FINAL TECHNICAL REPORT
March 1, 2008, through August 31, 2008

Project Title: **UNDERGROUND PERFORMANCE ASSESSMENT OF AN ENGINEERED COMPOSITE WOODEN CRIB FOR TAILGATE ENTRY SUPPORT IN LONGWALL MNING**

ICCI Project Number: DEV07-2
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ABSTRACT

A novel crib element, developed at SIU, is a composite engineered wood element to achieve improved properties of strength, stiffness, and yield for cribs that are used as standing supports in mines. Such an element uses approximately one-third less wood, weighs about 40% 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.

A field demonstration of these engineered wooden cribs was initiated in this project for tailgate entry support on a longwall face. The cribs were installed at American Coal Galatia Mine in the 1st West longwall headgate. The location chosen for this side-by-side performance comparison of engineered cribs and conventional cribs was the outside headgate entry, which becomes the tailgate entry for the adjacent 2nd West longwall panel. The 350-foot long demonstration area is roughly 500 feet inby the recovery room. As part of this project, cribs were monitored while the 1st West longwall face was completed. Monitoring and assessment of these cribs, when the 2nd West longwall panel advances past the demonstration site, will be undertaken as part of a separate follow-up project.

During installation of both engineered and conventional cribs, time studies were performed to measure transport and installation time. Transport times from pallet to construction site are reduced by about 50% since a worker can carry two engineered crib elements in a single pass as compared to one conventional crib element. Time studies indicate about 25-30% improved installation time when using the engineered cribs. Crib loading, compression, and roof-to-floor convergence data were collected from the time cribs were installed until the 1st West longwall had passed the demonstration area. Data to date have indicated only small roof-to-floor convergence in both areas. Because of their location in the outside headgate entry, loading of both engineered and conventional cribs is relatively small at this point. The engineered cribs to date have performed very similarly to conventional cribs. Comments from American Coal employees about weight, handling properties and crib construction have been very positive.

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, set up and bleeder entries and provide temporary support during the shield removal process when moving the longwall equipment from one face to the other. 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 1.5-2.0 million dollars annually.

Although cribs have been used since the inception of mining, in their current form they have the following disadvantages and/or limitations: 1) Since loading on the crib element is transverse to the wood grain, low crib stiffness leads to low load carrying capacity and large deformations, 2) The cross-section of the crib element is uniform even though most of the stress in the element is confined to a small area around contact points, thus making the element heavier, 3) The uniform cross-section also makes installation around irregular roof difficult, and 4) Handling crib elements for placement at heights above four feet requires considerable effort.

The principal investigator and the project team have developed a novel, engineered, wooden element called the ATLAS crib that overcomes most of the above disadvantages. Results of testing at the Illinois Coal Development Park in Carterville, IL and National Institute of Occupational Safety and Health (NIOSH) facilities in Pittsburgh, PA demonstrate that these crib supports can be a viable support for longwall gate entries. Product reviews from highly experienced industry professionals in Illinois have also been positive. This field demonstration project was designed to perform a side-by-side comparison of the performance of these supports with conventional cribs on an active longwall face in the Midwest. The project tasks were: 1) Establish field demonstration site, 2) Fabricate engineered crib elements for field demonstration, 3) Perform a demonstration of engineered cribs in the mine, and 4) Conduct data analysis and synthesis. This was a cooperative project between American Coal Galatia Mine, NIOSH, Illinois Clean Coal Institute (ICCI), and SIU. The goal was to develop data that would allow the industry to make informed decisions regarding use of ATLAS cribs in longwall mines. It was also hoped that such data would allow MSHA to permit the use of these supports with confidence in longwall mines throughout Illinois and the USA.

The crib demonstration was conducted on a longwall face operating at about 425 feet depth 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 4-6 inches of Anna Black Shale, 5.5 feet of Brereton Limestone, and about 23 feet of massive 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) with cross-cuts at 150-foot (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 location of the longwall face. Cribs are installed as supplemental supports in two rows spaced approximately 5–6 feet apart across the entry and eight feet or less along each row. Two additional cribs are placed in each cross-cut.

The demonstration area was located roughly 500 feet inby the recovery room in the outside entry of the 1st West longwall headgate and spanned a distance of about 250 feet. The demonstration area consisted of two adjacent sections; one having conventional cribs and the other having engineered cribs. In each area of demonstration, two rows of cribs were installed. Spacing was eight feet apart along the entry and approximately five feet apart across the entry. Installation of cribs was done during the period March 21-27, 2008.

Load monitoring and convergence monitoring equipment on cribs in both areas were installed on March 26 by NIOSH and SIU personnel. Two roof-to-floor convergence monitoring stations were located in the engineered crib area and one in the conventional crib area. The following results summarize the study to date.

- The engineered cribs were planned to be manufactured by a saw mill in southern Illinois with oversight by the project team. However, due to flooding, the saw mill could not fabricate the cribs. Thus, the SIU project team fabricated all of the engineered cribs for this demonstration at the Illinois Coal Development Park.
- In addition to the cribs for this demonstration project, over 2,000 crib elements, fabricated by four saw mills in the tri-state area, have been shipped to different mines for experimental trials.
- QA/QC protocols have been developed and implemented during the manufacturing process. The results of quality assurance checks on manufactured cribs were used for process improvement and training purposes. A shipment from one saw mill was rejected when it did not meet QA/QC requirements.
- Guidelines for proper installation of engineered cribs were developed.
- Prior to installation of engineered cribs in the test area, training was provided to miners on proper installation of engineered cribs.
- The installation time for an engineered crib was typically about 25-30% less than a conventional crib.
- Significant time and cost savings accrue from engineered cribs where crib elements must be manually transported over a considerable distance to a construction site. This is because two engineered crib elements can be easily carried by a worker (one in each hand) since they are about 40% lighter.
- Site preparation for engineered cribs is much easier since only four smaller areas, equal to the size of each base, need to be prepared.
- Based on available data to date, engineered cribs are performing very similarly to conventional cribs.
- At the demonstration mine, input was sought from the Chief Engineer, longwall coordinator, section bosses, and workers carrying and installing the engineered cribs. Almost all comments received were positive.

- During the project team’s last visit to the demonstration area as part of this project on July 1, 2008, the cribs seemed to be performing as well as the conventional cribs based on visual observations.
- During the project period, engineered cribs were shown to several coal company high-ranking professionals at their mines to seek their input. This was done in lieu of an advisory committee. These included Willow Lake, Wild Cat Hills, Gibson County Coal, Sunrise Mining Company, and Vermillion Grove. Again the comments received were positive.
- Overall, this demonstration study to date is considered a success. Over 2,000 crib elements have been shipped to mining companies for experimental evaluation. One mining company plans to install them in front of mine seals while another mining company has used them to support weak roof areas.

OBJECTIVES

The overall goal of this project is to develop an improved supplementary roof support system for tailgate entries in longwall mining. Toward this goal, the objectives of this demonstration study were to:

1. Evaluate the performance of the SIU developed, engineered wooden crib support system in a longwall tailgate entry.
2. Assess the installation time, reduced weight and ergonomic advantages of the developed crib elements.

INTRODUCTION AND BACKGROUND

Problem Statement and Development of Engineered Wooden Crib: Coal mines use wooden cribs to provide standing support between the roof and floor of an excavation. Cribs are more extensively used in longwall mining than in room-and-pillar mining. They are used primarily to support gate, set up and bleeder entries and to provide temporary support during the shield recovery process. 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 1.5-2.0 million dollars.

The currently used crib has several disadvantages and/or limitations including the following: 1) Since loading on the crib element is transverse to the wood grain, low crib stiffness leads to low load carrying capacity and large deformations, 2) The cross-section of the crib element is uniform even though most of the stress in the element is confined to a small area around contact points, thus making the element heavier, 3) The uniform cross-section also makes installation around irregular roof difficult, and 4) Handling the crib elements for placement at heights above four feet requires considerable effort.

The principal investigator and the project team have developed a novel, engineered, wooden element that overcomes most of the above disadvantages. Results of testing at the Illinois Coal Development Park in Carterville, IL and NIOSH facilities in Pittsburgh, PA have demonstrated that these crib supports are viable support systems for room-and-pillar and longwall mining areas. Reviews of these supports by highly experienced industry professionals have also been extremely positive.

Description of a Novel Composite Crib Element: One recommended geometry for such an element is shown in Figure 1. It consists of four, 5.75-inch x 5.75-inch x 2.25-inch or other appropriate size pieces of wood (plate elements) that may be loaded axially or transversely with the grain. Two of these are attached on opposite sides at one end of a wooden board (center element) 1.75-inch x 5.75-inch x 36-inch with grain oriented transverse to the loading direction. They may be attached with nails, screws, or glue alone or in combination. The other two plate elements are similarly attached to the other end of the wooden board. Such fabricated elements can then be stacked to construct cribs similar to conventional cribs. Below are several advantages of the engineered wooden crib element as compared to the current prismatic wooden element:

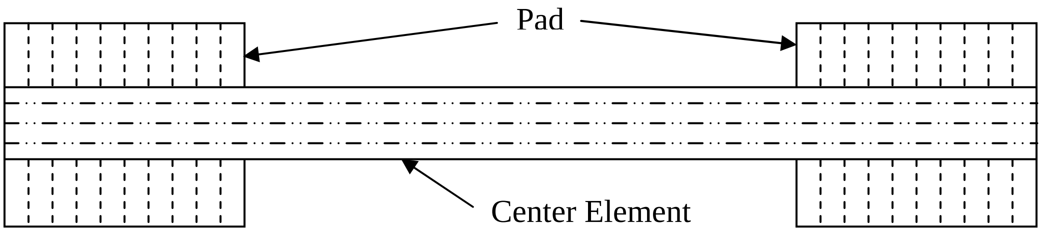


Figure 1: Schematic of a typical novel engineered crib element.

1. Since two-thirds of the total element may be loaded with the wood grain in the axial direction, it is capable of carrying significantly higher loads prior to failure.
2. Similarly, since elastic modulus in the axial loading direction is much higher than the parallel direction, the element can have much higher overall stiffness. Therefore, it should offer significant resistance to rock movement soon after installation.
3. A 30-inch long center element uses about 25% less wood as compared to a conventional element. For a 36-inch long center element, the reduction in use of wood amounts to over 30%. In both cases, the engineered element is considerably lighter than the conventional element.
4. The 1.75-inch x 5.75-inch x 36-inch center element, connecting the two rectangular contact points, has more than adequate strength to carry tensile and bending stresses for most applications. Furthermore, the element geometry allows lifting the element securely during the crib construction process.
5. The 1.75-inch x 5.75-inch x 36-inch board is loaded perpendicular to the grain which would normally yield at low stress level of 400-600 psi. Since it is squeezed between two plate elements (that have low Poisson's ratio) and it is further reinforced vertically and horizontally by nails and/or screws, and/or horizontal resistive forces offered by glue, the overall board can carry higher vertical loads prior to yielding or failure. The center element does, however, provide the yielding behavior of a crib and it can be engineered.
6. Since the load carrying capacity of an engineered crib can be much higher, the number of cribs required to support an area may be reduced.
7. Due to the geometry of the engineered crib element, its resistance to air flow is significantly reduced (about 50%) when compared with a conventional crib.
8. The geometry of the contact area for the engineered crib element can be readily changed by changing the size of the plate elements connected to the 5.75-inch x 1.75-inch x 36-inch center element. For example, the contact area for ATLAS 300 series crib is 7.75 inches x 9.75 inches rather than 5.75 inches x 7.75 inches for ATLAS 100 and ATLAS 200 series cribs. Designs can be changed to vary the load carrying and lateral stability requirements of the crib.

Although cribs have been used for roof support since the inception of mining, this crib concept has not been reported in the literature to the best of the PI's knowledge. Highly positive comments from industry and enforcement agencies alike indicate high commercial potential. The market for ATLAS cribs includes both coal and non-coal mines all over the world. It is estimated that the tri-state area alone has a market for about two million crib elements annually.

NIOSH Tested Crib Designs: Three different crib designs bearing the ATLAS trademark were developed and tested: ATLAS Series 100, ATLAS Series 200, and ATLAS Series 300. These are shown in Figures 2-4.

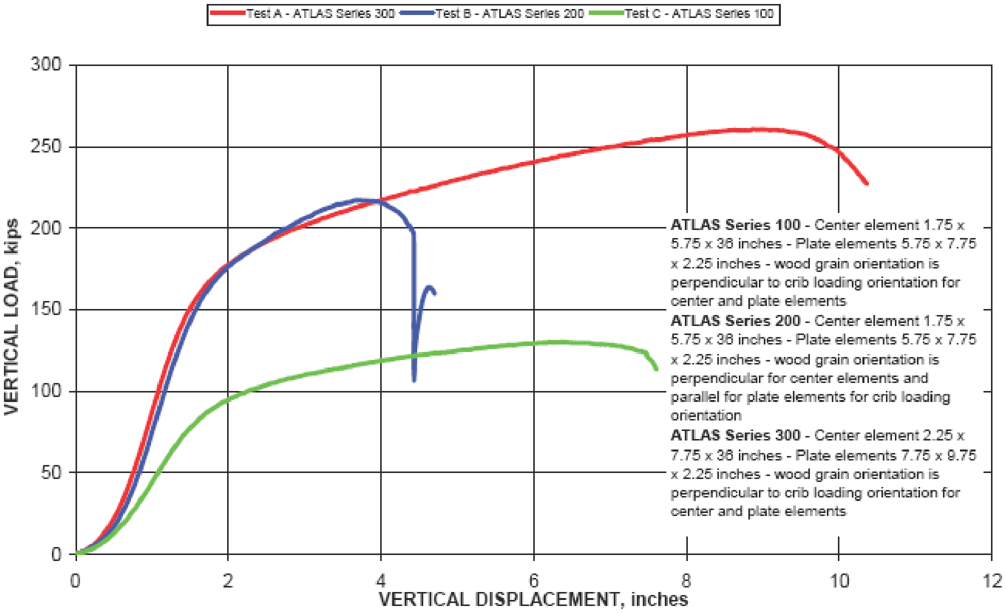
- Series 100 cribs are designed to replace current cribs with essentially similar load (60-70 tons) carrying characteristics and with added advantages of being lightweight and providing low airflow resistance. Examples of major application areas include all areas of room-and pillar mining, and relatively competent ground.
- Series 200 cribs are designed to provide high initial stiffness, and high load (~ 110 tons) carrying capacity with limited overall displacement (~4 inches) at failure. Examples of major application areas include all areas of room-and pillar mining, including areas of weak ground, roof fall areas, in front and behind mine seals, gob edges of retreat mining areas; and in longwall mining for tailgate entry support, set up rooms, and bleeder areas where expected movements are limited.
- Series 300 cribs are designed to provide high initial stiffness and high load (~135 tons) carrying capacity with large vertical and horizontal displacements at failure (~10 inches). Its characteristics are similar to CAN supports used in longwall tailgate entries. Examples of major application areas include weak ground, roof fall areas, areas with floor heave, gob edges of retreat mining areas, and longwall tailgate entry support, longwall set up rooms, and longwall bleeder areas where expected movements can be large.

Figure 2: ATLAS series 100.

Figure 3: ATLAS series 200.

Figure 4: ATLAS series 300.

NIOSH tested the performance of ATLAS 100, 200, and 300 Series cribs in their facilities according to standard protocols. Results were submitted to the project team and selected Mine Safety and Health Administration District Offices for use in approving these cribs in mines (Batchler, 2008). Summary results are presented in Figure 5 and a deformed crib during a differential loading test is shown in Figure 6.



ATLAS Series 100 - Center element 1.75 x 5.75 x 36 inches - Plate elements 5.75 x 7.75 x 2.25 inches - wood grain orientation is perpendicular to crib loading orientation for center and plate elements

ATLAS Series 200 - Center element 1.75 x 5.75 x 36 inches - Plate elements 5.75 x 7.75 x 2.25 inches - wood grain orientation is perpendicular for center elements and parallel for plate elements for crib loading orientation

ATLAS Series 300 - Center element 2.25 x 7.75 x 36 inches - Plate elements 7.75 x 9.75 x 2.25 inches - wood grain orientation is perpendicular to crib loading orientation for center and plate elements

Figure 5: Performance comparison between various ATLAS cribs.

Figure 6: ATLAS series 100 severely arching due to differential loading.

Summary verbatim comments from the NIOSH report follow:

“**Conclusions and Recommendations:** The ATLAS cribs can be designed to exceed the vertical load capacity performance of a ‘conventional’ 4-point crib made from mixed hardwood 6 x 6 x 36-inch timbers. However, the 4-point crib typically yields over 15 inches, where the ATLAS series cribs ranged from 4.4-10 inches. The grain orientation has a large effect on the performance of the ATLAS crib. By changing the grain orientation of the plate elements, the peak load capacity of the support can increase by 70% but displacement at which the peak load occurs decreases by 72%. Increasing the size and corresponding surface area of the corner bearing element by 70% increased the peak load capacity by 100% and maximum convergence by 40%. The bidirectional test indicated that the ATLAS cribs can withstand horizontal movement and still maintain their load capacity, convergence, and stability. The ATLAS cribs were also able to withstand the 2-inch differential load created from the foam contact offset.

The amount of moisture in wood can affect its material properties. Since these cribs were newly cut, it is recommended that a crib from each ATLAS series be tested at a later date when the wood has sufficient time to dry out.”

EXPERIMENTAL PROCEDURES

Each task had its own unique experimental procedures. Since experimental procedures for this project correlate closely with experimental results, those procedures are described in detail in the Results and Discussion section, which follows.

RESULTS AND DISCUSSION

Task 1: Establish Field Demonstration Site

The goal of this task was to establish a field demonstration site on a longwall tailgate entry in an Illinois mine. Such a site would allow substantial loading of the cribs when the longwall face passes. It would also allow monitoring their performance in extreme loading conditions over a period of time. Since cribs are generally carried manually over considerable distance (100-200 feet), such a site would also allow evaluation of their ergonomic advantages related to handling and crib construction by mine personnel.

The demonstration was conducted at the American Coal Galatia New Future Mine on the 1st West longwall face. The mine operates at about 425 feet depth 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 4-6 inches of Anna Black Shale, 5.5 feet of Brereton Limestone, and about 23 feet of massive sandstone. The immediate floor strata consist of claystone and shale with up to 10 feet of claystone in some areas.

The gate road development is a three entry system with entries 80 feet apart (center to center or c-c) and with cross-cuts at 150-feet (c-c) intervals (Figure 7). An extra “bleeder” entry surrounds the perimeter of a set of longwall panels to provide positive ventilation and an escape route in the event of emergencies. This bleeder entry is also part of the "set–up rooms" that connect gate road development entries. Supplemental supports are required in all bleeder entries and in the tailgate entry serving an active longwall face. Since the headgate of any given longwall panel usually becomes the tailgate of the next panel, tailgate entry supports are actually installed while the entry is on the headgate side of a longwall panel. Roof control plans require installation of these supplemental supports to be maintained about 200 feet ahead of the advancing longwall face. Cribs are installed in two rows spaced approximately 5–6 feet apart across the entry and eight feet or less along each row. Two additional cribs are placed in each cross-cut.

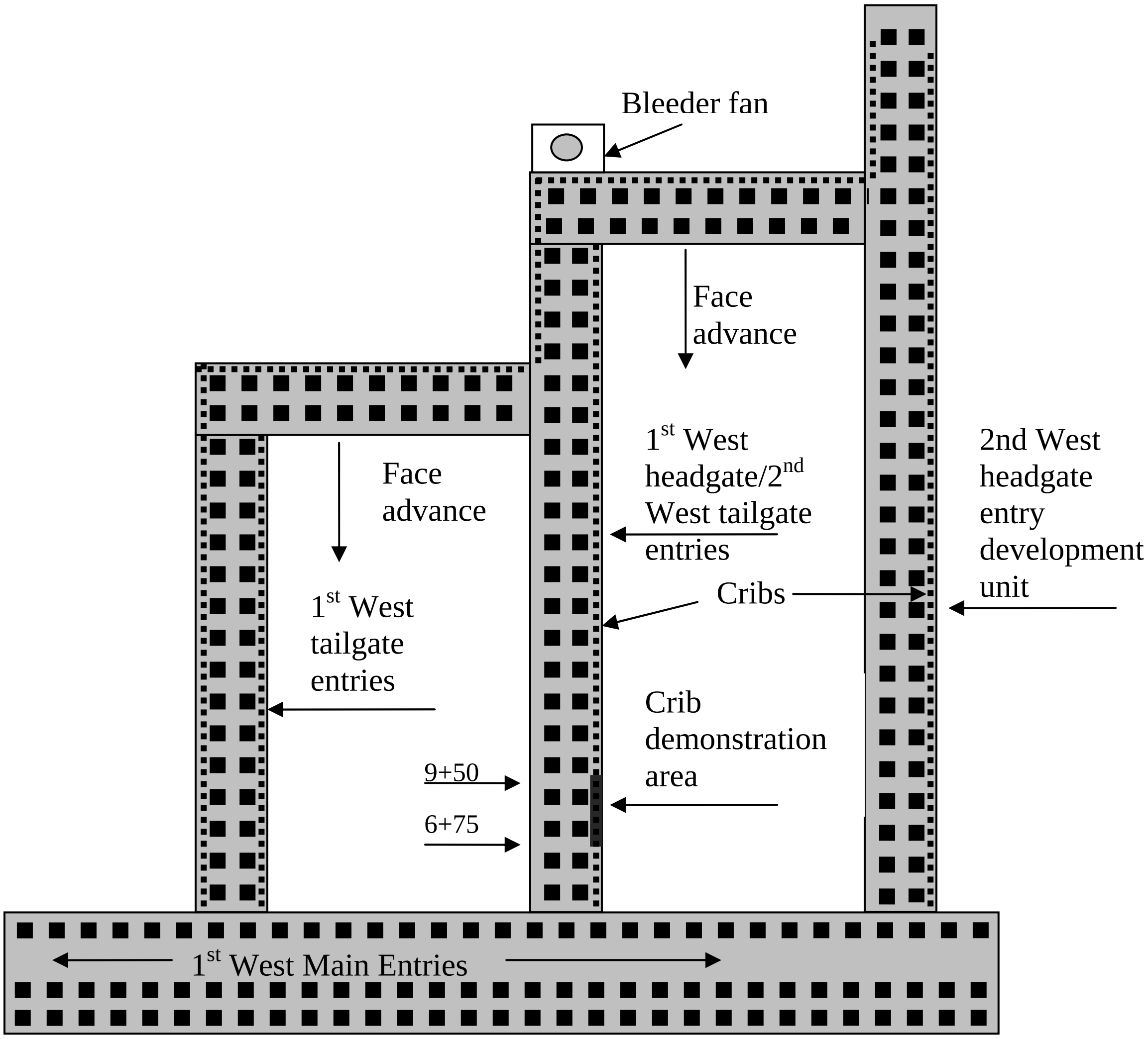


Figure 7: Crib demonstration area.

The demonstration area for engineered cribs is located in the right hand entry of the 1st West headgate/2nd West tailgate and spanned a distance of about 175 feet from footage mark 8+50 to 6+75 (Figure 7). Adjacent to this area from footage mark 9+50 to 8+50 was the area where conventional cribs were installed for side-by-side comparison. The average mining height in this area was about 7.5 feet. Two rows of cribs, five feet apart across the entry, were installed. The spacing between cribs along the entry was about eight feet. Engineered cribs were installed ahead of the longwall face. Installation of the these cribs began on the evening shift of March 21, 2008, with SIU personnel training employees in the proper installation of these cribs, The last crib was built on March 27, 2008. The cribs are located approximately 160-170 feet away (as the crow flies) from the longwall face. Therefore, high loads on the cribs are not expected during mining of 1st West longwall face. However, these cribs will be subject to very high loading when the 2nd West longwall face passes the area.

Task 2: Fabricate Engineered Crib Elements for Field Demonstrations

The goal of this task was to identify fabrication techniques, costs and to establish quality control. The project team had planned to work in cooperation with Taylor Saw Mill in Enfield, IL to fabricate the needed elements and perform quality control/quality assurance procedures. A fire at the saw mill in January 2008 temporarily closed it. Due to time constraints imposed by the advancing longwall, SIU personnel took on the task of fabricating the crib elements at the Illinois Coal Development Park in Carterville, IL.

ATLAS 100 Series cribs were used for the demonstration since the coal company wanted to compare the performance of this standard engineered crib with their conventional crib. Wood material was received from four Southern Illinois saw mills. SIU personnel prepared the wood components, assembled the crib elements and bases, packaged the elements and delivered them to the mine. Several fabrication improvements were identified during this process. The assembly time was decreased and the overall product quality was improved by eliminating the manual turning over of sub-assembled components. This minimized misalignment of individual components and improved the effectiveness of nails. Elements and bases were packaged so as to be able to construct two complete 6.5-feet high cribs from one package with minimal waste. These packaged units were designed for efficient material handling using a fork lift both on the surface and underground. Crib construction site waste was limited to just the steel banding, which is non-flammable and can be easily disposed of.

Quality Assurance and Quality Control: Dimensional QA/QC protocols, developed by the project team, are given in Table 1, along with an element diagram. In addition, moisture content of wood was also monitored. The dimensional protocols were developed to minimize uneven stacking of the elements in the cribs that can affect load carrying capacity as well as lateral stability of installed cribs. It should be noted that center element thickness minimal value is 1.75 inches knowing fully well that variations will occur. This was done purposely to reinforce to the manufacturers that this is the critical thickness. QA/QC data were taken for 100 randomly selected crib elements during the manufacturing process. This data included width, length, and height or thickness of each plate element and center element, and width, length, and overall height of the assembled element. In addition, element weight and the moisture content of plate and center elements were also measured. These data were also used for process improvement and training purposes for fabrication of crib elements. QA/QC data was collected on randomly selected ATLAS crib elements using a digital caliper, a dial caliper and a tape measure. Data from several saw mills are presented in Tables 2-5. QA/QC data are summarized in Table 6. The largest percentage of elements below recommended value is related to the center element thickness. However, data showed that if the center element minimum thickness value was set slightly below 1.75 inches (~1.70 inches), almost all elements pass the QA/QC control.

For the study mine demonstration, individual crib components were inspected before assembly for dimensional tolerance and wood quality. Once assembled, 100 of the finished crib elements were randomly selected for inspection. A small number of elements were rejected for not meeting dimensional tolerances and wood defects.

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

ATLAS series crib element maximum and minimum dimensional tolerances (inches)										
ATLAS crib series	**A - Pad thickness**		**B – Center element thickness**		**C - Pad length**		**D - Center element and pad width**		**E - Center and total element length**	
	Max.	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**
ATLAS 100	2.5	2.25	2	1.75	8	7.625	6.125	5.75	36.25	35.875
ATLAS 200	2.5	2.25	2	1.75	8	7.625	6.125	5.75	36.25	35.875
ATLAS 300	2.5	2.25	2.75	2.5	10	9.625	8.125	7.75	36.25	35.875

*Dimensions A, B, C, D, and E are defined below in the diagram of an ATLAS element.

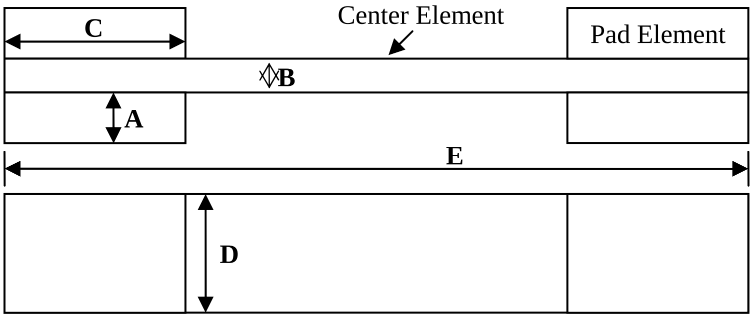


Table 2: QA/QC data for saw mill 1.

Element Specification	**No of Elements Tested**	**Target Dimension (in.)**	**Minimum Dimension (in.)**	**Mean Value (in.)**	**Std. Dev. (in.)**	**% At or above target**	**% Below accepted minimum**
Pad Thickness	50	2.25	2	2.182	0.14738	98	2
Pad Length	50	7.75	7.625	8.022	0.14474	98	2
Pad Width	50	5.75	5.75	5.766	0.03374	98	2
Center Thickness	25	1.75	1.75	1.72	0.10537	40	60
Center Height	25	36	35.875	36.033	0.04083	100	0
Center Width	25	5.75	5.75	5.7837	0.02609	96	4
Total Element Height	50	6.25	6.125	6.2	0.15497	94	6

Table 3: QA/QC data for saw mill 2.

Element Specification	**No of Elements Tested**	**Target Dimension (in.)**	**Minimum Dimension (in.)**	**Mean Value (in.)**	**Std. Dev. (in.)**	**% At or above target**	**% Below accepted minimum**
Pad Thickness	50	2.25	2	2.143	0.03891	100	0
Pad Length	50	7.75	7.625	8.082	0.03156	100	0
Pad Width	50	5.75	5.75	6.094	0.44696	66	34
Center Thickness	25	1.75	1.75	1.761	0.064	60	40
Center Height	25	36	35.875	36.025	0.04419	100	0
Center Width	25	5.75	5.75	6.1338	0.074	100	0
Total Element Height	50	6.25	6.125	6.082	0.08408	28	72

Table 4: QA/QC data for saw mill 3.

Element Specification	No of Elements Tested	Target Dimension (in.)	Minimum Dimension (in.)	Mean Value (in.)	Std. Dev. (in.)	% At or above target	% Below accepted minimum
Pad Thickness	91	2.25	2	2.301	0.09393	100	0
Pad Length	91	7.75	7.625	7.859	0.42023	100	0
Pad Width	91	5.75	5.75	5.9006	0.06727	98	2
Center Thickness	57	1.75	1.75	1.7939	0.05006	61.40	38.59
Center Height	57	36	35.875	35.921	0.12694	57.80	42.10
Center Width	57	5.75	5.75	5.7807	0.14327	56.14	43.85
Total Element Height	101	6.25	6.125	6.4331	0.12351	99	1

Table 5: QA/QC data for saw mill 4.

Element Specification	No of Elements Tested	Target Dimension	Minimum Dimension (in.)	Mean Value (in.)	Std. Dev. (in.)	% At or above target	% Below accepted minimum
Pad Thickness	160	2.25	2	2.177	0.09643	98.75	1.25
Pad Length	160	7.75	7.625	8.033	0.1137	99.38	0.63
Pad Width	160	5.75	5.75	5.953	0.1175	87.50	12.50
Center Thickness	40	1.75	1.75	1.567	0.10999	2.50	97.50
Center Height	40	36	35.875	35.989	0.16192	82.50	17.50
Center Width	40	5.75	5.75	6.042	0.13306	95	5
Total Element Height	80	6.25	6.125	6.096	0.12893	25	75

Table 6: QA/QC data for cribs supplied to demonstration mine.

Element Specification	**No of Elements Tested**	**Target Dimension (in.)**	**Minimum Dimension (in.)**	**Mean Value (in.)**	**Std. Dev. (in.)**	**% At or above target**	**% Below accepted minimum**
Pad Thickness	100	2.25	2	2.165	0.194	99	1
Pad Length	100	7.75	7.625	8.05	0.096	99.5	0.5
Pad Width	100	5.75	5.75	5.95	0.211	83	17
Center Thickness	50	1.75	1.75	1.741	0.089	54	46
Center Height	50	36	35.875	36.03	0.0422	100	0
Center Width	50	5.75	5.75	5.96	0.185	98	2
Total Element Height	50	6.25	6.125	6.14	0.085	51	49

ATLAS Crib Installation Procedures: The developed procedures are described below.

Site preparation: ATLAS cribs should be installed on a relatively level surface. Site preparation should include the removal of loose material to ensure good contact between crib pads or bases and the immediate, relatively competent floor strata. Loose material can be shoveled or scraped away to expose a relatively competent, level surface on which crib pads or bases can be set. One of the advantages of ATLAS cribs is that site preparation is easier than for conventional cribs.

Crib construction:

- Where crib bases are required to distribute load over a larger area due to weak, immediate floor strata, the installation of the ATLAS crib must begin with four bases that can be supplied along with the crib. They are placed flat and level upon the floor in a position to accept the first layer of crib elements and oriented in such a manner that element pads are centered on base pads.
- Once the initial layer is installed, subsequent layers of elements should be installed by placing the next layer of elements perpendicular to the preceding layer and centering pads upon each other. The ends of pads should overhang the width of pads by approximately 0.75 of an inch to 1 inch (See Figure 8).
- Stacking should continue until the crib structure reaches the roof or until the remaining space is less than the height of a crib element. The remaining space may be filled in with competent wood blocking material that is centered upon the

upper most pads. The blocking material is available in thickness of 1-inch, and 2-inch. Wedges are used to tighten the crib structure against the roof and floor.

- Proper tightening of the crib includes inserting wedges in pairs from opposing sides and positioning them to allow full contact between the wedges and element pads. Wedges should be hammered in until the crib structure contacts the floor and roof at all four corners and all layers of the crib structure are in full contact with adjacent layers. Sufficient preloading of the crib structure aids in immediate roof support and reduces the unloading of the crib due to shrinkage during the drying process.

Constructed height limit: Conventional and ATLAS cribs perform best when the aspect ratio (height of the crib divided by distance between centers of contact areas) is less than 3.5. For 36-inch long elements, it is recommended that crib height should not exceed about 8-feet. Beyond that height, buckling of crib can occur at reduced load.

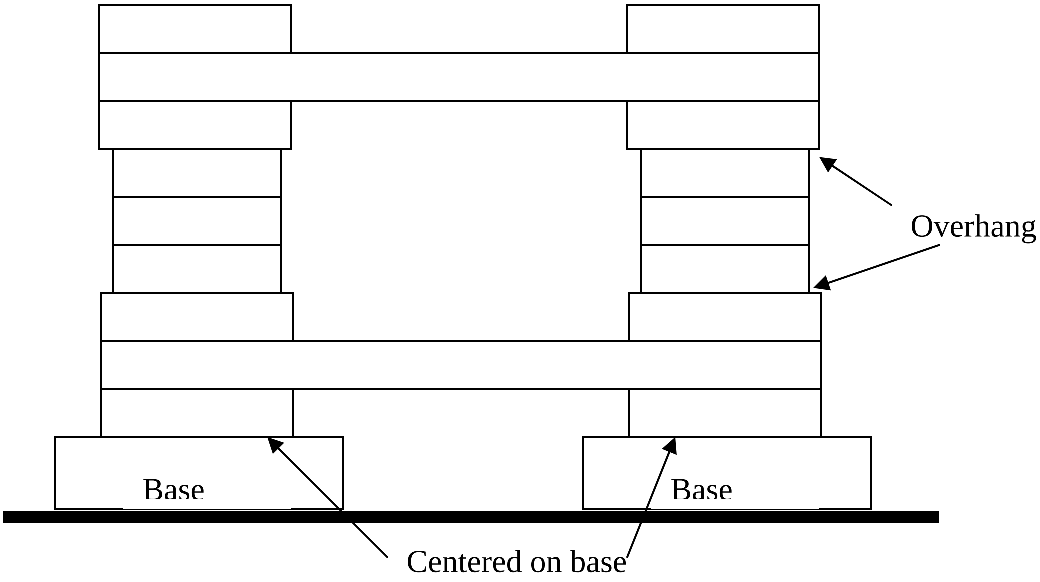


Figure 8: Proper installation of an ATLAS crib.

Engineering Properties of Different Species of Wood: Strength-deformation properties of different species of woods are of major interest in this project. Therefore, samples of four different species of wood from the tri-state area were procured and tested for strength-deformation properties with grain orientations parallel and perpendicular to loading direction. Although this was not part of the original project, it was considered an important task for future design of engineered crib systems. The results of these studies are summarized in Table 7.

Table 7: Strength–deformation properties of different wood species.

Species and test orientation to grain Pa = Parallel Pr=Perpendicular	**Average initial yield stress (psi)**			**Average elastic modulus prior to yield (psi)**			**Ultimate strength (psi)**			**Average elastic modulus post-yield (psi)**			**Average moisture content (%)**		
	1 day	**30 days**	**60 days**	**1 day**	**30 days**	**60 days**	**1 day**	**30 days**	**60 days**	**1 day**	**30 days**	**60 days**	**1 day**	**30 days**	**60 days**
Hickory – Pa	2495	2929	2724	162839	137592	122638	>2800	>2800	>2800	N/A	N/A	N/A	46.8	19	18.2
Hickory - Pr	995	1025	1026	38728	23224	26368	2289	2459	2634	5775	5867	6463	46.2	17.4	21
Red oak - Pa	2551	2754	2731	197877	195869	181614	>2800	>2800	>2800	N/A	N/A	N/A	37.4	19	22.5
Red oak - Pr	956	969	988	36681	34703	32476	1768	2015	2673	3203	4496	4985	33.8	20.9	21.2
Sycamore - Pa	2587	2889	2785	166326	173581	124713	>2800	>2800	>2800	N/A	N/A	N/A	48.1	21.8	18.3
Sycamore - Pr	843	643	677	33099	17209	21666	1907	2687	1866	3023	3672	3583	47.3	28.2	22
Poplar - Pa	2382	2541	2866	107497	152239	124925	2382	>2700	>2800	N/A	N/A	N/A	72	25.6	19
Poplar - Pr	288	364	431	15766	14735	18133	2083	2529	2945	7653	2554	2830	68.7	37.1	19.2

Note: Sample sizes for parallel and perpendicular orientations for hickory, red oak and sycamore species were 9 and 18, respectively. Similar sizes for poplar were 5 and 12.

Task 3: Perform Field Demonstration of Engineered Cribs in Mines

The objective of this task was to evaluate material handling characteristics, installation techniques and performance of the engineered cribs in underground environment.

Installation of Cribs: The demonstration area was shown earlier in Figure 7. The initial installation of the cribs began at the footage mark of 8+50 in the 1st West headgate return entry. The longwall face location at the time crib installation began was approximately at the 10+50 footage mark. Packaged ATLAS engineered cribs were located in the 1st West headgate return entry at cross-cut 7+25 requiring them to be manually transported about 125 feet to the construction site at 8+50. Mine employees were able to carry two ATLAS elements per trip thus reducing the transport time by about 50%. Once all ATLAS crib elements were manually relocated to the construction site, SIU personnel instructed mine employees on proper installation procedures. Two rows of cribs, five feet apart across the mine entry, were installed. Spacing between cribs along the entry was about eight feet. Installation of these cribs began on the evening shift of March 21, 2008 and the last crib was built on March 27, 2008. Some of the installed ATLAS cribs are shown in Figures 9 and 10.

Figure 9: Installed ATLAS crib.

Figure 10: Installing an ATLAS crib.

Crib packaging was designed to allow handling using typical material handling equipment such as forklifts. The underground forklift used at the mine, called a CLA, had fixed stationary forks that were not compatible with openings in the ATLAS crib units. A redesign of the packaged unit will allow for handling by almost all types of material handling equipment commonly used at mines.

Training of Mine Workers and Installation Time Study Results: The project team instructed mine employees in the proper procedures developed for constructing an engineered crib. This included site preparation, crib base placement, stacking and alignment of the novel crib elements and tightening procedures. Once trained, time studies were performed on construction of engineered and conventional cribs. Since the two types of cribs were located in adjacent areas, site conditions and cribs heights were very similar. Time studies on construction of six cribs of each type indicate about 25-30% improvement in installation time of a novel engineered crib. Mine workers provided very positive reviews of the weight and handling characteristics of the engineered crib. These attributes were specially touted when the underground personnel had to manually carry elements over large distances.

Monitoring of Crib Performance: Continuous monitoring equipment, provided by NIOSH, was installed on March 26, 2008, by NIOSH and SIU personnel, to monitor crib loading and roof-to-floor convergence in the demonstration area. Three conventional cribs and six engineered cribs were instrumented. Two roof-to-floor convergence monitoring stations were located in the engineered crib area and one in the conventional crib area. In addition, load cells designed by SIU were installed in two conventional and two engineered cribs.

The crib load monitoring equipment consisted of wire extensometers mounted on the crib structure. The extensometer transducer was attached near the roof to a crib element using screws and the wire was extended to an eye bolt inserted into an element near the floor (Figure 11). Here it is assumed that crib compression is directly related to the 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 attached to a roof bolt plate and the wire attached to an anchor that was grouted approximately 12 inches into the floor (Figure 12). An intrinsically safe, battery operated, digital data acquisition system (DDAS) was placed in a nearby cross-cut and each wire extensometer was attached to the DDAS with a data cable. Data was continuously collected until removal of the DDAS unit on May 7, 2008 at the request of NIOSH for use in another study. NIOSH has not yet provided the calibration curve for relating wire extensometer displacement and load on cribs. Therefore, results are presented here in units of displacement.

(a) (b)

Figure 11: Wire extensometer attached to (a) bottom element, and (b) top element.

(a) (b)

Figure 12: Wire extensometer attached to (a) roof bolt anchor, and (b) floor anchor in a roof-to-floor convergence monitoring station.

Crib Load Monitoring by SIU Load Cells: In a previous study on performance of fly ash cribs, SIU had successfully developed and used load cells to monitor load on cribs. Such a cell consists of a composite polymer material sandwiched between two 6-inch square by 0.5-inch thick steel plates. Compression of the composite material, at the four corners of the plate, is manually monitored by a 0.001-inch resolution caliper. 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 a considerable amount of time is required to gather the data. SIU is in the process of modifying this load cell so that it can monitor data continuously.

The SIU project team installed these load cells in two engineered and two conventional cribs. These were placed at approximately five feet above the floor level between each of the four contact points of a crib layer (see Figure 13). A digital micrometer was used to measure the distance between the two steel plates at each of the four corners of the load cell assembly. The average displacement data was plotted as a function of face advance. A total of 16 measurements at different times were taken for each of the four monitored cribs with installed load cells. The load-deformation behavior of the composite polymer material used is given by the following equation.

$$\text{Load (kips)} = 0.0274\, D - 0.025 \qquad (1)$$

where, D = displacement in inches.

Figure 13: SIU developed load cell in one corner of an ATLAS crib.

Moisture Gain/Loss Studies: After crib installation, moisture was monitored in four elements over a period of one week. Moisture data was collected near the wood surface using a GE Protimeter. The data presented in Table 8 indicates that there was a very small change in moisture content over the one week period.

Table 8: Data on moisture gain/loss at Galatia mine.

Crib Element	**Moisture Content March 31, 2008**	**Moisture Content April 8 , 2008**
ATLAS 5B	32.4%	32%
ATLAS LC1	26.3%	26%
Conventional 2B	21.8%	21%
Conventional LC2	26.8%	28%

Task 4: Data Analysis and Synthesis

The purpose of this task was to collect and analyze data from industrial engineering studies and monitoring equipment to make an assessment of the performance of the engineered cribs when compared to conventional cribs. Results are presented below.

Monitoring of Loads on Cribs Using NIOSH Equipment: Data collected on the DDAS during the period from March 26 to May 7 for all conventional and ATLAS cribs are summarized in Figure 14. For 475 feet of advance of the longwall face, the displacement units related to load on cribs varied 30 to 85. The displacement units carried by ATLAS cribs are very similar. Therefore, both sets of cribs are carrying similar loads. Data for ATLAS cribs further shows a slightly flattening trend for incremental load after the longwall face passes, which was expected.

Similar data plotted as a function of time rather than face distance is shown in Figure 15. Although this data is not as meaningful as the data as a function of face advance, from an interpretation point of view, it is presented here for the sake of completeness. This data again shows that both types of cribs are performing very similarly. Overall, the ATLAS cribs also appear to have more uniform load distribution than conventional cribs.

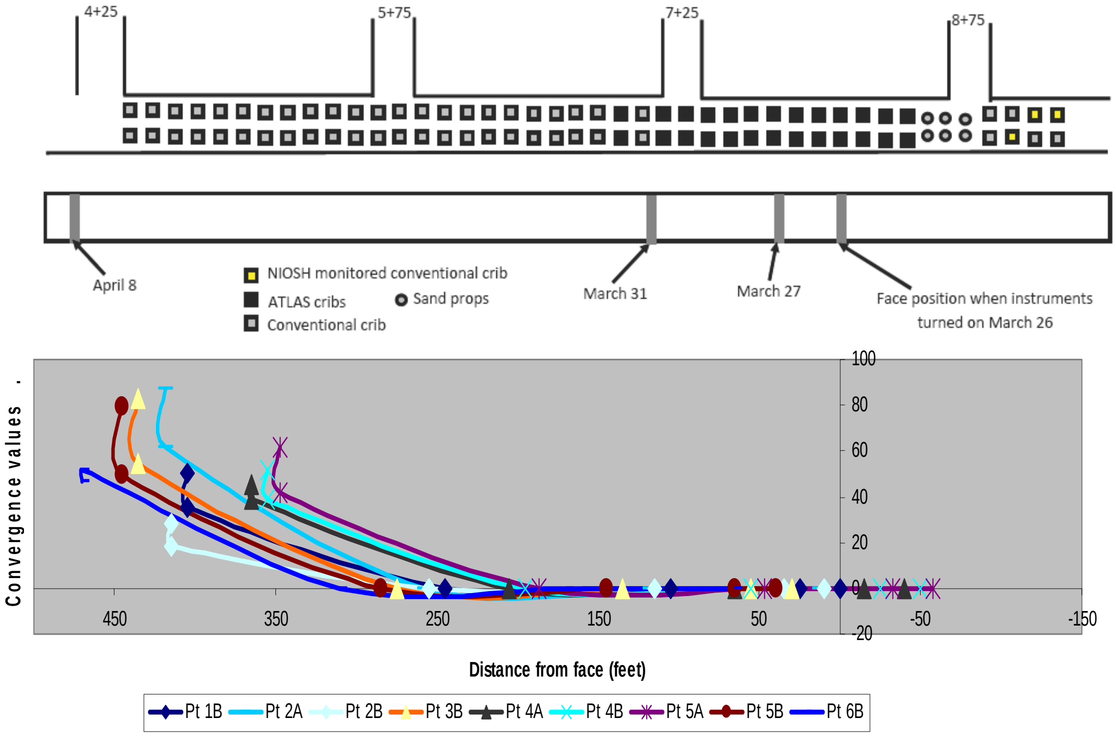


Figure 14: Load on cribs vs. distance from face using NIOSH equipment.

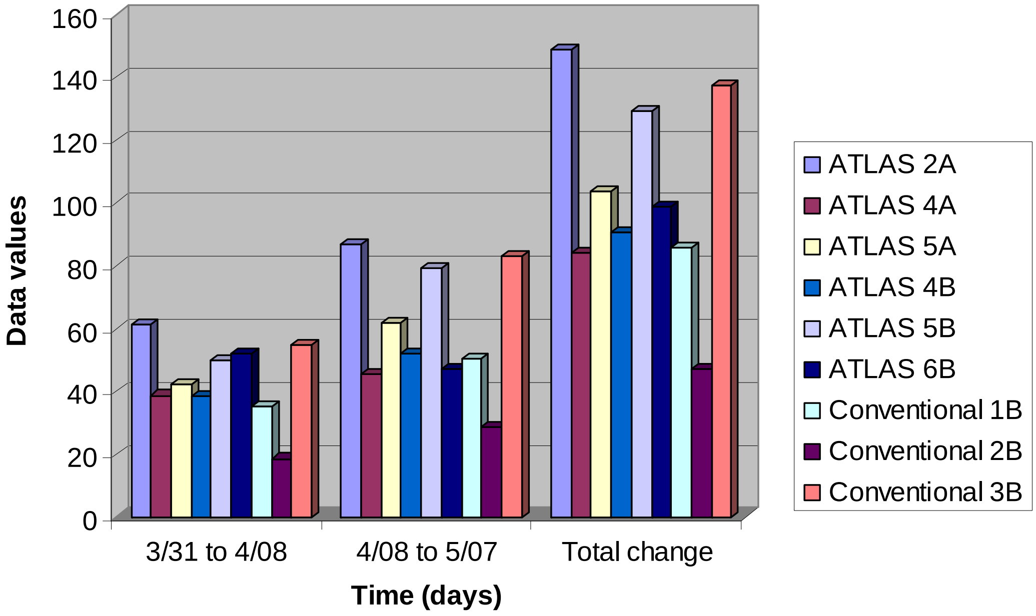


Figure 15: Crib loading as a function of time using NIOSH equipment.

Roof-to-Floor Convergence Data Using NIOSH Equipment: Data collected using the DDAS during the period from March 26 to May 7 for one point in the conventional crib area and two points in the ATLAS crib area are summarized in Figure 16. The data values are very similar indicating that both sets of cribs are providing similar resistance to roof-to-floor movements.

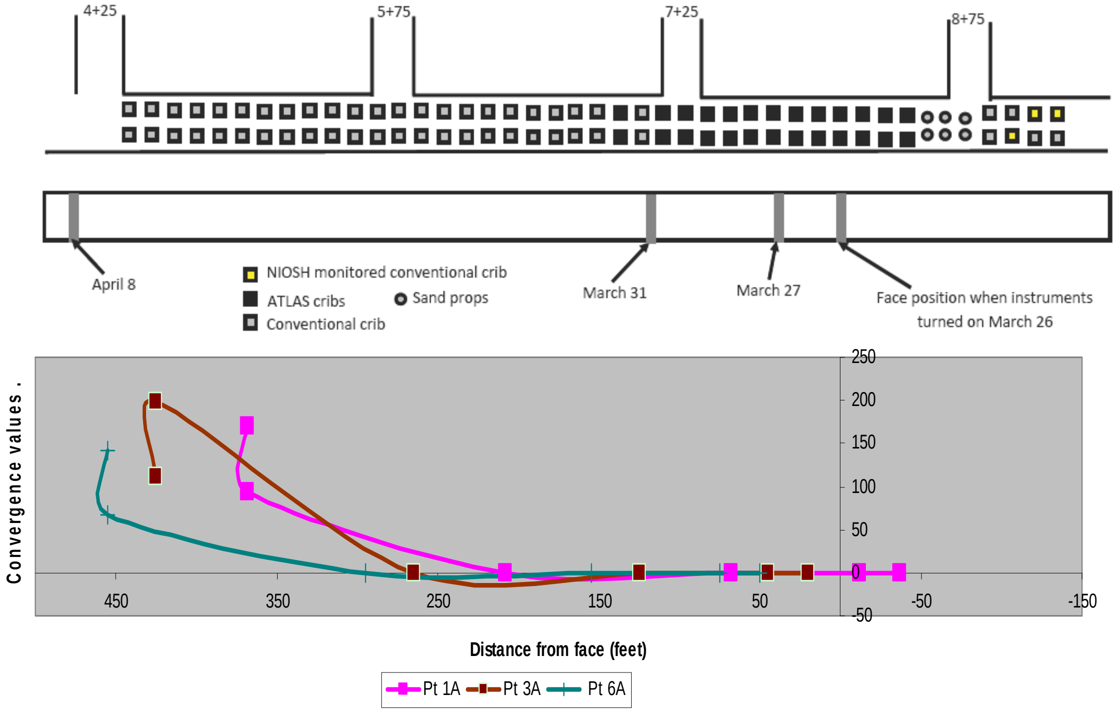


Figure 16: Roof-to-floor convergence vs. distance from face using NIOSH equipment.

Similar data, as a function of time for a 42-day period, is shown in Figure 17. Roof-to-floor convergence is increasing as a function of time in both areas but the value during the period 4/08 to 5/07 is slightly higher in areas with conventional cribs. This is most likely due to time effects since longwall mining through the conventional crib area was done before the area with engineered cribs. The higher value for ATLAS cribs during the period 3/31 to 4/08 is because mining was done adjacent to them. The influence of this mining on conventional cribs was small since the distance from active mining is large.

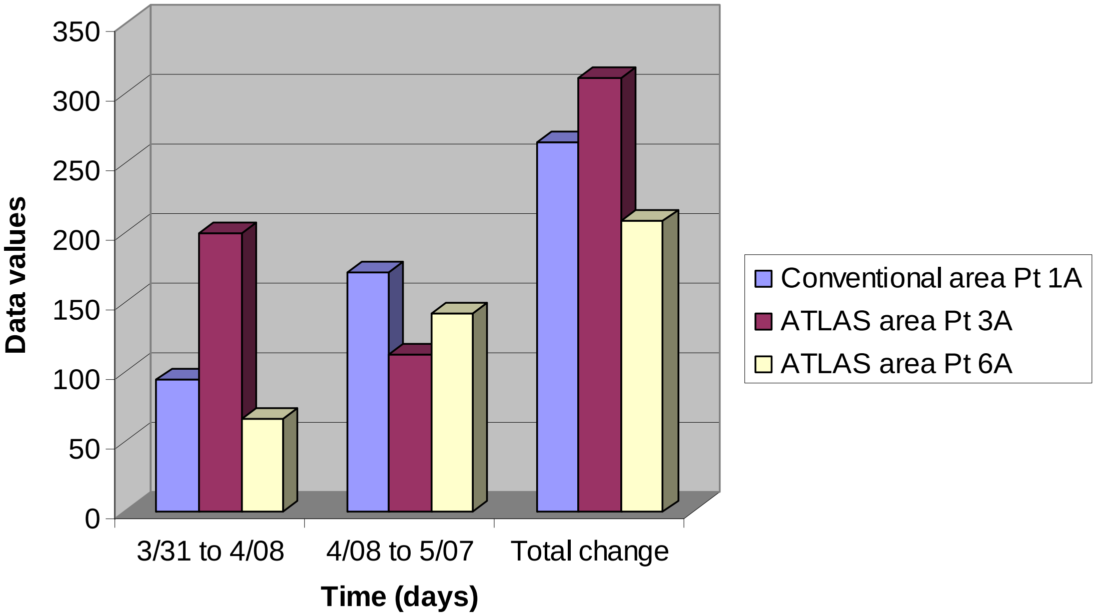


Figure 17: Roof-to-floor convergence as a function of time using NIOSH equipment.

SIU Load Cells Monitoring Data: Manually collected data from conventional and ATLAS cribs during the period March 26 to May 7 are summarized in Figure 18. Again, data shows that both types of cribs are performing very similarly. The slope of the load increase as a function of face advance is slightly higher for ATLAS cribs. This could be due to the slightly higher stiffness of ATLAS cribs. The initial drop in load is most likely due to shrinkage of wood.

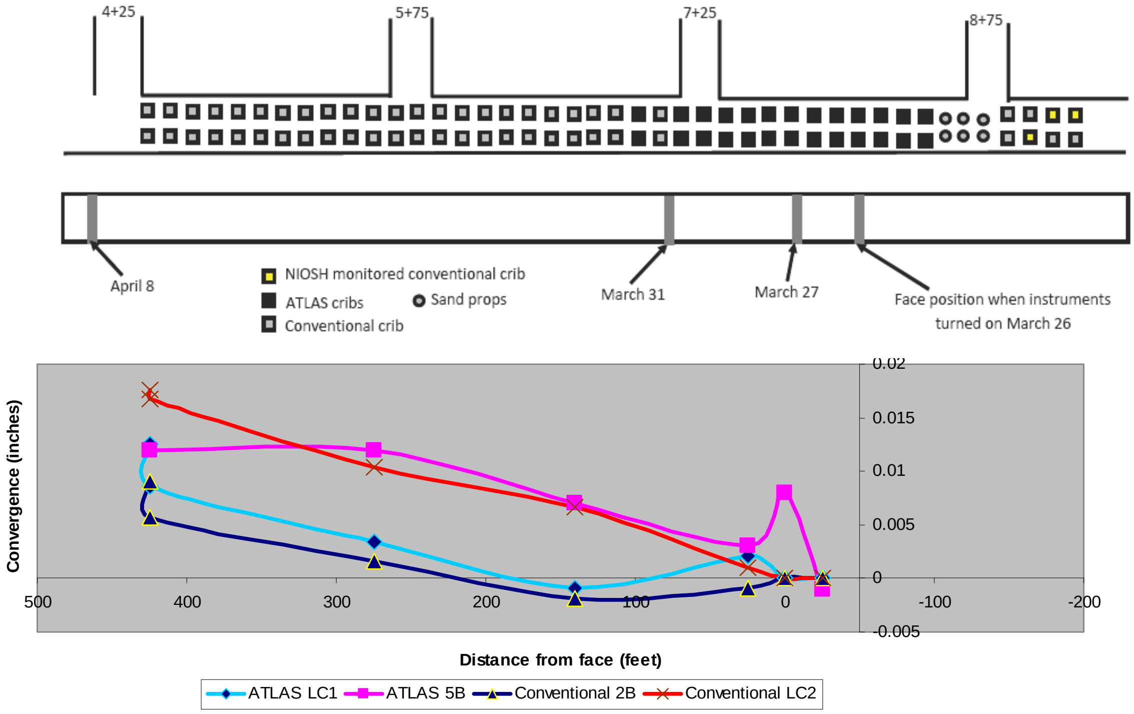


Figure 18: Crib loads as a function of time using SIU load cells.

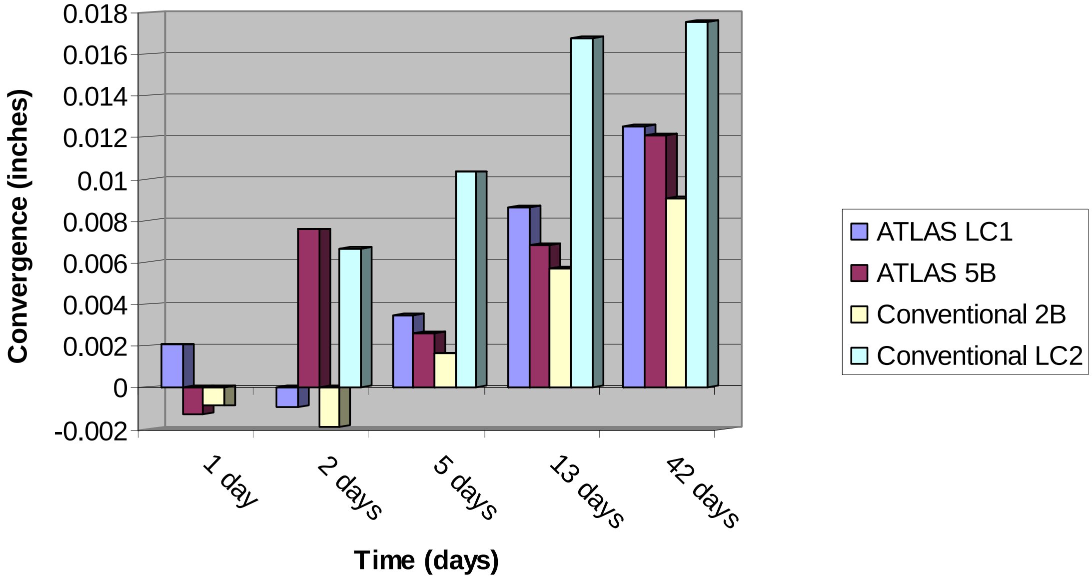


Figure 19: SIU load cell data on cribs as a function of time.

Visual Observations: During the period of the study, several visits were made to the demonstration area to make 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. This would not have been expected since the loads being carried by the cribs are very small as compared to expected loads when the 2nd West longwall face passes in the fall of 2008.

Summary of Data Collected to Date: All data collected to date confirm that ATLAS cribs are performing as well as or slightly better than conventional cribs. It should be mentioned, however, that cribs are currently not taking much load. The real test of their performance will occur when the 2nd West longwall passes the demonstration area. NIOSH has already sent their data logger to the project team for initiation of data gathering for the expected large increase in load and roof-to-floor convergence that will occur at that time.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

- During the study period, engineered cribs were manufactured by four saw mills in southern Illinois and western Kentucky with oversight by the project team. The developed QA/QC protocols were implemented during manufacturing. Results of QA/QC studies indicate that manufactured cribs were within allowable limits from three saw mills. A shipment from the fourth saw mill was stopped since it did not meet QA/QC protocols.
- Installation procedures were developed for engineered cribs. Training was provided to American Coal Galatia Mine workers on the proper installation of engineered cribs prior to their installation in the demonstration area.
- The installation time for an engineered crib was typically about 25-30% less than the installation time for a conventional crib.
- Significant time savings can accrue from engineered cribs where the crib elements must be manually transported over a long distance. This is because two engineered crib elements can be easily carried by one person since they are about 40% lighter. Therefore, manual transportation time is reduced by about 50%.
- Site preparation for engineered cribs was much easier since only four small areas, equal to the size of each base, need to be prepared.
- Based on available data to date, engineered cribs are performing very similar to conventional cribs.
- Input was sought from the American Coal’s chief engineer, longwall coordinator, section bosses, and workers carrying and installing the engineered cribs. Almost all comments received were positive.
- During the project period, engineered cribs were demonstrated to high-ranking coal company professionals at several mines to seek their input. This was done in lieu of an advisory committee. The mines included Wild Cat Hills, Gibson County Coal, Sunrise Mining Company, and Vermillion Grove. Again, comments received were positive.

- During the last visit to the demonstration area on July 1, 2008, engineered cribs seemed to be performing as well as the conventional cribs from a visual perspective.
- Overall, this demonstration study to date is considered a success. Over 2,000 crib elements were shipped to mining companies for experimental trials. One mining company plans to install them in front of mine seals while another mining company has used them to support weak roof areas.

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 one or two large size demonstrations are performed and the data widely disseminated to industry and MSHA.
- Based on the previous recommendation, the ICCI has already approved another field demonstration at the Galatia Mine where ATLAS 100 series cribs will be installed in cross-cuts next to the belt entry on the 2nd West headgate to evaluate their performance when the longwall face passes. This demonstration should be completed by October 2008.
- 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 should stay focused to meet the demand for ATLAS cribs in the tri-state area. If additional longwall faces are implemented in Illinois, most of the demand for ATLAS cribs will be in Illinois.

REFERENCES

Batchler, Timothy J. (2008), Performance Comparison of ATLAS Series Wood Cribs, National Institute for Occupational Safety and Health Mine Roof Simulator, Project CAN: Z6NL, Development and Evaluation of Innovative Roof Support Technologies, January 16, 2008.

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