MISTAKES, MISCONCEPTIONS, AND KEY POINTS REGARDING SECONDARY ROOF SUPPORT SYSTEMS

Thomas M. Barczak, *Research Physicist*
National Institute for Occupational Safety and Health
Pittsburgh Research Laboratory
Pittsburgh, PA

ABSTRACT

Roof support systems are necessary to provide stable mine openings and much research has been conducted to design a variety of roof support systems that will function in various manners to ensure that stable ground conditions are achieved. Despite these advancements in technology, mistakes continue to be made in the evaluation and/or installation that significantly degrade the support capability or lead to erroneous determinations of support expectations. The purpose of this paper is to discuss misconceptions about how roof supports perform and factors that impact their performance. The goal is to present practical information that will assist mine operators and engineers in selecting, installing, and evaluating roof support systems properly, and help them to avoid mistakes that can lead to erroneous expectations and potentially catastrophic results that may lead to roof falls. The paper is limited to a discussion of secondary roof support systems and powered roof supports such as longwall shields.

INTRODUCTION

Roof support is an essential component of being able to mine safely. Some form of roof support is employed in every underground coal mine, but the support strategy may differ significantly from mine to mine. Generally, due to economic constraints, the minimal amount of support necessary to ensure a high probability of roof stability is accepted as standard practice. As such, this design philosophy requires a good understanding of the support performance and ground interaction to achieve an optimum roof support system. Since this design philosophy leaves little room for error, any mistake in understanding the roof support capability, or how the support interacts with the ground to achieve roof stability, or improper installation procedures can be costly and lead to unsafe conditions.

The scope of the paper is limited to secondary roof supports and powered roof supports such as longwall shields. Topics which are analyzed in the paper include: (1) proper ways to assess support capacity and costs, (2) understanding the difference in material properties and full scale support performance, (3) understanding factors that lead to uncontrollable convergence and support design issues for this condition, (4) learning how to evaluate support loading data, (5) understanding the impact of support load density on ground deformations and how to make equivalent comparisons of support systems, (6) understanding factors that do and do not increase support stiffness and/or control the yield capability of the support, and (7) proper installation practices for various support technologies.

The paper is presented in a form of bulletized items with only a brief technical explanation for each. Complete theoretical assessments of the issues are not necessarily provided. The goal is to provide concise summaries of the various issues with practical information relative to each topic. This format is provided to facilitate the use of this paper as a reference guide for roof support application. A more detailed explanation of the issues can be found in the references.

Figure 1. Instability in 4-point wood crib caused by single soft timber

SECONDARY ROOF SUPPORT SYSTEMS

1. ***Remember that the performance of wood cribs can be controlled by the response of just a single layer of timbers (figure 1).***

   For example, you might think that you have an oak crib because the majority of the timbers in the crib are oak, but a single layer of a weaker timber such as poplar can degrade the performance of the crib to that of the weaker timber. In this case, the capacity of the crib would be reduced by 27% due to the weakness of the poplar timbers. The consequences of degrading the crib capacity by employing mixed wood species is shown in table 1.

Table 1. Comparison of an all oak crib with one constructed from mixed oak and poplar timbers. Analysis derived from STOP using 15 tons/ft @ 2 in as design criteria.

Evaluation Parameter	All oak crib (6x6x36 in timbers)	Mixed oak/poplar crib (6x6x36 in timbers)
Support load density, tons/ft	15.0	15.0
Support spacing, in	91.1	61.3
Installation rate, ft per shift	84.4	56.7
Installation cost, $/ft of entry	28.90	42.90
Savings per 10,000 ft of entry	$140,000	$0 (Baseline)

2. ***Another mistake that is made with conventional crib construction is to place the wide side of the timber in the vertical orientation during crib construction.***

   Again, this does not necessarily have to be every layer, a single layer with this orientation can significantly degrade the crib performance. Table 2 summarizes the consequences of wide-side-up, 4-pt crib construction using 5x6x36-in (oak) timbers.

Table 2. Comparison of an all oak crib constructed from 5x6x36 in timbers in a wide-side-down and wide-side-up orientation. Analysis derived from STOP using 15 tons/ft @ 2 in as design criteria.

Evaluation Parameter	All oak crib	
	Wide-side-down (6x5x36-in timbers)	Wide-side-up (5x6x36-in timbers)
Support load density, tons/ft	15.0	15.0
Support spacing, in	91.1	63.6
Installation rate, ft per shift	74.7	58.6
Installation cost, $/ft of entry	28.90	37.30
Savings per 10,000 ft of entry . . .	$83,000	$0 (Baseline)

3. ***Do not use the same crib design at different mining heights and expect to have the same ground control capability.***

   The stiffness of a conventional crib and most timber supports constructed in piecemeal fashion from several layers of timbers decreases as the height increases (1). Hence, if the same crib design is utilized at higher mining heights, the convergence will generally increase resulting in the potential for degraded ground stability. As an example, a 10-ft-high, 4-point crib constructed from 6x6-in cross section timbers will have 62% of the capacity at 2 in of convergence compared to that of the same crib constructed to a 5 ft height. This means that 40% more cribs will be required at the 10-ft mining height to provide an equivalent support load density.

4. ***For unconfined concrete supports, do not use the full material strength to estimate the support capacity.***

   A common mistake in estimating the capacity of concrete supports constructed from donut or rectangular sections is to multiply the contact area by the material strength as measured in the laboratory under ASTM specifications. In full-scale crib constructions, the concrete fails from stress concentrations, such as block discontinuities, that are not present in the laboratory test samples. These and other factors significantly degrade the achieved capacity of the concrete support. A conservative measure of strength is to take 50 % the measured laboratory strength to predict the full scale support capacity of an unconfined concrete support structure (2).

5. ***When following Mine Safety and Health Administration (MSHA) guidelines for selecting the minimum diameter requirements for timber posts, the posts will generally fail from buckling at loads less than their crushing strength.***

   There are two ways in which a timber post can fail. Either the wood can crush as the load exceeds the compressive strength of the timber, or the post will buckle, either near the middle of the post or near some defect such as a knot that weakens the wood. Buckling is a form of instability that is controlled by the slenderness ratio, or ratio of the height of the prop to its diameter. Using the MSHA guidelines for the determining the minimum diameter for a given mining height, a post will develop applied stress less than half of its crushing strength (3). Table 3 shows an example using green poplar posts. The achieved capacity relative to the crushing strength is even less for dry posts.

Table 3. Expected buckling loads of minimum MSHA recommended post diameters (made from poplar wood) as a percentage of the maximum (crushing) load capability of the post.

Post length, ft	MSHA recommended minimum post diameter, in	Buckling load	
		Tons	Pct of crushing load
5	4	8	47
7	5	12	45
9	6	16	43
11	7	22	43
13	8	29	44
15	9	37	44
17	10	46	44

6. ***A common mistake in comparing passive roof support systems is to make comparisons at some constant convergence and ignoring the fact the achieved convergence will be controlled by the installed load density of the support.***

Roof support systems should be compared on an equivalent basis in terms of their capability to provide roof control. A common mistake is to evaluate different roof support systems which are installed in the same support layout (i.e., spacing and number of rows of supports), despite differences in their stiffness and performance characteristics.. Only when the supports are installed with the same support load density, can an equivalent functional comparison of roof support capability be provided.

Here's why. The convergence and hence ground stability will be determined by the installed support load density. Higher support load density will generally result in lower convergence and hence more stable ground conditions. In order to achieve equivalent support load density for different roof support systems, the installation (number of rows and support spacing) must be adjusted according to the performance characteristics of the individual support (4).

Failure to examine supports at the same installed load density can cause you to avoid considering supports with higher unit costs but superior roof support capability. Here is an example (table 4). A longwall tailgate entry is supported with two rows of 4-point cribs constructed from 6x6x36-in mixed hardwood timbers on a 71.4 in spacing. This system provides a support load density of 16.7 tons/ft, which in this mine controls the convergence to 3 in. If a 24-in Link-N-Lock crib is employed in this same arrangement, the Link-N-Lock system will provide a support load density of 23.3 tons/ft and reduce the convergence to 1.4 in. Comparing the installed cost of the two systems, the conventional wood crib system can be installed at relative cost of $32.50/ft while the Link-N-Lock would require a relative cost of $46.30/ft to install. However, if the Link-N-Lock was installed on a 157 in spacing, it would provide the same 16.7 tons/ft of support capacity at 3 in of convergence, and could then be installed at a cost of only $21.10/ft.

Table 4. Examining supports at same load density.

Analysis parameters	Identical Layout		Equivalent Load Density	
	4-Pt crib (6x6x36 in)	Link-N-Lock 24-in	4-Pt crib (6x6x36 in)	Link-N-Lock 24-in
Number of rows	2	2	2	2
Center to center spacing, in	71.4	71.4	71.4	157
Support load density, tons/ft	16.7	23.3	16.7	16.7
Convergence, in	3.0	1.4	3.0	3.0
Installed cost, $/ft . . .	$32.50	$46.30	$32.50	$21.10

7. ***When considering the cost of a support system, the full installation cost for the application of the support system including the material handling efforts should be considered, and not simply the material cost of an individual support.***

Many of the emerging roof support technologies provide both superior roof support as well as superior material handling advantages (5). If the benefits of these additional factors are not adequately considered in an analysis, an unfair advantage is given to conventional supports which may have lower unit material costs, but provide less support capability and are more costly, time consuming, and difficult to put in.

As an example (table 5), a comparison is made between a pumpable crib support and conventional 9-pt cribbing. The pumpable crib support developed and marketed by Heintzmann Corporation has one of the most expensive material costs, while a conventional wood crib has one of the lowest material costs. Yet, despite nearly twice the unit costs, the Pumpable crib can be installed at a lower total installed cost and provide twice the support capacity at 1 in of convergence because the higher capacity of the punmpable crib allows it to be installed at lower support density and the pumpable support can be transported and installed with considerably less effort.

Table 5. Comparison of pumpable support and C. Point crib.

	Pumpable Crib 30 in	9-Point Wood Crib (6x6x36-in timber)
Number of rows	1	2
Support spacing, in	120	110
Installed load density @ 1 in of convergence, tons/ft	24	12
Unit support costs, $/support . . .	$316	$154
Installed support cost, $/ft	$31.60	33.70
Installation rate, ft per shift	555	70
Construction labor, $/ft	$3.51	$8.54

8. ***Preloading does not change the stiffness or the overall performance characteristics of a roof support system, but it may improve the apparent stiffness and stability of the roof structure.***

The benefits of preloading is not that it changes the stiffness or performance of the support, but rather it may improve the condition of the rock structure by building a more competent roof beam much like a pretensioned roof bolt. The load development in the support itself as a function of continued ground movement does not change because of the preload. It's stiffness is the same with or without preload, just as a roof bolt does not change stiffness due to preload. Since preload causes deformation of the support, its loading cycle essentially begins at a different point on the load-displacement curve, but it is the same curve that illustrates its load-displacement profile.

9. ***Increasing the density or number of supports does not improve their individual yield capability (figure 2).***

Another common misconception is that the yield capability of support systems can be increased by increasing the number of supports or density of supports used in an application. Using timber posts as an example, it does not matter if there is one post or ten posts, they will all fail at less than one in of convergence. The confusion is generally related to the improved ground control that is often provided by increasing the number of supports. Increasing the number of supports will increase the support load density, which in turn will tend to reduce the convergence in the area. The reduced convergence allows supports such as posts to function in areas where fewer supports would fail, but if the convergence was not controlled by the additional support capacity provided by the extra supports, then they would still fail as the convergence increased beyond their yield capability, which remains a constant regardless of the support density.

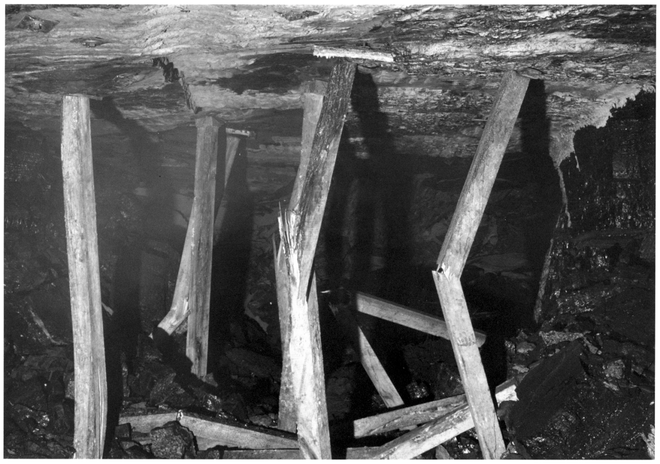

Figure 2 - Increasing the number of timber posts does not change their individual yield characteristics

10. ***The capacity of a cable truss is not twice the capacity of a cable bolt of the same diameter.***

The fallacy in assuming that a cable truss has twice the capacity of a cable bolt since it is anchored at both ends stems from the fact the cable truss is a single piece, and that roof produces loading in the entire cable. In order for the cable truss to have twice the capacity of one cable bolt, the center section of the cable truss along the roof line would have to have zero load, which just isn't the case. The actual capacity of the cable truss is a bit more complicated, being determined primarily by the mechanics of the truss operation (figure 3), but the primary point to remember is that the roof loading produces a resultant load at the corner of the truss which produces tension in both the anchor component of the truss and the horizontal component along the roof line. Due to friction at the roof and/or contact block, only about 80% of the load generated in the angle member is transferred into the horizontal member of the cable (6). This coupled with the fact that the stress concentration at the corner where the block and/or rock contacts the cable creates a stress concentration which causes failure of the cable at these locations with less than ultimate loading (estimated to be around 87% of ultimate loading (7)) in other parts of the cable, decrease the capacity of the cable from this simplified rigid body analysis. The bottom line is that a cable truss can typically support a rock load of about 120% of the rated capacity of the cable (6). However, even this can be misleading in comparison to cable bolt support, because the truss is such a softer system that is not really providing roof control as much as it is simply supporting the weight of damaged and broken roof rock.

***11. Truss systems primarily provide containment of damaged roof, and relatively little control over roof deformation prior to failure of the rock mass*.**

Trusses are such a soft support system that they provide little resistance to roof deformations, and as such, cannot be compared directly with cable bolts or standing roof support systems. For example, the stiffness of a cable truss is approximately 5 tons/in. Even a weak 4-point wood crib constructed from 6x6 in poplar timbers, which is one of the softest standing roof supports, would have a stiffness of 5 times this. This means that the roof must move 5 times as much when a cable truss is installed to generate the same resistance to vertical (dead weight) loading as a single 4-point wood crib. Cable trusses act as a means of containment to damaged roof which acts to provide some residual stability, but do relatively little in preventing the damage from occurring.

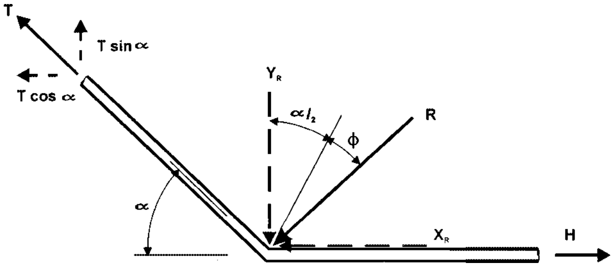

Figure 3. Rigid-body analysis of a cable truss

Figure 4. Standing supports, even something as strong as a Can, cannot eliminate or control floor heave

12. ***Floor heave and pillar yielding cannot be controlled by standing roof support systems (figure 4).***

The capacity of any standing roof support system is generally too small to control floor heave and pillar yielding and horizontal stress to some degree. The forces that are causing these ground reactions are due primarily to the main roof and overburden weighting. From the perspective of standing roof support design, the convergence associated with floor heave or pillar yield, should be considered as "uncontrollable". The consequence of this in terms of designing standing roof support is that these uncontrollable ground displacements will produce associated displacement and loading in the support. One of the design issues in floor heave or yielding pillar conditions is that the support must be able to survive this deformation without being damaged to the point where it becomes unstable or loses the required capacity to support the roof. Another concern with standing roof support structures is that these uncontrollable ground movements will produce levels of loading in the support that will exceed the bearing strength of the immediate roof and floor, and thereby cause damage that can lead to further roof instability and roof falls. Even if the effect is localized where the support simply punches into the roof or floor, the support capability is then degraded and this may lead to more global promotion of roof instability.

13. ***Capping material can dramatically change the performance characteristic of a roof support (figures 5a, 5b).***

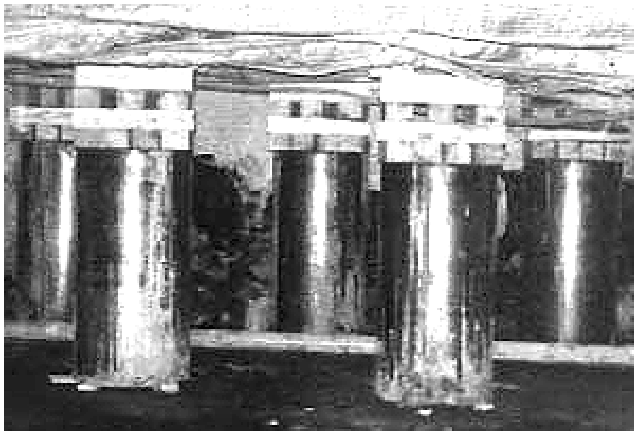

Figure 5a. Can supports are typically topped off with timbers to establish roof contact

Figure 5b. If too few timbers are used, the timbers deform and control the loading of the support causing it to be less stiff than intended

The important point to remember here is the weak link principle. It is always the least stiff material which controls the initial response of a support. Hence, if the capping material is softer than the rest of the support material, then the capping material will control the loading of the support until it is squeezed to the point where the stiffness in the capping material is equivalent to that of the other support material. Here are a few examples. When cap blocks are used on timber posts, the cap blocks, even though they may be of the same wood type, are softer than the post because the wood is softer when loaded perpendicular to the grain than parallel to the grain. Hence, using cap blocks softens the response of the timber post, resulting in more overall deformation or yield before the post fails. Another good example is the Burrell Can. With the Can the goal is to make sure that there are sufficient timbers on top of the Can to transfer the loading into the Can without significant deformation of the wood. When too few timbers are used, the applied loading causes the wood to deform before the Can reaches its yield load capacity. In other words, the wood is the softer member and controls the loading (deformation) of the support rather than the material in the Can. If sufficient contact area is created with the use of enough wood, the then applied stress in the wood from the roof loading will be below the yield strength of the wood, meaning that the Can will be the softer of the two components and it will control the response of the support rather than the wood.

14. ***Passive roof supports do not have any load carrying capacity until they are squeezed from the roof and floor convergence.***

The load carrying ability of a passive roof support can only be defined as a function of displacement of the support. It has no load carrying capacity until it is squeezed and generally increases in capacity as the amount of displacement continues, up to the point where its ultimate strength is reached. Care must be made at comparing the peak load capacities of different supports since the peak capacities can occur at widely varying degrees of convergence. The relationship of load to displacement is called the stiffness of the support. Stiffer supports develop load more quickly (with less displacement) than softer supports. Figure 6 is an example of a support having a peak load of over 1,000 tons, but this capacity is reached at nearly 5 ft of displacement, well beyond the useful range of allowable convergence in coal mines.

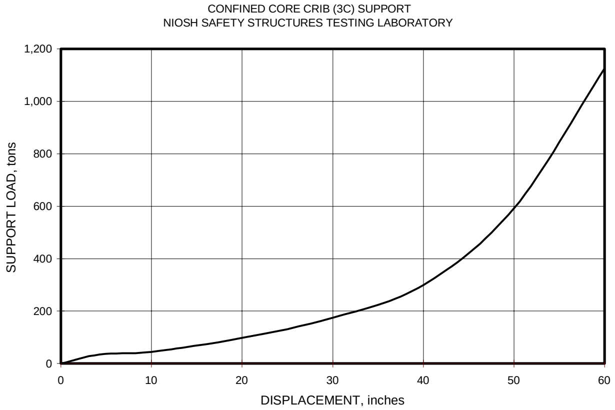

Figure 6. Example of a passive support with over a 1,000 tons of ultimate capacity, but at a convergence which is unacceptable for roof control

15. ***Headboards and footboards should be used on the Propsetter support to prevent punching into roof or floor.***

One of the most common mistakes made in the installation of the Propsetter is not to use the footboard or headboard. This mistake is generally made for one of two reasons: either the materials are not available after having been used elsewhere or they are not used in order to avoid having to cut the prop to the correct height. Propsetters are sold with footboards and headboards as a unit. On occasion, the headboards or footboards are misplaced, but it more likely that extra footboards will be used in unexpected high areas where the prop will not reach the reach of the roof without them. This can be avoided by buying extra footboards and/or headboards.

Without this head and foot board, the chance that the prop will punch into the roof or floor greatly increases. Both the 8.5 in and 10 in diameter Propsetter produce around 2,000 psi of roof bearing stress at peak loading without the headboard. The floor loading can be even greater than this because of the pod formation on the bottom of the prop as it accepts load and deforms. Hence, the prop will punch into weak roof or floor materials, and in doing so causes further damage to the roof and floor materials and seriously degrades the roof support capability of the prop.

16. Full contact crib supports such as the Link-N-Lock and Tri-Log should not be wedged only at corners as is typically done in conventional cribbing (figure 7).

The purpose of designing a crib to provide full timber contact is to increase its stiffness and capacity. When these systems are wedged at the corners only, the contact area at the roof layer is diminished. Until there is sufficient load to crush the wedging, the initial loading will be controlled by the wedged contact area and not the full crib timbers as intended, resulting in considerably less support resistance during the initial roof movements. As a minimum, wedging should be done at the corners of the crib as well as in the middle of the timbers. Ideally, wedging should be applied along the full perimeter of the crib to preserve the initial stiffness of the support.

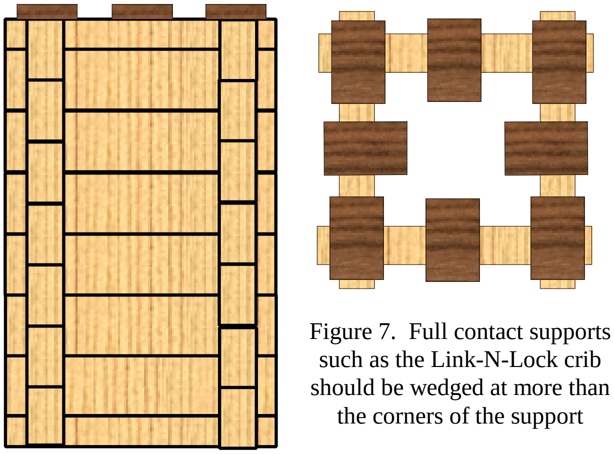

Figure 7. Full contact supports such as the Link-N-Lock crib should be wedged at more than the corners of the support

17. Splits in Propsetter typically do not significantly affect the peak capacity of the prop (figure 8).

A common misconception regarding the Propsetter support is that splits in the prop body caused by drying out of the timber will cause the prop to buckle prematurely and destroy the loading capability of the prop. This is not the case. Test results in the Mine Roof Simulator have shown that the Propsetter is still able to provide the rated capacity of the prop (figure 9). It will not buckle prematurely, since the wedging action is still maintaining control of the prop capacity. The dryness may degrade the post failure performance of the prop. On occasion, the neck of the prop in the wedged section may deform in a more brittle manner than planned, resulting in more load shedding after reaching the rated peak loading. When the prop is green, the wood fibers are more pliable and the brushing action is more reliable.

Figures 8. Splits in the Propsetter support typically do not decrease its rated capacity, which is controlled by the wedged section at the bottom of the prop and not the main body of the post.

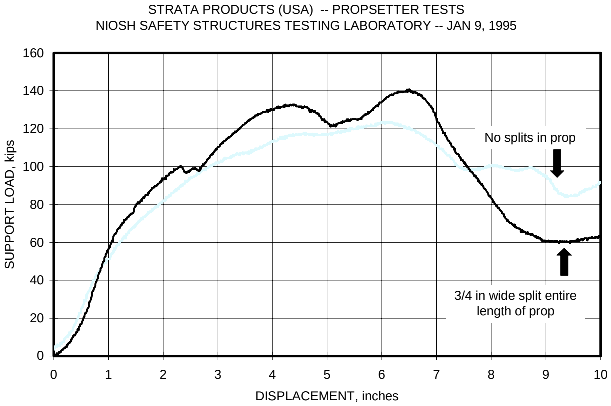

Figure 9. Load-displacement performance of Propsetter with and without splits in the prop due to drying out of the timber

18. Shrinkage of crib type timber supports can be detrimental to long term support applications.

One factor that is often overlooked in timber supports is that all wood will shrink. The rate of shrinkage is greater when the wood is initially green as is the case with most mine timbers when they are first installed. Mine timbers are often saturated at over 30% moisture content upon delivery to the mine, and as such may shrink for several months until the moisture content drops down below 15%. Since each timber shrinks, the more timbers used in the crib construction, the greater reduction in height will occur. In other words, as the seam height increases, the probability of the support shrinking away from roof contact increases.

The orientation of the grain also controls the rate of shrinkage. Shrinkage is most severe in the direction of the growth rings or in a tangential orientation (figure 10) and about 50% less across the growth rings (radially), and only slightly along the grain. Poplar, a common wood used in crib and prop construction, shrinks around 8.2% going from a green to a dry state (tangential shrinkage) (8). Therefore, a 6-in-thick crib timber can shrink to 5.5 in-thick timber when fully dried. Hence, an 8-ft-high crib would shrink by 6 in. While the natural humidity in the mine is likely to keep the timber from fully drying, it is not uncommon for cribs to shrink away from the mine roof in areas of static stress or in areas where the loading (convergence) rate is less than the shrinkage rate of the wood.

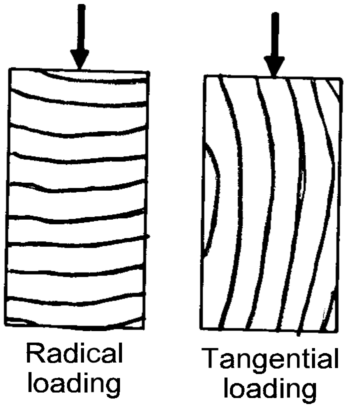

Figure 10. Shrinkage in wood is most severe in the direction of the growth rings (tangential) and 50% less in the radial direction

Figure 11. Prestressing of a support, such as the Hercules crib shown here, can help to offset the effects of wood shinkage and maintain the support tight against the mine roof and floor

Prestressing a timber support, such as the Hercules crib shown in figure 11, can help to offset the effect of the shrinkage. As the shrinkage occurs, the preload will be diminished but will extend the time that the support remains in contact with the roof. Since shrinkage is considerably less along the grain, timber posts are far less likely to shrink away from the mine roof than are wood cribs.

19. ***Standing supports should not be set on loose material.***

Setting a roof support on loose material typically reduces the effective stiffness of the support since the material is softer than the support. The result is that the support will provide relatively little resistance to the roof movement until this material is compacted. The proper installation procedure should be to prepare the floor by removing all debris to establish a firm and level foundation to set the support on.

20. ***Concrete cribs should not be wedged between the layers of concrete.***

Concrete is very susceptible to stress concentrations. Wedging between the layers of concrete blocks or donuts, which is sometimes done to level the crib during construction, creates stress concentrations that will cause the support to fail prematurely. Proper floor preparation should be used to establish a level foundation prior to building the crib. Slight tilting of the support is better than trying to spot level it during construction.

21. ***Laboratory testing of pumpable roof supports in bags will not provide an accurate representation of the peak loading capacity of the support unless the top is flat.***

Questions have arisen regarding the peak loading of these pumpable supports measured from full scale laboratory tests in rigid roof frames such as the Mine Roof Simulator. When these supports are poured on the surface without a rigid roof, the bags will typically crown as the bag is filled under the pump pressure. Since the peak loading capability is a function of the contact area, the crowning reduces the contact area and thereby reduces the peak loading capacity. If the material is brittle, as is used in current pumpable support systems as marketed by Heintzmann Corporation and Fosroc Corporation, the material fractures and sheds load after the peak loading is reached. Hence, the full diameter of the support is never realized in the development of the support loading. In the mine, the bag is likely to conform to the roof contour as it filled, and hence the full area will be established to provide support capacity consistent with the bag diameter and the material strength.

22. ***The stability of supports is dependent on the aspect ratio of the support structure. Failure to abide by the design rules for a particular support will lead to premature failure.***

The aspect ratio is defined as the ratio of the support height to its width. For example, a 24 in Link-N-Lock constructed to a 6-ft height would have an aspect ration of 3.0. The required aspect ratio to maintain stability is different for each support. Proper aspect ratios are best determined from full scale testing in the laboratory, although it should also be recognized that stability can also be affected by other factors such as the symmetry of the loading and the roof and floor contact. Below are some rules of thumb for several commonly used support systems. (1) Conventional wood cribs – 4.3, (2) Link-N-Lock cribs – 4.0:, (3) Tri-Log cribs – 4.0:, (4) Link-N-X cribs – 3.0:1, (5) Concrete cribs – 6.0:1, (6) Can Support — 5.0:1, and (7) Pumpable crib – 4.0:1. The aspect ratio for conventional wood cribbing is with the width measured from the distance between the centerline of the crib timbers (not the actual length of the timber) (figure 12), or the width equals the length of the timber minus twice the overhang distance plus the timber width. For example, a 36-in length timber that is 6 in wide with a 3-in overhang would have an effective width W = 36 - (2 * 3) + 6 = 24 in.

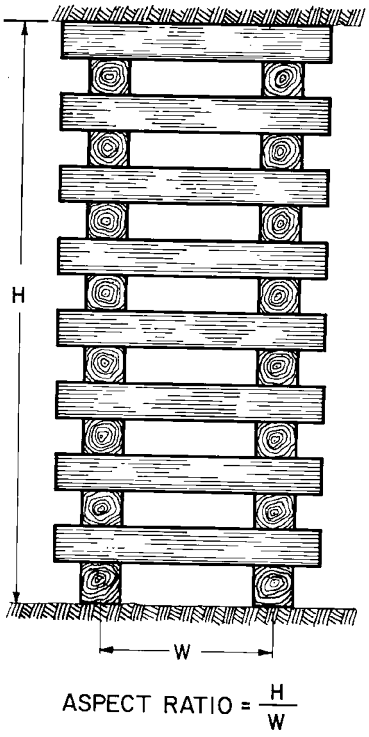

Figure 12. Determination of the aspect ratio for wood crib

23. ***When supports of different stiffness are mixed, the stiffer support will do the majority of the work.***

Stiffer supports will develop loading more quickly in response to convergence then will softer supports. Hence if softer supports are mixed in between stiffer supports, the stiffer support will be doing most of the work. For example, if a longwall tailgate is supported with a single row of alternating 4-point and 9-point cribs, each on 10 ft center-to-center spacing, the 9-point cribs (on a 20-ft spacing) will be doing most of the work. It is possible that the 4-point cribs may not provide adequate control in the spans between the 9-point cribs. Another scenario is when some supplemental support is used to alleviate roof control problems. If the supplemental support is significantly stiffer than the roof support system that is normally used, it can improve ground control. However, if the stiffer support system is installed at large spacings, two things may unintentionally happen. Either the support capacity will not be distributed far enough to improve ground conditions over the total span which is likely in weaker roof conditions, or in stronger roof, the stiffer support may get overloaded and fail prematurely since it is doing the bulk of the work. A unfortunate consequence of this second action is that the support may be banned from further consideration, when in fact had it been used as the main secondary roof support on a normal spacing it would have performed well.

POWERED ROOF SUPPORT SYSTEMS

24. ***Staging of hydraulic leg cylinders will affect the stiffness of the support.***

Staging of multi-stage cylinders can have a significant affect on the stiffness and response of the support to ground movements. Generally, the stiffness of a particular stage will increase as the extension of the stage decreases, or as the height of the support decreases (9). This is one reason why two longwall shields, sitting side by side one another, will have different levels of loading at the completion of a mining cycle. Another consequence of this behavior is that it can complicate the use of the support loading as a measure of roof loading and instability.

25. ***Increasing the capacity of longwall shields does not guarantee that they will yield less often or last longer.***

An often overlooked consequence of increasing the capacity of longwall shields by increasing the size of the leg cylinders is a proportional increase in stiffness. The increased stiffness means that the shield will develop more loading with less ground movement. This can be beneficial if the shield capacity is controlling the ground movements of the immediate roof, but in conditions where main roof weighting is the controlling factor, then it is likely that the convergence will not be fully controlled by the shield capacity. In this case, the increased stiffness simply results in increased shield loading. Under this type of load behavior, an 800-ton shield is just as likely to load to yield after setting as would be a 1,000-ton shield (figure 13). Consequently, the life of a 1,000-ton shield is not likely to be any longer than that of an 800-ton shield, assuming similar structural margins of safety in the component designs (10).

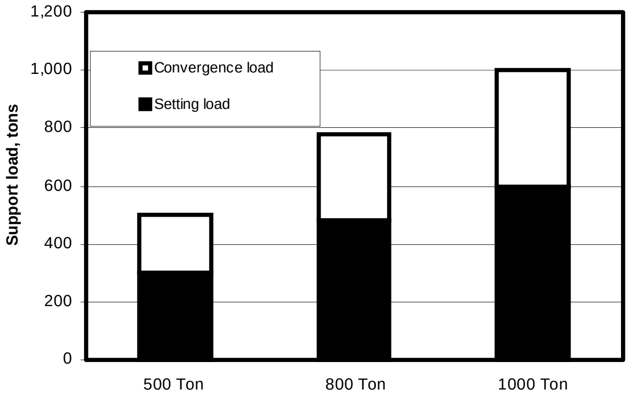

Figure 13. Due to increases in stiffness, higher capacity shields develop more loading for the same convergence than softer, lower capacity shields

26. ***No change in leg pressure is generally assumed to mean there is no increase in roof loading. This is not the case whenever the bottom stage of the leg cylinder is fully extended (figure 14).***

A common misconception is that no increase in leg pressure in supports with hydraulic leg cylinders must mean that there is no increase in roof loading. In multi-stage leg cylinders, such as those used in all longwall shields and mobile roof supports, the bottom stage is where the pressure measurements are taken. When this bottom stage is fully extended (to its full stroke) when the support is set against the mine roof and floor, there will be no increase in the measured pressure in the bottom stage until the pressure in the top stage exceeds the setting force generated by the bottom stage against the mechanical stops (9). Hence, the greater the setting pressure, the longer the period will be when the bottom stage will not record an increase in roof loading following the setting of the support. An example of the measured pressure for this condition on a longwall shield is shown in figure 14.

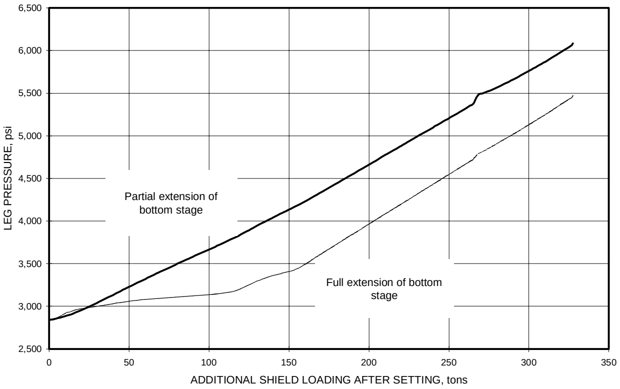

Figure 14. Whenever the bottom stage is fully extended when the shield is set, there will be a period in which there is no measured changed in hydraulic pressure in the bottom stage when roof loading occurs

27. ***Corrosion can cause structural failures in longwall shields without any load being applied.***

Corrosion is one the most overlooked factors in shield design and is a reason for premature failures. Corrosion causes stress concentrations which lead to microscopic and eventually macroscopic failures of the steel. Since it does not require load to be present, corrosion can be a reason why aging shields with relatively low operating cycles still experience structural failures (11). The effects of corrosion are also overlooked in the design of shield components. One common example is the design of link clevises, which are subject to both wear and corrosion. Figure15 shows the effects of corrosion on a lemniscate link clevis in a longwall shield. As seen in the figure, the clevis has numerous pits in the steel from the corrosion. These pits dramatically reduce the surface area of the contacting pin, resulting in significantly increased stress levels. Since poor assumptions are often made regarding the contact arc of these pin and clevis areas in the original design phase, then the decreased contact area caused by the corrosion is enough to reduce the margins of safety and can cause localized yielding of the steel. Since corrosion effects are not simulated as part of the performance testing program during the procurement of the shield, the impact of corrosion is often overlooked in the design phase.

28. ***Internal leakage in hydraulic leg cylinders reduces the load carrying capacity of a longwall shield and can result in no load carrying capacity if the leak is large enough.***

A common misconception is that internal leakage (i.e., from worn seals) will not result in loss of load carrying capacity since the fluid is still contained in the cylinder. This is not true. When the seals leak, the hydraulic fluid travels back through the return line to the supply tank. Fluid loss in either the top or bottom stage results in a pressure drop in both stages, and a proportional reduction of support capacity. Even if the staging valve leaks and the fluid is still contained within the cylinders, there will be a loss of support capacity due to a readjustment of the staging caused by a drop in pressure in the top stage (9).

Figure 15. Corrosion of a lemniscate link bore can significantly increase the stress from link loading and increase the probability of failure

29. ***Preloading does not increase the stiffness of a support.***

Another misconception regarding preloading concerns whether it increases the stiffness of a support. It does not. This is true for standing roof supports as well as powered roof supports such as longwall shields or mobile roof supports. Once the support is set at whatever preload, the load development as a function of convergence will be the same as if the support was not preloaded. Hence, in terms of longwall shields, any additional ground movement will produce the same increase in shield loading when the support is set with 2,500 psi leg pressure as it would when it is set with 4,500 psi leg pressure. In other words, the shields capability to resist additional ground movements is not improved by a higher setting force.

CONCLUDING REMARKS

A wide variety of secondary roof supports are routinely used to provide additional roof support in almost every mining application. Many of these roof supports systems have been used for years while new ones are being developed to provide superior roof control. Despite their widespread use, some of the basic principles that govern their performance and resulting ground support capability are not always well understood.

This paper provides an overview of practical issues that can affect support performance and provides useful information to make sure that the support is properly used and constructed. This is accomplished by providing a series of bulletized topics that address specific issues. The format allows the user to quickly scan the list of topics and review ones that are relevant.

The National Institute for Occupational Safety and Health (NIOSH) Support Technology Optimization Program (STOP), although not discussed in this paper, provides a forum to properly design standing roof support systems, taking into account the many issues addressed in this paper (12-14). An updated version of this software, Version 2.3, was released in May 2001 and is discussed in detail in another paper in this proceedings.

REFERENCES

1. Barczak, T.M. and Gearhart, D.F. Engineering Methods for the Design and Employment of Wood Cribs. U.S. Department of Interior, Bureau of Mines IC 9361, 1993, 17 p.

2. Barczak, T.M., Schwemmer, D.E. and Tasillo, C.L. Practical Considerations in Longwall Face and Gate Road Support Selection and Utilization. U.S. Department of Interior, Bureau of Mines IC 9217, 1989, 22 p.

3. Barczak, T.M. Performance Characteristics of Wood Cribs and Alternative Roof Support Technologies. U.S. Department of Health and Human Services, Public Health Service, Center for Disease Control and Prevention, National Institute for Occupational Safety and Health IR 4944, 2000, 81 pp.

4. Barczak, T.M., Mucho, T.P. and Dolinar, D.R.. Design Methodology for Standing Roof Supports. U.S. Department of Health and Human Services, Public Health Service, Center for Disease Control and Prevention, National Institute for Occupational Safety and Health IC 9453, 2000, pp. 133-151.

5. Barczak, T.M. Material Handling Considerations for Secondary Roof Support Systems. U.S. Department of Health and Human Services, Public Health Service, Center for Disease Control and Prevention, National Institute for Occupational Safety and Health IC 9453, 2000, pp. 193-206.

6. Dolinar, D.R. and Martin, L.A. Cable Support for Longwall Gateroads. U.S. Department of Health and Human Services, Public Health Service, Center for Disease Control and Prevention, National Institute for Occupational Safety and Health IC 9453, 2000, pp. 165-191.

7. Tadolini, S.C. and McDonnell, J.P. Recent Developments in Cable Support Technology. SME Preprint 98-26, 1998.

8. Forest Products Laboratory. Wood Handbook: Wood as an Engineering Material. U.S. Department of Agriculture, Forest Service, Agriculture Handbook 72, Washington DC., 1987, pp 3-15.

9. Barczak, T.M. and Gearhart, D.F. Safety and Performance Considerations in Hydraulic Roof Support Systems. In: Proceedings of 17th International Conference on Ground Control in Mining, Morgantown, WV, 1998, pp. 176-187.

10. Barczak, T.M. Shield Design, Construction, and Operation. In: Proceedings of Longwall USA, 1998, pp. 5-49.

11. Barczak, T.M. Examining Longwall Shield Failures from an Engineering Design and Operational Perspective. U.S. Department of Health and Human Services, Public Health Service, Center for Disease Control and Prevention, National Institute for Occupational Safety and Health IC 9453, 2000, pp. 223-245.

12. Barczak, T.M. Optimizing Secondary Roof Support with the NIOSH Support Technology Optimization Program (STOP). U.S. Department of Health and Human Services, Public Health Service, Center for Disease Control and Prevention, National Institute for Occupational Safety and Health IC 9453, 2000, pp. 151-165.

13. Barczak, T.M. Optimizing Secondary Roof Support with the NIOSH Support Technology Optimization Program (STOP). In: Proceedings of 19th International Conference on Ground Control in Mining, Morgantown, WV, Aug. 8-10, 2000, pp. 74-84.

14. Barczak, T.M. Updating the NIOSH Support Technology Optimization Program (STOP) with New Support Technologies and Additional Design Features. To be published in: Proceedings of 20th International Conference on Ground Control in Mining, 2001.