MATERIAL HANDLING CONSIDERATIONS FOR SECONDARY ROOF SUPPORT SYSTEMS

By Thomas M. Barczak[1]

ABSTRACT

Secondary roof support systems play a vital role in preserving the safety of underground mine workers by preventing the unintentional collapse of the mine roof. Hundreds of thousands of standing roof supports are constructed each year in underground coal mines. Historically, wood and concrete cribs and timber posts have been used for secondary roof support. These support constructions require the handling of heavy and bulky materials, causing numerous injuries to the mine workers and resulting in more than 40,000 lost workdays in the past 9 years. Since 1993, various alternative support technologies have been developed. These new support technologies not only provide superior roof support, but many also have significant material handling advantages by using smaller and lighter weight materials, fewer components, mechanically installed support systems, and pumpable support systems. The National Institute for Occupational Safety and Health (NIOSH) has conducted extensive material handling research and has developed recommended lifting thresholds to reduce material handling injuries. An analysis of roof support construction reveals that conventional support materials used in wood and concrete cribbing exceed the recommended lifting thresholds, while the engineered support systems are closer to the recommended weight thresholds. Finally, recommendations are made relative to proper lifting techniques and material handling practices to prevent injury to mine workers when constructing roof supports in underground coal mines.

---

[1] Research physicist, Pittsburgh Research Laboratory, National Institute for Occupational Safety and Health, Pittsburgh PA.

INTRODUCTION

The primary goal of roof support is to prevent unplanned roof falls from occurring. While falls of ground are the leading cause of *fatalities* in underground coal mining, many more *injuries* from the effort required to install these essential roof support systems than from the fall of ground due to poor roof support design. There is also continued pressure to install supports more quickly to keep pace with the escalating productivity, particularly in modern longwall mining operations. These requirements, coupled with the fact that the workforce is aging, strongly suggest that a higher priority should be given to the material handling considerations and construction practices during the roof support selection process.

During the 1990s, there was an unprecedented increase in the development of standing roof support systems to replace conventional wood and concrete cribbing and timber posts that have historically been used for secondary roof support throughout the mine. These innovative roof support systems were designed to provide superior roof control, but most also provide material handling benefits that allow supports to be constructed with less effort and at faster rates.

This paper highlights the material handling characteristics of these modern roof support systems and describes their impact on the installation of secondary roof support and safety of the mine workers performing this function. A complete assessment of the transportation and construction requirements for each support is made to provide mine operators with a guide for evaluating these alternative support technologies. Regardless of the physical properties of the support, injuries can also be prevented by using proper lifting techniques and avoiding excessive stress that occurs when recommended lifting thresholds are exceeded. These issues are also addressed through some practical examples.

INJURY INFORMATION

According to the Mine Safety and Health Administration (MSHA) accident database, over 55% of the permanent disabling injuries in underground coal mining during 1992-94 were due to material handling [MSHA 1996]. An even greater number of nondisabling injuries may be linked to material handling in mining. It is likely that these accident trends will continue and perhaps grow worse due to an aging workforce. It is also very likely that younger and inexperienced miners that will replace retiring miners will also experience a high incidence rate for these kind of accidents until they become more skilled.

The construction of secondary support systems has historically required repetitive lifting of large volumes of bulky support materials. Coupled with the poor conditions, underground limited space and maneuverability, and the fact that many of the support materials exceed 40 lb, this activity is responsible for numerous injuries to mine workers. Such activity has been classified by the National Occupational Health Survey of Mining as a heavy lifting risk factor, exposing miners performing this activity to a high risk for musculoskeletal repetitive trauma disorders [Winn and Biersner 1996]. Thus, material handling should also be a primary consideration in the application of longwall tailgate support technologies.

A review of the MSHA accident database reveals that 1,483 lost-time accidents were reported from 1990 to 1998 associated with timber handling. Further review of these accidents indicates that 1,204 were directly related to support construction, accounting for 40,147 lost workdays during this 9-year period. The average lost time per incident was 33.34 days. Figure 1 shows the number of material handling accidents attributed to crib construction from 1990 to 1998; figure 2 shows the incidence rate for the same period. Generally, both the number of accidents as well as the incidence rate dropped during this period, except for a moderate increase in 1998. Without more extensive data than are available in the current database, there is no apparent reason for the increase in 1998. It could be that more attention has been drawn to material handling issues recently, and minor incidents that were previously not reported or mislabeled are now being reported. It might also be a 1-year anomaly.

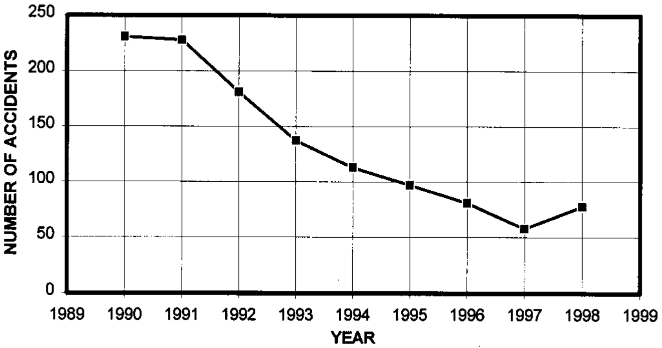

Figure 1.–Number of timber-handling accidents.

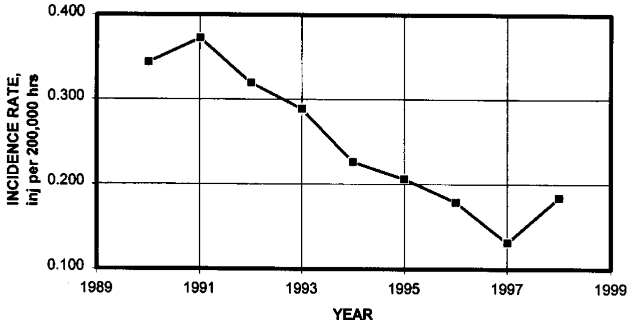

Figure 2.–Incident rate for timber-handling injuries.

The decrease in injuries from roof support construction correlates with the implementation of new support technologies that exhibit material handling advantages over conventional wood cribbing. These alternative support systems are addressed in detail in the remainder of the paper. Before 1992, all longwall tailgates used either conventional wood or concrete cribbing. As shown in figure 3, only 39% of the longwall tailgates were supported with conventional wood or concrete cribbing in 1996. Figure 4*A* compares the incidence rate for timber material handling injuries with the replacement of conventional cribbing with engineered timber supports. As seen, the trend of decreasing material accidents continues during the period when new support technologies were introduced. Figure 4*B* shows that the severity of injury decreased considerably after 1994, correlating with the implementation of the engineered alternative support systems. These findings suggest that these lighter weight support materials are having a positive impact on reducing material injuries associated with support construction in underground coal mines.

Figure 5 shows a breakdown of lost workdays due to timber handling injuries in underground coal mines. As might be expected, 71% of the lost workdays are due to back-related injuries. Figure 6 depicts the number of lost workdays per

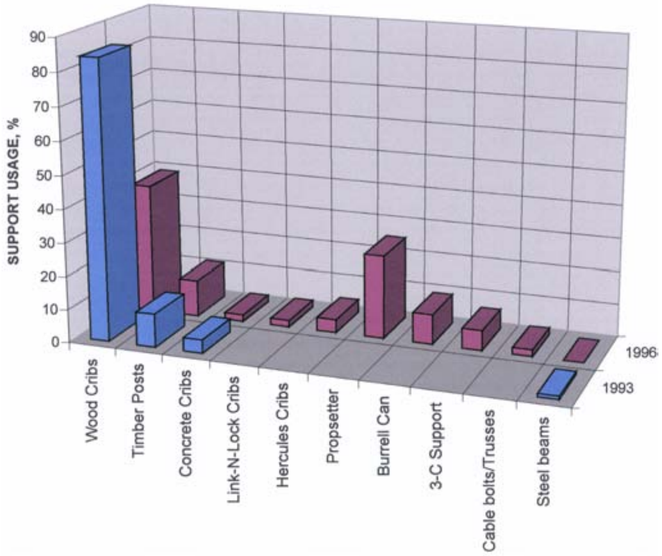

Figure 3.–Comparison of support technologies used in 1993 and 1996.

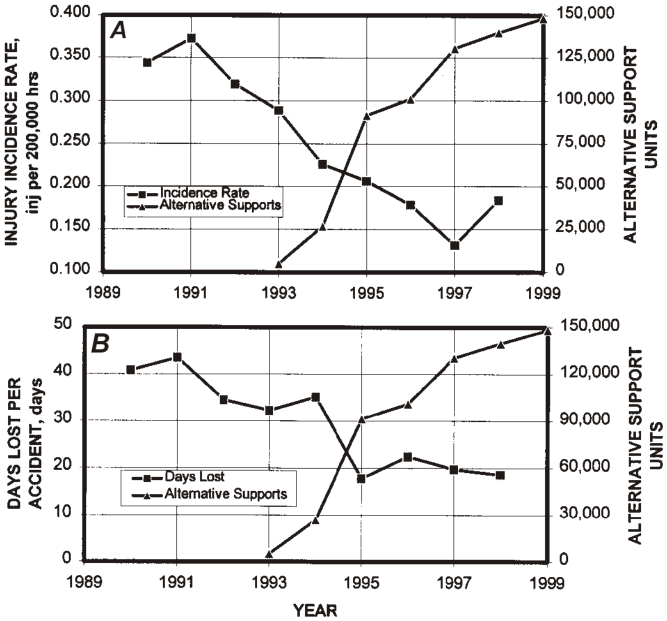

Figure 4.–A, Comparison of timber-handling incident rate with the implementation of alternative engineered timber support systems. B, Comparison of days lost due to timber handling with the implementation of alternative engineered timber support systems.

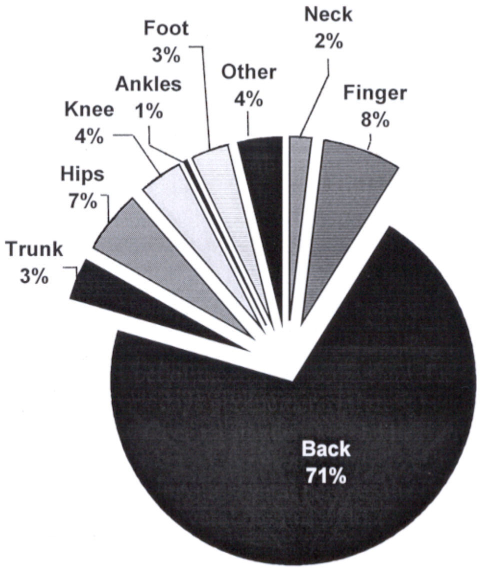

Figure 5.–Assessment of lost workdays relative to body part for timber-handling injuries.

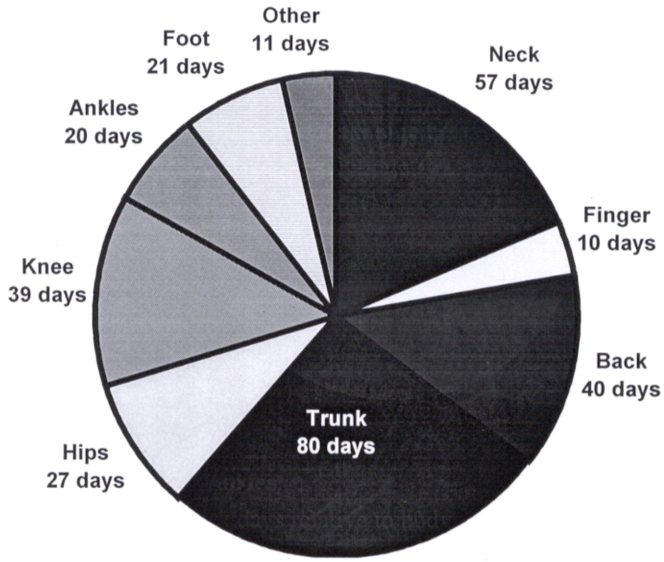

Figure 6.–Bodily assessment of lost workdays per incident for timber handling accidents.

incident. Here it is seen that the most severe injuries are to the trunk of the body (80 days per incident). The next most severe injury is to the neck (57 days per incident), followed by back injuries at 40 days per incident. In conclusion, timber handling activities can result in injury to several parts of the body, and many injuries will be severe enough to cause several days to several months of lost work time.

SUPPORT DESIGN IMPROVEMENTS THAT REDUCE MATERIAL HANDLING REQUIREMENTS

Conventional wood and concrete cribs require piecemeal construction of relatively heavy and bulky materials weighing 35 to 55 lb. Significant material handling advantages are realized in various alternative support technologies by the use of lighter weight and more compact support components; other support systems use fewer components in the support construction. Manual material handling is all but eliminated in supports that are installed with a machine. Innovative supports that are pumped in place in the mine greatly reduce transportation requirements and minimize manual effort in the confined space of the underground mine where material handling efforts are considerably more difficult than on the surface.

SMALLER AND LIGHTER WEIGHT COMPONENTS

Conventional wood cribs are typically constructed in four-point or nine-point configurations, as shown in figure 7. In these configurations, the roof load is carried only through the area where the adjacent timbers contact one another. For example, in a four-point wood crib, this occurs only at the four corners of the support structure. As seen in figure 7, over 50% of the timber *does not* contribute to the capacity of the support. Modern engineered timber supports, such as the Link-N-Lock crib and the Link-N-X crib developed by Strata Products USA and the Tri-Log crib developed by American Commercial, Inc., as shown in figure 8, achieve full timber contact by notching the timbers. By establishing full timber contact, the timber dimensions can be reduced without sacrificing supporting capability. Table 1 compares the timber dimensions and weights for conventional wood cribs and selected engineered timber supports.

As shown in table 1, the timber weight is reduced by about a factor of about 3 for selected designs of the Link-N-Lock, Tri-Log, and Link-N-X cribs. In addition, these designs provide 1.6 to two times the support capacity of a conventional four-point oak crib. Comparing these engineered timber supports to a four-point crib constructed from poplar timbers, which most closely represents that of a mixed hardwood crib, it is determined that despite half the timber weight, the support capacity is increased by a factor of 2.4 to 3.0 for the engineered crib support structures.

CONSISTENT MATERIALS

Studies have shown that one of the risk factors for back injuries is unexpected or unanticipated movements [Marras et al. 1987]. When materials are of different and unknown weights, there is an increased chance of back injury. Thus, a miner constructing conventional wood crib supports from timbers consisting of mixed wood species where one piece of wood may weigh 30 lb and the next piece may weigh 50 lb is more prone to injury than if the timbers are all of the same weight. Engineered timber supports such as the Link-N-Lock, Link-N-X, Hercules, and Tri-Log cribs all use the same species of timber for the support construction. Thus, these timbers are much closer in weight than the mixed wood species used in conventional wood crib supports. This reduces the injury potential that occurs when a miner is expecting a light piece of wood, but instead gets a much heavier piece of wood during the support construction process.

FEWER COMPONENTS

The Hercules crib is an example of a support that is designed to provide superior support capability with fewer pieces required for the support construction. It is constructed from preformed mats that are stacked on top of one another (figure 9). The Hercules crib can be constructed in a variety of configurations to provide a wide range of support designs and

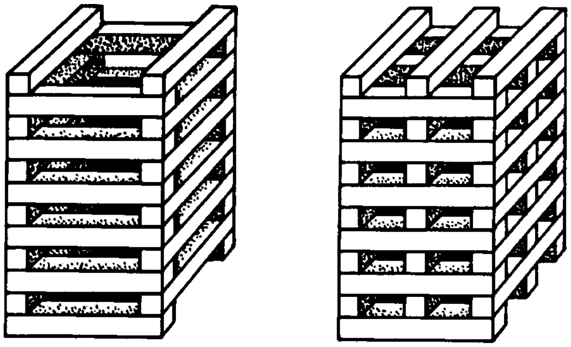

Figure 7.–Construction of four-point and nine-point conventional wood crib supports.

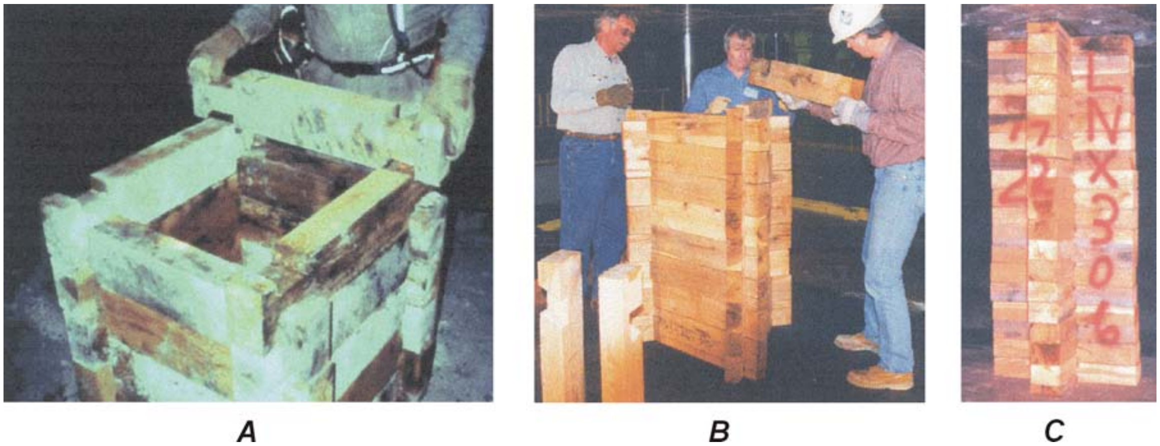

Figure 8.–*A*, Link-N-Lock crib; *B*, Tri-Log crib, and *C*, Link-N-X crib.

Table 1.—Comparison of conventional wood cribbing to engineered crib support systems

Parameter	Four-point oak crib	Link-N-Lock (24-in)	Tri-Log (30-in)	Link-N-X (30-in)	Four-point poplar crib
Timber length, in	36	24	30	30	36
Timber width, in	6	3.5	4	6	6
Timber rise, in	6	6	6	4	6
Timber weight, lb	40.5	13.1	19.1	19.1	31.6
Support weight per foot of height, lb/ft	208	102	88	90	126
Capacity at 2 in of convergence, tons	52	94	105	85	35

performance profiles. The comparison in table 2 shows the HM-9(308) provides 38% more capacity than a four-point oak crib. The HM-9(308) mat weighs slightly more than a 6- by 6- by 36-in oak timber, but since each mat provides a full layer in the Hercules support, the material weight per foot is 18% less than a four-point crib.

There is also a variety of prop-type supports that are constructed as units rather than the piecemeal construction required for crib-type supports (figure 10). The unit weights of these supports are typically greater than the unit weights of the piecemeal crib components, but since they are installed as unit and generally stood in place as opposed to being lifted, the cumulative effort to install the support is considerably less. In addition, the construction of the prop-type supports does not require lifting of material above the shoulder and thus reduces the risk of injury by eliminating this awkward lifting condition. The primary advantages of the prop supports from a material handling perspective are twofold: (1) supply cars can transport more support units and (2) supports can be installed in less time than crib-type supports since there are considerably fewer pieces to handle. Table 3 documents transport volumes and installation rates of various prop-type supports in comparison to conventional wood cribbing.

MECHANICALLY INSTALLED SUPPORT SYSTEMS

Other support systems are installed with machines that all but eliminate the material handling effort by the miners. Table 4 describes relevant material handling parameters for three mechanically installed support systems. The Burrell Can developed by Burrell Mining Products pioneered the development of mechanically installed supports. The Burrell Can is installed with a hydraulically powered gripper claw that can be attached to a loading machine or a scoop (figure 11*A*). Strata Products has recently developed the Star Prop that can be installed with the aid of the Prop Handler or the Microtrax. Figure 11*B* shows the installation of Propsetter supports using these mechanical aids.

Table 2.—Comparison of a Hercules crib to conventional four-point oak crib

Parameter	Nine-point oak crib (6x6x36 in timbers)	Hercules crib HM-9(308)
Timber weight, lb	40	44
Support weight per foot of height, lb/ft	162	132
Capacity at 2 in of convergence, tons	52	72

Table 3.—Comparison of prop-type supports to conventional four-point wood crib

Parameter	Four-point crib	Propsetter	ACS	Yippi prop	Stretch prop
Transport volume, ft^3	24	4.6	4.3	2.8	3.7
Supports per supply car	16	84	91	140	107
Installation rate, supports per shift	15	48	53	80	60

Figure 9.–Hercules crib.

Table 4.—Comparison of some mechanically installed support systems

Parameter	Burrell Can (24-in diam)	Propsetter (10-in diam)	Star Prop (standard design)
Installation rate, supports per shift	[1]40	50	50
Transport numbers, supports per car	12	65	43
Capacity at 2 in of convergence, tons	85	68	85

[1] The installation rate of the Burrell Can support can vary considerably, depending on the availability of equipment for delivery of the supports and timbers for topping off the supports. The 40 supports per shift is a representative installation rate for Burrell Can supports that includes delivery time as part of the installation process in a well-planned operation; however, this rate can range from 30 to 50 supports per shift.

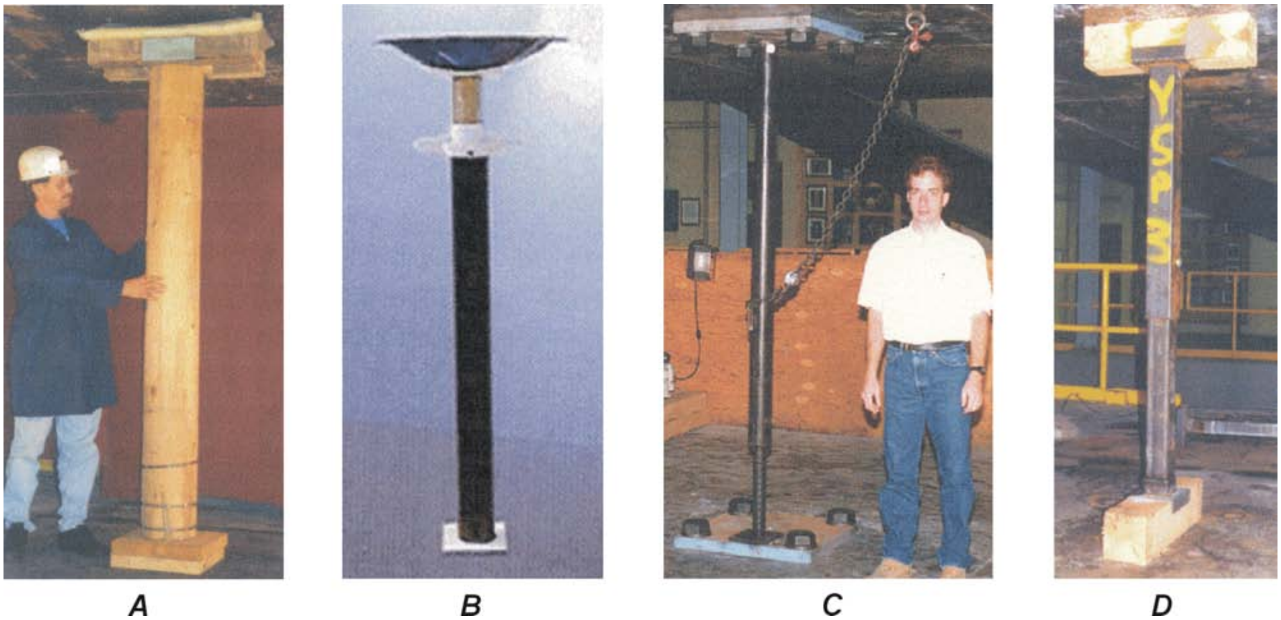

Figure 10.–*A*, Propsetter; *B*, ACS; *C*, Yippi support; *D*, Stretch prop.

Figure 11.–*A*, Installation of the Burrell Can; *B*, installation of the Propsetter support.

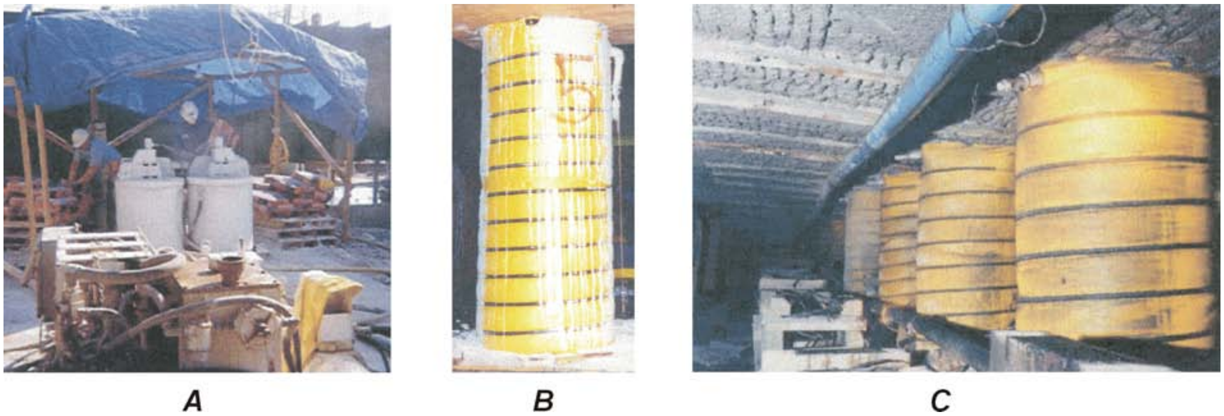

Figure 12.–*A*, Surface pumping station for Pumpable Crib; *B*, Pumpable Crib; and *C*, underground installation of Pumpable Crib in longwall tailgate.

PUMPABLE ROOF SUPPORT SYSTEMS

Another technology that offers material handling advantages is the use of pumpable support systems where a cementitious grout is pumped in place into some form in the mine entry. This process greatly reduces the transportation effort and can reduce the material handling effort with support installation. Both Heintzmann Corp. (figure 12) and Fosroc Corp. offer pumpable support systems. The Stretch Prop (figure 10*D*) developed by Ferrocraft, Inc., is a prop-type support that uses a pumpable cementitious grout to extend and fill the support during the installation process. Table 5 compares the Heintzmann Corp.'s pumpable crib to a conventional four-point oak crib.

Table 5.—Comparison of pumpable crib and conventional Four-point oak crib

Parameter	four-point oak crib	Pumpable crib
Supports per supply car	16	100
Construction work, ft-lb	5,838	900
Installation rate, supports per shift . . .	15	[1]50
Capacity at 2 in of convergence, tons	52	240

[1] The installation of the pumpable crib in this example is based on a surface pumping operation and a underground crew using a total of 7 people. The installation rates may vary depending on the crew size and the pumping requirements, but the 50 supports per shift is considered to be representative of a typical operation.

RECOMMENDED LIFTING THRESHOLDS TO REDUCE MATERIAL HANDLING INJURIES

Low-back pain and associated injuries from lifting are the most costly occupational health problems facing our Nation [NIOSH 1997]. As a result, the National Institute for Occupational Safety and Health (NIOSH) has conducted extensive ergonomic research to evaluate lifting mechanics and their impact on the human body. Through this research, a lifting equation has been developed that determines a recommended weight limit (RWL) for lifting in various postures [Waters et al. 1993]. The RWL is defined for a specific set of task conditions as the weight of the load that nearly all healthy workers could perform over a substantial period of time (e.g., up to 8 hr) without an increased risk of developing lifting-related lower back pain.

$$RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM,$$

where RWL = recommended weight limit;

LC = load constant = 51 lb; and HM, VM, DM, AM, FM, and CM are various multipliers.

The lifting equation begins with a load constant (LC) of 51 lb, which is the maximum recommended lifting weight under ideal conditions. Interpreted as the most optimal conditions, no more than 51 lb should be lifted regardless of the task characteristics. Putting this into perspective relative to support construction, a 6- by 6- by 45-in oak timber that has been dried for about 30 days weighs 52 lb, whereas a green 6- by 6- by 36-in oak timber weighs as much as 52 lb. The 51-lb upper limit is then decreased through six multiplicative coefficients that further define the lifting task. The variables that impact the recommended weight limit are defined as follows:

1. *Horizontal Position (HM):* The horizontal position refers to the horizontal distance of the lifted object (where the person holds the object) from the centerline of the person's feet or, more specifically, the ankles (figures 13-15). The recommended weight limit is reduced as the object's distance from the body increases.

2. *Vertical Position (VM):* The vertical position refers to the distance the object is from the floor level before lifting

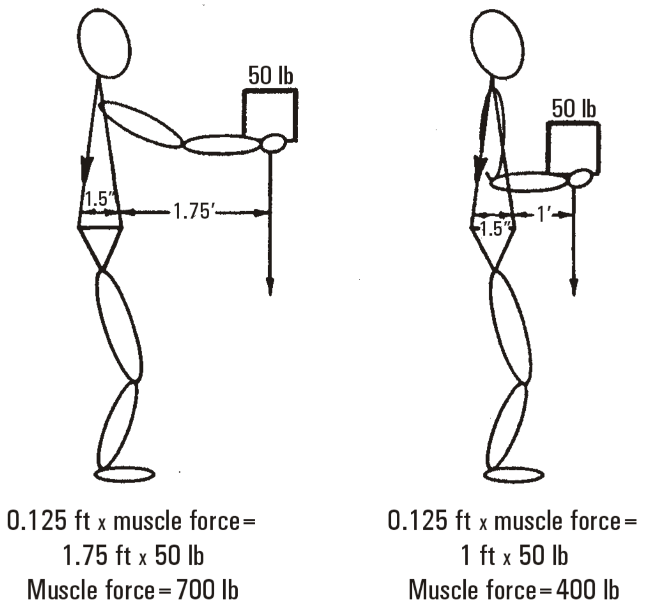

Figure 13.–Biomechanics of lifting showing effect of horizontal distance on muscle force.

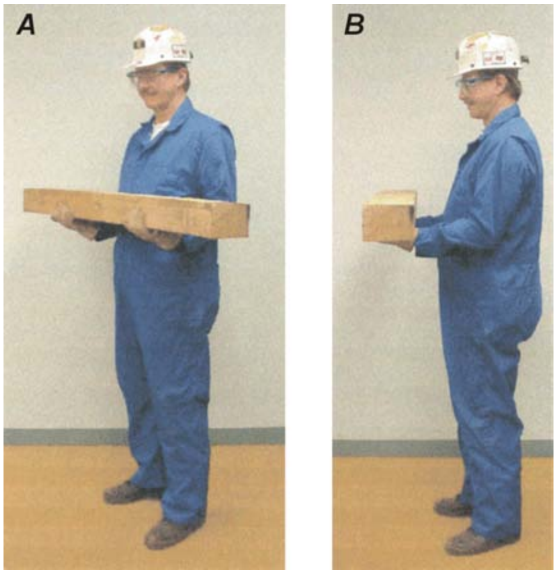

Figure 14.–Material should be kept close to the body (*A*) as the material is held away from the body (*B*) the risk of injury increases.

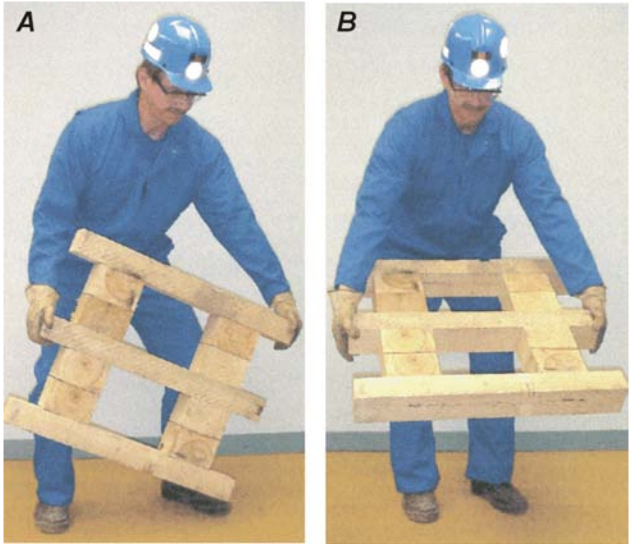

Figure 15.–Picking up a 40-lb Hercules mat. Holding the mat so that it is positioned close to the body (*A*) reduces the lifting effort compared to lifting the mat in a horizontal position (*B*) where the center of gravity is farther from the body.

Figure 16.–Avoid twisting.

is executed. The optimum distance is 30 in for an average worker who is 5 ft 6 in tall [Waters et al. 1994]. The vertical position multiplier decreases linearly with an increase or decrease in height from the optimal 30-in position.

3. *Lifting Distance (DM):* The vertical lifting distance is how high the object is lifted. The recommended weight limit is reduced as the lifting height increases. The multiplier ranges from 1.0 for a height of 10 in to 0.85 for a maximum height of 70 in.

4. *Twisting Factor (AM):* The twisting factor is referred to as the asymmetric component, which is defined as the rotation (twisting) of the body required to place the object at a destination (figure 16). It is expressed in angular degrees relative to the feet position at the origination of the lift and the twisting of the body at the lift destination. The recommended weight limit can be decreased significantly for asymmetric lifting compared to symmetric lifting.

5. *Frequency Factor (FM):* The lifting frequency refers to the average number of lifts in typical 15-min period. In addition to the number of lifts, the lifting frequency multiplier is influenced by the duration of the lift and the vertical position of the hands at the origin of the lift. The duration of the lift is classified into three categories: (1) short, (2) moderate, and (3) long.

These categories are based on the work/rest pattern of the job. Short duration defines lifting tasks that have a duration of 1 hr or less followed by a recovery (nonlifting) time equal to 1.2 times the work time. Moderate duration includes lifting periods of 1 to 2 hr followed by a recovery time of 0.3 times the work time. Long duration is defined as lifting periods between 2 and 8 hr, with standard industrial rests allowances (morning, lunch, and afternoon breaks). As one would expect, the lifting limits are reduced as the frequency of lifting and/or the lifting period increase.

6. *Handling Factor (CM):* The handling factor technically referred to as the "coupling component" attempts to evaluate the worker's gripping method used on the object. It also considers the vertical location of the hands throughout the entire range of the lift. The coupling component is also divided into three categories: (1) poor, (2) fair, and (3) good. The coupling multiplier ranges from 0.9 to 1.0.

Some representative support construction examples are shown in table 6. Analyzing these data, it can be shown that the lifting threshold is most sensitive to how close the support material is held to the body during the lifting process (horizontal factor). The recommended lifting weight is reduced from 42 to 14 lb when the horizontal distance increases from 0 to 12 in with an initial horizontal origin 6 in from the body (feet) centerline. From a biomechanics analysis as shown in figure 13, it is apparent that muscle force greatly increases as the object is moved farther from the spine. The lifting threshold is also reduced when the body must turn to position the support material during the lifting process. For example, with zero horizontal lifting the recommended lifting weight decreases from 42 to 36 lb when the angular rotation changes from 0° to 45°. Twisting causes increased stresses in the intervertebral disks in the spinal column [Gallagher et al. 1990]. Excessive twisting may cause some of the disk fibers to break, which severely weakens the disk. It is the opinion of some researchers that back injuries caused by twisting are much less likely to heal than injuries due to simple bending [Gracovetsky and Farfan 1986].

The reduced material handling requirements for the engineered timber supports are clearly seen when these factors are considered. Reviewing a previous example, a typical wood crib is constructed from oak timbers weighing 40 lb while the engineered Link-N-Lock (24 in) and Tri-Log cribs (30 in) are constructed from timbers that weigh 13.1 and 19.1 lb, respectively. Therefore, while the standard crib exceeds the recommended lifting thresholds in all but ideal conditions, the Link-N-Lock and Tri-Lock crib meet the typical and extreme conditions. Thus, significantly less musculoskeletal injuries would be expected from the construction of these engineered timber supports compared to conventional wood cribbing.

Table 6.—Recommended lifting weights for selected task parameters relevant to roof support construction

Lifting height, in	Horizontal hand position from centerline of feet, in		Lifting frequency, lifts/min	Asymmetric angle, °	Recommended liftingweight, lb
	Origin	Destination			
60	6	6	1	0	42
60	6	12	1	0	21
60	6	18	1	0	14
60	12	12	1	0	21
60	12	18	1	0	14
60	18	18	1	0	14
60	6	6	1	30	38
60	6	6	1	45	36
60	12	12	1	30	19
60	12	12	1	45	18
60	18	18	1	30	13
60	18	18	1	45	12

INJURY PREVENTION THROUGH PRACTICAL LIFTING TECHNIQUES AND MATERIAL HANDLING PRACTICES

Miners constructing roof supports in an underground mine environment are at risk of musculoskeletal injuries. As previously described, these injuries can be minor or severe enough to cause permanent disability. Although NIOSH is conducting research to promote the development and application of lightweight materials and mechanical aids to reduce the effort required for support construction, injuries can also be prevented by following proper lifting techniques and support construction practices. Following are several practical recommendations to this effect.

1. Hold the support material as close to the body as possible.

As discussed previously, the recommended lifting weights decrease significantly when the lifted object is moved away from the body. Thus, material handling practices that facilitate keeping the material close to the body, as shown in figure 14*A*, should be seriously pursued. Handling material in the manner shown in figure 14*B* should be avoided, particularly when the material weight exceeds 20 lb. Another example is shown in figure 15 with the Hercules crib mat. Ideally, two people should lift the mat. If this is not possible, then lifting the mat in a vertical orientation is better than in the horizontal position. Another good practice is to position oneself as close as possible to the destination of the support component during the lifting process. For example, when constructing a crib, it is better to walk to the side of the crib where the timber is being installed than to reach across the support structure to lift the crib block in place. Although this may take more time, it significantly reduces the stress on the back and, overall, will reduce fatigue so that longer construction times can be realized.

2. *Avoid lifting above the shoulders.*

When possible use a ladder or some other device to increase the standing height as opposed to lifting above the shoulder. Lifting effort increases significantly once the object is lifted above the waist, because the arms are now required to accomplish the lifting without any further benefit from the leg muscles. Lifting above the shoulder requires more energy and can create an additional risk factor due to awkward lifting where the arms might need to be extended or the body twisted. Lifting materials above the shoulders may also jeopardize the miner's balance, creating an unstable posture that increases the risk of falling and causing further injury.

3. *Avoid lifting from the floor.*

As much as possible, have support material stacked and delivered to the work site on pallets to minimize material lifting from the floor level. Often in underground mines, the packaging is unnecessarily destroyed during the transportation process. The lifting equation research suggests that a 30-in starting height is the most efficient for an average height person. As a rule, any material handling task should avoid lifts and placements below the knuckle (measured from a relaxed standing posture) and above the shoulder.

4. *Lift in one smooth operation.*

A large number of back injuries are attributed to sudden or unexpected movements. The back stress incurred by the worker in this situation is often two to three times as great as when the load is expected [Marras et al. 1987].

5. *Avoid excessive twisting during the lifting process.*

When stacking support materials such as in building a crib, there is a natural tendency to keep the feet still and twist the body to minimize the support construction time (figure 16). However, this practice causes excessive strain on back muscles and vertebrae and should be avoided, particularly when lifting materials in excess of 35-40 lb. Repositioning the body to remain directly in front of the lifting destination will significantly reduce the likelihood of severe back injury that can result from twisting motions.

6. *Use mechanical assists whenever possible.*

Several examples of support systems that are designed for installation with mechanical assists were previously described. The use of these systems and the development of others should be encouraged. Figure 17 depicts one apparatus used for setting timber posts.

7. *Rest when needed.*

The basic premise of this recommendation is that muscle fatigue can lead to or increase the likelihood of musculoskeletal injury. As the metabolic demands associated with support construction increase, more frequent rest periods are required. The *Work Practices Guide for Manual Lifting* [NIOSH 1981] recommends that for occasional lifting, the metabolic energy expenditure rate should not exceed 9 kcal/min for physically fit males and 6.5 kcal/min for physically fit females. Energy expenditure in crib building has been measured in one study at 8.48 kcal/min [Gallagher 1987]. Thus, crib building approaches the recommended energy threshold for a physically fit male.

The American Industrial Hygiene Association has developed algorithms to determine the recommended rest interval for various work-related tasks. The rest break will allow the heart rate and breathing rate to return to normal, as well as allowing the metabolic end products of the muscle exertion to dissipate and reoxygenate the muscle. The work rest cycles are based on the energy expenditure required to perform the task. Using the 8.48 kcal/min for conventional wood crib, the recommended rest interval equates to 75% of the work time [Gallagher 1987]. This means that if a crib crew spent 30 min constructing a crib, the recommended rest time is 22 min before building the next crib to prevent excessive muscle fatigue.

8. *In low-seam heights, lift from a stooped position versus a kneeling position.*

Studies have shown that miners have a significantly lower lifting capacity, 10 lb over on average, in the kneeling posture than in the stooped posture [Gallagher et al. 1990]. In terms of biomechanics, the large muscles of the lower back contract much more vigorously in the kneeling posture than in the stooped posture. This implies a greater compressive loading of the spine when kneeling, thus a greater chance of back injury. However, this recommendation needs to be qualified in the sense that if the load can be placed between the legs when squatting, then the load is closer to the spine, causing less stress on the back.

Figure 17.–Apparatus used for setting timber posts. (Photo courtesy of Strata Products USA).

9. Get help when the required lifting load exceeds the recommended weight limit.

It is important to remember that the recommended weight limit is significantly less than a person's maximum lifting capacity. The intent of the recommended weight limit is to define thresholds that will prevent injury. By asking for help, the probability of back injury can be significantly reduced when the load is shared among two or more people.

10. Promote your own physical fitness.

Support constructing can be a very demanding job. Studies have shown that many back injuries may be prevented by strengthening the lower back and abdominal muscles. Stretching before lifting can also be very important in preventing back strains.

SUPPORT MATERIAL HANDLING PRODUCT GUIDE

Material handling requirements can be divided into two functions: (1) delivery of material into the mine and (2) construction of the roof supports. A summary assessment of various support technologies for these material handling functions is provided in tables 7 and 8.

Support materials are typically loaded onto either supply cars or shield carriers and transported into the mine by a rail haulage system. A typical supply car will be 7 ft wide and 20-24 ft long. The car volume then depends on the bed height above the track rail, which is determined by the seam height. The shield cars are smaller (14-16 ft long), but are 8-12 in lower, which allows more clearance to the mine roof. Thus, a higher stack of material can be transported on them. At the mine entry, the supports are typically unloaded by a diesel- or battery-powered forklift, bucket scoop, or shield hauler. How the supports are packaged is critical to the overall material handling requirements. Generally, the goal is to bundle and unload the materials in full support increments. This will minimize the construction effort by placing the correct amount of material in the vicinity where the support is to be constructed and avoid the extra and generally manual effort in carrying surplus materials to a new location. Table 8 documents the relevant parameters associated with transportation of support material into the mine.

Table 7 shows that prop-type supports (Propsetter, Star Props, Lock-N-Load Props, Alternative Crib Support (ACS), and Yippi Prop) and the pumpable supports in collapsible containers (Pumpable Crib and Tekcrib) provide significant transportation advantages in terms of reduced volumes compared to crib-type supports that are constructed in piecemeal fashion or large-diameter, precast, concrete support structures.

The next issue pertains to the construction of the supports. The primary factor to consider is the labor involved in the support construction and the rate of installation of the support structures. From an injury perspective, the size, weight, handling method, and the number of pieces handled per unit time are relevant factors are previously addressed. The energy required to construct the support would be a useful method to define the risk assessment for musculoskeletal injuries. However, an energy analysis that considers the physiological demand on the human body is quite complex and is beyond the scope of this paper. Instead of this complex analysis, a computation of work (weight of piece times the lifting height) can be done. The efficiency of the support construction can be judged in terms of the installation rate and the construction effort (work). Table 8 compares the relevant parameters for construction of the various support technologies.

Table 8 shows that the construction effect increases dramatically for supports that require piecemeal construction using large numbers of heavy pieces such as conventional concrete cribbing. The work required for constructing a steel-fiber-reinforced donut concrete crib is 40% more than the work required for a conventional four-point wood crib. As a result, the installation rate for these supports are among the lowest of all support technologies. The benefits of the engineered crib supports (Link-N-Lock, Link-N-X, and Tri-Log cribs) are clearly seen in comparing the construction work to that of conventional wood cribbing. The least effort is required for the construction of the Propsetter, ACS, and the Burrell Can supports. Average installation rates for the Propsetter and the ACS are three times greater than rates achieved with conventional wood cribbing. The installation rate with the Burrell Can support depends on the logistics of unloading and installation activities that require machinery to accomplish. Installation rates vary from 30 to more than 50 supports per shift. The Pumpable Crib that is poured in place currently requires manual labor to lift the 55-lb grout bags from a pallet positioned on a forklift near the pump. Heintzmann Corp. plans to develop a batch system for the grout pumping activity, which will all but eliminate the material handling efforts for this support, with the exception of installing the forms to hold the bag during pumping and dismantling them afterward. With a three-person pumping crew underground and four people handling material at the pump station aboveground, 50 Pumpable Cribs per shift have consistently been installed in a test section at a mine site in western Pennsylvania. Even if seven people were used on a crib construction crew, the number of conventional four-point wood cribs constructed per shift would probably be in the range of 35-40.

Table 7.—Transport parameters (normalized to 8-ft mining height)

Support system	Support design	Pieces per support	Transport volume, ft^3/support	No. of supports per supply car
Conventional wood cribs	four-point cribs[1]	32	24.0	16
	nine-point cribs[1]	48	36	11
Conventional concrete cribs . .	Stopping block cribs (16 by 16 in)	32	16.2	24
	SFR donut cribs	32	29.9	15
	SFR 24 -by 24-in solid crib . . .	72	32.0	12
	SFR four-point crib (24×24 in) .	48	21.3	18
Hercules cribs	HM-4	24	21	19
	HM-9 and HM-9 (308)	24	40	10
	HM-16	16	49.8	8
Link-N-Lock cribs	24-in Link-N-Lock	64	18.7	21
	27-in Link-N-Lock	64	21.0	19
	30-in Link-N-Lock	64	23.3	17
	36-in Link-N-Lock	64	28.0	14
	42-in Link-N-Lock	64	32.7	12
	48-in Link-N-Lock	64	37.3	11
	60-in Link-N-Lock	64	46.7	8
Link-N-X cribs	24 in (standard design)	32	9.3	42
	27 in (standard design)	32	10.5	37
	24 in (high-capacity design) . . .	48	16.0	25
	30 in (high-capacity design) . . .	48	20.0	20
	36 in (high-capacity design) . . .	48	24.0	16
Lock-N-Load props	Standard design	4	3.2	124
Propsetter	8.5-in diameter	3	4.6	84
	10.0-in diameter	3	6.0	65
Star Props	100 ton (12-in diameter)	3	9.2	43
	60 ton (10-in diameter)	3	6.7	58
Tri-Log cribs	30 in (standard design)	48	19.8	20
	36 in (standard design)	48	23.7	17
	30 in (high-capacity)	48	29.7	13
	36 in (high-capacity)	48	35.6	11
	48 in (high-capacity)	48	47.5	8
Burrell Can	18-in diameter	4	18.0	22
	24-in diameter	4	31.6	12
	30-in diameter	4	49.1	8
	36-in diameter	4	70.4	6
Confined core crib (3-C)	36-in diameter	4	70.4	6
ACS or 55-ton prop	Flat plate (8 in)	1	2.8	139
	Timbers as header	4	4.3	91
	Pizza head plate	2	4.1	95
Pumpable Crib[2]	30-in diameter	1	3.9	100
Tekcrib	42-in diameter	1	7.7	51
Tekprop	18-in diameter	1	12.8	31
Stretch Prop	6-ft collapsed length	3	3.7	107
Yippi Prop	Standard design	1	2.8	140

[1] Based on 6- by 6- by 36-in oak timbers.

[2] Material assessment considers only that used underground, i.e., the bags for forming the support. It does not include the hardware required to support the bags for filling since this hardware is used over and over again. Since the supports were pumped from the surface, the grout material is not included in this assessment.

Table 8.—Support construction parameters (normalized to 8-ft construction height)

Support system	Support design	Weight per piece, lb	Total support weight, lb	Construction work, ft-lb	Installation rate,[2] supports per shift
Conventional wood cribs	four-point cribs[1]	40	1,280	5,760	15
	nine-point cribs[1]	40	1,920	8,640	12
Conventional concrete cribs	Stopping block cribs (16 by 16 in)	52	1,664	8,055	19
	SFR donut cribs	56	1,792	8,064	19
	SFR 24- by 24-in solid crib	53	3,816	17,172	9
	SFR four-point crib (24×24 in)	53	2,544	11,448	13
Hercules cribs	HM-4	47	752	3,008	32
	HM-9 (308)	44	1,056	4,752	26
	HM-16	41	1,968	8,856	16
Link-N-Lock cribs	24-in Link-N-Lock	13	813	3,658	24
	27-in Link-N-Lock	15	941	4,234	24
	30-in Link-N-Lock	17	1,069	4,810	19
	36-in Link-N-Lock	21	1,318	5,933	16
	42-in Link-N-Lock	25	1,574	7,085	16
	48-in Link-N-Lock	29	1,824	8,208	15
	60-in Link-N-Lock	37	2,330	10,483	14
Link-N-X cribs	24 in (standard design	14	343	1,201	64
	27 in (standard design)	16	518	2,333	45
	24 in (high-capacity design)	13	638	2,554	32
	30 in (high-capacity design)	18	854	3,417	30
	36 in (high-capacity design)	22	1,152	4,282	21
Lock-N-Load props	Standard design	44	88	513	96
Propsetter	8.5-in diameter	132	168	820	48
	10.0-in diameter	184	216	1,049	40
Star Props	100 ton (12-in diameter)	247	301	1,668	40
	60 ton (10-in diameter)	172	210	1,220	40
Tri-Log cribs	30 in (standard design)	19	916	3,667	26
	36 in (standard design)	24	1,133	4,531	21
	30 in (high-capacity)	18	846	3,806	17
	36 in (high-capacity)	22	1,593	7,167	14
	48 in (high-capacity)	31	2,241	10,083	13
Burrell Can	18-in diameter	N/A	162	1,134	40
	24-in diameter	N/A	270	1,890	40
	30-in diameter	N/A	405	2,835	40
	36-in diameter	N/A	567	3,969	40
Confined core crib (3-C)	36-in diameter	N/A	567	3,969	40
ACS or 55-ton prop	Flat plate (8 in)	151	151	680	64
	Timbers as header	151	232	1,247	53
	Pizza head plate	140	178	896	53
Pumpable Crib	30-in diameter	N/A	200	900	50
Tekcrib	42-in diameter	N/A	160	720	60
Tekprop	18-in diameter	N/A	80	360	59
Stretch Prop	6-ft collapsed length	50	77	231	69
Yippi Prop	Standard design	92	92	414	80

[1] Based on 6- by 6- by 36-in oak timbers.

[2] The installation rates may vary considerably due to the labor and equipment used in support construction and delivery of support material to the working area. The numbers shown are representative installation rates. The installation rates are not normalized to man-hours or effort. The support construction crew is generally two or three people, although the PumpableCrib installation currently uses as many as seven people (all of whom work for the support manufacturer).

CONCLUSIONS

Material handling is an important aspect of secondary roof support construction and more attention should be paid to it in the support design and selection process. With more than 40,000 lost workdays attributed to timber-handling injuries in the past 9 years, the construction of conventional wood cribs and timber supports is the primary cause of injury to these underground mine workers. Included in this paper is a detailed summary of the various roof support systems and a description of relevant material handling parameters to facilitate consideration of material handling factors in the selection of a standing roof support system.

In recent years, several alternative support technologies have been developed, which in addition to providing superior roof control, offer material handling advantages. Surveillance data show that the increase in use of these alternative support technologies is consistent with the decreasing trend of material handling injuries due to roof support construction in recent years. The severity of these injuries has decreased by nearly 50% during 1995-98, which is when the use of alternative support technologies attained proportions where they exceeded the number of conventional cribs. Thus, these new support technologies are having a positive impact on reducing material handling injuries to coal miners.

Using the NIOSH lifting equation, which defines lifting thresholds for various conditions and lifting scenarios, it is seen that the weight of conventional crib timbers exceeds the recommended lifting threshold. Conversely, the weights of the engineered timber products is within the recommended lifting thresholds and provides further confirmation that these lightweight materials are reducing material handling injuries. Systems that are installed with mechanical aid, such as the Burrell Can Support (Burrell Mining Products) and the Star Prop Propsetter (Strata Products USA), or pumpable support systems that are installed in place in the mine, such as the Pumpable Crib (Heintzmann Corp.), can substantially reduce the effort required to install supports and thus dramatically reduce the risk of injury to the mine worker. Therefore, depending on the other parameters being held fairly constant, these alternative supports should reduce the risk of musculoskeletal injuries due roof support construction in underground mines.

When material handling is required, following some basic lifting practices can make a difference in preventing injury. Most importantly, the material should be held as close to the body as possible to reduce the stress on the back, and twisting of the body during the lifting process should be minimized and avoided, if possible. Extra care must be exercised in the restricted environment of an underground mine to avoid injury. Each miner is different, but everyone has a comfort zone in being able to lift materials of a certain weight for a given amount of time. The probability of injury increases when muscle fatigue occurs, so proper rest periods to avoid over exertion can mean a lot in preventing injuries.

ACKNOWLEDGMENTS

The author acknowledges the efforts of Deno M. Pappas, civil engineer, NIOSH Pittsburgh Research Laboratory (PRL), who collected pertinent injury data pertaining to the construction of roof support systems in underground mines. These data provide valuable insight into the type and magnitude of injuries involved in support construction and were useful in comparing injury trends for alternative support technologies that have material handling advantages over conventional wood and concrete cribs. The author also acknowledges Kim M. Cornelius, industrial engineer; Lisa J. Steiner, safety engineer; and Sean Gallagher, research physiologist, also with NIOSH PRL, for their contributions in the application of the NIOSH Revised Lifting Equation and for their research accomplishments pertaining to the biomechanics of lifting heavy materials. Much of their work is being adopted for the roof support construction application, which is addressed in this paper.

REFERENCES

Gallagher S [1987]. Back strength and lifting capacity of underground miners. In: Proceedings of the Human Engineering and Human Resources Management in Mining, Bureau of Mines Technology Transfer Seminars, Pittsburgh, PA, July 7-8; St. Louis, MO. July 15-16; and San Francisco, CA, July 21-22. Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines, IC 9145, pp. 21-32.

Gallagher S, Bobick TG, Unger RL [1990]. Reducing back injuries in low coal mines: redesign of materials-handling tasks. Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines, RI 9614.

Gracovetsky S, Farfan HF [1986]. The optimum spine. Spine *11*(6):543-573.

Marras WS, Rangarajulu SL, Lavender SA [1987]. Trunk loading and expectation. Ergonomics *30*(3):549-560.

NIOSH [1981]. Work practices guide for manual lifting. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 81-122.

NIOSH [1997]. Musculoskeletal disorders and workplace factors. A critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back. Bernard BS, ed. U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 97-141.

Waters TR, Putz-Anderson V, Garg A, Fine LJ [1993]. Revised NIOSH equation for the design and evaluation of manual lifting tasks. Ergonomics *36*(7):749-776.

Waters TR, Putz-Anderson V, Garg A [1994]. Applications manual for the revised NIOSH lifting equation. U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 94-110.

Winn FJ, Biersner T [1996]. Exposure probabilities to ergonomic hazards among miners. Int J Ind Ergonomics *18*:417-422.