THE EFFECT OF STANDING SUPPORT STIFFNESS ON PRIMARY AND SECONDARY BOLTING SYSTEMS

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ABSTRACT

Standing crib supports have been applied in underground mining programs to resist large roof movements and sustain high-loads. The strength and deformation capability of these systems has been documented under both laboratory and field conditions. The parameter that has not been examined and is not well understood is the effect that a crib or other types of standing support has on the primary and secondary bolting systems. A crib support system with low system stiffness may allow large amounts of closure and deformation and cause the bolting systems to yield or even fail. Conversely, cribs or standing support that are too stiff may experience brittle or buckling failures, negating the advantage of the intrinsic supports previously installed. Utilizing a combination of field measurements and 3-dimensional finite element modeling techniques, the relationship between system stiffness and the subsequent performance of the installed bolting system is evaluated. Additionally, a simple method for calculating the combined system stiffness for standing supports, when using materials with different strengths such as steel, concrete, wood, etc., is presented.

INTRODUCTION

Tailgate entries are often the most hazardous areas in longwall mining operations. Establishing and maintaining a stable tailgate entry is a complex challenge for the mine engineer. The entry provides access and a secondary travel-way for the miners and completes the ventilation loop that removes gases and dust from the working face. Higher loading pressures usually exist around the tailgate entry which makes them difficult to support and maintain. Moderate entry closure or partial blockage of the tailgate entry can be tolerated but the criteria between moderate and extreme can cause production delays and remedial work under hazardous conditions. The majority of tailgates are controlled by standing or crib supports and are routinely supplemented with vertical cables, cable slings, cable trusses, rigid trusses, and longer high capacity bolts.

Crib support design requirements depend on the nature of the strata loading behavior. Researchers have shown that a zone approximately one-tenth of the overburden depth is the area that continually moves forward during longwall panel extraction and loads the intrinsic and standing support systems (1-3). For example, if the overburden depth is 500 ft, the zone approximately 50 ft in front of the longwall face would be subjected to higher stresses and subsequent loading. If the tailgate entry is examined as if it were a test frame for determining the physical property characteristics of rock or soil samples, two testing modes are routinely selected; displacement (rate) or load control. In the displacement control method, the rock testing machine is programmed to load the sample at an established closure rate. It will continue to “close” at the rate irrespective of the load applied to the sample. Conversely, in the load control setting the machine is programmed to apply an established force to the sample, irrelevant of the strain or closure on the sample. If this concept is applied to increase the understanding of tailgate entry performance, the standing crib supports are the samples being tested. Assuming that tailgate entry loading is completely displacement or rate-controlled, the standing supports can’t stop the continuous closure and are compressed and eventually failed by the constant roof to floor deformation. If the primary and secondary bolting system can prevent the decoupling of the strata layers or the creation of isolated rock sections, then there essentially would be no benefit to having a standing support system. It can be argued that a standing roof support system would, if anything, do more harm than good since it may puncture into the roof and floor and cause further instability of the rock mass. On the other hand, if the loading is completely load-controlled, the most critical design parameter would be the stiffness of the support because a passive standing support requires convergence of the mine roof and floor to compress the support and generate its load carrying capacity. If the support is too soft, too much deformation will occur which can initiate the failure of the mine roof as shown in figure 1. If too much deformation or closure occurs, the primary and secondary bolt systems may experience tensile failures directly related to combinations of excessive elongation, roof bending and bed slippage, which can ultimately result in shear type failures.

When both load-controlled and displacement-controlled behavior occurs, as is often the case, there are conflicting design requirements and compromises must be made to achieve the optimum support design. Depending on the amount and timing of the displacement-controlled loading, the same support system may work fine in one application and fail in another. Displacement-controlled loading or uncontrolled convergence can make soft supports perform well in areas where stiff supports fail miserably and vice-versa. A prime example of this is the 3C[1] support, which

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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.

is the predecessor to the modern Can support. As shown on figure 2, this particular support requires over a foot of convergence to provide a useful capacity for roof support. Yet the support has been used successfully in a longwall tailgate in the Western U.S. The reason it performed adequately was that the mine employed a yielding pillar design where both the pillar yield and large amounts of floor heave occurred that in effect mobilized sufficient load carrying capacity in the support by pre-compressing it prior to the passing of the longwall face. This concept can be illustrated in figure 3. Shown are two hypothetical ground reaction curves, one with little displacement-controlled activity and the second one with large amounts of displacement-controlled loading. As seen in the figure, the 3C support is much too soft to generate sufficient loading to achieve roof control in the first ground reaction curve, but does provide the necessary capacity when the uncontrolled convergence is large (4). In comparison, the Can support should perform well in both these environments, as it develops its load carrying capacity relatively quickly and is able to sustain this load carrying capacity through a large displacement range. On the opposite side of the spectrum, as shown in figure 4, concrete donut cribs and Magnum concrete supports, which are high capacity but very stiff supports, have failed prematurely in many western mines operating in similar conditions to the 3C support, yet have performed satisfactorily in several eastern mines. Again, different degrees of displacement-controlled loading were most likely the reason why successes turn to failures in the application of the same support technology.

Figure 1. Large roof deformations resulting from a *soft* crib system.

Another related issue is the effect that the crib loading can have on the intrinsic bolting system installed as primary and secondary support. For example, in some deep cover western mines, it has been reported that even soft, 4-point cribs eventually are squeezed enough by excessive convergence, appearing to be uncontrollable, in these mines to cause damage to the roof beam. Again, the success or failure of a support will be determined by the degree of displacement-controlled loading behavior of the ground. How the stiffness of the crib supports effects the loading of the internal bolting support systems and how the stiffness can be examined and modified will be examined in detail.

Figure 2. A longwall tailgate supported with 3C supports subjected to considerable convergence before useful support capacity is realized.

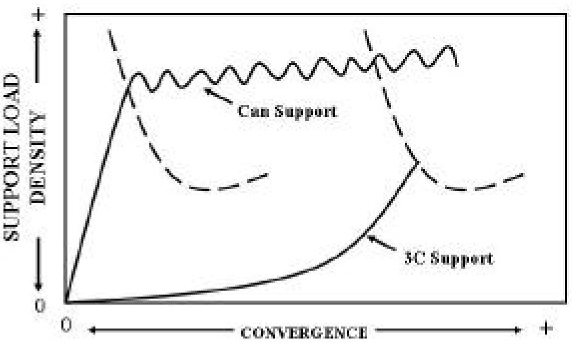

Figure 3. The Can support performs well in both load-controlled and displacement-controlled environment while the 3C support fails to provide roof control in the absence of the uncontrolled convergence.

Figure 4. Failure of stiff concrete supports in a displacement-controlled environment.

THE EFFECT OF CRIB STRENGTH DESIGN ON BOLT AND ENTRY BEHAVIOR

Concrete cribs in the form of donuts, Magnums, and pumpables have been used to control the deformation and loading behaviors in longwall tailgates, difficult intersections, and pre-driven longwall recovery rooms. These base systems are routinely "capped" or "finished off" by applying a layer of wooden crib materials, layers of plywood or fibre-board, or a pumped bag or pillow systems. The bag or pillow systems being employed are filled with a light-weight material with low compressive strengths and stiffness characteristics. Understanding the bag or pillow and the yield behavior is a critical design parameter for the accurate design of standing concrete type support systems. To examine the impact of various crib strengths, 3-dimensional finite element models were developed and analyzed. The purpose of the models, utilizing 3 different crib strengths, were three-fold; to examine the closure at the center of the entry, calculate the expected loads exerted on the cribs, and finally, to evaluate the effects of crib loading on the primary and secondary bolting systems.

To help illustrate the concept used for the model, a cross-section of the longwall tailgate entry is shown in figure 5. Again, applying the rule of "one-tenth the overburden depth", the cribs are not subjected to significant load before the longwall face moves into this calculated zone. The adjacent coal pillars, primary, and secondary bolting systems control most of the initial movements and subsequent loads. As the longwall face advances down the entry, the pillars, roof, and the floor are deformed under the forward abutment loads.

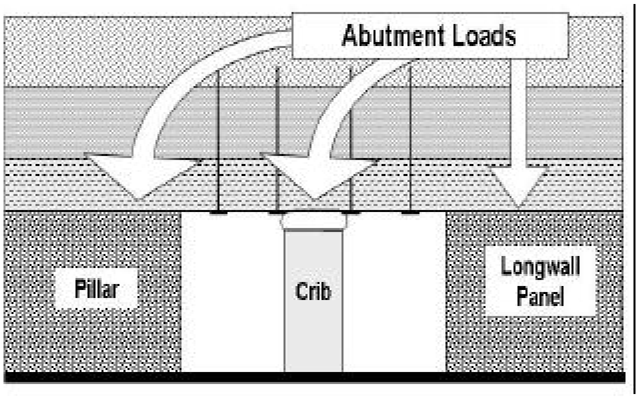

Figure 5. The abutment load distribution on a longwall tailgate entry.

The load applied to the crib is dependent on the level of abutment pressure, the stiffness of the crib and pillars, the behavior of the roof and floor strata, and the bolt support system during the initial development cycle. For example, a stiff crib system will attract a large portion of the abutment load, possibly causing the cribs to fail before the longwall can safely mine past the area. Conversely, a soft crib system will attract less abutment load but may provide insufficient support to the immediate and main roofs, potentially causing the primary and secondary bolting systems to fail and the roof to fall before the longwall can safely move past the crib supports.

THE CONCEPT OF THE COMBINED MODULUS AND STIFFNESS FOR CRIB SYSTEMS

When the concrete crib base is used in conjunction with a pillow or bag, which is softer than the crib, to support the recovery room, the combined modulus or stiffness of the bag and crib can be determined. It is important to distinguish the difference between combined stiffness, which is a structural property, and combined modulus, which is a material property that is independent of the size or shape of the support structure.

Figure 6 illustrates a diagram that represents the stiffness of the base, K_{CB}, and the bag or pillow, K_B. The determined value is the support system stiffness, K_T, of the crib and bag, estimated as follows:

$$K_T = \frac{K_B \times K_{CB}}{K_B + K_{CB}} \tag{1}$$

Where:
K_B = stiffness of the bag, lb/inch
K_{CB} = stiffness of the crib base, lb/inch, and
K_T = combined crib and bag or system stiffness, lb/inch.

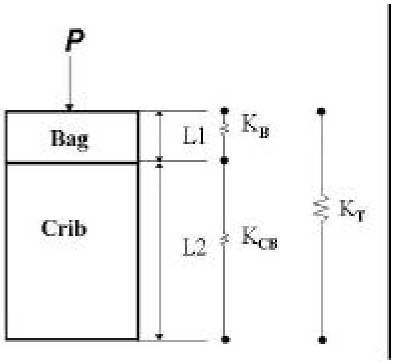

Figure 6. Concept of combined stiffness.

Because stiffness is a structural property that is directly related to the geometry of the structure being considered, it must be converted to a form useable in numerical techniques. Since stiffness is related to the modulus of the material, a physical property required for numerical analysis, an equation is developed to combine the modulus of different materials. This is termed combined modulus.

The Combined Modulus Equation

The combined modulus is a variable that is usually required in most numerical models. The value is used primarily to input a single physical property parameter for multiple layers of different materials. An equation, which makes the combination of modulus values for the crib material and the bag material, is presented.

Assume a load P is applied to the bag and crib, as shown in figure 6. The vertical compression of the bag created by the load P is:

$$\ddot{a}_1 = \frac{PL_1}{AE_1} \tag{2}$$

while the vertical compression of the crib created by the load P is:

$$\ddot{a}_2 = \frac{PL_2}{AE_2} \tag{3}$$

where: L_1 = height of the bag, inches,
L_2 = height of the crib, inches,
E_1 = Young's modulus of the bag, psi,
E_2 = Young's modulus of the crib, psi
A = cross-section area of the bag and crib, in^{2,} and
ä$_1$, ä$_2$ = displacement for bag and crib, respectively, inches

The overall compression of the bag and crib can also be calculated by the combined Young's modulus as:

$$ä_T = \frac{P(L_1 + L_2)}{AE_c} \tag{4}$$

where: E_c = combined Young's modulus, psi, and
ä$_T$ = total compression of both the bag and crib base, inches.

The compression of the bag and crib calculated by the combined Young's modulus in equation (4) is equal to the summation of the compression calculated separately in both equation (2) and (3).

Therefore:

$$\frac{PL_1}{AE_1} + \frac{PL_2}{AE_2} = \frac{P(L_1 + L_2)}{AE_c} \tag{5}$$

The combined Young's modulus can be derived from equation (5) as:

$$E_c = \frac{E_1 E_2 (L_1 + L_2)}{L_1 E_2 + L_2 E_1} \tag{6}$$

The combined Young's modulus of the bag and crib is a value between the modulus of the crib and bag.

The relationship between the modulus and stiffness can be derived because stiffness is a function of the area and the length. Using figure 6:

$$K_B = \frac{AE_1}{L_1} \quad \text{and} \quad K_{CB} = \frac{AE_2}{L_2} \tag{7}$$

K_T can be derived which is the same as equation (1):

$$K_T = \frac{AE_c}{L_1 + L_2} = \frac{AE_1 E_2}{L_1 E_2 + L_2 E_1} = \frac{\frac{AE_1}{L_1} \times \frac{AE_2}{L_2}}{\frac{AE_1}{L_1} + \frac{AE_2}{L_2}} = \frac{K_B \times K_{CB}}{K_B + K_{CB}} \tag{8}$$

The Application of the Combined Stiffness Equation

Even if the crib base is very stiff, a soft bag will always result in a soft combined system stiffness. Therefore, the stiffness of both the bag and crib base can be adjusted by design to provide an appropriate support system with a combined stiffness capable of controlling the closure of the entry and maintaining a stable roof condition.

A sensitivity analysis conducted to examine the impact of the height or thickness of the bag or pillow placed on top and also, varying the material modulus for the grout used in the bag or the combined stiffness of this support system is presented. As observed during underground investigations, the irregularities in the mine floor and roof can create different final heights for the bags or pillows. To complete the analysis, the material modulus for the bag grout defined from physical property testing was utilized as a base value. This modulus value was varied 50 percent higher and lower to provide a range for calculated values and subsequent analysis of the results. The bag or pillow heights were also varied from 2 to 15 inches thick, heights routinely encountered during field investigations. Table 1 summarizes the parameters evaluated.

Table 1. Values for parametric examination of combined crib modulus and stiffness.

Parameter Description	Value
Height of the concrete base	Fixed height = 96 inches
Concrete base modulus	E = 3,000,000 psi
Thickness of bag or pillow	Varied from 2 to 15 inches
Bag or pillow modulus	E = 5,000, 10,000, and 15,000 psi
Crib and pillow area	A = 1,810 in^2

If the combined stiffness, K_T, is examined using the parametric values and a crib and bag area of 1,810 in2, reductions in stiffness also occurs as the bag thickness increases. The actual reductions are shown in figure 7. If the material in the bag has a modulus of 15,000 psi and the thickness is increased from 2 to 15 inches the combined system stiffness is reduced from approximately 10,950,000 to 1,750,000 lb/inch. Even if the crib base has an extremely high stiffness value, a bag with a low stiffness can impact the stiffness of the entire system. Therefore, the material comprising both the bag and crib can be designed to provide an appropriate system with the combined strength and relative stiffness capable of sustaining the desired load within a designed amount of convergence. The effects of reduced system stiffness, with respect to entry behavior, and the intrinsic primary and secondary support loading should be considered.

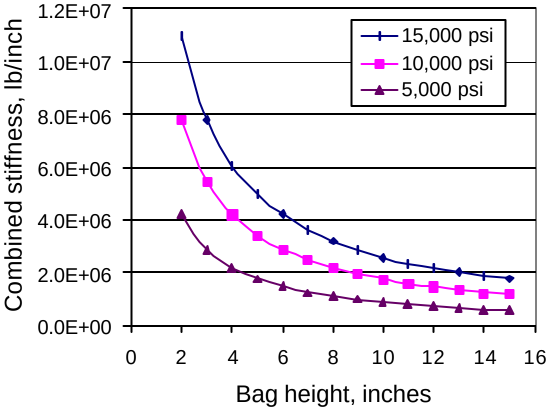

Figure 7. Combined support stiffness with various bag thicknesses and material modulus of elasticity.

Effect of Crib Stiffness on Roof Support System Behavior

To complete the numerical analysis on the effects of crib stiffness, with respect to the roof-to-floor convergence and support system behavior, 3-dimensional finite element modeling was completed using ABAQUS (5). The sub-model that was extracted from a calibrated global and gob model was utilized to provide the detail required for both the primary and secondary cable bolts load comparisons (6-7). The immediate roof, in the calibrated sub-model, consists of a 6-ft thick laminated shale overlain by gray shale of various thicknesses. A weak layer of claystone in the immediate floor is 1.5 ft thick with a competent limestone material underneath which is about 5 ft thick. In general, the roof in the calibrated model is considered weak with a calculated Coal Mine Roof Rating (CMRR) values that range from 40 to 45 (8).

A modeling matrix was designed to examine the tailgate entry as the longwall face approached the area. The entry was supported with the primary support system, resin-assisted, 7/8-inch diameter tensioned bolts and 15-ft long secondary cable bolts. A single row of concrete cribs on 10-ft row spacings was selected. Figure 8 shows the finite element mesh for a cross section of the longwall tailgate entry with the primary bolts and cribs installed. A plan view of the recovery room and the placement of the concrete cribs is shown in figure 9. Figure 9 also shows a cross-section of the bolting system with the specific installation lengths, diameters, and installed loads.

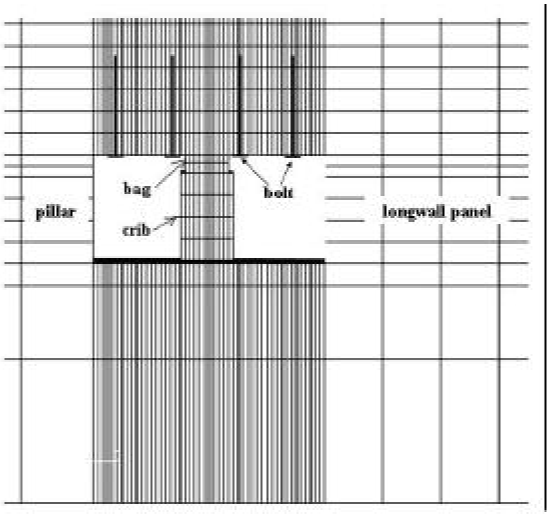

Figure 8. Cross section of the finite element mesh of the longwall tailgate sub-model section.

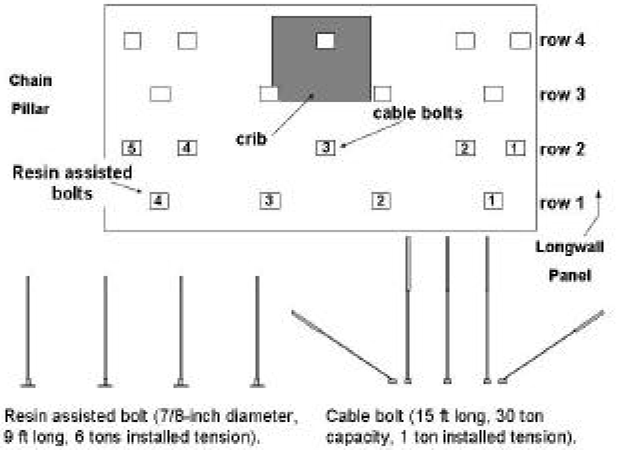

Figure 9. Plan view of the sub-model and cross-section of the installed bolting systems.

The crib and support loading was determined when the state of the longwall panel was computed at 100 and 10% of the intact coal yield state. This occurred when the longwall face was approximately 35 ft outby and 10 ft outby, respectively. This longwall panel state occurs after a large amount of yielding has taken place and the coal can only maintain 10% of its original strength. The numerical model and field results predicts that this would occur when the longwall face was approximately 10 ft away from the panel corner. It is difficult to determine or estimate how much residual strength a pillar will have after completely yielding. In this modeling application, the panel material is being completely removed by the longwall shearer so no residual strength can be realized from the extracted coal. As the longwall begins to remove the material in front of the longwall face, it will eventually collapse and lose load carrying capacity. A value of 10% of the original coal strength was used and deemed appropriate for this high loading situation. The pillar adjacent to the longwall panel was developed with a final crosscut width of 50 ft that resulted in a solid coal block of 32 ft. The numerical model predicted that the pillar would experience a yield zone of about 4 ft as the longwall face was mined to within approximately 16 ft.

MODELING RESULTS FOR DIFFERENT CRIB STIFFNESS VALUES

The effects on individual bolting systems, roof-to-floor closure, and crib loading were analyzed using the 3-dimensional sub-model extracted from the global model. To complete the analysis, materials were selected and used for the crib base and the bag or pillow top and compared with the results from the calibrated case. The stiffness values used for the soft, normal, and stiff cribs are shown in table 2. The numerical results obtained for the roof-to-floor closure, determined at the center of the entry, and the maximum crib loads for both distances are shown in table 3 and graphically in figure 10. As the cribs sustain or carry more of the applied loads, the roof-to-floor closure is reduced. This does not imply that if enough stiff cribs are used closure could be completely eliminated. A certain amount or degree of closure will always be unavoidable or uncontrollable, even with the highest capacity cribs on dense patterns.

Table 2. Crib stiffness values used in numerical model.

	Crib stiffness (lb/inch)
Soft crib	5.66×10^4
Normal *crib*	5.66×10^5
Stiff crib	5.66×10^6

Table 3. Roof-to-floor closure and crib loading results.

Crib Stiffness	Longwall face distance, >35 ft outby		Longwall face distance, 10 ft outby	
	Closure, inch	Crib load, lbs	Closure, inch	Crib load, lbs
No cribs	1.65		2.54	
Soft crib system	1.61	80,698	2.45	131,089
Normal crib system	1.50	626,417	2.32	1,124,371
Stiff crib system	1.44	1,130,400	1.82	1,632,800

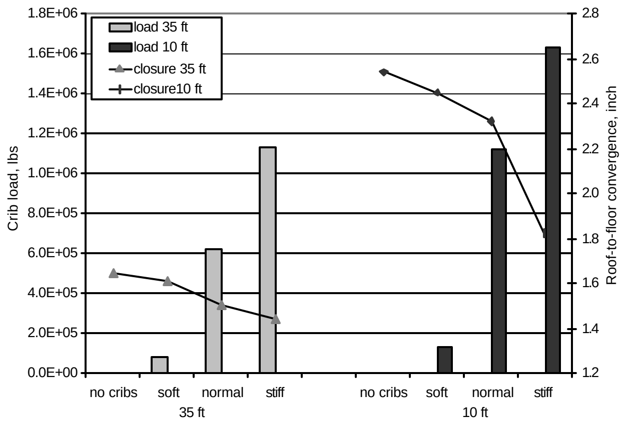

Figure 10. The roof-to-floor closure and the individual crib loads when the longwall face is 35 and 10 ft outby.

As the loads carried by the yielding longwall panel block and adjacent chain pillar are reduced, the entry roof is subjected to additional loading and subsequent closure; requiring the cribs to carry more of the abutment loads. When the face is 35 ft outby the selected crib location, a normal crib allows 1.50-inches of roof-to-floor closure and is subjected to approximately 626,000 lbs of load. If no cribs are present, this closure is increased to 1.65 inches. A soft crib allows 1.61-inches of entry closure and is subjected to smaller crib loads. During the critical loading phase, when the face is 10 ft away, the entry would be subjected to 2.54-inches of closure if no cribs are installed. A soft crib would prevent only 0.09-inches of closure and support 131,000 lbs of load. A stiff crib would allow only 1.82-inches of roof-to-floor closure but be subjected to 1,632,800 lbs of load. This high degree of loading is approaching the ultimate capacity of these types of support systems which could result in brittle or ultimate crib failure. The results indicate that as the crib system becomes softer, the roof-to-floor closure increases and the load carried by the cribs reduced. This relationship can be intuitive once mine loading and stresses are well understood. What is not easily understood is the effect that a softer or stronger crib support system can have on the intrinsic primary and secondary bolting support system or the effect that a roof bolting system can have on minimizing crib loading and room closure.

THE LOADING BEHAVIOR OF BOLTING SYSTEMS WHEN USED IN CONJUNCTION WITH CRIB SYSTEMS OF VARYING STIFFNESSES

To examine the behavior of the primary and secondary roof support systems, the model was used in conjunction with the various crib systems previously described. The specific loads applied to the bolts were analyzed with no cribs and the three defined crib support systems when the longwall face was 35 and 10 ft inby.

Tensioned Bolts Installed in Row 1

The specific individual loads on the first row of bolts, presented in table 4 and graphically shown in figure 11, were determined with no cribs installed, and cribs that were soft, normal, and stiff when the longwall face was 35 and 10 ft inby. If no cribs are installed, the mine roof entry sag is the highest in the middle when the face is 35 ft outby, loading the middle entry bolts, no. 2 and 3, to 16,605 and 15,309 lbs, respectively. As the face continues to advance and the panel reaches critical yielding, the loads on the bolts nearest the panel, no.'s 1 and 2, load to 45,378 and 34,619 lbs, respectively. This loading profile is a function of the effective roof span that increases toward the panel side as the coal yields and looses load carrying capacity. On the opposite side, the chain pillar yields but the depth is only about 4 ft which allows the remaining pillar to carry load and prevent load transfer onto the bolting system. The bolt behavior changes when the cribs are placed in the entry. The combination of a yielding panel and chain pillar is resisted by the crib, creating a shorter roof span that results in the bolt nearest the panel edge to carry the highest amount of load. As shown, the standing supports are not able to eliminate all the closure. The respective loads are a function of both the closure and crib stiffness. Clearly, the standing support has an immediate impact on the subsequent loading of the primary tensioned bolting system, especially when the cribs are stiff.

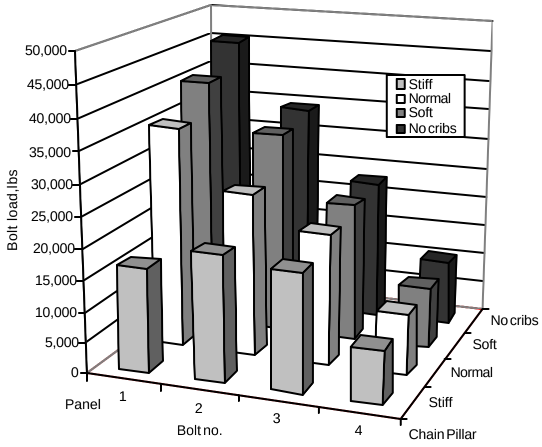

Figure 11. Individual loads on the bolts in row 1 when the longwall panel is 10 ft outby with no, soft, normal, and stiff cribs.

Table 4. Individual bolt loads when the longwall is 35 and 10 ft inby.

Roof Bolt No.	No cribs		*Soft*		Normal		*Stiff*	
	35 ft	10 ft	35 ft	10 ft	35 ft	10 ft	35 ft	10 ft
1	9,187	45,378	9,048	40,626	7,760	35,793	6,650	16,680
2	16,605	34,619	16,469	32,962	15,639	26,325	14,799	20,199
3	15,309	22,914	15,244	22,426	14,810	21,136	14,271	18,932
4	7,665	10,605	7,650	9,889	7,543	9,646	7,461	8,425

Table 5. Individual bolt loads when the longwall is 35 and 10 ft inby.

Cable Bolt No.	No cribs		*Soft*		Normal		*Stiff*	
	35 ft	10 ft	35 ft	10 ft	35 ft	10 ft	35 ft	10 ft
1	6,222	13,914	6,162	12,354	5,743	12,284	5,266	8,293
2	3,301	7,846	3,102	7,037	2,900	3,894	2,745	2,866
3	2,989	3,966	2,814	3,775	2,740	3,494	2,635	3,226
4	2,335	3,632	2,178	3,425	2,121	3,075	2,009	2,904
5	2,264	3,840	2,259	3,650	2,208	3,232	2,110	3,023

Cable Bolts Installed in Row 2

To continue this brief analysis, the next bolt row analyzed consisted of 15 ft long cable supports. The cables are simply thrust tight against the roof and 1 ton (2,000 lbs) of tension is applied. The two outside cables were angled over the longwall panel and the pillar to help maintain the roof after undermining takes place on the panel side and help minimize the damage of the high stress concentrations and subsequent plastic roof failure on the chain pillar side. The specific cable loads for the 4 support conditions are presented in Table 5 and graphically in figure 12.

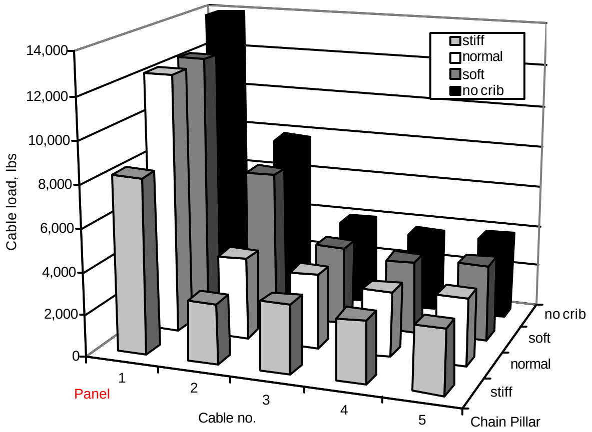

Figure 12. Individual loads on the cables in row 2 when the longwall panel is 10 ft outby with no, soft, normal, and stiff cribs.

The cable row examined is 2 ft closer to the crib and the stiffness of cable supports are considerably lower than the 7/8-inch diameter resin assisted bolts. The cable subjected to the highest loading in all cases is the unit installed at an angle over the yielding longwall panel edge. As previously explained, this is the result of the effective roof span increasing and additionally, a slight rotation and movement of the roof onto the yielding longwall panel block. The loading condition on the cables, when no cribs were installed and the longwall face was 10 ft inby, indicate a maximum load on cable no. 1 of only 13,914 lbs, which is significantly below the design capacity strength of 58,600 lbs. The largest load changes take place on cable no. 1 and no. 2. It is interesting to note that the loads on cable no. 2 can be reduced by increasing the stiffness of the crib from a soft system to a normal and stiff unit. The cables installed at an angle over the chain pillar are subjected to only small amounts of load because the yield zone of 4 ft does not create high shear strains in the immediate and main roofs. If these forces are increased the cables loads would increase substantially.

CONCLUSION

The design and subsequent performance of a crib system can have a direct effect on the bolting system used for primary and secondary supports. As the forward abutment forces are increased during subsequent longwall extraction, the residual strength of the longwall coal block is minimized and eventually is zero. When this occurs the intrinsic bolts are required to carry more loads. If the cribs systems are stiff, the loads on the cribs are higher and the subsequent bolt loads are less. Conversely, when the system stiffness or strength of the cribs was reduced, the cribs carried less abutment load and the closure necessitated that the bolting systems provided more of the resistance to maintain the entry. As shown, using the design equations presented, the desired system stiffness for a crib can be created by adjusting heights and stiffness values of individual crib components.

As evidenced by the 3-dimensional finite element modeling and subsequent analysis, the bolting systems not directly supported near a crib may be subjected to higher loads and were required to perform more of the work. During the tailgate support design process, the bolting system used must consider two distinct loading conditions; the immediate roof loads realized during the initial gate road development and the heavy abutment forces applied to the secondary supports used to maintain an adequate tailgate during the longwall panel extraction process. As clearly shown, if the crib system is soft, the bolts carry more loads and roof-to-floor closure is increased. If the cribs are too stiff and experience brittle failure before the longwall panel can safely mine past the area, the bolting support system may play a vital role in maintaining the immediate roof and assist in delaying main roof caving. Longwall tailgate behavior is complex, which necessitates the correct combinations of intrinsic bolting systems and/or roof-to-floor supports. The ultimate goals of these research efforts are to provide support systems that ensure the stability of the entries during the longwall extraction process, which directly improves the health and safety for the underground workforce.

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