.28	0.2
Pittsburgh	1.23	41	16.0	0.24	0.3
Dorchester	1.21	45	19.0	0.23	0.11
Jawbone	1.03	65	19.0	0.23	0.22
Eagle	1.04	60	19.0	0.2	0.21
Pittsburgh	1.27	38	14.0	0.5	0.24
Jawbone	0.91	65	19.0	0.23	0.22
No. 2 Gas	0.86	67	19.0	0.15	0.58

Second Survey Data used for plot in Figure 5.3.2.

VITA

Cary Pearson Harwood, Jr. was born in Tazewell, Virginia. He graduated from Tazewell High School in 1989. He was admitted to Virginia Polytechnic Institute and State University in 1989 and graduated with a Bachelor of Science degree in Civil Engineering in 1994. He was then admitted for graduate studies in 1994 at Virginia Polytechnic Institute and State University in the Department of Mining and Minerals Engineering, where he is presently pursuing his Master of Science degree.