FACTORS TO CONSIDER WHEN PURCHASING A NEW SET OF LONGWALL SHIELDS

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ABSTRACT

Purchasing a new set of longwall shields requires a substantial investment. A poor shield design can lead to economic hardships, safety concerns for the mine workers, and closure of the mine. This paper addresses several key points that should be considered in the procurement process: (1) understanding your goals and the logic in selecting a higher capacity shield, (2) the importance of completing performance testing before production shield fabrication begins, (3) making sure performance testing is properly done, (4) measuring load (stress) development during performance testing, (5) testing a shield to failure, and (6) the value of buying extra shields. In addition, several challenges are proposed for consideration in future shield designs. These include (1) 100,000 life-cycle expectancy, (2) improved hydraulic diagnostic capability, (3) smart load control by optimizing setting pressures, (4) lubricated link joint design concepts, (5) composite material applications to reduce shield weight, (6) incorporating periodic weighting predictive algorithms into the data-processing software, (7) advanced component load measurement on two to three specially instrumented shields to detect loading in the structural components, and (8) constant set leg cylinder design.

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INTRODUCTION

A new set of longwall shields can cost over $20 million. This represents a major investment for any mine operator. Currently, these new shields are expected to last for more than 60,000 loading cycles, representing 18-20 panels of mining [Barczak 1999]. A poor design or even a marginal design that reduces the operating life of the shield can be the difference between a mine staying in business or closing. In addition to the economics pertaining to the initial shield investment, time and money spent in making repairs to damaged shields can be very costly.

There are also safety issues when failures occur. Poor shield performance can contribute to instability in the overlying rock mass leading to roof falls in the immediate face area, cavity formation above the shields, or even "iron-bound" shields when excessive yielding occurs. The well-planned removal of shields in properly designed recovery rooms is difficult enough. There are hazards associated with increased exposure of the mine workers to unsupported ground and with moving very heavy equipment in a confined work environment. Unplanned removal of shields due to unexpected failures that require complete removal of the shields or changing out of shield components before the completion of the panel are that much more difficult and hazardous. The safety issues and ground control issues are interrelated. Poor shield performance can lead to ground control problems, and stoppage in face advancement to remove and/or change out shield components can cause the ground conditions to worsen and create a "snowball" effect.

Thus, proper shield design is essential to any longwall operator. Engineering issues pertaining to shield design are addressed by the author in another paper in these proceedings [Barczak 2000a]. This paper provides several key points pertaining to the procurement process, including the reasons for buying a higher capacity shield, performance testing strategies to ensure that the shield design is adequately evaluated, and the benefits of buying extra shields and implementing a well-planned preventive maintenance program once the shields are purchased. In addition, traditional strategies of testing a shield through a limited number of cycles are challenged with recommendations to test a shield to failure. The paper concludes with proposed ideas and challenges for future shield designs.

EVALUATE YOUR CURRENT DESIGN FIRST

Before new shields are purchased, your current shield design should be evaluated. Loading histories, if kept, can provide valuable information to properly size your next support system. Questions to answer include: How often were the supports at yield pressure and when did this occur? Were there any ground control problems, and what were they? Were the shields rebuilt? Were any structural modifications made to the shields? To what degree were the pin bores worn, and when did the wear occur? What was the reliability of the leg cylinders? How often did leakages occur? How often were the cylinders rebuilt? How reliable was the control system for operating the shields? Were there any warranty issues?

Performance testing of an aging shield can provide insight into how much life expectancy is left in your current shields, as well as reveal valuable information about making improvements in the design of the new shields when they are purchased. The National Institute for Occupational Safety and Health (NIOSH) has developed a series of tests using the unique Mine Roof Simulator load frame (figure 1) for conducting safety performance testing of aging longwall shields. These procedures are described by the author in another paper in these proceedings [Barczak 2000b]. The Mine Roof Simulator is an active load frame that can apply both vertical and horizontal loading to a shield and accurately simulate the in-service loading conditions.[2]

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[2] Further information on using the Mine Roof Simulator for shield testing may be obtained by contacting the author at (412) 386-6557 or by e-mail at: thb0@cdc.gov

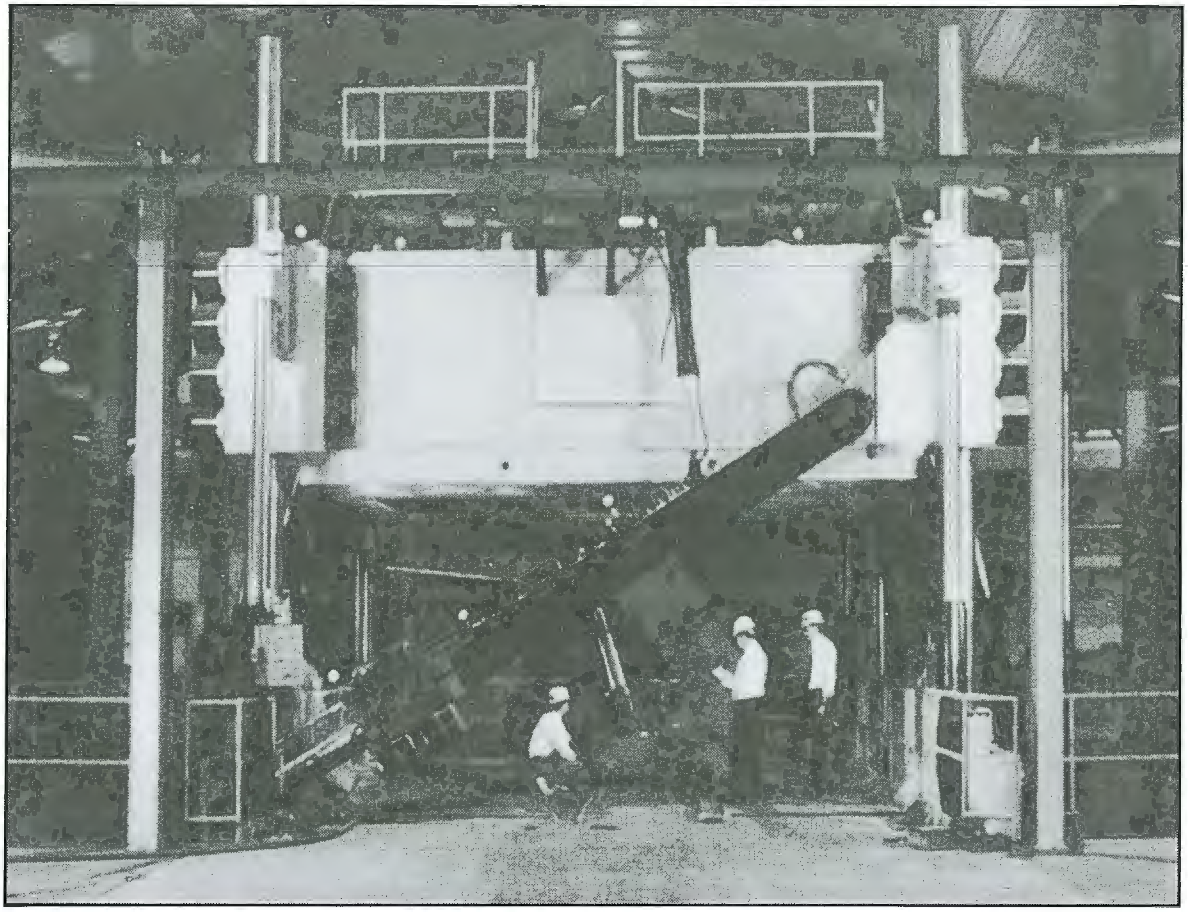

Figure 1.—The Mine Roof Simulator at NIOSH's Pittsburgh Research Laboratory.

KEY POINTS TO CONSIDER WHEN BUYING NEW SHIELDS

1. Identify your goals in buying a bigger shield.

Shield manufacturers now provide two-leg shields with capacities approaching 1,200 tons, nearly four times the capacity of the first shields installed in the United States in 1975 [Fiscor 1999]. Likewise, shield life expectancies are now 60,000 to 70,000 cycles, more than double what it was just a decade ago. Although there is a natural tendency to buy the biggest shield available, you should really consider your goals when making this decision. Are you looking for more support capacity to improve ground control, or is your primary goal to extend the life of the shield, or do you wish to achieve both goals?

If your primary goal is to extend shield life and your previous support of lower capacity was providing adequate ground control, then consideration should be given to derating the higher capacity shield if you choose to purchase one. Derating can be accomplished in two ways: (1) reducing the setting pressure and (2) lowering the yield pressure. The goal is to reduce the total loading on the support as a percentage of the yield load rating of the support. The total shield load will be the sum of the setting load and load developed in response to the convergence. This total load will be limited by the yield pressure of the leg cylinders. The load developed in response to the convergence will be controlled primarily by the stiffness of the leg cylinders. Since the stiffness increases with increasing leg cylinder diameter, a higher capacity shield will develop more load than a lower capacity shield for the same convergence. Thus, unless the increased setting force results in decreased face convergence, the increased setting force will unnecessarily increase the overall shield loading.

Derating a shield by reducing the operating yield pressure will control the total loading and associated component stress development. This will provide an additional margin of safety and extend the life of shields where high component stresses are observed. Whether yielding is detrimental or not probably depends on the rock mechanics and source of the shield loading. If the convergence is caused by main roof weighting that is irresistible in terms of the available shield capacity, then promoting yielding at a slightly lower yield pressure is not likely to have any significant impact on roof stability.

If you need the extra capacity for ground control *and* you want to improve the life expectancy, then be prepared to pay a premium for the shield and insist on a conservative design. A conservative design can be qualified in terms of the component stress developments, recognizing that the chance for failure increases as the component stresses increase and that fatigue and corrosion failures can occur for nominal stress developments well below the yield strength of the steel. Quantifying stress limitations can be difficult since there are several factors involved. However, a reasonable rule of thumb is that no component should be stressed beyond 80% of the yield strength of the steel under *any* in-service load condition, and stresses should be below 60% of the yield strength for *typical* load conditions. Classical structural design often requires that stresses be kept below 50% of the yield strength to prevent the occurrence of fatigue-related failures [Barczak 1999].

In summary, there is a common misconception that higher capacity shields will be loaded to a lesser degree than lower capacity shields simply because they have a higher support capacity. Since the setting pressures have remained constant and the stiffness increases as the capacity of the shield increases because of the larger leg cylinder diameter, higher capacity shields are just as likely to be fully loaded as lower capacity shields under the current operating practices.

2. Make sure that performance testing is completed before production shield fabrication begins.

A prototype shield should be fabricated and thoroughly performance tested *before* fabrication of the production shields begins. A shield consists of five major components (canopy, base, caving shield, lemniscate links, and leg cylinders) all connected together. Each component must be properly designed to effectively transfer roof loading through the support structure. If one component is underdesigned, additional load may be transferred to other shield components, potentially creating a domino effect that will likely reduce the life expectancy of the support. Also, once a fabrication is made, modifying the existing fabrication to correct the fundamental design deficiency will generally not be possible or at best be less effective than redesigning the component completely. Additionally, modifying an existing fabrication can be difficult when complex geometries and high-strength steels are involved. Furthermore, the weight of a modern-day shield needs to be minimized. Correcting a design deficiency by adding a reinforcement plate to a fabrication generally will not result in an optimum strength-to-weight ratio for that component. Once the production shields are fabricated, any change in design can be costly, and the tendency will be to minimize the cost by avoiding the modification if possible or implementing the lowest cost modification, which may allow the support to pass the performance testing, but will not provide the operator with the best design possible.

3. Make sure that performance testing is properly done.

Performance testing must properly simulate the in-service load conditions. NIOSH has developed a set of safety performance testing protocols that take advantage of an active load frame called the Mine Roof Simulator. This biaxial load frame can apply both vertical (compression) and horizontal (racking) loads simultaneously to simulate the ground movements and shield interaction. These test procedures are described in detail by the author in another paper [Barczak 2000b] and provide the most direct simulation of the in-service loading conditions [Barczak 1999]. In comparison, tests conducted in a static load frame rely on external pressurization of the leg cylinder to generate support loading. The limitation imposed by the static load frame is the inability to directly simulate the forward translation of the canopy due to slippage of the support on the mine roof or floor and the face-to-waste racking of the shield by the strata caving into the gob. These conditions can increase the load development in the caving shield and lemniscate links by several hundred percent.

Slippage of the canopy on the mine roof due to loss of frictional resistance at the roof interface can be simulated in static and uniaxial active load frames by placing rollers on the canopy to create a "frictionless canopy test." Unfortunately, the zero-friction test with rollers on the canopy is not very practical for extensive cyclic loading since the rollers may require frequent adjustments due to frictional effects. Thus, this test is typically not included in the manufacturer's performance testing protocol. If the frictionless canopy test cannot be conducted, then the support should be configured so that it is standing on the toe of the base; this will require horizontal constraints at the toe of the base and rear of the canopy (at the caving shield connection). The horizontal force couple generated by this configuration allows load transfer to the caving shield-lemniscate assembly, similar (although not as severe) to that obtained with the zero-friction test.

Likewise, face-to-waste racking of the shield cannot be directly simulated by a static or uniaxial active load frame. The contact configuration that most closely duplicates the caving shield-lemniscate assembly response for this condition in static or uniaxial load frames is to configure the support so that it is simply supported on the rear of the base. Face-to-waste racking of the shield canopy causes a reversal in the state of stress in the lemniscate links from compression to tension.

Because reversal of the loading accelerates fatigue failures, both the base-on-toe *and* the base-on-rear configuration should be incorporated into safety testing protocols conducted in static or uniaxial load frames.

Longwall operators in cooperation with the shield manufacturers have developed and refined performance testing procedures for longwall shields using static load frames. Consolidation Coal Co. in particular has led this effort. The so-called "Consol Test" consists of several combinations of canopy and base contact configurations that are categorized as follows:

(1) Offset yield loading;
(2) Base toe loading;
(3) Three-point canopy torsional loading;
(4) Two-point canopy torsional loading;
(5) Side shield loading and base torsional loading;
(6) Diagonal base contact;
(7) Three-point base contact torsional loading;
(8) Symmetric base edge loading;
(9) Asymmetric base edge loading;
(10) Leg socket loading; and
(11) Canopy dishing.

These tests are designed to be used in static- or single-axis load frames. These test configurations have proven to be among the most effective protocols for performance testing of shield supports in a static frame. The operator should consult the support manufacturer and discuss these or equivalent tests to be used for the performance testing program.

4. Measure the load development as part of the performance testing.

It is not enough to simply measure the leg pressures during performance testing. Some measurement of load transfer through all the support components should be conducted as part of the test program to verify the effectiveness of the test procedures and to evaluate the stress developments within the shield. This can be done with a few strain gauges to measure nominal load (stress) development in each component. Photoelastic plastic can be used to isolate areas of expected stress concentration.

5. Consider testing a shield to failure.

Most companies conduct performance testing only through a limited number of cycles, generally equal to the warranty period provided by the shield manufacturer, which is typically 50% to 60% of the life expectancy of the shield. This practice is adequate to discover fundamental flaws in the shield design. However, for a well-designed shield, this approach will not evaluate fatigue failures that occur near the end of the shield life. In addition to providing a more definitive estimate of the life expectancy of the shield, testing a shield to failure will provide insight into the nature and severity of the fatigue-related problems that will eventually occur. It will also provide the mine operator with insight as to when to look for these problems because they are often difficult to see when they first develop, but can be catastrophic if left unattended. In addition, by testing the shield to failure, the impact of the failure(s) on the shield structural integrity and performance of the shield can be determined beforehand.

In summary, by testing the shield to failure, the mine operator will be in a much better position to (1) plan for the next shield procurement cycle, (2) develop a monitoring plan for inspecting the shields for failures, and (3) develop a strategy for repair and modification of the shields when failures do occur. The manufacturers, and in turn the mine operators, will also benefit from failure testing by providing critical information on the limitations of current shield design that can lead to design improvements in the future.

6. Consider buying several extra shields.

There is clear evidence that mines that purchase additional shields and institute good preventive maintenance program will maximize the useful life of their longwall shields. A good rule of thumb is to purchase 10% more shields than is necessary for the face. For example, a 1,000-ft face would require 174 shields (1.75 m wide). If 17 extra shields were purchased so that 17 shields could be removed from operation during each longwall move, the entire face would be recycled in 10 panels of mining. Mining a 10,000-ft-long panel will require about 3,300 shield cycles; thus, each shield will be changed out at least once during the shield's warranty period. More importantly, once the warranty period is over and the shields have been in operation for 35,000-40,000 cycles, a detailed inspection and rebuild program can be instituted. Problems such as leg cylinder rebuild and restoring pin tolerances to design specifications could be corrected as they arise, and preventive measures, such as painting and crack inspection and repair, could be done on a regular basis. Although this adds cost to the initial purchase, a good preventive maintenance program will pay big dividends in maximizing the life of a shield.

CONTINUE PUSHING THE ENVELOPE

Improvements in shield design have been made largely through mine operators pushing the envelope in terms of expectations. Ten years ago, a life expectancy of 60,000 loading cycles was unheard of, yet today it is the standard. Likewise, 1,200 tons of support in a two-leg shield was unthinkable 20 years ago, yet shield capacities continue to increase as each new generation of supports is developed. Although there certainly are limitations in any engineering design and factors such as the weight of the shield will soon pose a barrier to increased size with current technologies, one must remember that the unthinkable 20 years ago is now the standard. Additional improvements in shield design will be made as long as mine operators continue to push the envelope in shield design.

Below are some items to consider for setting goals for the next generation of shield supports.

1. 100,000 Life Cycle Expectancy.—The increases in life expectancy realized during the past 10-20 years should continue in the near future. It is not inconceivable for a shield to survive 100,000 loading cycles. To reach this goal, some improvements in design may be necessary or at least closer attention will need to be paid to fundamental design practices. In particular, components will need to be sized such that stress levels are kept at moderate levels with respect to the yield strength of the steel. Stress concentrations due to sharp changes in geometry must be avoided, and weldments must be of high quality. More corrosion-resistant materials may be used in certain areas to reduce stress corrosion. Make sure that the link bores have sufficient bearing areas to avoid high levels of stress, and allow for the additional stresses caused by corrosion in the design of the link bores.

2. Hydraulic Diagnostic Capability.—All shields will experience leakage in the leg cylinders or other hydraulic components that degrade the support capability. An algorithm should be specifically written into the control computer that monitors leg pressure histories that will provide the longwall coordinator with a record of bad leg cylinders that need to be repaired. Another option is to have the computer reset leg cylinders that are leaking below a designated setting pressure. While this capability exists on some modern faces, it should become a standard part of the operating system.

3. Smart Load Control.—The benefits of derating a shield by reducing the total loading on the shield were discussed earlier in this paper. A challenge for future shield designs would be for the control computer to optimize the set pressure by monitoring load development history and adjusting the set pressure to minimize overall shield loading once a ground reaction curve for the longwall face is established. The set pressure could be adjusted as the conditions change to continually optimize the support capacity utilization.

4. Lubricated Link Joints.—Pin joints are necessary to accommodate the kinematics of a shield, but these joints are by far the leading cause of structural rebuild. Efforts should continue to enhance the use of wear-resistant materials, such as impregnating the pins with zinc phosphate, but consideration should also be given to a lubricated joint to reduce the wear.

5. Composite Material Design.—Even with the use of high-strength steels, modern shields weigh as much as 30 tons. Weight is a major barrier in increasing the shield widths beyond 2 m with the current steel constructions. Composite materials of equivalent strength weigh only one-fourth that of steel fabrications. Although several engineering and economic issues need to be explored before the feasibility of using high-technology composite materials for shield construction can be determined, this could lead to a new generation of shield supports in the future.

6. Forecasting Periodic Weighting and Heavy Roof Loading.—Most modern shield systems are capable of capturing shield loading histories to the point where we are overloaded with data. These data, if properly managed, can be useful in evaluating leg cylinder leakage and optimizing setting pressures, as suggested in items 2 and 3 above. Another area of value is the prediction of periodic weighting intervals. There has been some research in this area already. For example, NSA Engineering, Inc., developed a shield monitoring program that couples with its GeoGuard™ software [Sanford et al. 1999]. The system was recently tested in an Australian mine where severe face weighting was observed, resulting in hazardous face conditions and weeks of lost production.

7. Advanced Component Load Measurement.—Currently, only the leg cylinder pressure is monitored. No loading information is obtained on any other components. It would not be difficult in the design process to include strain gauges on selected components that could be monitored by the computerized data acquisition system. This need not be done on every production shield; in fact, two or three shields could serve as instrumented shields and provide valuable information on the actual load conditions observed underground. This information could then be used to refine performance testing, as well as help to identify load conditions that actually contribute or cause structural failures. Even measurement of the link loading alone would provide valuable information that is currently not available.

8. Constant Set Leg Cylinder Design.—Current shields use a two-stage cylinder design where the first stage extends and retracts first. This operation typically causes the first stage to be near full extension most of the time. In addition, seal leakage, which occurs on almost all aging shields, causes the bottom stage to extend outward and further promotes full extension of the bottom stage. Since the setting force and the subsequent capacity of the shield to resist roof loading is reduced in proportion to area differential between the top and bottom stage when the bottom stage is fully extended, this is not a good design to ensure that the full capacity of the shield is used. In other words, why buy a 1,000-ton shield when its performance is degraded to that of a 500-ton shield most of the time? There are alternative designs available, most notably that employed by Fazos, Inc., which do not use the conventional two-stage design used in most modern shields. The Fazos design uses a central core to eliminate the use of independently acting stages. Although this design works, it has not been adopted by the major shield manufacturers. An alternative approach would be to configure the standard two-stage design with a system that would cause the top stage to extend first. This could be done by using a nominal hydraulic pressure in the retract annulus of the bottom stage during the extend operation. For current shields, a mechanical device (strap or chain holster) could be built that would attach to the cylinder casing and the base that would prevent the bottom stage from extending. This would not be used on every mining cycle, but would be done periodically as part of a preventive maintenance program to restore full setting capability to the leg cylinders, which are routinely at full bottom-stage extension.

CONCLUSIONS

Improvement in shield design continues to be made with greater life expectancies than ever before. This can certainly benefit mine operators, but the increased cost of modern shields also places greater emphasis on ensuring that the shield design is good since the consequences a poor design can be catastrophic from both an economic and a mining perspective.

Proper planning is essential for a new shield procurement. Sufficient time must be built into the procurement process to ensure that a prototype shield is adequately tested before fabrication of the production shields begins. Otherwise, design changes may not be able to be made in time and/or the modifications will not be as effective as changing the original design. Performance testing needs to be done properly, and every effort should be made to simulate the in-service conditions that occur in the mine. Testing a shield to failure, even if it incurs additional costs, will give insight into when and what to expect when fatigue-type failures plague the support as it ages and needs to be rebuilt or nears the end of its useful life. Purchasing additional shields and implementing a preventive maintenance plan that allows for scheduled rebuild of hydraulic cylinders and inspection and repair of structural components at the onset of problems will pay big dividends in extending the life of the shields.

One misconception is that modern shields by virtue of being higher capacity will last longer than lower capacity shields of previous generations. Modern-day shields are just as likely as lower capacity shields of previous generations to be fully loaded. In fact, the higher strength steels used in modern-day shields generally are prone to more brittle and catastrophic failures when excessive loading occurs than previous generation shields. This fact, coupled with the higher cost and longer life expectancy, makes it more important than ever that shields be properly designed. Thus, it is important to determine the design quality and limitations of the shield during the procurement process.

Improvements in shield design will continue as long as operators continue to demand improvements to which there are engineering solutions. A life expectancy of 100,000 cycles is a reasonable goal that can be accomplished with current technology. Modern longwall faces all have computers collecting data and providing automation of the support operation. The next logical step is to use the data to further improve the diagnostic capabilities and optimize the shield performance. This will be a challenge to shield operators and will require some experimentation on operating longwall faces, but again is within the realm of current technology. The next major improvement in shield design may be the use of composite materials to lighten the weight of the shield. Reducing weight could break the 2-m width barrier that limits current designs using high-strength steel fabrications.

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