Standing support alternatives in western United States longwalls

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Abstract

Mines in the western United States have had limited choices for standing support. Wood cribs were often too soft and unstable. The introduction of the Can support in the early 1990s provided an effective alternative, and it remains the dominant form of tailgate support. Water-filled prestressing cells are now used to cap the Can and preload it to provide an active roof load. The Cluster Prop, consisting of three timber wedge props bundled together, provides more capacity than an equivalent sized Can support and improves transport efficiency. However, the Cluster Prop is less stable and does not maintain a consistent load throughout its loading profile. Pumpable roof supports are another alternative support, but they have not been proven in high deformation environments. This paper compares the performance characteristics of these various support systems.

Introduction

Gate roads and longwall recovery rooms require proper support to ensure successful longwall operations regardless of geographic region. But various circumstances make this particularly difficult for western U.S. longwalls. Nowhere in mining is the compatibility of secondary supports more critical than in western U.S. mines, where convergence is often an order of magnitude greater than in most eastern U.S. mines. In particular, the stiffness of the support must be compatible with the ground reaction, to avoid premature support failure or unintentional damage to the roof and floor when the support is too stiff and catastrophic failure of the roof when the support is too soft (Fig. 1).

Historically, timber cribs and posts were the dominant form of secondary support. However, the demands placed on these supports by longwall mining, coupled with the low-strength, short supply and increasing cost of mine timber in western U.S. mines, have necessitated the development of alternative support systems. Beginning in the mid-1990s, the National Institute for Occupational Safety and Health (NIOSH) in conjunction with various support manufacturers promoted the development of innovative support systems. A report published in the *Proceedings of the 15th International Conference on Ground Control in Mining* documented these initial support developments (Barczak and Molinda, 1996).

The first alternative to the wood crib in western U.S. mines was the Confined Core Crib (3C) support (Fig. 2). The 3C support was developed by John Frederick at Southern Utah Fuel Company (SUFCO)[1] and was successfully employed for years in the SUFCO mines (Frederick, 1994). The 3C support is a corrugated steel container filled with minus 76-mm (3-in.) pumice rock that was readily available at the Utah mine site. The steel container provides confinement to the pumice rock as it was loaded by the convergence of the mine entry. Initially, the 3C is a very soft support due to the void ratio of the pumice fill. However, despite this soft response, the support performed adequately in the two-entry yield pillar tailgates in the SUFCO mines where moderate floor heave, occurring prior to the longwall panel front abutment, caused sufficient convergence to compact the fill material and thereby stiffen the support for improved performance as the face approached. The 3C support was the predecessor of the Can support. The Can support, as shown in Fig. 3, has replaced wood cribbing and continues to be the dominant form of standing support in western mines today.

The Propsetter support (Fig. 4) was developed in the mid-1990s by Strata Products. It has become one of the most commonly used longwall supports in eastern U.S. mines. But its use in western U.S. mines has been limited, in part, by its limited yield capability and stability in the plus 3-m (10-ft) mining height applications.

This paper discusses enhancements to the Can support technology and recent support innovations that provide alternatives to the Can support for western tailgate applications. Specifically, the use of a new prestressing technology for Can supports will maximize its stiffness and help to offset the deficiencies caused by topping the Can with timbers. A new timber support called the Cluster Prop was developed by Strata Products USA. It has been successfully used in several eastern U.S. mines as an alternative to the Can support. A comparison of the performance capabilities of the Cluster Prop with the Can support is included. Pumpable roof supports is

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[1] Mention of any company name or product does not constitute endorsement by the National Institute for Occupational Safety and Health.

Table 1

Impact of wood cribbing on overall stiffness of the Can support system.

Wood crib **8 x 8 x 24 in.)**	**System stiffness** **st/in. (t/cm)**
No wood crib	400 (143)
9 pt - 2 layers	138 (49)
9 pt - 3 layers	116 (41)
9 pt - 4 layers	99 (35)
16 pt - 2 layers	178 (64)
16 pt - 3 layers	167 (60)
16 pt - 4 layers	145 (52)

another technology that has performed well in eastern U.S. longwall tailgates. It has recently been introduced to western U.S. mines. However, the evaluation is incomplete on how well these supports can perform in high deformation environments.

Improving the performance of the Can support

The Can support remains a fundamentally sound support design with an excellent performance record. No other support now on the market can match the stability and high yield performance of the Can support. It has performed well with both high mining heights and high deformation environments that include 0.6- to 0.9-m (2 to 3 ft) of floor heave that produces large lateral displacements of the base of the Can relative to the roof contact (Fig. 5). The Can is installed by a machine that eliminates much of the material handling required for the support installation. It has been shown to dramatically reduce material handling injuries compared to wood crib construction. From a design perspective, it has only one significant drawback; it has to be topped off to establish roof contact. Normally, this is done with conventional wood crib blocks.

A closer examination of the impact of the crib blocks on the performance of the Can reveals just how important this material is to preserving the performance potential of the Can. The first point to understand is that the wood crib blocks will always reduce the stiffness of the support. The wood crib blocks stacked on top of the support act in series with the Can. The equivalent stiffness of the complete system can be theoretically determined from

$$K_{system} = \frac{K_{Can} \times K_{WoodCrib}}{K_{Can} + K_{WoodCrib}} \qquad (1)$$

FIGURE 1

The compatibility of standing support with the loading conditions is essential for western longwall operations.

Hence, if the wood cribbing on top of the Can had the same stiffness as the Can itself, then the overall stiffness of the support system would be reduced by 50 percent. In other words, the Can would be twice as stiff if it was not topped off with wood cribbing, assuming the two components had equal stiffness.

Table 1 shows the estimated initial stiffness of a 0.91-m- (3-ft-) diam, 1.83-m- (6-ft-) tall Can topped off with two to four layers of a 9-point or 16-point wood-crib structure made from 0.2- x 0.2- x 0.91-m (8 x 8 x 36-in.) Lodgepole pine timbers. The stiffness values shown in this table have been derived from full-scale tests of these structures conducted in the NIOSH Mine Roof Simulator. As seen from this table, the initial stiffness of a 0.91-m- (3-ft-) diam Can is reduced from 143 t/cm (400 st/in.) to 35 t/cm (99 st/in.) if the Can is topped off with a 9-point crib structure that is four layers tall (0.81 m or 32 in.).

A full wood timber contact layer should *always* be used on the top of the Can, even if fewer timbers are used above the immediate layer. Without a full immediate contact layer, the crib blocks will punch into the Can and initial capacity of the Can will be reduced to that provided by the contact area of the timbers instead of the full contact area of the Can. In addition, the yield capacity of the cribbing structure should always be greater than the yield capacity of the Can. The NIOSH Support Technology Optimization Program (STOP) software can be used to estimate the yield capacity of the wood crib structure in comparison to the Can (Barczak, 2000). For example, if a 9-point crib would be constructed on top of a 0.91-m- (3-ft-) diam Can, the 9-point crib would limit the capacity of the Can through the first 152 mm (6 in.) of convergence. Only after the wood crib has gone though several inches of plastic deformation (assuming it remains stable during this transformation) is it likely to gain sufficient stiffness to transfer load fully to the Can and cause the Can to yield. Another design consideration is the size of the Can for a particular seam height. The recommended height-to-diameter aspect ratio for application of the Can support is 5 to 1. For example, in a 3-m (10-ft) seam height, the minimum Can diameter would be 0.6 m (2 ft).

Recently, a new prestressing technology was introduced that can eliminate a lot of these issues. Thin-walled steel diaphragms that can be inflated with water have been designed for prestressing a wide variety of roof support products, including the Can (Barczak et al., 2004). The prestressing units (PSUs) designed for the Can support are generally square in shape and fabricated in different sizes to accommodate different sized Can supports (Fig. 6).

The PSU can be expanded up to about 152 mm (6 in.) after it is placed on top of the Can to close the gap between the Can and the mine roof. If the Can support can be sized to within 152 mm (6 in.) of the installation height, then wood cribbing can be eliminated. In this configuration (no wood cribbing), the PSU can be inflated with sufficient pressure to cause any size Can to yield. This eliminates all the stiffness reductions typically associated with wood cribbing on top of the Can and allows the full capacity of the Can to be applied immediately to the mine roof and floor on installation.

If a moderate amount of timber is used in conjunction with the PSU, i.e., a full timber contact layer or header board, then the PSU will still have sufficient inflation expansion to generate yield loading in most applications. If the PSU is used without any timber, it should be placed on the closed end of the Can. Tests have shown that the welded seam sections on the open end of the Can will puncture the PSU on occasion when the Can deforms. The PSU can also be placed on the floor and the Can set on top of the PSU. There will still be plenty of pressure to lift the Can and preload the support in this configuration.

FIGURE 2

Confined Core Crib (3C) support was the first viable alternative to wood cribbing in western longwall tailgates.

These PSUs can also be equipped with a hydraulic yield valve to control the load development on the Can or avoid over-pressurization of the PSU to prevent premature rupture. The yield valve is a simple spring-loaded system that is incorporated internally into the inlet check valve. If the PSU were not properly sized, the Can would yield before the PSU would yield. In this case, a yielding PSU may not be needed. For long-term applications of a year or more, it might be desirable to have the PSU yield prior to the Can yielding. This will help to reduce the risk of premature failure of the PSU due to corrosion.

If an oversized PSU is used (Fig. 6), which would be typical for Can applications, the PSU should be inflated with sufficient pressure to cause the PSU to fully balloon around the Can support. If this is not done, then the PSU will reduce the initial stiffness of the support as it is reshaped from the roof loading. The amount of pressure it takes to fully reshape the PSU during the inflation depends to some degree on the thickness and size of the PSU. But, as a rule, a minimum setting pressure of 1.4 MPa (200 psi) will be adequate in most cases. The reshaping can be visually seen and the operator will not have a problem in knowing that the unit is properly inflated.

The key point is that the unit should be used to preload the Can and not just to fill the gap between the Can and mine roof. The operator should also be aware that the preload is governed by the larger roof contact area and not the area of the Can. This may be important if the operator is trying to achieve a certain amount of preload on the support. Some caution should be exercised in selecting the size of the PSU. If the PSU is too large, folds may occur in the ballooned areas around the Can. These folds can reduce the rigidity of the PSU and substantially reduce its stiffness to the point where the PSU and not the Can is controlling the stiffness. The folds will also increase the probability of premature failure of the PSU.

Although the Can has considerable capacity to absorb lateral displacements induced by floor heave, a study of this performance conducted by NIOSH through full-scale testing in the Mine Roof Simulator showed that this capability can be enhanced by proper fabrication of the Can. Cans in excess of 1.83 m (6 ft) in height are constructed in two or more sections that are welded together at horizontal seams. The welds tend to create a stress concentration due to the annealing that occurs during the welding. The stress concentration can cause a fold to occur near the weld during the early phases of the loading cycle (Fig. 7). This hinge action will cause the Can to shed load throughout the loading cycle once the joint forms and horizontal displacements occur. The amount of load shedding can vary depending on how much rotation is occurring at the joint. But it can reach as high as 36 to 45 t (40 to 50 st) on a 610-mm- (24-in.-) diam Can. The load shedding is much less likely to occur if the deformation is confined to the top and bottom areas of the Can.

FIGURE 3

The Can support has replaced wood cribbing and is now the dominant secondary support used in western tailgates.

FIGURE 4

The Propsetter support has provided a yielding timber prop, and, although it is one of the most commonly used supports in eastern longwall tailgates, its application in western mines is limited due to its yield capability and stability in the higher mining heights.

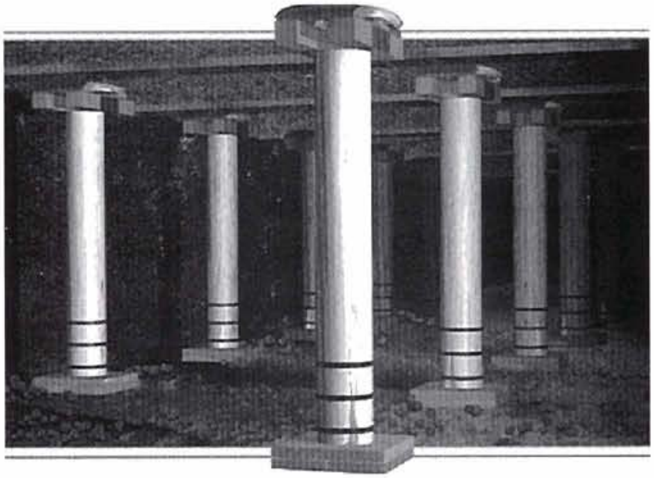


FIGURE 6

A water-filled prestressing unit (PSU) is now available for topping off the CAN and applying a substantial active loading to the mine roof and floor.

FIGURE 5

The Can is the most stable support presently available. It can accommodate large roof-to-floor convergence as well as large lateral displacements.

Based on this observation, Can constructions where pieces are added on both ends of a center, main body, section will provide optimum performance. Figure 8 shows a 0.61-m (24-in.) Can that has gone through 0.64 m (25 in.) of both vertical and horizontal displacement without failure or instability that results in significant load shedding. Lateral displacements larger than that caused the Can to rip open.

In summary, the key to using the Can support successfully is to preserve the stiffness capability of the Can by avoiding too much wood cribbing on top. Because the wood acts in series with the Can, any amount of wood will degrade the initial stiffness of the Can, but the softer the crib structure used on top of the Can, the softer the Can response prior to yield will become. The hydraulic PSU technology can overcome this problem by preloading the Can to its yield rating so that this load is immediately applied to the mine roof and floor upon installation of the support.

Cluster Props as alternative tailgate support

An alternative to the Can support is the Cluster Prop. The Cluster Prop, as shown in Fig. 9, is based on the Propsetter support, which relies on the wedges cut into the bottom section of the timber post to control yielding of the prop. Three Wedge Props are bound together with three strong steel bands positioned at the top, middle and bottom section of the props. This allows the three props to perform in unison and provide a stiff, high capacity, yet yielding support system. Currently, two Wedge Prop sizes, 216-mm- (8.5-in.-) diam and 254-mm- (10-in.-) diam, are used in the Cluster Prop design in western U.S. mines. The recommended operating ranges for the 216-mm (8.5-in.) Cluster Prop is 1.83 to 2.74 m (6 to 9 ft). The recommended operating range for the 254-mm (10-in.) Cluster Prop is 1.83 to 3.66 m (6 to 12 ft). Each size is available from the manufacturer, Strata Products USA, in 152-mm- (6-in.-) length increments.

The performance curves for the 216-mm (8.5-in.) and 254-mm (10-in.) Cluster Props as measured during full-scale testing in the NIOSH Mine Roof Simulator are shown in Fig. 10. It includes the 0.61, 0.76, and 0.91 m (24, 30, and 36-in.) diameter Can performance. These conclusions are drawn from the performance curves.

The 216-mm (8.5-in.) Cluster Prop is rated at an average yield capacity of 136 t (150 st) and the 216 mm (10-in.) Cluster Prop at 204 t (225 st). Overall, the equivalent sized Cluster Prop provides more support capacity than that of the Can support.

The Cluster Prop will be slightly stiffer than the Can as a passive support, particularly when a lot of wood cribbing is used in conjunction with the Can. The 254 mm (10-in.) Cluster Prop is stiffer than the 216-mm (8.5-in.)

Cluster Prop due to its larger cross-sectional area.

The yield behavior of the Can is more controlled with less load shedding and is more consistent than that of the Cluster Prop. This is because the Cluster Prop relies on deformation of wood that can be erratic, while the Can relies on the confinement and folding of the steel container to control the post yield load.

The Can has larger yield capability than the Cluster Prop. The Can will yield through 50 percent strain. The Cluster Prop has been shown through full-scale testing to yield up to 0.51 m (20 in.) without headboards or footboards, provided the wedge props are yielding in unison. The yield capability of the Cluster Prop is less consistent and can be impacted by the loading conditions. It will be maximized when the props yield in unison and will be minimized if the props act independently. Hence, the steel strapping must maintain sufficient confinement to provide uniform behavior.

Installation issues can also be critical to optimizing the performance of the Cluster Prop. The Cluster Prop will perform best when used with no more than a rugged, 102-mm- (4-in.-) thick footboard or headboard, and it can be used without a headboard or footboard. Like the Can support, any additional material in series with the prop will soften the overall response of the support. Its yield range is limited to the yielding of the Wedge Props. Attempting to extend the yield range by adding soft crib block timbers on top of the support (Fig. 11) is not recommended. The wood crib timbers, in addition to softening the support response, create a hinge point that can severely degrade the stability of the support, particularly in floor heave conditions where the base of the prop is moved laterally from the roof contact.

The Cluster Prop can be installed with either end up. Traditionally, the prop is installed with the wedged end of the props down, but from a performance perspective this orientation does not matter. If used without a footboard or headboard, it may make more sense to install the wedged end against the roof if the floor is too soft to handle the bearing load when installed with the wedged end on the floor. Because the prop performance will be optimized when the wedge formation and crushing of the individual props act in unison, the orientation of the props with respect to the lateral movement or any condition that is likely to cause uneven loading of the individual props may help to determine how the prop is installed. As a rule, the Cluster Prop should be installed as vertically as is practically possible, although a 5° tilt was determined not to have a dramatic effect on the prop performance during full-scale laboratory testing.

The Cluster Prop, like the Can support, is installed with a mechanical aid. Unlike the Can system that uses a hydraulically powered clamp, the Prophandler is simply a mechanical clamp and a static tray from which the Cluster Props are slid into position. One advantage of Cluster Prop over the Can support is an improvement in haulage productivity because more units of equivalent capacity can be transported on the same supply car due to their smaller size and physical shape. Up to 100 of the 254-mm (10-in.) Cluster Props can be transported in the same load compared to 35 Cans that are 0.91-m- (36-in.-) diam.

FIGURE 7

Buckling of Can caused by welding of sections together can create a hinge point during lateral displacement that may cause load shedding during yielding.

Pumpable roof support technologies

Pumpable roof support technologies have advanced with new developments in the late 1990s. Heitech (part of Heintzmann Corp.) has led the development of a two-component, quick-setting grout system that can be pumped for more than 4.8 km (3 miles) through a surface borehole, into a fabric bag hung from the mine roof. The bag not only provides a structure to form the support, but also provides confinement to the fractured grout once its peak capacity is exceeded. The support can be sized to satisfy specific loading conditions, 0.61-m- (24-in.-) and 0.76-m- (30-in.-) diam are the two standard sizes used in eastern U.S. tailgates.

The performance curves for these two supports are shown in Fig. 12. As seen in these figures, the pumpable

FIGURE 8

The limit of lateral displacement is shown where 635 mm (25 in.) of lateral displacement occurred prior to the Can ripping open.

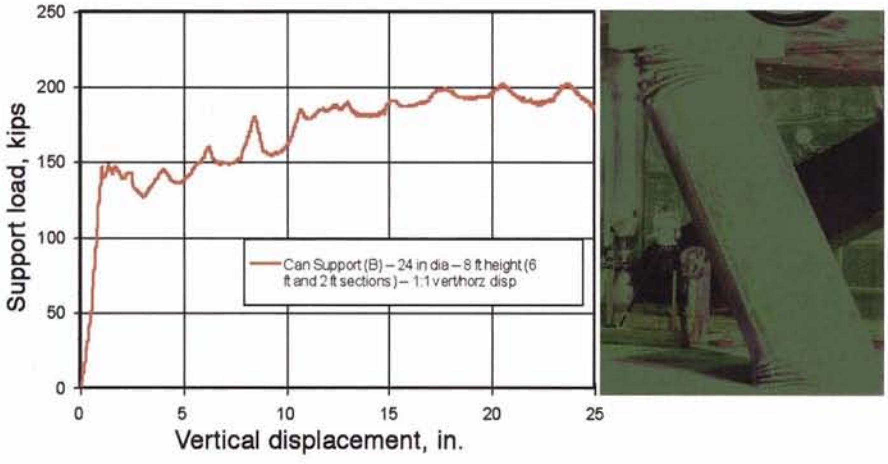


FIGURE 9

The Cluster Prop consists of three Wedge Props bundled together as shown in this longwall gate-road application.

support provides a very stiff response, considerably stiffer than the Can support. But unlike the Can, which uses an air-entrained material that can be volumetrically crushed and a steel container that can sustain its peak support capacity during yielding, the pumpable support sheds considerable load during its post peak behavior. This is because the fabric bag does not have the rigidity of the steel Can container and cannot provide sufficient confinement to prevent this load shedding. A residual load of about 91 t (100 st) can be maintained through several inches, but the pumpable crib is never going to have the yield capability of a Can support. These supports have been successfully employed in a few eastern U.S. longwall tailgates and have performed very well for these applications.

Successful trials of this support technology have also been conducted in bleeder entries in at least one western U.S. longwall with nearly a foot of floor heave. But the floor material moved around the support and did not induce much (probably less than 51 mm or 2 in.) deformation within the support. It is still unknown as to whether this technology can perform well in a high deformation environment where the convergence cannot be controlled by the support capacity. Hence, its application potential in yield pillar tailgates or areas of excessive floor heave remain unknown.

Summary and conclusions

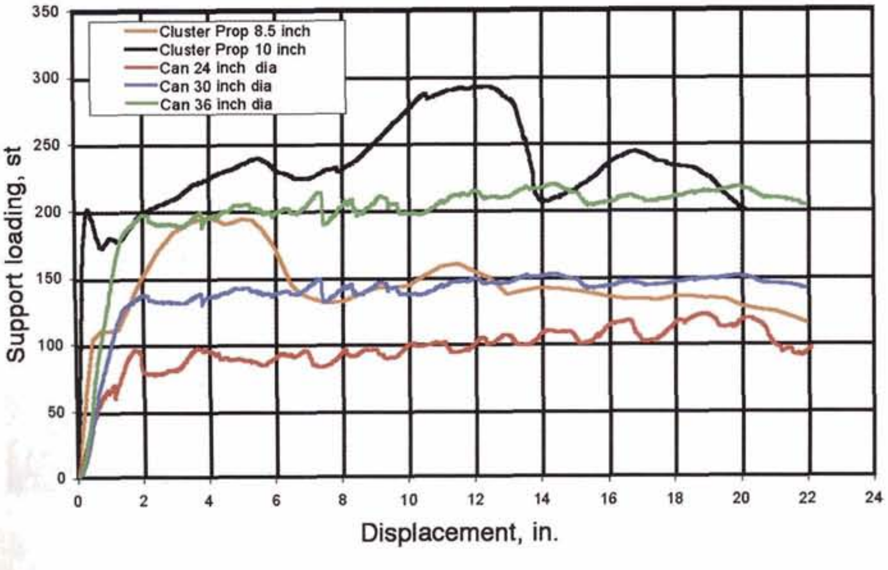
Secondary support in western United States mines has evolved as Can supports replaced conventional wood cribbing. The Can continues to be an effective design with a very successful performance record. The key is to maintain the performance capability of the Can by proper capping practice, which historically has been done with crib timbers. Poor practice in this regard can significantly soften the support response and degrade its stability as well.

Recently, a water-filled diaphragm was developed as a prestressing unit (PSU) for Can applications. The PSU can eliminate the need for wood cribbing if the Can is sized to within 152 mm (6 in.) of the installation height. The PSU can also preload the Can to its yield capacity and provide a substantial active load to the mine roof and floor. Prestressing secures the Can in place and prevents it from being dislodged, unintentionally by pillar sloughage or other events, once it is set in place. The PSU can also be used to control load development by utilizing a yield valve in the PSU.

Other support concepts have been introduced in the past two or three years that can provide an alternative to the Can. These include the Cluster Prop and the pumpable roof support. The Cluster Prop is a timber support that uses three Wedge Props to provide a support system with equivalent capacity to the Can. It is slightly stiffer than the Can prior to yielding and can yield through about 508 mm (20 in.) of convergence. But its yield load is less controlled than that provided by the Can support. Its primary advantage is improved haulage productivity because more units of equivalent capacity can be transported on the same supply car due to their smaller size and shape.

FIGURE 10

Comparison of Cluster Prop to the Can support performance.



Pumpable roof supports continue to perform well in eastern U.S. longwall tailgates and at least one successful trial has been achieved in a western U.S. longwall bleeder entry application. The pumpable roof support is significantly stiffer than the Can prior to yielding. But the fabric bag does not have sufficient rigidity to sustain the peak loading, and this is the primary performance difference between the pumpable roof support and the Can. The pumpable roof support's capability to perform in a high deformation environment, where the convergence cannot be controlled by the support capacity, is doubtful but extensive trials in such applications have not yet been done.

Other advancements have been made in support applications for longwall support recovery. Here too, the Can in combination with the hydraulic PSUs, have been successfully employed. Other supports that show promise include the Rocprop and Omni Prop. The Rocprop has some proven history in this area in both eastern and western U.S. mines, while the Omni Prop has just recently been introduced to the U.S. market following a successful history in South African mines. Both of these products provide a relatively small, easily transported support that can be quickly set and provide a substantial active roof load. They also provide very controlled yielding. These performance characteristics make them well suited for longwall recovery operations. They are often used in conjunction with roof beams to help control the span in the immediate working area during shield recovery.

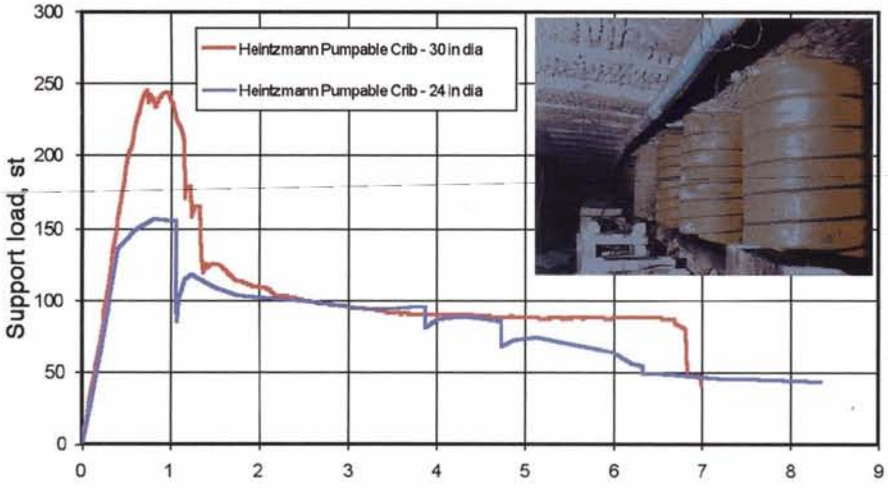
Because of these innovations in support technology, there are now a variety of support systems to assist in gate road and shield recovery ground control. Each system has its advantages and disadvantages. There is not an ideal roof support for all conditions. However, these new support systems provide mine operators with several alternatives to the conventional wood cribs that have historically been used for secondary roof support and the more recent Can support applications. Performance data for these support systems, presented in this paper, will help to ensure their safe utilization. ■

FIGURE 11

Adding crib timbers to the top of a Cluster Prop is not advisable. As shown in this figure, this can create a hinge point that can severely degrade the stability of the support in high deformation environments.

FIGURE 12

Performance assessment of Pumpable Roof Supports from Heitech showing load-displacement curves for 610- and 762-mm- (24- and 30-in.-) diam supports typically used in longwall tailgate applications.



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