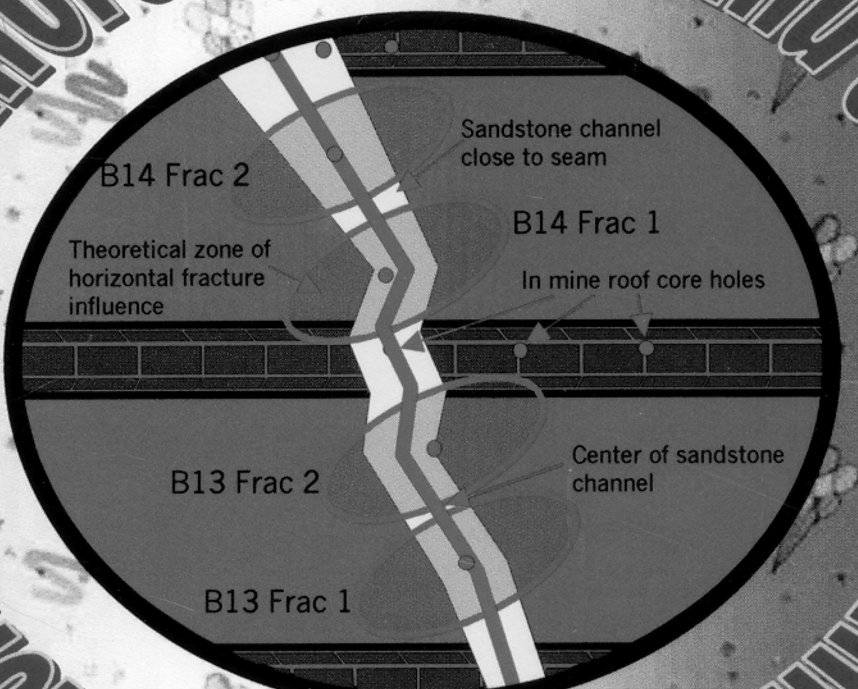
20th International Conference on Ground Control in Mining



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UPDATING THE NIOSH SUPPORT TECHNOLOGY OPTIMIZATION PROGRAM (STOP) WITH NEW SUPPORT TECHNOLOGIES AND ADDITIONAL DESIGN FEATURES

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ABSTRACT

The initial Support Technology Optimization Program (STOP), Version 1.0, was released at the 19th Ground Control Conference. This original program has since been updated to Version 2.3 which was released in May, 2001. This paper describes the additional features of Version 2.3, focusing primarily on the following three aspects: (1) including uncontrolled convergence into the design requirements for standing roof supports, (2) the addition of design procedures for cable bolts as an alternative secondary roof support, and (3) the addition of new standing roof support technologies. Another new feature which should facilitate the development of design criteria for standing roof support is the capability to define ground reaction curves through convergence measurements alone without having to make support loading measurements. There are several other new features provided in Version 2.3 which are only briefly addressed in the paper. These include: (1) additional graphics capabilities to facilitate rapid assessment of support comparisons, (2) an East-West designation for support selection to more accurately provide cost and support availability data, (3) additional safety measures including a safety factor to identify support design near the peak support capacity, checks to see if the support dimensions comply with aspect ratio requirements, and a measure of roof coverage for the design layout of the support system. These new features of STOP provide more capabilities to design and analyze secondary roof support systems for conditions which could not be fully analyzed in the original version of the program.

INTRODUCTION

The Support Technology Optimization Program (STOP) was initially created and released in August 2000 (1). The program has gained wide acceptance by the mining industry, providing both an engineering foundation for support design as well as a means to examine and compare new support technologies. STOP provides a means to optimize roof support applications, and in so doing, helps to ensure the safety of mine workers by preventing roof falls due to improper support design. The safety of the mine workers is also enhanced by providing comparative information on material handling requirements for specific roof support products, allowing the user to identify support technologies which minimize material handling requirements. Since there are over 5,000 lost work days per year in coal mines due to material handling injuries occurring during support construction, material handling requirements are an important parameter to consider in support selection.

The purpose of this program upgrade was to enhance its capabilities for support design and to keep it up to date in terms of available support technologies. The original version of STOP allowed the user to define capacity requirements based on a specified convergence, since passive standing roof supports develop load carrying capacity only in relation to the closure of the mine entry. The underlying premise in this design methodology is that the roof support capacity is controlling the ground movements, and hence roof stability. While this is often the case, there are conditions where all the convergence cannot be controlled by the capacity of secondary roof supports. Examples of convergence which typically cannot be controlled by secondary supports includes floor heave and pillar yielding. STOP can now accurately accommodate this uncontrolled convergence behavior into the support design.

Several new standing roof support technologies have been added to the program. These include: (1) Tekpak support developed by Fosroc Inc, (2) Meshpack support developed by Strata Products USA, and (3) RBS and Big John Props developed by American Commercial Inc. The capabilities of these new support technologies will be analyzed through the STOP. In addition to these standing roof support technologies, design capabilities for cable bolts have been incorporated into the program.

A major part of support design is to be able to define the design criteria. STOP has provided several options to facilitate the definition of the design requirements, one of which is the Ground Reaction Curve. The Ground Reaction Curve is the most powerful design option in that it is a measure of the support and strata interaction, which if known, allows one to design a support system which will limit the convergence in the mine opening to a designated level, and hence ensure stability of the mine entry based on in-mine observations of ground behavior. In the original version of STOP, this information could be inputted into the program provided measurements of both support loading and convergence were obtained. In the new version, only convergence measurements are required, and the support loading, which is much more difficult to measure underground, is estimated from the data base of support performance obtained through laboratory testing of the supports. This makes it much easier for the user to define ground reaction data, and, therefore, to reap the benefits of its design capabilities.

Additional enhancements in the design capabilities of the program include additional safety measures including a safety factor to identify support design near the peak support capacity, checks to see if the support dimensions comply with aspect ratio requirements to ensure support stability, and a measure of roof coverage for the design layout of the support system.

The purpose of this paper is to present these new capabilities, provide some examples of their use, and to present the new support technologies which have recently become available for secondary roof support applications.

NEW FEATURES IN STOP

The three most notable changes to the STOP are: (1) the capability to include uncontrolled convergence into the design requirements for standing roof supports, (2) the addition of design procedures for cable bolts as an alternative secondary roof support, and (3) the addition of new standing roof support technologies.

Uncontrolled Convergence

As described in the Introduction, not all convergence can be controlled by man made roof support structures. However, these ground movements induce loading in standing roof supports, which may at times damage the support, and hence should be considered in the design of these support systems. Following is a description of how STOP accommodates these uncontrolled ground movements into the design of standing roof supports.

First, the user can specify the amount of uncontrolled convergence in any of the design criteria options. The timing of the uncontrolled convergence is also part of the design consideration. Two options are available: (1) *Independent* or (2) *Concurrent*. When the *Independent* option is selected, the design convergence is set to the controlled component of the convergence, and a security check is made to see if the support can maintain the required capacity through the total convergence, which is the sum of the controlled and uncontrolled component. If the support cannot maintain the capacity through this range of convergence, a warning is issued in the *Warnings box*. Essentially, this option is saying that timing of the uncontrolled convergence is such that it should not be counted on to generate the required capacity of the passive roof support system to maintain roof control, however, the support must be stable enough to continue providing this necessary capacity to control the roof deformation should floor heave or pillar yielding occur.

Here is an example of independent, uncontrolled convergence. A 100-ton Heintzmann ACS support is selected for analysis. The design criteria are chosen based on the performance of a conventional 4-point wood crib support system, which has previously been successfully utilized in this situation. Using the current support system to establish the design criteria (figure 1), a load density of 11.6 tons/ft at 3 in of convergence is established for a double row of 4-point cribs constructed from 6x6x36 in poplar timbers on a 96-in spacing. It is also shown that an uncontrolled convergence of 5 in is set. As seen in the design criteria summary at the bottom of the form, the uncontrolled convergence timing is designated as *Independent* and a *security check* is set up at 8 in of convergence equating to the sum of the controlled (3 in) and uncontrolled convergence (5 in). Figure 2 depicts the performance window for the ACS support. It is seen that the required spacing of a single row of ACS props to provide the required 11.6 tons/ft at the design convergence of 3.0 in is 77.1 in. However, as the *Warnings box* shows, the ACS support is in yield at 3 in of convergence and fails to provide the required 11.6 tons/ft at 8.0 in when the uncontrolled convergence is added to controlled component. It is seen from the *Ground Behavior and Support Performance box* that the ACS reaches its peak loading at about 2.25 in and sheds loads fairly quickly after reaching its peak load.

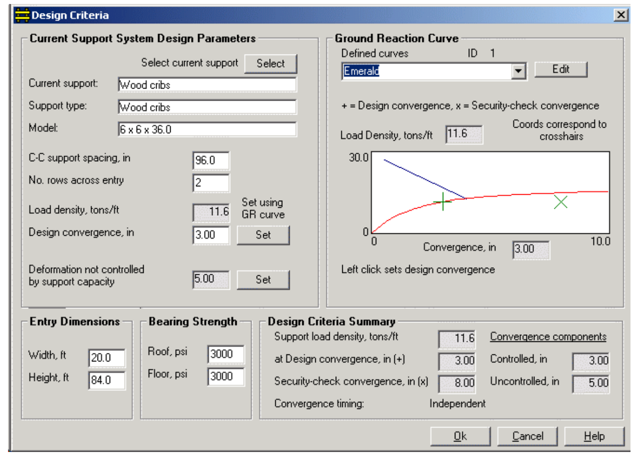

Figure 1. Design criteria based on the performance of a 4-point wood crib with an uncontrolled convergence of 5 in included with a design convergence of 3 in.

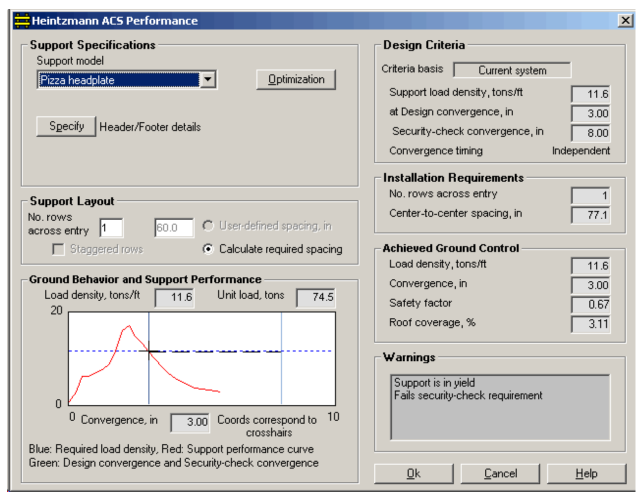

Figure 2. The ACS support system fails to provide the required capacity at 8 in of convergence.

The other option is for the designation of the timing of the uncontrolled convergence to be *Concurrent*. This means that it is occurring at the same time as the controlled component of the convergence and is thus acting to mobilize the support capacity to provide roof control. The design convergence for the support analysis is then set to the sum of the controlled convergence and the uncontrolled convergence. In this case, the security check is set at the controlled component of the convergence. The idea is to check to see if the uncontrolled convergence did not occur, would the support have the same or greater capacity as it would with the uncontrolled convergence.

The previous example of the 4-point wood crib support system as the current support system is again used, except now the timing of the uncontrolled convergence will be designated as *concurrent* and the design convergence will include the 5 in of uncontrolled convergence. As seen in figure 3, the load density requirement at 8 in of convergence for the wood crib support system on a 96-in spacing is 14.9 tons/ft. Figures 4 and 5 depict the assessment of the current 4-point wood crib (figure 4) and a Propsetter support (figure 5). The wood crib system continues to provide greater support capacity as the convergence continues (see the performance curve in the *Ground Behavior and Support Performance box*). Hence, if the uncontrolled convergence did not occur, the wood crib system at the 96-in spacing would not provide 14.9 tons/ft at 3 in of convergence, and hence, the wood crib support system fails the security check. The Propsetter on the other hand, reaches its peak loading early in the loading cycle, and although the support is yielding at 8 in of convergence, it provides the required support capacity at 3 in of convergence as well.

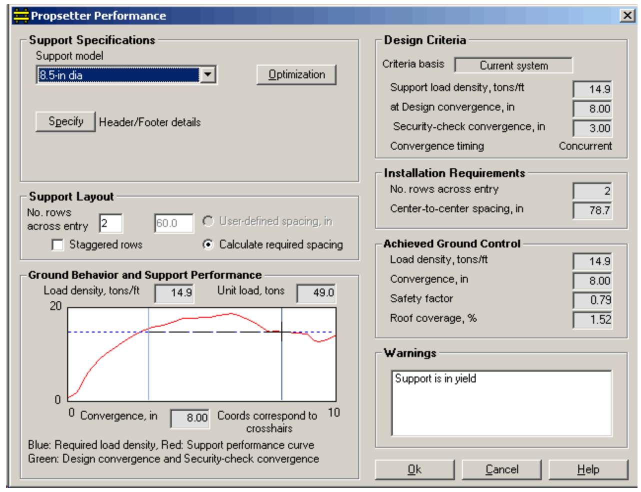

Figure 5. The Propsetter support on the other hand can provide the required 14.9 tons/ft at both 3 and 8 in of convergence

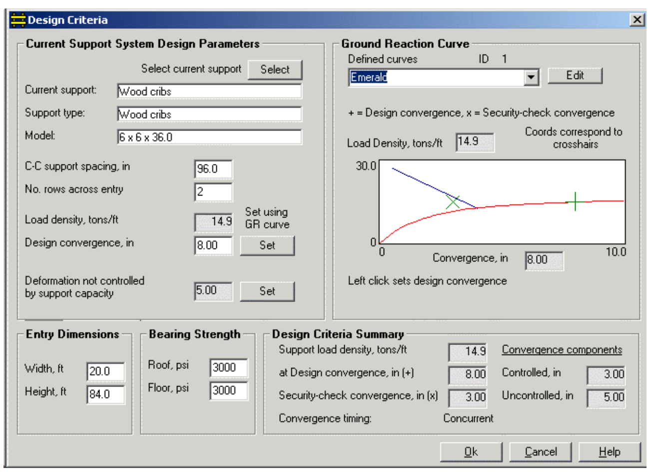

Figure 3. Design requirements set at 14.9 tons/ft with at a design convergence of 8 in including 5 in of uncontrolled (concurrent) convergence

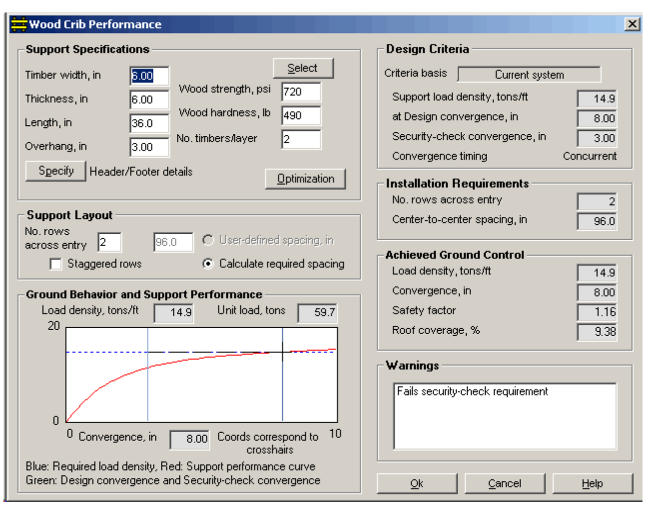

Figure 4. A conventional 4-point wood crib fails to provide the required 14.9 tons/ft at 3 in of convergence

Using a Ground Reaction Curve to define the design criteria affords the user an additional capability with uncontrolled convergence that is concurrent with the controlled component by allowing the user to adjust the spacing to determine a spacing that will make the support in compliance with the security check. Here is an example. Again we will use a 4-point wood crib support system for analysis. In this case, a hypothetical Ground Reaction Curve is selected for the design criteria as shown in figure 6. The design convergence is set at 8 in with 5 in of uncontrolled convergence occurring concurrently with the controlled component. The required support load density is 20.8 tons/ft using this ground reaction data. It is seen from figure 7, that a double row of 4-point wood cribs constructed from 6x6x36-in oak timbers will provide this capacity when employed on a 115-in spacing. However, this system also fails the security check at 3 in of convergence, meaning that if the uncontrolled convergence (i.e., floor heave) did not occur, the wood crib would not provide 20.8 tons/ft at 3 in of convergence. However, by selecting the *User Defined Spacing* option in the *Support Layout* (figure 8), it can be seen that at an 84-in spacing, the same 4-point wood crib design provides 20.8 tons/ft and meets the security check, meaning that at this spacing the support would control the roof even if the floor heave did not occur.

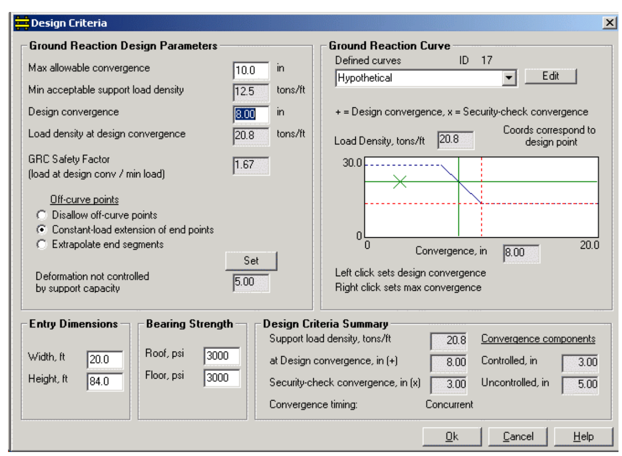

Figure 6. Design criteria of 20.8 tons/ft established from a Ground Reaction Curve at 8 in of convergence including 5 in of uncontrolled convergence

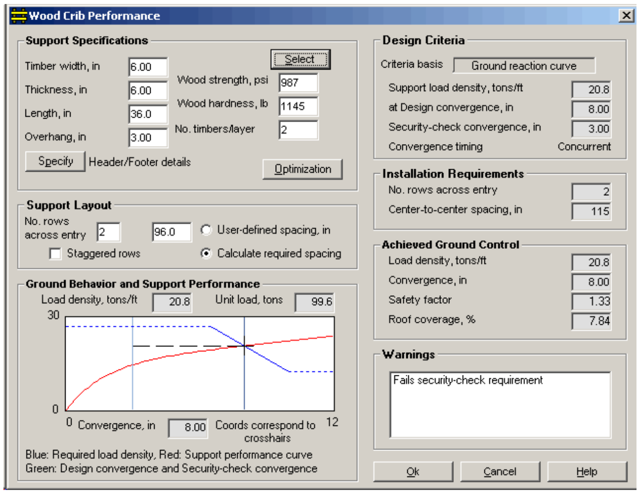

Figure 7. Double row of wood cribs on a 115-in spacing provides the required 20.8 tons at 8 in of convergence but not at 3 in

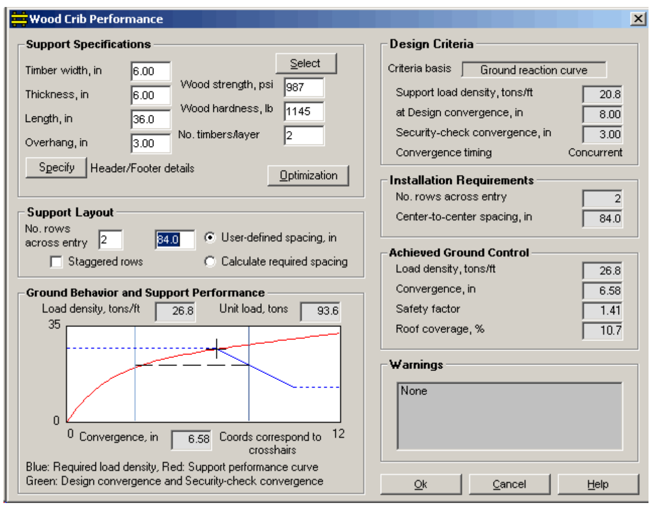

Figure 8. Reducing the spacing of the 4-point crib system to 84 in allows the system to meet the security check requirements

Cable Bolts

A category for intrinsic support has been added to the support selection module. In this category, cable bolts have been added as a support selection option. The current methodology for cable bolt design is based on a detached block approach using a shear or arch type failure geometry (2). This criteria can be specified in the design criteria window, where a separate design criteria section for cable bolts is provided (figure 9). As an intrinsic support, the cable bolt will only see roof loading, whereas the complete roof to floor closure will be seen by a standing roof support system. Therefore, a separate design criteria section is provided.

The *Edit* button (figure 9) can be pressed to activate the cable bolt "detached block" design criteria. The design criteria for cable bolt window (figure 10) is similar to that for standing support, except the convergence criteria is changed to "roof displacement" and a safety factor is included in the design requirements. The roof displacement requirement is defaulted to 1 in, but the user can select any value. This criteria sets a limit for the amount of roof displacement that is permitted to occur before the cable bolt system provides sufficient loading to put the dead weight of the roof mass into equilibrium. The safety factor is similar to that computed for standing roof support, except it is now used as part of the design requirement. The safety factor is defaulted to 1.5, meaning that the ultimate capacity of the cable bolt is 1.5 times the design load requirement necessary to support the dead weight of the roof rock at the designated failure height. In other words, the cable bolt load must not exceed 67 % of the ultimate load capacity of the cable. The minimum acceptable safety factor is 1.25, equating to a cable bolt being utilized at 80 % of the ultimate capacity of the bolt.

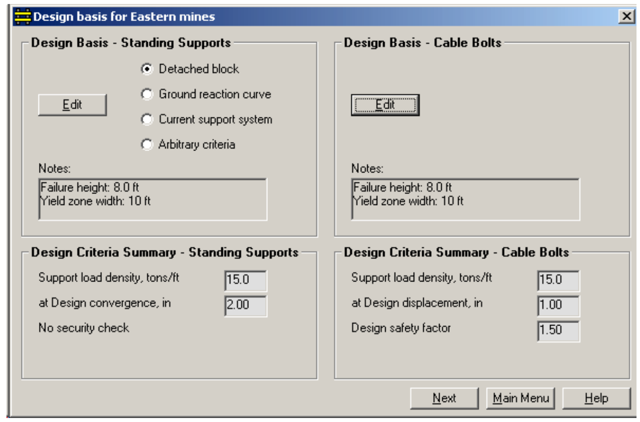

Figure 9. Separate design criteria for cable bolts can be provided by activating the Edit button under the Design Basis - Cable Bolts frame in the upper left corner of the window

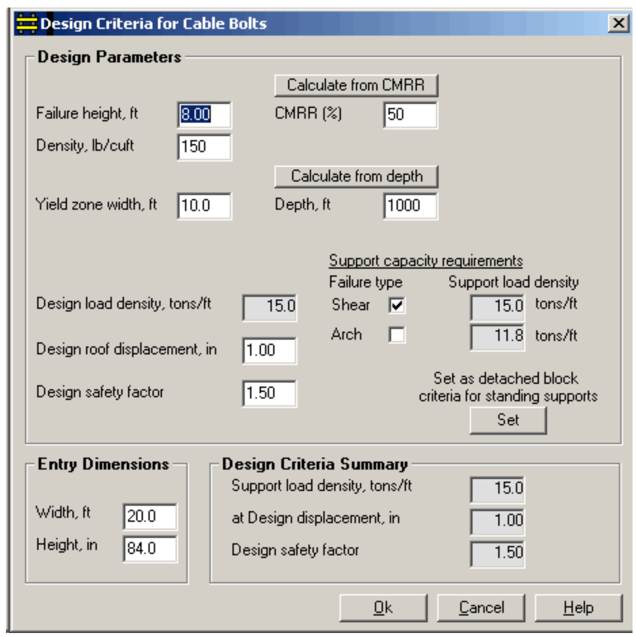

Figure 10. Design criteria using a detached block basis for cable bolts

The *Performance* window for cable bolts is shown in figure 11. The design approach for cable bolts in somewhat different than that used for standing support. Since the cable bolt spacing is likely to be fixed relative to the primary roof bolt spacing (most likely in between the roof bolt spacing), the design goal is to determine the number of cables across the entry (equivalent to the number of rows of supports in standing support evaluations) that are needed to satisfy the design criteria. There are also options to consider in terms of the cable layout or pattern of cable bolts used. First the user can select the *number of roof bolt sets* in which the cable set will be employed. A roof bolt set is defined as a set of roof bolts across the mine entry. Specifying a single set of roof bolts means that the cables set must be employed between every row of roof bolts and this pattern will continue down the entry. On the other hand, if 2 roof bolts sets are specified, then the cables must be employed in a spacing equivalent to two rows of roof bolts. A cable set is defined as the number of cables used in relation to the space option down the entry, which again is defined by the number of roof bolts sets. The *number of cables per set* is the parameter calculated by the program.

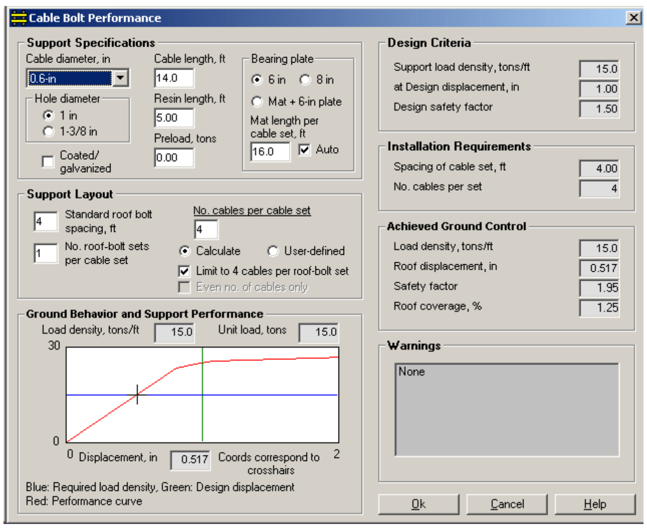

Figure 11. Performance window for defining a cable bolt system and determining the number of cables and spacing pattern necessary to satisfy the load requirements

Some examples will help to clarify the cable design procedure using STOP. The first requirement is to select the cable parameters to be used in the design. These are shown in the upper left hand area of the performance window. In this example, a 0.6-in diameter cable bolt with a length of 14 ft and 5 ft of resin anchorage is selected for evaluation. Other parameters selected include the hole size (1 in in this case), and the plate options (6 in plate in this case). It is also seen that the cable is put in without any pretensioning in this example.

Using the criteria displayed in figure 10, the cable bolt design criteria for this example is 15.0 tons/ft at 1 in of roof displacement with a safety factor of 1.5. As seen in figure 11, the *standard roof bolt spacing* is set at the default value of 4 ft, and the *number of roof-bolt sets per cable set* is set at the default value of 1. The program is asked to calculate the required number of cables for these criteria, (the *Calculate* radio button is pushed), and the program determines that 4 cables per cable set are needed (figure 11). Hence, the recommended design is 4 cables across the entry spaced in between each row of roof bolts. The *Achieved Ground Control* information provided on the right side of the window shows that the load density of 15 tons/ft is provided at 0.517 in of roof displacement and a safety factor of 1.95 in relation to the ultimate capacity of the support. The load-displacement performance of the cable bolt system relative to the design requirements is also graphically shown in the bottom left area of the window.

If the *no. of roof-bolt sets per cable set* is increased from 1 to 2, then the available spacing of the cable set is 8 ft, and the program computes that 7 cables are required in a pattern with 3 cables in the first row and 4 cables in the second row (figure 12). With this pattern of cables, the design requirements are met at slightly greater *roof displacement* (0.591 in) and with less of a *safety factor* (1.71). In essence, this design is moving closer to the minimum requirements set forth in the design criteria by allowing a pattern of 7 cables in 8 ft as opposed to 4 cables every 4 ft.

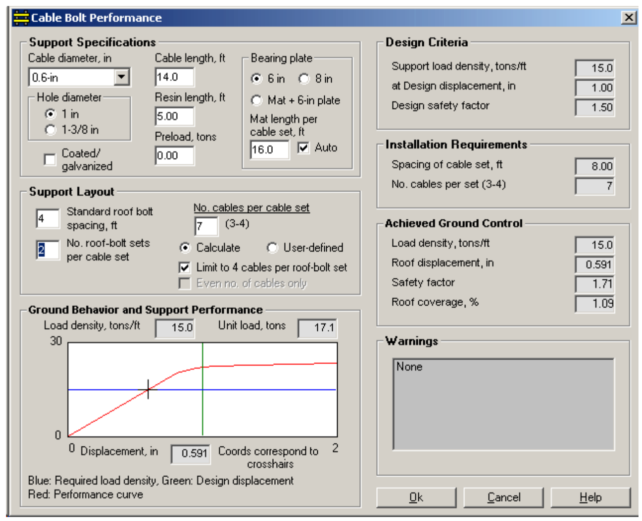

Figure 12. Increasing the number of roof-bolt sets per cable set to 2, allows 7 cables to be used in the 8-ft spacing to provide a design closer to the minimum design requirements

Instead of having the program compute the required number of bolts, the user can define this. For example, if the *no. roof-bolt sets per cable set* is set at 1, and the *user-defined* number of cables is set at 3, then the *safety factor* drops to 1.46 which is below the requirement of 1.5, and a warning to this effect in issued in the *Warnings* box on the lower right area of the window (figure 13).

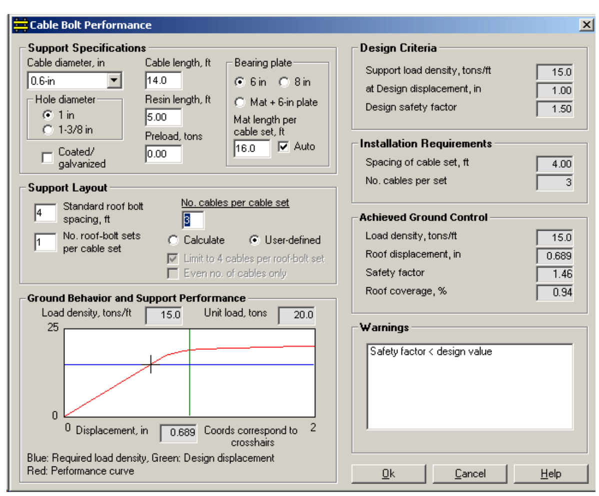

Figure 13. When 3 cables per cable set are chosen, the safety factor requirement is not met and a warning is issued to this effect

Other design options besides bolts per row are available to the user when the program is computing the cable layout. One is to limit the number of cables across the entry to a maximum of 4. This limitation stems from installation restrictions with drilling the holes for the cable bolts, and to some extent the practical limit of the area of influence of a single cable bolt. When this option is chosen and more than 4 cables are required to satisfy the design requirements, the 4 cable per row limit will reduce the *safety factor* and may reduce it below the design requirements. The other option is to limit the number of cables per row to an even number. Again this limitation may be due to the hole drilling practices, particularly with a dual-boom bolter. When this option is chosen, the *safety factor* is likely to be increased since the number of cables will be rounded to the nearest even number increment.

Pretensioning of a cable is also one of the design options. The effect of preload is to essentially shift the performance curve to the left, meaning that some of the deformation of the cable will be used up by the pretensioning. From a ground control perspective, the effect of pretensioning is generally to reduce the amount of roof displacement required to achieve equilibrium of the rock mass by building a more competent roof beam. The reduction in roof displacement will be in proportion to the amount of active roof loading applied by the pretensioning. If the pretensioning is too high, the required safety factor limit will be exceeded and a warning will be given to this effect. An example of pretensioning is shown in figure 14.

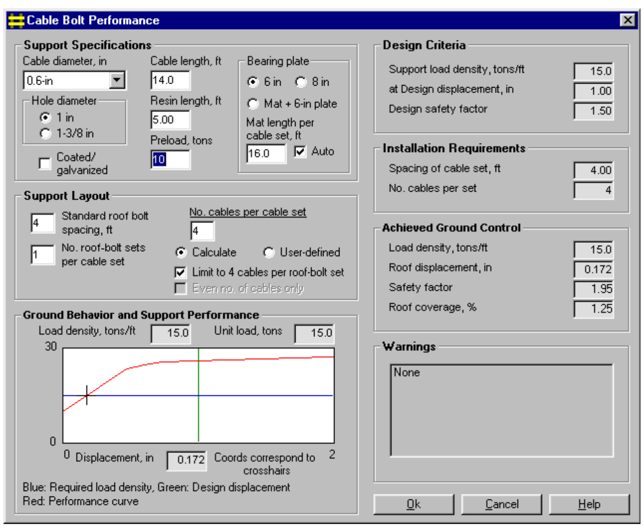

Figure 14. Pretensioning of a cable bolt can be used to reduce the required roof displacement necessary to meet the load criteria

As done with all of the standing supports analyzed in STOP, the cable bolt design process also includes estimated cost and material handling data. Figure 15 shows an example of this information. Shown in the figure are the cost models used for the cable bolts.

It is seen that all components of the system (bolt, resin, and plate) are included in the cost structure. The fixed cost of $0.25 per cable in the construction model is to account for bit replacement.

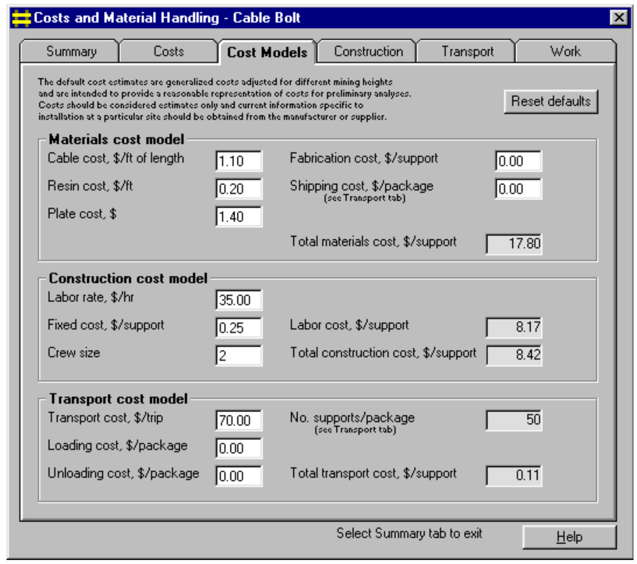

Figure 15. Cost and material handling data are also available for cable bolts

New Support Technologies

In addition to cable bolts, several new standing roof support technologies have been added to this version of STOP (Version 2.3 – April 19, 2001). These include: (1) RBS Prop, (2) Big John Prop, (3) Tekpack, and (4) Meshpack. In addition to these new support concepts, additional models have been added to the Star Prop, Heintzmann Pumpable Crib, and the Tri-Log Crib. A brief analysis of these new support technologies is provided through the capabilities of STOP.

RBS Prop – The RBS Prop is a yieldable timber post. The yield capability is provided by a specially designed head piece which sits on top of a conventional timber post (figure 16). The head piece consists of a threaded plastic section similar to a large bolt, that threads into a steel shell lined with a threaded plastic sleeve. The yield is provided by the shearing of the plastic threads.

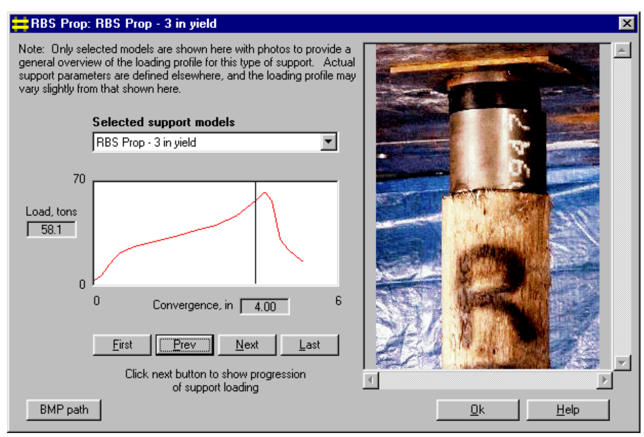

Figure 16. Performance information on the RBS prop

As seen from figure 17, the load-displacement profile for the RBS prop is similar to that of a conventional 4-point wood crib constructed from (6x6x36 in) mixed hardwood timbers, although the crib is slightly stiffer during the period when the load is controlled by the shearing of the threads in the RBS prop. Hence, for convergence control between 1.5 and 4 in, the RBS prop will require a tighter spacing than would a conventional 4-point crib. Figure 18 shows one example at a design load density requirement of 12 tons/ft at 2 in of convergence achieved with a double row of supports.

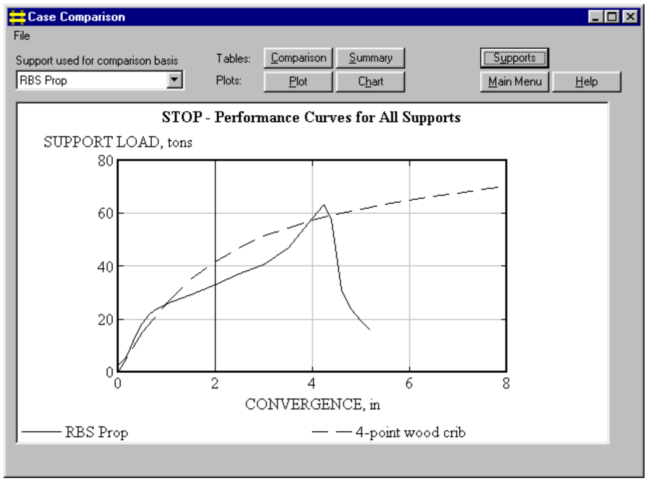

Figure 17. Load-displacement performance plot of RBS prop and wood crib

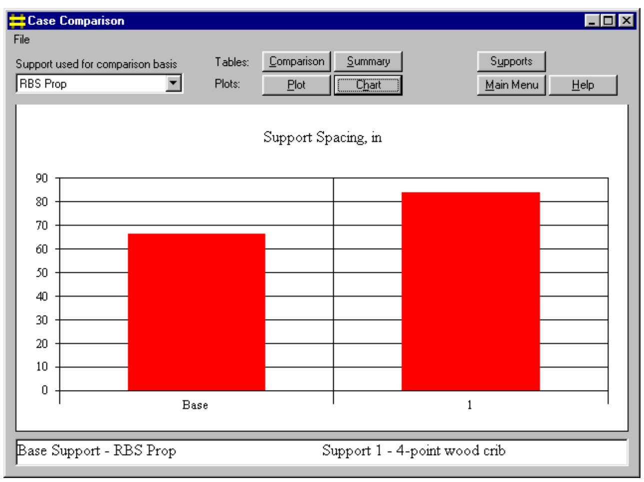

Figure 18. Spacing comparison for RBS prop and 4-point wood crib system

Big John Prop – The Big John Prop utilizes the same threaded plastic end piece as does the RBS Prop to provide controlled yielding (figure 19). The difference in the two systems is that the Big John utilizes cut sections of timber for the post instead of the round sections used in the RBS Prop. The Big John Prop is currently marketed with 2, 3, and 4 ply sections of timber measuring nominally 3.5 x 6 in in cross section. This provides for higher ultimate loading capability since the ultimate capacity is controlled by the buckling strength of the prop and the built-up sections of timber have a much larger area than the 8-in-diameter timber post used in the RBS prop. The load-displacement profile prior to full thread shearing is the same as the RBS Prop since it is the same end piece (figure 20).

Figure 19. Design information on the Big John Prop

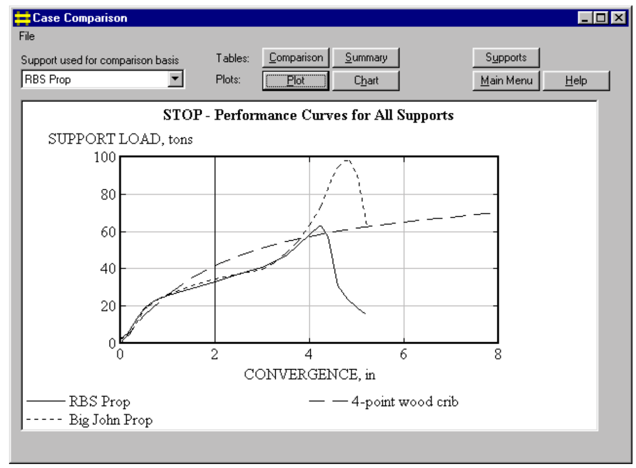

Figure20. Comparison of the RBS and Big John Props to a conventional 4-point wood crib

Tekpack Support – The Tekpack Support is marketed by Fosroc Corporation and is very similar to the Pumpable Crib support marketed by Heintzmann Corporation (figure 21). Both support systems utilize a two-part specialized grout that is pumped into a fabric bag which acts a form during pumping and provides sufficient confinement to provide some residual loading capacity once the material fractures during load application.

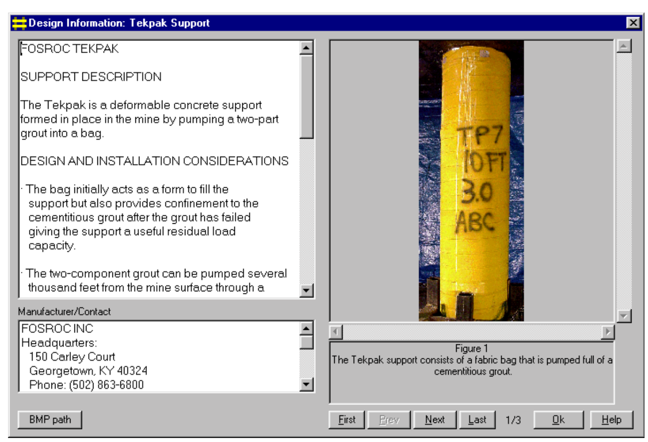

Figure 21. Design information on the Tekpack support

Meshpack Support – The Meshpack support (figure 22) is another support that is pumped in place using a fabric bag to act as a form. Unlike the Pumpable Crib (Heintzmann Corporation) and the Tekpack support (Fosroc), the Meshpack support marketed by Strata Products USA uses a more conventional cementitious grout consisting primarily of Portland cement and flyash. The two component grout mixes used in the previously mentioned supports require the water to be retained by the bag to interact with the grout. In contrast, the Meshpack is a weeping system where the water is allowed to weep (drain) out of the bag. The large volume of water used is primarily for solids material transport during pumping and is not fully used as an agent in strengthening the mix. Steel bands and wire mesh provide additional confinement to the bag as seen in figure 22.

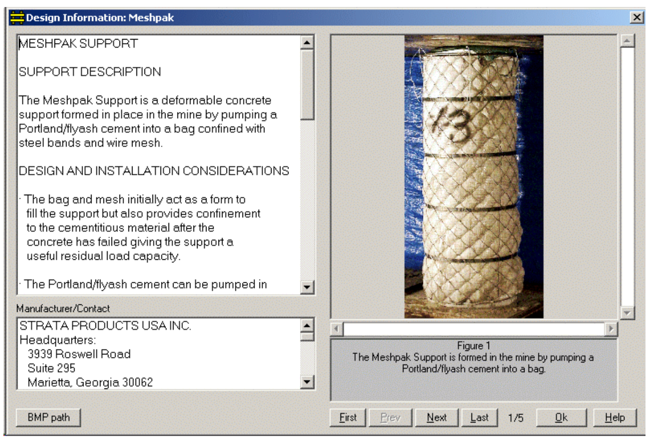

Figure 22. Design information on Meshpack support

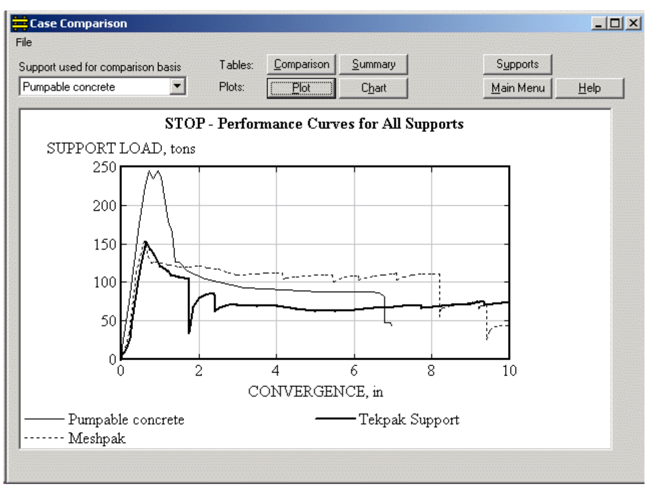

Figure 23. Comparison of Pumpable crib, Tekpack, and Meshpack supports

The Meshpack is the strongest of the three pumpable supports (Heintzmann Pumpable Crib, Fosroc Tekpack Support, and the Meshpack) due to the inherent strength of the pumped material. It also has the highest post failure strength, due in part to the extra confinement provided by the steel bands and wire mesh. The downside of this higher strength and larger residual load capacity is that it cannot be maintained for as much convergence. As seen from figure 23, the residual load in this laboratory test specimen lasted through 8 in of convergence before a large load shedding event occurred. At the writing of this report, this support is new on the market and no field trials in active mines have yet been conducted.

MAKING IT EASIER TO DEFINE GROUND REACTION CURVES

In the original version of STOP, the user had to input both the measured support load and convergence to define data points for a ground reaction curve at a particular mine site (3). Now the user can define data points for determining the ground reaction curve by only measuring and inputting the convergence in the mine associated with a particular support application (figure 24). The program will use this convergence measurement to calculate the estimated support loading and resulting support load density for the layout of the support system. It should be noted that the ground reaction will vary depending on the location in the mine relative to the mining activity as well as several other factors including geology and overburden depth. The goal is to evaluate the ground behavior in the worse load condition. For example, in a longwall tailgate, the convergence measurements should be made at the tailgate corner, since the abutment loading will be most severe at this location. The caveats of measuring the convergence are explained in more detail in the cited reference material number 3. This should facilitate the development of ground reaction data since convergence is relatively easy to measure, while the more difficult measurement of support loading is no longer required.

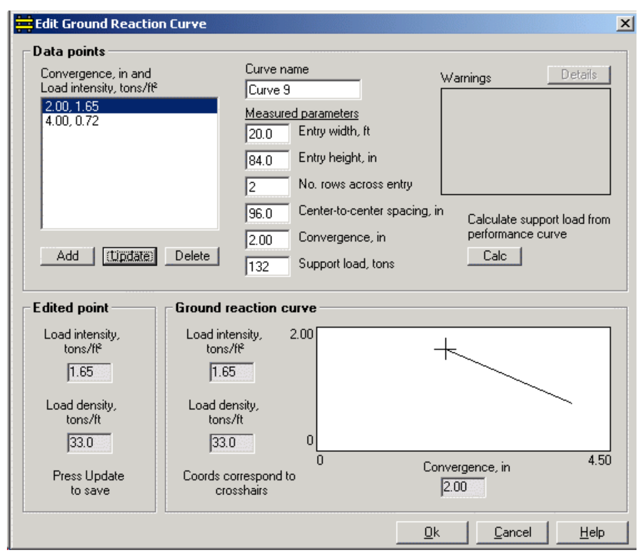

Figure 24. Using the program to define a ground reaction curve from convergence measurements alone with support loading calculated from the laboratory test data

ADDITIONAL FEATURES

East-West Support Settings

Some supports that are available in the East are not available in the West. In addition, those that are available in both the East and the West typically will have different costs associated with them, particularly if the supports are made in the East and shipped to the

West. Even supports which are made and used in the West, such as conventional wood cribbing, can have significantly different costs than their Eastern counterparts due to differences in the cost of materials (wood). In the new version of STOP, the costs and support availability and various default settings are customized for eastern and western mine applications. As part of the input, the user can select which area of the country is relevant to the analysis.

Additional Graphics Capabilities

The original STOP (Version 1.0) allowed the user to plot either the unit support load or the support system load density as a function of convergence for any of the supports chosen for analysis. Version 2.3 allows the user to chart any of the 24 different analysis parameters. For instance, the normalized installed support cost per foot of entry is shown in figure 25. This capability significantly increases the visual graphics available for support analysis and helps facilitate the rapid evaluation of support parameters.

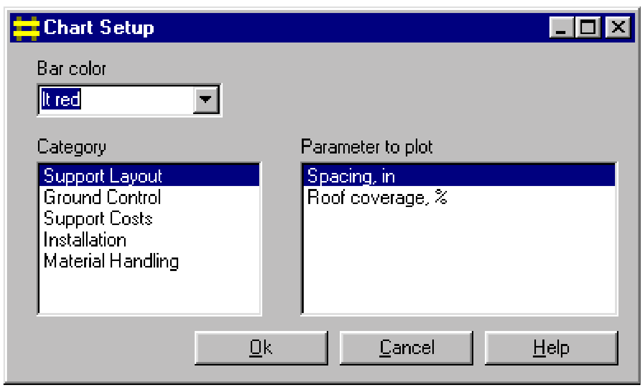

Figure 25a. Plotting of the support spacing

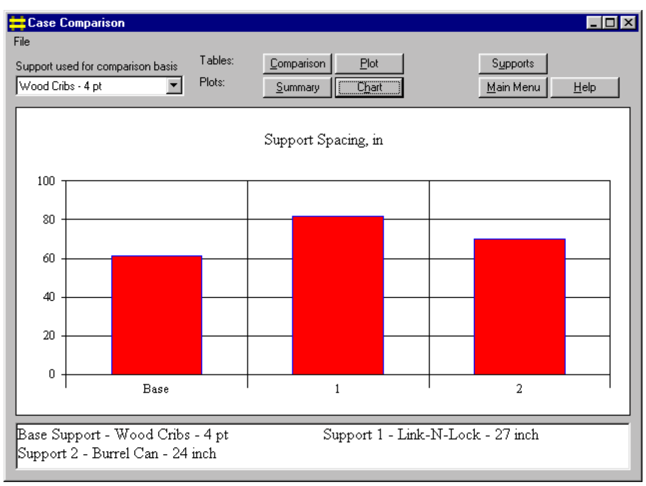

Figure 25b. Plotting of the normalized support costs

Roof and Floor Bearing Strength

The design criteria now includes the roof and floor bearing strength. This is needed to see if the support load will cause the support to punch into the roof or floor, which could significantly degrade the capability of the support to maintain roof control. It should be noted that default setting for both the roof and floor strength is 2,000 psi. This may or may not be appropriate for a particular mine, so this parameter should be updated by the user when establishing the design criteria.

Support Header and Footer

The program also now allows the user to specify the header and footer used with the support. Inputs are asked for the roof and floor contact area. The user can input values or use the set of defaults contained within the program which are believed to be representative for that particular support. Roof coverage dimensions are also provided. On occasion, these dimensions may be larger than those used in the roof contact bearing area computation. For example, the foot print of a wood crib is determined by the box area derived from the length of the timbers, while the contact area is determined by the actual timber contact area with the floor and hence will be much smaller.

Warnings box

On each of the *Performance* windows for the various support technologies, a *Warnings* box is shown on the bottom left portion of the window just below the *Achieved Ground Control* area. Messages are posted in this box pertaining to a variety of rules relevant to a particular support. Some example messages include:

- Support is in yield.
- Exceeds roof bearing strength.
- Exceeds floor bearing strength.
- Support is too short (poor aspect ratio).
- Skin-to-skin spacing exceeds W/2.
- The achieved convergence exceeds the design convergence.

Safety Factor

A load safety factor has been included under the *Achieved Ground Control* box to provide insight into how close the loading of the support is to its peak capacity for the recommended support installation. The *Safety Factor* is the ratio of the maximum support capacity to the actual support loading achieved using the current design. The maximum support capacity is defined for each support as part of the internal program data base. For supports such as wood cribs that continue to build load through very large displacements, the peak load is defined at 20% strain. When the support has yielded (exceeded its peak loading), the safety factor will be the inverse of the ratio of the peak load to the actual load and hence will be less than 1. A safety factor of 1.0 means that the support is operating at its peak capacity. This typically is not desirable since any additional convergence will cause most supports to shed load. A safety factor of 2.0 means that the support is at 50% of its peak supporting capacity.

Aspect ratio checks

Checks are now make to see if the support dimensions comply with rules established from laboratory testing. If not, a warning is issued in the *Warnings* box that the support is too short. Aspect ratio requirements for several commonly used support technologies are as follows:

Conventional wood cribs – 4.3*
Link-N-Lock cribs – 4.0:1
Tri-Log cribs – 4.0:1
Link-N-X cribs – 3.0:1
Concrete cribs – 6.0:1
Can Support — 5.0:1
Pumpable crib – 4.0:1

CONCLUSIONS

The additional features incorporated into the STOP enhance the design capabilities of the program. The three most noticeable additions are the capability to incorporate uncontrolled convergence into the design criteria for standing roof supports, the addition of cable bolts as a support technology with design procedures to determine the number of cables per row required to support a detached roof block in suspension, and the addition of new standing roof support technologies.

Since standing roof supports are almost always passive roof supports, convergence plays a major role in their design and capability to provide adequate roof control. In the initial version of STOP, it was generally assumed that the support capacity had a direct bearing on the roof deformation and ultimately roof stability. While this is generally the case, there can be convergence which is not controlled by the capacity of the standing roof supports, most notably convergence which is induced by floor heave and pillar yielding. The uncontrolled convergence caused by these events will produce deformation and loading of the support structure, just as the roof deflection or controlled convergence. Hence, it is critical to know if the support can survive these uncontrollable ground movements and continue to provide the necessary capacity to control the mine roof. In addition, it is important to know if the extra loading produced by these uncontrollable ground movements will cause support loads that will cause failure of the immediate roof or floor strata, and in doing so, degrade the roof or floor stability or degrade the effective capacity of the support. On the other hand, if the magnitude of the uncontrolled convergence changes or is not present under all conditions, then it should not be required in order to create the support force necessary to control the mine roof. For this problem, STOP provides a security check to see if the required support capacity would be available at a reduced level of convergence, and if not, allows the user to tighten the support spacing to determine what support spacing would be necessary to provide the required support capacity under these conditions.

The addition of the cable bolt design section provides another type of roof support system that can be designed and analyzed in STOP. Cable bolts are sometime used in lieu of standing support in longwall tailgates and in other applications where the restriction of space in the mine entry is an issue. STOP now provides design capabilities for cable bolts in which unique design criteria can be established specifically for cable bolts, and the required cable bolt pattern that is necessary to satisfy these design criteria can be optimally determined. Estimated cost calculations can be computed and compared with standing supports.

The revolution of new standing roof support technologies continues in 2001. Four new support technologies have been added to STOP, keeping the program up to date with the very latest support technologies. Each of these technologies were described with examples in the paper, showing that viable new alternatives exist to the multitude of choices for secondary roof support systems.

A key ingredient in any support design is to be able to define the design requirements. STOP provides several options for doing this, including the use of a Ground Reaction Curve, which is nothing more than a measure of how the ground behaves relative to the amount of support that is installed. In this new version of STOP, the capability to define Ground Reaction Curves has been simplified. Now, this information can be obtained by simply measuring the convergence seen in the mine with a particular support application, and the program will automatically compute the support loading and thus eliminate the need for underground measurements of support loading to determine the ground reaction information for that support system. This should facilitate the use of this powerful design methodology.

The other major modification incorporated in this new version of STOP is the additional graphics capabilities. The program now provides the user with the opportunity to plot or chart any of the design parameters. This graphical analysis facilitates comparison among the different support technologies, and in doing so, enhances the capability to select the optimum support system for a particular application.

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