ABSTRACT

Cribs are extensively used as standing support in underground coal mines. A novel engineered crib element, developed at Southern Illinois University Carbondale (SIUC), is a composite wood element designed to achieve improved strength, stiffness, and yield properties for cribs. The engineered element uses approximately one-third less wood, weighs about 40 percent less, and offers less ventilation resistance than a conventional crib element. Installation and manual transport times are also reduced along with the risk of physical injury to miners during these operations.

This novel engineered crib element has been named the ATLAS crib. A field demonstration of ATLAS cribs in a longwall gate entry was initiated by Illinois Clean Coal Institute project number DEVO7-2. During that project, conventional and ATLAS cribs were installed side-by-side in a longwall headgate return air course entry. Their performance was monitored while the longwall face mined past them. The current project continues monitoring the previous installation, this time while the adjacent longwall face mines past the demonstration area. In this scenario, the cribs are on the tailgate side where they are subjected to the highest possible load. In addition, ATLAS cribs were installed in crosscuts on the headgate side of the adjacent longwall panel next to the belt entry where they were subjected to very high loads during mining. Eight (8) cribs were installed in four (4) crosscuts and their performance was monitored as the longwall face mined through the area.

Structurally, ATLAS cribs performed extremely well in both areas. Data collected by the National Institute of Occupational Safety and Health on crib and roof-to-floor convergence indicate that, as a function of distance from the face, both were very similar for ATLAS and conventional cribs. ATLAS cribs were slightly stiffer than conventional cribs. Visual observations by mine operations staff, Mine Safety and Health Administration professionals, and SIUC project team members confirmed this information. In addition, mine professionals indicate that ATLAS cribs demonstrated significant ventilation advantages over conventional cribs. Based on these performance results, the cooperating company is now demonstrating ATLAS crib performance over a much larger area covering a 600-ft length of tailgate entry.
EXECUTIVE SUMMARY

Coal mines typically use wooden cribs to provide standing support between roof and floor. Cribs are more extensively used in longwall mining than in room-and-pillar mining. In longwall mining, they are used primarily to support gate, setup and bleeder entries and provide temporary support during the shield removal process when moving longwall equipment from one panel to the next. A typical crib is made of 6-inch x 6-inch x 30-inch or 6-inch x 6-inch x 36-inch prismatic wooden elements, although other sizes may also be used. It is not uncommon for a typical longwall coal mine to use 400,000 to 500,000 crib elements each year at a cost of over two (2) million dollars annually.

Although cribs have been used since the inception of mining, current usage is subject to the following disadvantages and/or limitations:

1. Loading on the crib element is transverse to the wood grain resulting in low crib stiffness, which leads to low load carrying capacity and large deformations.
2. The cross-section of the crib element is uniform along its entire length even though most stresses are around contact areas at either end. Consequently, wood in the center of the element sees small loading. However, this makes the element heavier than it needs to be.
3. The uniform cross-section makes installation around irregular roof difficult.
4. Due to weight and dimensional characteristics, handling crib elements for placement at heights above four (4) feet requires considerable effort.

Dr. Chugh and the project team developed a novel, engineered, composite wooden element in 2007 that overcomes most of the above disadvantages. They named it the ATLAS crib. Results of preliminary testing at Illinois Coal Development Park and National Institute of Occupational Safety and Health (NIOSH) facilities demonstrated the viability of ATLAS crib supports for longwall tailgate entries and generated positive reviews from highly experienced industry professionals. Therefore, a field demonstration (ICCI project number DEV07-2 titled “Underground Performance Assessment of an Engineered Composite Wooden Crib for Tailgate Entry Support in Longwall Mining”) was initiated in early 2008 to perform a side-by-side comparison of the performance of these supports with conventional cribs on an active longwall panel. This was a cooperative project between American Coal Company’s Galatia Mine, NIOSH, ICCI, and SIUC. The project tasks were to establish a field demonstration site in a longwall mine, fabricate the required number of engineered crib elements, install these engineered crib elements in the mine, monitor crib performance, and analyze performance monitoring data collected during the demonstration period. The goal was to develop data that would allow industry to make informed decisions regarding use of engineered cribs in longwall mines. Such data would also allow MSHA to confidently permit their use in longwall and room-and-pillar mines throughout Illinois and the USA.

As a continuation of the previous study, the current crib demonstration was conducted in two (2) areas of a longwall panel at a depth of about 425 feet in the Herrin #6 seam. The longwall face is 1,000 feet wide and the average mining height is approximately 6.5 feet. The immediate roof strata consist of 4.0 to 6.0 inches of Anna Black Shale, 5.5 feet of...
Brereton Limestone, and a sandstone layer about 23 feet thick. The immediate floor strata consist of claystone and shale, with up to 10.0 feet of claystone in some areas. Gate road development is a three-entry system with entries 80 feet apart (center to center or c-c) and crosscuts at 150-ft (c-c) intervals. Supplemental supports are required in all bleeder entries and in the tailgate entry serving an active longwall face. The roof control plan requires these supplemental supports to be maintained about 200 feet ahead of the retreating longwall face.

Cribs are one form of supplemental support and as such are installed in the outside headgate entry in two (2) rows spaced approximately 5.0 to 6.0 feet apart across the entry and 8.0 feet or less along each row. Two (2) additional cribs are installed in each crosscut adjacent to this outside entry. Supplemental supports are also installed in each headgate crosscut connecting the belt (inside) entry and the travel (center) entry, often called the “air” crosscut (XC). Two (2) cribs are installed in each crosscut adjacent to the belt entry to support the belt entry as the longwall face goes by.

This project has two (2) demonstration areas. The first is located in the outside entry of the 1st West longwall headgate near the recovery room. This area becomes the tailgate entry of the 2nd West longwall panel. It extends over a distance of about 250 feet with a section of conventional cribs and a section of engineered cribs. In each section, two (2) rows of cribs were installed with 8-ft spacing along the entry and approximately 5-ft across the entry. Cribs were installed during March 21-27, 2008 under the previous ICCI project.

Also during the previous project, load and convergence monitoring equipment was installed on March 26 by NIOSH and SIUC personnel. When mining finished in the 1st West longwall panel and equipment was relocated to the 2nd West longwall panel, the NIOSH data logger was removed on May 7 and returned to NIOSH at their request. During the current ICCI project, the data logger was reinstalled by NIOSH personnel on November 19, 2008 when the 2nd West longwall panel was within 1,000 feet of the demonstration area. As part of this project, convergence monitors were installed on two (2) additional conventional cribs and two (2) roof-to-floor convergence points were installed in the conventional crib area. Data from all instrumentation was collected until December 22, 2008, by which time the longwall face had passed all instrumented cribs. At that time, the data logger was removed and sent to NIOSH for data retrieval and analysis.

A second demonstration area for this project is in headgate “air” crosscuts on the 2nd West longwall panel. This demonstration area extends from XC-30 thru XC-20. Crib convergence points, mounted on several ATLAS cribs, were used to monitor their performance. The following results summarize the study to date:

- Structurally, ATLAS cribs in the 2nd West longwall tailgate performed very similar to conventional cribs.
- ATLAS and conventional cribs were intact in the gob area at least 125 feet behind the row of shields at the face.
• ATLAS cribs also performed very well and similar to conventional cribs in all four (4) headgate crosscuts. This comment is based primarily on visual observations and input from mine operations staff. Actual monitoring data was very limited because of the unsafe working environment around these cribs.

• Mine professionals liked the ventilation characteristics of ATLAS cribs. Air flow is much less restricted with ATLAS cribs than with conventional cribs. This advantage over conventional cribs, as noted by mine professionals, may allow them to be used to support the return entry during development rather than in advance of the longwall face. This would simplify supply logistics and crib installation and provide support sooner after excavation, thus minimizing premature roof movement and/or failures.

• Guidelines for installation of engineered cribs were developed.

• Prior to installation of engineered cribs in the test area, training was provided to workers on proper installation of engineered cribs.

• Installation time for an engineered crib is typically about 25-30% less than for a conventional crib.

• Significant time and cost savings accrue from engineered cribs where the crib elements must be manually transported over a considerable distance to the construction site. This is because two (2) engineered crib elements can easily be carried by a worker (one in each hand) versus one (1) conventional crib since engineered cribs are about 40% lighter.

• Site preparation for engineered cribs is much easier since only four (4) smaller areas, equal to the size of each base, need to be prepared.

• At the demonstration mine, comments received from the chief engineer, longwall coordinator, section bosses, and workers carrying and installing engineered cribs were positive.

• Based on ATLAS crib performance in the two (2) demonstration areas of this project, the cooperating company agreed to a follow-up project and has installed additional engineered cribs in a much larger demonstration area in the 2nd West headgate/3rd West tailgate extending 600 to 700 feet and involving about 5,400 ATLAS crib elements. The mining company decided that for this demonstration, all ATLAS cribs would be installed by mine professionals.
OBJECTIVES

A novel, engineered, composite wooden element (known as the ATLAS crib) was developed in 2007. ATLAS cribs overcome most of the disadvantages of conventional cribs. Following positive reviews by highly experienced industry professionals, a field demonstration project was initiated to collect data from a side-by-side performance comparison of these supports with conventional cribs on an active longwall face in an Illinois coal mine. In the first phase of this project funded by the Illinois Clean Coal Institute (ICCI) in cooperation with the National Institute of Occupational Safety and Health (NIOSH) and American Coal Company’s Galatia Mine, the project team installed ATLAS cribs in the 1st West longwall panel headgate return entry that extended over a distance of about 250 feet. The goals of this second phase were to: 1) Monitor first phase cribs when the 2nd West longwall face mines past the demonstration area, and 2) Install and monitor the performance of ATLAS cribs in 2nd West longwall headgate entry crosscuts where significant loading occurs. The overall objective of this multiphase project is to develop data that allows industry to make informed decisions regarding use of ATLAS cribs in room-and-pillar and longwall mines. Such data will also allow Mine Safety and Health Administration (MSHA) to permit the use of these supports with confidence in longwall and room-and-pillar mines throughout Illinois and the USA.

INTRODUCTION AND BACKGROUND

Coal mines typically use wooden cribs to provide standing support between roof and floor. Cribs are more extensively used in longwall mining than in room-and-pillar mining. In longwall mining, they are used primarily to support gate, set-up and bleeder entries and provide temporary support during the shield removal process when moving longwall equipment from one panel to the next. A typical crib uses prismatic wooden elements of 6-inch x 6-inch x 30-inch or 6-inch x 6-inch x 36-inch, although other sizes may also be used. It is not uncommon for a typical longwall coal mine to use 400,000 to 500,000 crib elements each year at a cost of over two (2) million dollars annually.

Although cribs have been used since the inception of mining, currently used cribs have several disadvantages and/or limitations. First, since loading on the crib element is transverse to the wood grain, low crib stiffness leads to low load carrying capacity and large deformations. Second, the cross-section of a crib element is uniform even though most of the stresses in the element are confined around contact areas thus making the element heavy. Third, the uniform cross-section makes installation around irregular roof difficult. Fourth, handling crib elements for placement at heights above four (4) feet requires considerable effort.

Dr. Chugh and the project team developed a novel, engineered, composite wooden element (see Figure 1) in 2007 that overcomes most of the above disadvantages. Results of testing at Illinois Coal Development Park and NIOSH facilities demonstrated that these crib supports are viable for longwall tailgate entries (Batchler, 2008; Gearhart, 2008). Reviews of these supports by highly experienced industry professionals were also positive. Under a previous ICCI grant, a field demonstration project performed limited
side-by-side comparison of the performance of these supports with conventional cribs on an active longwall face in the Midwest (Chugh et al., 2008). This was the first phase in a cooperative project between American Coal Company’s Galatia Mine, NIOSH, ICCI, and SIUC and it established the feasibility of using ATLAS cribs in longwall and room-and-pillar mining operations.

The first phase demonstration area was located in the 1st West longwall panel headgate return entry and extended over a distance of about 250 feet (see Figure 2). The demonstration area consisted of adjacent sections; one having conventional cribs and the other having engineered cribs. In each demonstration area, two (2) rows of cribs were installed with cribs spaced 8.0 feet apart along the entry and approximately 5.0 feet apart across the entry. Installation of the cribs was completed during March 21-27, 2008.

Crib convergence and roof-to-floor convergence monitoring equipment was installed on March 26, 2008 by NIOSH and SIUC personnel. Crib convergence is used as an estimate of load on cribs. The NIOSH data logger was removed on May 7 when mining of the 1st West longwall panel finished and longwall equipment relocated to the 2nd West longwall panel. The data logger was returned to NIOSH for data analysis and results were reported in Chugh et al. (2008).

EXPERIMENTAL PROCEDURES

Mine Description: The second phase of this ATLAS crib demonstration was conducted in two (2) areas on the 2nd West longwall panel operating at about 425-ft depth in the Herrin #6 coal seam. The longwall face is 1,000 feet wide and the average mining height is approximately 6.5 feet. The immediate roof strata consist of 4.0 to 6.0 inches of Anna Black Shale, 5.5 feet of Brereton Limestone, and a 23-ft thick layer of sandstone. The immediate floor strata consist of claystone and shale with up to 10 feet of claystone in some areas. Gate road development is a three-entry system with entries 80 feet apart (center to center or c-c) and crosscuts at 150-ft (c-c) intervals. Supplemental supports are required in all bleeder entries and in the tailgate entry serving an active longwall face. The roof control plan requires tailgate entry supplemental supports to be installed when the tailgate entry is the outside headgate entry and installation should occur 200 feet ahead of the longwall face. Cribs are installed in two (2) rows spaced approximately 5.0 to 6.0 feet apart across the entry. In each row, spacing between cribs is eight (8) feet or less. Two (2) additional cribs are placed in the opening of each crosscut along the entry. Additionally, supplemental supports are installed in each headgate “air” crosscut connecting belt entry and travelway at the belt entry opening of the crosscut. Two (2) cribs are installed in each crosscut to provide support for the belt entry as the longwall advances. A typical layout of the longwall face showing supplementary supports is shown in Figure 3.

Demonstration Areas: The first demonstration area was a 250-ft section of the 1st West headgate return/2nd West tailgate described earlier. Initial studies on that area are reported in Chugh et al. (2008). The second demonstration area was in headgate “air” crosscuts in the 2nd West longwall panel. As shown in Figure 4, this demonstration area involves
three (3) crosscuts: XC-30, XC-29, and XC-20. The goal of this task was to install and monitor the performance of ATLAS 100 Series cribs in four (4) to five (5) crosscuts in the 2nd West longwall panel headgate. Convergence points mounted on several ATLAS cribs were used to monitor their performance.

Two (2) cribs are typically installed in each “air” crosscut just ahead of the advancing longwall face. The “air” crosscut is established by removing the permanent belt entry isolation stopping just before the longwall face advances past the previous “air” crosscut. Supplemental supports are positioned near the interface where the crosscut intersects the belt entry. Crib supports in these crosscuts have two (2) functions: 1) Provide additional support in order to maintain safe access to the longwall face, and 2) Prevent migration of the caved area into the crosscut and adjacent entry after the longwall face passes. These cribs are subjected to significant loading as the roof strata above the longwall face caves and compacts.

**ATLAS Crib Specifications:** ATLAS Series 100 cribs used in crosscuts were commercially fabricated by a local pallet manufacturer to dimensional tolerances designated by SIUC as shown in Table 1.

**Monitoring Crib Performance:** Crib loads were monitored using a wire extensometer with precision potentiometer mounted on crib elements. The extensometer was attached to a crib element near the roof using screws and a wire was extended to an eye bolt inserted into another crib element near the floor (see Figure 5). This measurement technique assumes that crib compression is related to crib load, which is a reasonable assumption prior to initiation of crib yield.

A roof-to-floor convergence point similarly consisted of a wire extensometer with precision potentiometer attached to a roof bolt plate and a wire attached to an anchor that is grouted approximately 12 inches into the floor (see Figure 6). An intrinsically safe, battery operated 16-channel digital data acquisition system (DDAS) was placed in a nearby crosscut and each wire extensometer was attached to the DDAS with a data cable.

Three (3) conventional cribs and six (6) engineered cribs were instrumented as described above. Two (2) roof-to-floor convergence monitoring stations were located in the engineered crib area and one (1) in the conventional crib area. In addition, load cells designed at SIUC (see Figure 7) were installed in two (2) conventional and two (2) engineered cribs.

During this project, the data logger used in the earlier study was reinstalled by NIOSH personnel on November 19, 2008 when the 2nd West longwall panel was within 1,000 feet of the crib demonstration area. Two (2) additional convergence monitors and two (2) roof-to-floor convergence points were installed in the conventional crib area. Data from all instrumentation was collected until December 22 by which time the longwall face had mined past all instrumented cribs. The data logger was returned to NIOSH personnel for data retrieval and data analysis. NIOSH has not yet provided the calibration curve for
relating wire extensometer displacement to load on cribs. Therefore, results are presented here in units of displacement.

**Manual Crib Load Monitoring:** About six (6) years ago, SIUC successfully developed and used load cells to monitor loads on fly ash cribs. Such a cell consists of a composite polymer material sandwiched between 6-inch square and 0.5-inch thick steel plates (see Figure 7). The compression of the composite material is calibrated for load-deformation characteristics prior to use. The advantage of this load cell is that it measures the true load on the crib and is unaffected by the yielding behavior of wood. However, since measurements are taken manually, it does not provide data continuously and collecting data takes a considerable amount of time.

SIUC installed these load cells in two (2) engineered and two (2) conventional cribs. They were placed approximately 5.0 feet above floor level between each of the four (4) contact points of a crib layer as shown in Figure 7. A digital micrometer was used to measure the distance between the two (2) steel plates at each of the four (4) corners of the load cell assembly. The average displacement data was plotted as a function of face advance. A total of 16 measurements were taken at different times for each crib being monitored with load cells. The load-deformation behavior of the composite polymer material used is given by the following equation.

\[
\text{Load (lbs)} = 345 \times \text{deformation (in inches)} \times 0.01
\]

This equation was valid for loads larger than 0.05-inch of deformation.

**RESULTS AND DISCUSSION**

Results from the first phase were reported in Chugh et al. (2008). Since this study is a continuation of the previous study, some of those results are included again in this report for completeness.

**NIOSH Monitoring of Loads on Cribs:** Data collected from March 27, 2008 to May 8, 2008 for three (3) conventional and six (6) ATLAS cribs are summarized as a function of distance to the face in Figure 8. Enlarged views of the data for conventional and ATLAS cribs are given in Figures 9 and 10. Over a 475-ft advance of the longwall face, load on conventional and ATLAS cribs varied from 30 to 85 displacement units. Data for ATLAS cribs further shows a slightly flattening trend for incremental load after the longwall face passes, which is expected. Crib loading data as a function of time rather than distance to the face is shown in Figure 11. Although data that is a function of time is not as meaningful as data that is a function of face advance from an interpretation point of view, it is presented as an aid to understanding crib behavior. Both data sets show that conventional and engineered cribs are performing very similarly, but overall, ATLAS cribs appear to have more uniform load distribution than conventional cribs.

**NIOSH Monitoring of Roof-to-Floor Convergence:** Data collected using the DDAS from March 27, 2008 to May 5, 2008 for one (1) point in the conventional crib area and
two (2) points in the ATLAS crib area are summarized in Figure 12. These data values are very similar indicating that both sets of cribs are providing similar resistance to roof-to-floor movements. Roof-to-floor convergence increases in both areas are similar but the increase is slightly higher in areas with conventional cribs. This is most likely due to longwall mining passing the conventional crib area before passing the area with engineered cribs.

**SIUC Load Cell Monitoring Data:** Data collected manually from March 27, 2008 to May 8, 2008 on SIUC loads cells in conventional and ATLAS cribs are summarized as a function of face advance in Figure 13. Similar data as a function of time for a 265-day period is shown in Figure 14. This data shows once again that both types of cribs perform very similarly. The slope of the load increase as a function of face advance is slightly higher for ATLAS cribs. This is most likely due to slightly higher stiffness for ATLAS cribs. The initial drop in load is likely due to wood shrinkage.

**Installation and Performance of ATLAS Cribs in Crosscuts on the Headgate:** The first set of ATLAS cribs was installed by mine professionals in headgate “air” crosscut (XC-30) on September 17, 2009 (see Figure 15). The face was about 20 feet from the intersection (survey station 43+40) when cribs were installed and load monitoring was initiated. Load data was collected for 24 hours after installation while the face advanced 55 feet to survey station 42+85. Data indicated a load of about 5.6 tons on the instrumented crib (see Figure 17). These cribs were structurally sound without any distortion, buckling or other visual signs of distress. Visual observations on October 27, 2009 (39 days after the face passed) indicated both cribs were still intact and structurally sound. However, load monitoring could not be pursued due to unsafe roof conditions and caved roof material surrounding both cribs.

A second set of ATLAS cribs was installed by SIUC staff in XC-29 (see Figure 16) on September 18, 2009. The longwall face at the time of installation was at survey station 42+85 or 119 feet away. After installation, the longwall face had a mechanical failure of the shearer ranging arm requiring its replacement. One (1) ATLAS crib was removed to allow transport of ranging arms to and from the shearer. It was later reinstalled on September 20, 2008. Load data collected on September 22, 2008 (longwall face located at survey station 42+06 and 40 feet from XC–29) indicated approximately 8.8 tons on the instrumented crib. On September 23, 2008, the longwall face advanced past XC–29 to survey station 41+42 and the total load was just over 16 tons on the instrumented crib (see Figure 17). Visual observation found both cribs to be intact and structurally sound with no obvious signs of distress. On September 24, 2008, the second (inby) ATLAS crib was dislodged (not failed) when caved roof material struck the crib around mid-height. An investigation indicated that several factors contributed to its dislocation. The crib was 105 inches high and SIUC load cells were installed near mid-height. Caved rock hit the crib near the location where the load cell was installed. There was consensus among all present that a conventional crib would also have been dislodged under similar circumstances.
The last monitored ATLAS crib was installed on October 27, 2008 in XC–20 when the longwall face was located at survey station 29+69 or 136 feet away (see Figure 18). Data collection from these cribs could not be accomplished due to unsafe roof conditions in the crosscut. Visual observations before access was restricted by water in the center gate entry indicated both cribs were structurally sound.

At XC–8, one (1) conventional and one (1) ATLAS crib were installed along with a steel “sand prop” located about three (3) feet from the ATLAS crib. The steel sand prop with a load capacity of about 60 tons buckled under the load but both cribs remained intact without any visual signs of distress. In summary, ATLAS cribs were installed in four (4) crosscuts and monitored as a part of this study. In all cases, ATLAS cribs performed at least as well as the conventional cribs.

**Visual Observations:** During the period of this study, several visits were made to the demonstration area to note visual observations on both types of cribs. Both sets of cribs looked equally good. There were no indications of buckling or loose cribs in either area. Similar observations were made independently by MSHA inspectors touring the area. These observations have helped develop confidence in the use of engineered cribs.

**NIOSH Monitored Crib and Roof-to-Floor Convergence Data Analysis:** These analyses refer to data collected from November 19, 2008 to December 22, 2008. Two (2) approaches used for analysis are discussed below.

**Approach 1:** DDAS data from March 27, 2008 to May 5, 2008, for points in the first phase demonstration area, were summarized in Figure 8. This data was collected during mining of the 1st West longwall panel. Similar data was collected again on the same cribs from November 19, 2008 to December 22, 2008 during mining of the 2nd West longwall panel with the demonstration area in the tailgate entry. Results of this monitoring are summarized in Figure 19. Key points relative to this analysis are as follows:

- The data logger was removed on December 22, 2008 when the face was located at survey location 7+35.
- Only 12 of 16 monitoring points survived the longwall face advancing past their location. Three (3) roof-to-floor convergence stations were dislodged due to unknown reasons.
- Crib convergence is observed beginning about 1,000 feet ahead of the face. However, the amount of convergence is minimal until the face actually passes a specific location. Beyond that point, convergence increases rapidly.
- Conventional cribs and ATLAS cribs experienced average convergence of about 1.5 inches when the face had advanced about 125 feet beyond them. Thus, performance was similar for both types of cribs.
- Roof-to-floor convergence monitoring points 6A in the ATLAS crib area and 8B in the conventional crib area indicate almost identical convergence values in their respective areas as recorded by crib monitoring points.
- Based on ATLAS crib performance in this second phase, the cooperating mine is now demonstrating these cribs over a larger area (see Figure 20).
**Approach 2:** Convergence data for each crib as a function of face advance is shown in Figures 21 through 33. It is important to note that monitoring systems on conventional and ATLAS cribs were slightly different. Conventional cribs were monitored with convergence pins located around the center of crib elements while ATLAS cribs were monitored with monitoring pins located at contact points of different crib elements. Therefore, ATLAS crib convergence data is much more sensitive to deformation than conventional crib convergence data. For example, localized deformations at contact points of elements for conventional cribs may not even register on the data logger.

Crib convergence data was recorded for different distances from the crib to the longwall face. The average value of all conventional and all ATLAS cribs data for a particular distance from the face is plotted in Figure 34. Similarly, roof-to-floor convergence data are plotted in Figure 35. However, only one (1) point in the conventional crib area and one (1) point in the ATLAS crib area were usable in collecting roof-to-floor convergence data. Results of these analyses are summarized as follows:

**Crib convergence**

- Overall behavior of conventional and ATLAS cribs are very similar. ATLAS cribs may have performed slightly better.
- For face locations up to about 0 feet, average deformation of ATLAS cribs was almost identical to average deformation for conventional cribs. For face locations within 0 to -50 feet, ATLAS cribs show small amounts of divergence while conventional cribs do not show this behavior. This is because ATLAS crib monitoring pins are located on crib element contact points. Based on ground movement mechanics around a longwall face, observance of such behavior is expected. The same behavior is not observed in the conventional crib area since monitoring points are located around the center of crib elements rather than at contact points.
- For face locations at about -125 feet, both cribs behaved almost identically.
- ATLAS crib convergence data for face locations -125 feet and -200 feet were not available since the data logger located in XC-7 had to be removed when the face was at 7+35. However, the project team did observe that ATLAS cribs were intact as far as they could be seen. All cribs were surrounded by caved rock.
- The standard deviation in crib convergence values was higher for conventional cribs than for ATLAS cribs for all face locations.
- ATLAS crib convergence data shows large variations when the face location is between 0 and -100 feet. This is because the monitoring pins were located at element contact points. Within this region, loads are dynamically changing. These variations are observed in ATLAS cribs first and later in conventional cribs.

**Roof–to–floor convergence**

- Monitoring stations 1, 5, 14 and 16 were roof-to-floor convergence points. Most of these points showed a sudden drop after a period of time and no firm conclusions can be drawn from the data. A project team member found two (2)
roof-to-floor convergence points dislodged. It is not known whether this occurred due to floor heave or mine personnel working in the area.

- The data for one point in the conventional crib area (station 16) and one point in the ATLAS crib area (station 11) were usable. Figure 35 shows a plot of this data as a function of face location. The station 16 showed a total of 5.0 inches of roof-to-floor convergence while an instrumented crib at location 9+28 showed 3.0 inches of convergence. This would indicate about 2.0 inches of floor heave between cribs.
- In the ATLAS crib area, convergence is slightly smaller than in the conventional crib area. Data show divergent behavior when monitored cribs are close to the face area, but by the time the face location is approximately -125 feet, roof-to-floor convergence is similar. Once again, data for face locations beyond -125 feet was not collected because the data logger had to be removed.

**Summary comments:** Data collected to date suggest that ATLAS cribs have performed as well or slightly better than conventional cribs under all loading conditions typically encountered during mining of adjacent longwall faces. Some slight differences in behavior are explained as follows:

- Installed conventional cribs with 36-inch elements measured 30 to 32 inches between contact points (end to end) as compared to 35 inches for ATLAS cribs.
- Since ATLAS cribs consist of a center element and plate elements with large surface areas, they could have lost more moisture as a function of time, and therefore behaved stiffer than conventional cribs.
- Some data from the previous study indicated less deformation during initial loading for ATLAS cribs than for conventional cribs.
- The contact area for ATLAS cribs could have been larger than for conventional cribs. The project team thinks that this needs to be investigated further.
- The geology of immediate roof and floor strata could vary throughout the demonstration area although it is not very likely based on visual observations.
- Overall, ATLAS cribs in the tailgate entry performed slightly better than conventional cribs when the 2\textsuperscript{nd} West longwall mined through the demonstration area.
- Structural performance advantages noted in this report along with field proven ventilation advantages should provide significant market entry potential for ATLAS cribs.

**CONCLUSIONS AND RECOMMENDATIONS**

**Conclusions**

- During the study period, engineered cribs were manufactured by four (4) saw mills in southern Illinois and western Kentucky with oversight by the project team. Developed QA/QC protocols were implemented during manufacturing. Results of QA/QC studies indicated that manufactured cribs were within allowable limits from three (3) saw mills. A shipment from the fourth sawmill was stopped when it did not meet QA/QC protocols.
• Installation procedures were developed for engineered cribs. Training was provided to workers on the proper installation of engineered cribs prior to their installation in demonstration areas.
• Installation time for an engineered crib was typically about 25-30% less than for a conventional crib.
• Significant time savings can accrue when building engineered cribs where crib elements must be manually transported over a long distance. This is because a miner can carry two (2) engineered crib elements versus only one (1) conventional crib element as engineered crib elements are about 40% lighter. Therefore, transportation time is estimated to be reduced by about 50%.
• Site preparation for engineered cribs was much easier since only four (4) small areas, each the size of one pad, need to be prepared.
• Based on available data to date from demonstrations in both areas, ATLAS cribs have performed as well or slightly better than conventional cribs. The convergence of ATLAS cribs is smaller than conventional cribs indicating that they offer more resistance to rock mass movement and carry more load than conventional cribs. This is due to their slightly higher stiffness as documented in laboratory testing.
• Input was sought from the chief engineer, longwall coordinator, section bosses, and workers carrying and installing engineered cribs. Almost all comments received were positive.
• Galatia professionals have indicated that ATLAS cribs are providing much better ventilation than conventional cribs.
• Based on these performance characteristics, mine professionals agreed to a third phase and are now performing a larger scale demonstration of these cribs in the 3rd West longwall panel.
• During the project period, engineered cribs were demonstrated to high-ranking professionals of several coal companies at their mines. Their input was sought in lieu of assembling an advisory committee. Numerous positive comments were received.
• During the SIUC team’s last visit to the demonstration area in December 2008, ATLAS cribs appeared to be performing as well as conventional cribs.
• Overall, this demonstration study to date is considered a major success. Over 9,000 crib elements were shipped to mining companies for experimental trials.
• One (1) mining company has installed them in front of mine seals while another has used them to support weak roof areas.
• At the request of a mining company, a demonstration area has been identified to evaluate ATLAS crib performance in room-and-pillar mine intersections.

Recommendations

• The industry has started using ATLAS crib elements in room-and-pillar mining and they seem to be pleased with their performance. Their extensive use in longwall mining will only occur after more large size demonstrations are performed and data are widely disseminated.
• Accordingly, the ICCI has already approved another field demonstration at the Galatia Mine where ATLAS 100 series cribs will be installed in the tailgate entry of the 3rd West longwall panel over a 600- to 700-ft distance. This demonstration should be completed in early 2010.
• The demonstration mine has expressed significant interest in using ATLAS cribs more extensively. The project team must expand their manufacturing capabilities to support this demand.
• The project team plans to stay focused to meet the demand for ATLAS cribs in the Illinois Basin. If additional longwall faces are implemented in Illinois, most of the demand for ATLAS cribs will be in Illinois.

Table 1: Dimensional QA/QC protocols for ATLAS cribs.

<table>
<thead>
<tr>
<th>ATLAS series crib element maximum and minimum dimensional tolerances (inches)</th>
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<tbody>
<tr>
<td>ATLAS crib series</td>
</tr>
<tr>
<td>Max.</td>
</tr>
<tr>
<td>ATLAS 100</td>
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<tr>
<td>ATLAS 200</td>
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<td>ATLAS 300</td>
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*Dimensions A, B, C, D, and E are defined in Figure 1.

Figure 1: Plan and side view of a typical novel engineered ATLAS crib element.
Figure 2: 1st West headgate return/2nd West tailgate crib demonstration area.

Figure 3: Typical headgate crosscut supplemental support locations.
Figure 4: 2nd West headgate crib demonstration map.

Figure 5: Wire extensometer attached to bottom element (a) and top element (b).

Figure 6: Wire extensometer attached to floor anchor (a) and roof bolt anchor (b) in a roof-to-floor convergence monitoring station.
Figure 7: Load cell developed at SIUC installed in one corner of an ATLAS crib.

Figure 8: NIOSH crib loading data for conventional and ATLAS cribs as a function of distance to the face (March 27, 2008 to May 8, 2008).

Figure 8: NIOSH crib loading data for conventional and ATLAS cribs as a function of distance to the face (March 27, 2008 to May 8, 2008).
Figure 9: NIOSH crib loading data for conventional cribs.

Figure 10: NIOSH crib loading data for ATLAS cribs.
Figure 11: NIOSH crib loading data for conventional and ATLAS cribs as a function of time (March 27, 2008 to May 8, 2008).

Figure 12: Roof-to-floor convergence as a function of face distance.
Figure 13: SIUC load cell convergence versus face advance.

Figure 14: SIUC load cell convergence versus time.
Figure 15: Crosscut 30 crib installation.

Figure 16: Crosscut 29 crib installation.

Figure 17: 2nd West longwall headgate crib loading versus face location.
Figure 18: Crosscut 20 crib installation.

Figure 19: NIOSH crib loading data for conventional and ATLAS cribs as a function of distance to the face (November 19, 2008 to December 22, 2008).
Figure 20: Third phase ATLAS crib locations in the 2nd West longwall headgate.
Figure 21: Crib convergence versus face distance (Pt. 4A / Station 1).

Figure 22: Crib convergence versus face distance (Pt. 1B / Station 2).

Figure 23: Crib convergence versus face distance (Pt. 2A / Station 3).

Figure 24: Crib convergence versus face distance (Pt. 2B / Station 5).

Figure 25: Crib convergence versus face distance (Pt. 3B / Station 6).

Figure 26: Crib convergence versus face distance (Pt. 4B / Station 8).
Figure 27: Crib convergence versus face distance (Pt. 5A / Station 9).

Figure 30: Crib convergence versus face distance (Pt. 6B / Station 12).

Figure 28: Crib convergence versus face distance (Pt. 5B / Station 10).

Figure 31: Crib convergence versus face distance (Pt. 7A / Station 13).

Figure 29: Crib convergence versus face distance (Pt. 6A / Station 11, this is a roof-floor point, not crib).

Figure 32: Crib convergence versus face distance (Pt. 8A / Station 15).
Figure 33: Crib convergence versus face distance (Pt. 8B / Station 16).

Figure 34: Averaged crib convergence data as a function of face advance.

Figure 35: Averaged roof-to-floor convergence data as a function of face advance.
REFERENCES


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