Project Title: FIELD ASSESSMENT OF SIU ENGINEERED WOODEN CRIBS IN LONGWALL AND ROOM-AND-PILLAR MINING

ABSTRACT

The ATLAS crib, developed at SIUC in 2007, is a composite engineered wood element used to provide supplemental roof support in longwall and room-and-pillar mining areas of underground mines. The ATLAS crib element achieves improved properties of strength, stiffness, and yield while using approximately one-third less wood, weighing about 40 percent less, and offering 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.

Field demonstrations of ATLAS Cribs on a longwall face were conducted under ICCI Project Number DEV07-2 “Underground Performance Assessment of an Engineered Composite Wooden Crib for Tailgate Entry Support in Longwall Mining” and ICCI Project Number 08-1/US-2 “Monitoring and Analysis of SIUC Engineered Wooden Cribs in Two Longwall Mining Areas”. During these projects, ATLAS and conventional cribs were installed in headgate entry return air courses and in headgate belt entry intersections and side-by-side performance was monitored while the longwall face mined passed them. The current project is a continuation of ATLAS and conventional crib monitoring over a larger area (~1,000 ft of gate entry) while adjacent longwall faces mine passed and through the demonstration area subjecting cribs to the highest possible load.

Both ATLAS 100 and ATLAS 300 cribs were installed in a longwall gate entry as part of this project. In addition, ATLAS 100 and conventional cribs were instrumented in four adjacent intersections at a room-and-pillar mining operation and were monitored over a period of time for loading, shrinkage, and convergence. In both demonstration areas, ATLAS 100 cribs performed extremely well compared to conventional cribs. Data collected by NIOSH on crib convergence and roof-floor convergence indicate that ATLAS 100 crib areas had significantly lower convergence than conventional cribs areas in the longwall demonstration area. Thus, ATLAS 100 cribs resisted rock mass movements better than conventional cribs. In the room-and-pillar intersection area, ATLAS 100 cribs also demonstrated improved roof support and shrinkage characteristics when compared to conventional cribs. Mine professionals also indicated that ATLAS 100 cribs demonstrated significant ventilation advantages over conventional cribs. Similar data for ATLAS 300 cribs will be collected in a follow-up project.
EXECUTIVE SUMMARY

Upon creation of an excavation, the surrounding rock mass begins to deform. Deformation continues even after primary roof supports are installed creating a dynamic environment for loading and displacement of these installed supports. An understanding of this dynamic environment is a prerequisite for operating a safe and efficient mine. The dynamic environment depends upon regional and local rock mass geology, in-situ stress, and the geometry of the excavation. Changes can be significant as roof loading progresses toward collapse. As the US Mine Safety and Health Administration (MSHA) has a goal of zero roof falls in underground mines, more emphasis is being placed on adequate roof supports. Part of a recent ICCI project titled “Development of Improved Roof Support Systems for Illinois Underground Mines” determined that: 1) Frequency of roof falls per million tons of production has not decreased in the last 25 years, 2) 80% of roof falls in underground coal mines occur at intersections and the majority of these falls occur in four-way type intersections, 3) Roughly one-third of falls occur within 90 days after excavation, and 4) Most falls reach a height of one to two feet above the installed bolt length. Four-way intersections like that shown in Figure 1 are created when crosscuts, typically spaced at 60 to 100 feet intervals, are mined to intersect each side of an entry at the same point. The excavation size at such an intersection can become quite large when corners are mined, either intentionally or unintentionally. This area, although primarily supported with roof bolts, can deteriorate and exceed roof bolt load capacity and ultimately fail. Roof failures disrupt mining operations, ventilation, and the safe passage of personnel. Removing fallen material and rehabilitating intersection supports can become costly for the mine operator as well as create a long-term safety hazard to mine personnel. To minimize these occurrences, mine operators resort to supplemental support systems that are typically installed when roof conditions indicate a near-term failure or roof fall. Once roof conditions deteriorate to a point that visual observations indicate impending failure, installing supplemental supports may or may not prevent collapse. A key to preventing roof failure is to provide adequate supplemental support soon after excavation, especially in areas that are typically troublesome, such as intersections or areas where roof lithology is weak (i.e. absence or thinning of limestone).

Coal mines typically use wooden cribs to provide supplemental standing support between roof and floor. Such support is almost always required in longwall bleeder, set-up, and tailgate return entries and is often needed in room-and-pillar operations to maintain proper ventilation and more importantly, to provide safe egress for mine personnel in case of emergencies. Monitoring loads on these supports provides a better understanding of the dynamic environment. A simple approach to monitoring is to measure the deformation of a relatively low stiffness material between two steel plates. Roof-to-floor convergence around a support also provides data on compression of the support. In collecting this data, underground mining regulations prohibit exposure of personnel to unsupported roof. Non-permissible electrical equipment in face areas or in return air is also prohibited preventing the use of some sophisticated electronic measurement devices in these areas. NIOSH has been using approved precision potentiometers in conjunction with permissible data loggers for monitoring roof-to-floor convergence and displacement loads on supports such as cribs and posts. Continuous, automated monitoring of artificial
supports and roof-floor convergence is very desirable in areas such as longwall tailgate entries since workers tasked with gathering data are not exposed to hazardous conditions.

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 to provide temporary support during the shield removal process when moving longwall equipment from one area to another. A typical crib is made of 6-inch × 6-inch prismatic wooden elements that are 30 or 36 inches long, although other sizes may also be used. A typical longwall coal mine may use 400,000 to 500,000 crib elements each year at a cost of over $2.0 million or more annually. Performance monitoring of ATLAS 100 cribs over a 950-ft distance in a longwall tailgate entry has demonstrated that overall, they perform at least as good as or better than conventional cribs. Roof-to-floor convergence in the section of tailgate entry supported by ATLAS 100 cribs was less than in the section of tailgate entry supported by conventional cribs, confirming results obtained in an initial demonstration done over a 250-ft distance. Mining delays kept the longwall from passing the demonstration area with ATLAS 300 cribs during the timeframe of this project; however, a follow-up project will be able to collect and analyze that data.

For the room-and-pillar support study, the mine operator chose an area where geologic conditions typically lead to roof falls. This area included four intersections that had thinning limestone in the immediate roof, two of which had large open areas. These intersections were located in a main entry intake air course so it was important to keep them open to maintain ventilation to areas in-by and an escape route for miners in case of emergency. Based on finite element analyses, a support system consisting of four supplemental cribs and four posts was installed in each intersection with one crib and one post near each corner of each intersection. These sixteen cribs and sixteen posts were instrumented for load and convergence monitoring. Over a 245-day period, field monitoring indicated that: 1) Conventional cribs were losing contact with the mine roof creating a gap of about one inch, and 2) ATLAS cribs maintained contact with the mine roof but lost much of their pre-load at the time of installation. This loss of contact and pre-load is a direct result of moisture loss and shrinkage of individual crib elements.

Based on these observations, a task was initiated as part of this study to determine the rate and amount of shrinkage related to moisture loss and its effect on stiffness and load carrying capacity. Two sets of conventional cribs and two sets of ATLAS cribs were manufactured by a local sawmill and monitored in the laboratory over a 173-day period. One set was monitored for moisture loss and shrinkage while the second set was monitored for moisture loss and any associated change in response to loading. ATLAS 100 crib elements lost moisture more quickly than conventional crib elements due to a much greater surface area exposed to the atmosphere. Since ATLAS cribs lose moisture quicker, their stiffness increases as a function of time suggesting that they are more likely to provide better rock mass reinforcement than conventional cribs in the near term.
OBJECTIVES

ATLAS cribs, initially developed by Dr. Chugh and project team in 2007, have been tested at the National Institute of Occupational Safety and Health (NIOSH) support test facility. In addition, a small-scale field demonstration over a distance of about 250 ft was conducted at the American Coal Galatia Mine. As a result of these demonstrations and reviews by industry and Mine Safety and Health Administration (MSHA) professionals, this project was initiated to develop a large-scale (~1,000 ft) field demonstration. The goal was to demonstrate the performance of ATLAS cribs in side-by-side comparison studies with conventional cribs in longwall mining areas and as room-and-pillar intersection support allowing MSHA to confidently permit their use in longwall and room-and-pillar mines throughout Illinois and the US.

Specific objectives of this project were to: 1) Install 1,000 feet of ATLAS 100 cribs and 200 feet of ATLAS 300 cribs in a longwall headgate return entry, 2) Monitor the performance of installed cribs while the 4th West longwall face advanced passed them and then while the 5th West panel mined through the demonstration area subjecting cribs to extreme loading, 3) Install and monitor the performance of ATLAS and conventional cribs in high risk room-and-pillar intersections susceptible to failure due to the absence of limestone in the immediate roof, 4) Determine the rate of moisture loss and associated shrinkage for both ATLAS and conventional crib elements, and 5) Determine effects of moisture loss on load capacity and response to loading.

The project was performed as four tasks.

- **Task 1. Establish Longwall and Room-and-Pillar Field Demonstration Sites:** Install and monitor ATLAS and conventional cribs in longwall and room-and-pillar areas to compare performance.
- **Task 2. Assist with Commercial Production ofCribs and Wedges Developed at SIUC:** Establish QA/QC procedures for commercial production and monitor commercial production.
- **Task 3. Perform Field Demonstration of Engineered Cribs in Mines:** Perform industrial engineering (IE) studies to improve material handling and packaging procedures. Monitor roof-to-floor convergence in field demonstration areas and develop an automated load cell for load measurement on cribs.
- **Task 4. Data Analysis and Synthesis:** Analyze data collected from field and laboratory studies.

In addition to these tasks, meetings were held with industry professionals from operational, supply, regulatory, and research backgrounds to seek their input and advice. Furthermore, all ICCI reporting requirements were complied with.
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 to support gate, set up, and bleeder entries and to provide temporary support during the shield removal process when moving longwall equipment from one area to another. A typical crib uses 6-inch × 6-inch prismatic wooden elements that are 30 or 36 inches in length, although other sizes may also be used.

Although cribs have been used since the inception of mining, those currently employed have several disadvantages and/or limitations: 1) Loading is transverse to the wood grain resulting in low crib stiffness, low load carrying capacity, and large deformations, 2) The cross-section of the crib element is uniform even though most of the stresses in the element are confined around contact areas making the element heavier than it needs to be, 3) The uniform cross-section makes installation around irregular roof difficult, and 4) Handling crib elements for placement at heights above 4 ft requires considerable effort.

In 2007, Dr. Chugh and his project team developed the novel, engineered, composite wooden element shown in Figure 2 that overcomes most of these disadvantages. Results of testing at SIUC and NIOSH facilities demonstrated that these cribs are a viable support for longwall tail gate entries (Batchler, 2008; Gearhart, 2008). Feedback from industry professionals was also positive leading to further studies. Under two ICCI grants, a field demonstration project performed limited side-by-side comparison testing of the performance of these supports with conventional cribs on an active longwall face (Chugh et al., 2008). That project was a cooperative effort between American Coal Galatia Mine, NIOSH, the Illinois Clean Coal Institute (ICCI), and SIUC and it established the feasibility of using ATLAS cribs in longwall and room-and-pillar mining operations.

The demonstration area for the first grant was located between the 1st and 2nd West longwall panels in the return entry of the 1st West headgate and extended over a distance of about 250 ft. It consisted of two adjacent sections; one having conventional cribs and the other having engineered cribs. In each section, two rows of cribs were installed with cribs spaced 8 ft apart along the entry and approximately 5 ft apart across the entry. Crib installation took place over seven days and was completed on March 27, 2008. Load and convergence monitoring equipment was installed on March 26, 2008 by NIOSH and SIUC personnel. Once mining of the 1st West longwall panel was completed, the NIOSH data logger was removed on May 7, 2008 and returned to NIOSH for data analysis. Results were presented in Chugh et al. (2008).

Under the second grant, NIOSH’s data logger was reinstalled on November 19, 2008 and monitoring continued until December 22, 2008 while the 2nd West longwall panel mined through the demonstration area. Because the demonstration area became enveloped in the longwall gob of the 2nd West longwall panel, monitoring was terminated before cribs became fully loaded in order to recover the NIOSH equipment. Thus, to supplement data from the main demonstration area, the second grant also included monitoring of ATLAS
and conventional crib installations in three belt entry crosscuts in the 2nd West headgate adjacent to the 2nd West longwall panel. Results were presented in Gurley et al. (2009).

EXPERIMENTAL PROCEDURES

Mine Descriptions

Field demonstrations were conducted at two coal mines. Mine 1 is a longwall mining operation producing coal from the No. 6 coal seam at an average depth of 425 ft. The longwall face is 1,000 ft wide and the average mining height is 6.5 ft. The immediate roof strata consist of 4-6 inches of Anna Black shale, 5.5 ft of Brereton limestone, and about 23 ft of thick sandstone. The immediate floor strata consist of claystone and shale with up to 10 ft of claystone in some areas. Gate road development is a three-entry system with entries 80 ft apart (center-to-center or c-c) and crosscuts at 150 ft intervals. Supplemental supports are required in all bleeder entries and in the tail gate entry serving an active longwall face. The roof control plan requires these supplemental supports to be maintained about 200 ft ahead of the longwall face location. Cribs are installed as supplemental supports in a single row spaced approximately 8 ft apart. A typical layout of the longwall face tailgate entries with supplementary supports is shown in Figure 3.

Mine 2 is a room-and-pillar mining operation also operating in the No. 6 seam at an average depth ranging from 110 ft to 370 ft. The immediate roof strata consist of 1-2 feet of Anna Black shale overlain by limestone and sandy-shales. The coal seam thickness averages about 55 inches. The immediate floor strata consist of claystone down to a depth of 4-5 feet below the coal seam in some areas and are underlain by shales and limey shales. Entries are mined on 60 ft c-c spacing and crosscuts at 100 foot intervals in main entries and 60 foot intervals in panel development entries. Supplemental supports are typically used at four-way intersections that indicate signs of failure. This usually occurs in areas where limestone in the immediate roof thins or is absent.

Field Demonstration Areas

The study at Mine 1 was conducted in the 4th West longwall headgate return entry. The average width of this entry was 18.5 ft with an average mined height of about 80 inches. Once the 4th West longwall finished mining and was subsequently moved to the 5th West panel, the entry became the tailgate return for the 5th West longwall. A single row of supplemental crib supports spaced on 8 ft intervals crib-to-crib was installed near the center of the entry and down the entire length of the entry from the set-up room (footage location 77+00) to the recovery room (footage location 4+25). Installation occurred at least 200 ft ahead of the advancing 4th West longwall face in accordance with the roof control plan. All cribs were tightened against the roof with wooden wedges. The supplemental crib supports were ATLAS 100 cribs over a distance of 950 ft from footage location 69+80 to footage location 60+30 (see Figure 4). The supplemental crib supports were ATLAS 300 cribs over a distance of approximately 50 ft from footage location 8+00 to 7+50 (see Figure 5). In the ATLAS 100 crib installation area, the roof was competent and the mine floor was dry. The ATLAS 300 crib installation area had
competent roof and damp floor conditions. Cluster props (three round wooden props bound together in a triangular geometry using steel clamps) and ATLAS 100 cribs were used as supplemental supports on both sides of the ATLAS 300 crib demonstration area. Everywhere else, the supplemental crib supports were conventional cribs.

As shown in Figure 4, ATLAS 100 crib convergence monitoring areas were established near the mid-point of coal pillars located between crosscuts 45 and 43 and conventional crib convergence monitoring areas were established near the mid-point of coal pillars located between crosscuts 43 and 41. Similarly, ATLAS 300 cribs will be monitored but the 5th West longwall face did not pass this area until May 2010 after the end of this project’s grant period. Those results will be presented in the final report of a follow-up project.

The Mine 2 field demonstration was conducted in sub-main entry intersections. Mine management identified four intersections in entries 8 and 9 of the North sub-main at survey footage markers 6+80 and 7+40 (see Figure 6). This area was chosen due to thinning of limestone in the immediate overlying roof strata. The mine operator’s roof control plan requires installation of 8-foot long roof bolts as primary support when limestone thins to less than 1-foot in thickness. These four intersections have 8-foot long fully-grouted tension-rebar bolts installed as primary support. Cribs were installed diagonally at each corner of all four intersections as supplemental roof support (see Figure 7). The crib design was a 6-point crib, 36 inches wide and 72 inches long. Intersections #1 and #2 received crib supports made of conventional prismatic elements and intersections #3 and #4 received crib supports made of ATLAS 100 elements. Conventional cribs were constructed using alternating layers of three 3.25-in × 5.25-in × 36-in and two 5.75-in × 5.75-in × 72-in wooden timbers. ATLAS 100 cribs were constructed using six 11-in × 11-in × 3.5-in bases supporting alternating layers of three 6.25-in × 5.75-in × 36-in and two 6.25-in × 5.75-in × 72-in elements. Cribs were positioned to maintain an unobstructed travel way at least 8-foot wide through each intersection. This geometry was approved by mine management. It was also thought that this intersection support geometry may be suitable for bleeder entries.

**Industrial Engineering Studies**

IE studies were conducted at Mines 1 and 2 to determine best practices for packaging and handling of crib elements. Dimensional data were taken for forklifts used both on the surface and underground. Haulage equipment used underground to transport crib elements was measured to determine maximum height restrictions for packaged units. Surface and underground personnel were interviewed to seek input regarding packaging and handling procedures.

**QA/QC Procedure Development and Monitoring**

Dimensional tolerances for ATLAS crib elements were established in previous studies and were given to commercial crib producers. QA/QC data was collected periodically
from commercially produced crib elements. These are described later in this report and illustrated in Figure 8.

**Monitoring Crib Performance**

At Mine 1 crib loads were monitored using a wire extensometer mounted on crib elements. The extensometer was attached to a crib element near the roof using screws and the wire was extended to an eye bolt inserted into a crib element near the floor (see Figure 9). This measurement technique assumes crib compression is related to crib load, which is a reasonable assumption prior to initiation of crib yield.

Five ATLAS 100 cribs were instrumented for continuous monitoring; three between crosscuts 45 and 44 and two between crosscuts 44 and 43. Seven conventional cribs were instrumented for continuous monitoring; three between crosscuts 43 and 42 and four between crosscuts 42 and 41.

Similar to the crib-mounted monitoring station, a roof-to-floor convergence point consisted of a wire extensometer attached to a roof bolt plate with the wire attached to an anchor grouted approximately 12 inches into the floor (see Figure 10). Five roof-to-floor convergence points were located in the ATLAS 100 crib area and seven in the conventional crib area.

Two intrinsically safe, battery-operated, digital data acquisition systems (DDAS) were placed in crosscuts nearby instrumented cribs and roof-to-floor convergence points and each wire extensometer was attached to a DDAS with a data cable. ATLAS 100 cribs were instrumented on July 14 and 16, 2009 and conventional cribs were instrumented on July 28 and 29, 2009. Data recording began on August 1, 2009 and was continuously recorded until removal of the ATLAS 100 area DDAS on January 23, 2010 and removal of conventional area DDAS on January 30, 2010. Batteries and data storage modules were replaced in each DDAS on December 3, 2009.

At Mine 2, each intersection received instrumentation to determine roof-to-floor convergence and crib loading. Roof-to-floor convergence was monitored by grouting a steel rod into the floor strata directly below a roof bolt and measuring the distance between the bolt and the steel rod with an extensometer (see Figure 11). Measurement accuracy was to a resolution of 0.001-in. The second method of roof-to-floor convergence monitoring was achieved using a load cell designed at SIUC that is installed on top of a 6-in × 6-in wooden post. The load cell is comprised of a relatively low stiffness composite material pad sandwiched between two 0.5-in thick 6-in × 6-in steel plates. The compression of the composite material pad is a measure of roof-to-floor convergence and load acting on the post or a crib leg (see Figure 12). The distance separating the steel plates is measured manually to 0.001-in resolution at each corner using digital calipers. A calibration curve shown in Figure 13 correlating compression of the composite element and load in pounds was established.
The load applied to cribs is monitored by installation of steel pins in a vertical orientation and recording the distance separating these pins using a vernier caliper with a resolution of 0.01 inch (see Figure 14). The load can be calculated using a compression calibration curve based on the average elastic modulus of crib materials (see Figure 15).

**Monitoring Moisture Loss Rate and Element Shrinkage**

To determine moisture loss rate and associated shrinkage, two sets of freshly manufactured crib elements were received from a local sawmill. Set “A” consisted of ten ATLAS crib elements and ten conventional crib elements. This set was used to determine moisture loss rate, shrinkage in dimensions, and weight loss. Set “B” consisted of conventional and ATLAS 100 crib elements that were installed in SIUC’s 400,000 pound loading frame at the Illinois Coal Development Park (ICDP) to evaluate their load carrying capacity and stiffness characteristics as a function of moisture loss with time. Both ATLAS and conventional crib elements for Set A were received on May 15, 2009. Conventional elements of Set B were received on May 19, 2009 and subsequently installed in the loading frame. Upon completion of the load test, the conventional crib was removed from the load frame and replaced with ATLAS 100 elements of Set B that were received on December 12, 2009. Dimensions, weight, and moisture content of elements in both sets were recorded after they were received from the sawmill. Set A elements were monitored for shrinkage, moisture, and weight loss periodically over a 178-day period. Set B elements were monitored for moisture loss during load capacity and stiffness testing and were analyzed for shrinkage and weight loss after their removal from the loading frame.

A Timber Master digital moisture meter was used to collect wood moisture content. Moisture content, as measured by this meter, was recorded for six points along the length of each conventional element. Nine readings were taken for each ATLAS element; three along the length of the center element and one for each of the six pads. Each element was weighed using a digital scale to a resolution of 0.1-lb to determine weight loss with moisture loss. A Mitoyo digital caliper was used to measure height, width, and length dimensions for each element at several points as shown in Figure 8 with a resolution of 0.001-in. This data was used to determine shrinkage.

**Monitoring Load Capacity and Response to Loading**

Initially, the NIOSH equipment employed during this project could measure crib deformation and roof-to-floor convergence using precision potentiometers but could not measure the load on cribs. A load monitoring cell for cribs based on manual readings had been developed at SIUC (Chugh, 2002) and this project sought a way to connect the SIUC load cell to NIOSH’s permissible DDAS for electronic data gathering that would not place personnel in harm’s way.

Toward that goal, two mechanical prototype devices were developed based on string potentiometers. The potentiometer is excited by a regulated constant 4.95-volt DC power input. Higher voltage can provide higher resolution but in this case the excitation voltage
was kept below 5.0 volts to meet MSHA permissibility requirements. Each load cell was
developed using 60-durometer rated natural rubber as a composite, low–stiffness,
compressible material. This material was used successfully to monitor crib and post loads
in the intersection study at Mine 2 with data collection performed manually. The
 calibration chart for this composite material is shown in Figure 13. The size and type of
compressive element material can be engineered to meet specific load range applications.
Thermal qualities of the engineered materials are known and measurement can be
adjusted for temperature.

**Load Cell Design 1:** A 6-in × 6-in × 1-in compressive rubber element with a 1.5-in hole
in the center is sandwiched between two 8-in × 8-in × 0.5-in steel plates. The top bearing
plate has a wire anchor with an adjustment point at the center. The bottom bearing plate
has a 0.75-in hole at the center and a 0.75-in × 0.25-in countersunk area adjacent to the
hole. Two 0.25-in × 1.25-in bolts, located at opposite corners of these plates, hold the
assembly together until installation and are then removed. The base unit for Design 1 is a
6-in × 6-in × 0.375-in (side wall thickness) square steel tube with 6-in × 6-in × 0.5-in
steel plates welded at each end. The upper plate has a 0.75-in hole in the center. One side
is cut to accommodate the potentiometer which is supported by a welded steel frame.
The Design 1 load cell is shown in Figure 16.

**Load Cell Design 2:** This cell uses the same upper bearing unit as Design 1. The base
unit of Design 2 consists of two 6-in × 6-in × 0.5-in steel plates. A 0.5-in nylon pulley
assembly is fixed for exiting the wire at the center of the bottom plate. The other plate has
a 0.75-in by 4-in slot from the middle of one side through the center and it is positioned
over the pulley. Four countersunk 0.25-in × 1.25-in bolts pass through both plates and
attach the base to the upper bearing unit.

Load data is collected using a Digital Translations 9812 data acquisition module and a
Unimeasure XP-PA-2 series precision string potentiometer. It measures movement of the
upper bearing plate with a resolution of 0.001-in which is then correlated with the elastic
modulus of the composite material used to determine load.

Both load cells were calibrated to determine the performance of each design by
correlating data collected manually using an analog pressure gage and dial indicators with
the data collected using electronic means. These tests were performed using a load test
frame (see Figure 18) with the load applied by a 30-ton hydraulic cylinder and manually
operated hydraulic pump. The force applied to the load cell was calculated using the
effective area of the hydraulic cylinder and the system pressure gauge. A dial indicator
was positioned at each corner of the bearing plate and displacement was measured with a
resolution of 0.001-in. The average of the three dial gage readings was used as the
compression value of the composite element for each load increment. Simultaneously, a
pressure transducer was connected to the hydraulic pressure supply and data acquisition
module to provide continuous load monitoring during the calibration testing. Pressure
transducer and potentiometer displacement data were correlated to develop calibration
curves. Load was applied to the load cell in 500 psi increments and the hydraulic system
was allowed to stabilize prior to manually recording data.
RESULTS AND DISCUSSION

NIOSH Monitoring of Crib Loading in Longwall Mine 1

Data collected by the DDAS from August 1 to December 3, 2009 (Phase 1) for conventional and ATLAS 100 crib areas are summarized in Figures 19 and 20 and indicate a small initial convergence in the conventional cribs area as the 4th West panel advanced passed and out-by the monitored areas. Data also indicates that divergence in both roof-to-floor and crib monitoring stations began after the 4th West longwall panel advanced approximately 3,000 feet beyond the monitored areas. This behavior continued in the conventional crib area but stabilized in the ATLAS cribs area as the face advanced beyond 3,000 feet. This divergence in both roof-to-floor and crib monitoring stations may indicate shear movement of the rock mass in roof and/or floor strata.

Phase 2 focused on roof-to-floor convergence and crib loading as the 5th West panel advanced passed and out-by the monitored crib areas. Once the 4th West longwall panel was relocated, the monitored crib area became the tailgate return entry for the 5th West longwall panel. As this panel advanced passed the monitored areas, cribs were subjected to their highest loading and eventual failure. Collected data are summarized in Figures 21 and 22. The DDAS for the conventional crib area was removed January 23, 2010 and the longwall face had passed all monitoring stations at that time. Figure 21 shows that each conventional area monitoring station had undergone 1-2 inches of convergence when the station was in line with the 5th West longwall face. Once the face advanced 25 to 30 feet beyond each monitoring station, very high convergence was observed indicating high loading on cribs and their subsequent failure. Data indicates 10 inches of convergence, which is the maximum displacement capacity of the string extensometers.

The ATLAS area DDAS was removed on January 30, 2010. The 5th West longwall at the time of DDAS removal was 73 feet in-by the first ATLAS monitoring station. The early removal of the DDAS was due to limited access to the tailgate entry and lack of transportation to the longwall panel. Data in Figure 22 indicate that the ATLAS area experienced a maximum 0.375 inches of convergence as the 5th West face approached. Figure 23 compares the performance of conventional and ATLAS cribs as the 5th West longwall approached from 900 feet to a point 50 feet in-by each monitoring station. This data indicates the overall convergence in the ATLAS crib area was much less and more consistent than the conventional crib area.

Intersection Support in Room-and-Pillar Mine 2

ATLAS cribs were chosen as part of the room-and-pillar intersection support field demonstration to determine the effectiveness of their higher stiffness properties in minimizing roof rock mass movement. ATLAS cribs have demonstrated that they compress much less than conventional cribs when carrying similar loads (Chugh et al., 2008; Gurley et al., 2009). Cribs were installed in four intersections on January 19 and 20, 2009. Initial data was collected on January 20 with subsequent collections on
February 9, April 22, and Sept 2, 2009. Roof-to-floor convergence data presented in Table 1 indicates conventional cribs intersection #2 (CI2) and ATLAS cribs intersection #3 (AI3) experienced higher convergence than the other two intersections. Intersection AI3 would be expected to have higher convergence since it has the largest open area. The combined corner-to-corner diagonal measurement exceeded 69 feet for this intersection. Intersection CI2 has a larger open area than conventional intersection #1 (CI1) with corner-to-corner diagonal measurements of 63.92 feet and 60.25 feet, respectively (see Table 2). Data collected on September 2, 2009 indicates that each of the four monitored intersections continued to experience some incremental roof-floor convergence. Loading of individual post-mounted load cells is shown in Table 3. Load cell #1 in CI2 was slightly shifted due to loading. One side of the load cell was under much larger loading and therefore created dilation on the opposite side. This was exacerbated by the mounting post starting to lean outward as a result of the load cell acting as a hinge point. The combined load on the four post-mounted load cells located in CI2 was probably greater than indicated in Table 3. The total load for CI2 was calculated from only three load cells (load cell CI2 was omitted) rather than four. The dislodging of load cell #1 may also be a result of the low stiffness value of conventional cribs allowing more convergence before picking up load.

To determine loading on the cribs, convergence points were installed on selected cribs in each intersection as illustrated in Figure 14. Table 4 represents crib convergence data for 133 days from April 22 to September 2, 2009. During the visit on April 22, it was noted that all conventional cribs had lost contact with the mine roof and a gap of 1-inch or more was present. ATLAS cribs had lost considerable pre-loading due to moisture loss and shrinkage but remained in contact with the mine roof. Due to shrinkage, data collected prior to April 22 was rendered non-applicable. All cribs were re-tightened against the roof and pre-loading applied before convergence data was again recorded on April 22. Table 4 indicates that ATLAS cribs in intersections AI3 and AI4 saw an increased load of 6.5 and 7.8 tons and 5.6 and 4.4 tons, respectively from April 22 to September 2. Conventional cribs #2 and #4 located in intersection CI1 indicate an additional load of 2.5 tons and 7.8 tons, respectively during this period. A negative load or divergence was recorded from crib #3 in intersection AI2, which indicates expansion of the unconfined crib structure. This was due to continued shrinkage of individual crib elements and subsequent loss of contact with the mine roof.

Moisture data collected on September 2 indicates a substantial increase in moisture content of individual conventional and ATLAS crib elements (see Table 5). The change in moisture content was similar for both conventional and ATLAS cribs. This was due to seasonal changes with higher humidity resulting in condensation of moisture on mine surfaces during summer months.

**IE and QA/QC Studies**

Input from mine personnel emphasized that packaging of crib elements should meet the following criteria: 1) Ease of handling, 2) Minimize waste, 3) Conform to transport dimensional requirements, and 4) Compact and secure. The project team worked with
commercial crib producers to package in units a sufficient number of crib elements for constructing one or two complete cribs for a specific seam height. Units packaged for the field demonstration were designed for loading and unloading with surface and underground forklift equipment. They were packaged to meet dimensional requirements that would allow roof clearance during transport through the mine and to enable more crib elements to be carried in each transport unit. Since packaging was specifically designed for a seam height, it was noted during field installation of ATLAS cribs that there was almost zero waste. Proper packaging to reduce waste reduces supplemental roof support costs and minimizes combustible materials left in mine entries.

QA/QC dimensional data was collected on cribs constructed for field and laboratory studies. Tolerances established for overall element length, center element thickness and overall element height were plus/minus 0.25-in, 0.125-in, and 0.125-in, respectively. Table 6 indicates that 100%, 84.1%, and 76.3% of crib elements were in tolerance for overall length, center thickness, and overall height, respectively. As over tolerance is considered acceptable, over 95% of measured crib elements were compliant with specified dimensional tolerances.

**Load Response, Moisture, and Shrinkage Studies**

A conventional crib was placed in the loading frame at the ICDP on May 19, 2009. Moisture content data was recorded and the crib was loaded to about 60 tons. The crib was loaded after 20 days to 45 tons, after 62 days to 88 tons, after 114 days to 78 tons, and after 173 days to 77 tons. Figure 24 shows that loading after 20 and 62 days had a lower loading rate response than during initial testing indicating a change in stiffness of crib elements. Crib elements experienced the fastest rate of moisture loss and the most splitting during the first 60 days after manufacturing. These splits or gaps result from the drying process and become defects that significantly weaken crib elements. Deformations must close these gaps before crib elements can pick up load. The 114-day test showed a slightly quicker loading response than the 20-day and 62-day tests and was closer to the response seen in the initial test.

Loading of the crib after 173 days indicated a stiff response to loading. The increased stiffness may be partially attributed to the compression of wood fibers at contact points during previous loadings. Deformation occurring at these points was measured and the average reduction in individual element thickness was 0.38 inch while the cumulative reduction for the entire crib structure was 4.6 inches or 6.5% of the total crib structure height (see Figure 25).

ATLAS crib elements received from a local sawmill had moisture content recorded before installation in the ICDP loading frame on December 15, 2009. Initial loading to 79 tons was done on December 16. This crib was loaded again after 28, 58 and 98 days to 69, 96, and 96 tons, respectively. Figure 26 indicates that the 58-day response to loading was similar to the initial and 28-day testing up to about 60 tons and maintained its stiffness up to about 96 tons load. This was also seen during previous ATLAS cribs testing at NIOSH facilities in Pittsburgh, PA (Batcher, 2008). The 98-day testing
indicated a slightly slower initial response, but after 30 tons of load, stiffness is similar to initial and 28-day tests.

Data presented in Table 7 indicates the ATLAS crib responded to loading quicker than the conventional crib. The deformation per tons of load for the ATLAS crib is consistently lower for the first 60-day period. The 0.03-in deformation per ton of load for the ATLAS crib at 98 days is slightly higher than the 0.0228-in deformation per ton of load for the conventional crib at 114 days but is based on a peak load of 95.7 compared to 79.3 tons for the conventional crib. The conventional crib data after 173 days indicates a much quicker response to loading than previous testing and is due to compression of the wood at bearing points as stated previously and as illustrated in Figure 25.

Ten fresh, new ATLAS and ten fresh, new conventional crib elements were used to compare moisture loss rate and shrinkage. Upon receiving them from a local sawmill on May 15, 2009, dimensional data was recorded for points illustrated in Figure 8. Each element was weighed and the moisture content was determined using a moisture meter. Monitoring of this same dimensional, weight, and moisture data continued for 178 days with results shown in Figures 27 through 32 and Tables 8 and 9. Figure 29 indicates that ATLAS crib elements lost moisture at a faster rate initially losing about 45% of their original moisture in the first five days compared to 31% loss for conventional elements. After thirteen days, rates of moisture loss and weight loss for the different crib elements were similar. ATLAS crib elements have larger exposed end-grain surface area. Thus, they typically have less initial moisture content and lose moisture at a faster rate than conventional crib elements.

The moisture loss rate increased from September (day 116) to November (day 178) due to lower atmospheric humidity levels (see Figure 29). During the 178-day period from May 15 to November 9, 2009, average ATLAS and conventional crib element moisture content dropped from 22.6% to 9.3% or 41% and from 27.7% to 10.5% or 38%, respectively. During this same period, the average weight of ATLAS and conventional elements dropped from 24.8 to 19.6 lbs or 20.9% and 39.7 to 31.4 lbs or 20.8%, respectively.

**Development of Automated Load Cell**

Figures 33 and 34 represent an electronic plot of paired values returned by the string potentiometer and the hydraulic pressure transducer. Data collected in 2-second intervals are labeled “string” in these figures. The lower blue arch in Figure 33 represents points plotted as hydraulic pressure was released. Points labeled “dials” are average displacement values from four dial indicator readings paired with mechanical pressure gauge readings. The manual dial gages indicated total linear movement of 0.2355-in as pressure increased from 1,000 psi (3.61 tons) to 5,500 psi (19.85 tons). For the same range, the automated system indicated movement of 0.23006-in; a difference of 2.3%. That was the best comparison between the two systems. For several other points, differences were as high as 8%.
Any deviation from perfect alignment of wire anchor point to pulley exit will result in less string movement registered by the potentiometer. It is possible that the base of the Design 1 load cell deformed under load and flexed the mounting bracket, which would have contributed to error. The error present in electronic pressure measurement is included in the total error. This contributing factor is not present when using the permissible data logger since only distance is measured in the field.

Both load cell designs do not lend themselves to an accurate error calculation. Some elements of error are attributable to the test method and not to the device. Accuracy may be significantly improved by having a skilled machinist construct them. In applications where there is safe access to instruments at the end of testing, potentiometers can be recovered leaving only the least expensive components behind, thus reducing the cost of monitoring. Accurate alignment and more accurate calibration will produce load cells capable of delivering useful data. With well-machined components load measurement error can be reduced to less than 2%.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

- Monitoring of ATLAS 100 cribs over a 950 ft distance in a longwall tailgate entry has demonstrated that overall performance is at least as good as that of conventional cribs. In many respects, it proved to be better.
- Roof-to-floor convergence in the ATLAS crib area of the tailgate entry was less than in the conventional crib area. This validated a similar conclusion reached in an earlier study where the field demonstration was done over a distance of only 250 ft.
- Comments from coal industry professionals on the use of ATLAS cribs have been very positive and their confidence in using them has increased. This is true for both mine operators and MSHA officials.
- ATLAS 100 crib elements lose moisture more quickly than conventional crib elements because they have much larger surface area exposed to atmosphere.
- Since ATLAS cribs lose moisture quickly, their stiffness increases as a function of time. Therefore, in the near term, they are more likely to provide rock mass reinforcement than conventional cribs.
- The performance of ATLAS cribs as standing support for intersections in a room-and-pillar mine was successfully demonstrated. The intersection support geometry proved effective and no roof falls were experienced at any of the four intersections monitored during the study.
- NIOSH has included ATLAS crib data as part of their STOP computer software.

Recommendations

- Performance monitoring of ATLAS 300 cribs should continue with results developed as a separate report after the 5th West longwall face mines through that demonstration area.
- Based on studies completed to date, it is recommended that efforts to market the use of ATLAS cribs should be strengthened.
### Table 1: Roof-to-floor convergence data – Mine 2 intersection support.

<table>
<thead>
<tr>
<th>Intersection*</th>
<th>Mean convergence (in)</th>
<th>Total mean convergence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1/20 to 2/09</td>
<td>2/09 to 4/22</td>
</tr>
<tr>
<td>CI1</td>
<td>0.01249</td>
<td>0.05150</td>
</tr>
<tr>
<td>CI2</td>
<td>0.03322</td>
<td>0.10890</td>
</tr>
<tr>
<td>AI3</td>
<td>0.00265</td>
<td>0.13300</td>
</tr>
<tr>
<td>AI4</td>
<td>0.03006</td>
<td>0.09700</td>
</tr>
</tbody>
</table>

*CI1 and CI2 are conventional cribs while AI3 and AI4 are ATLAS cribs.

### Table 2: Intersection diagonal (corner-to-corner) distances – Mine 2 intersection support.

<table>
<thead>
<tr>
<th>Intersection</th>
<th>Distance (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CI1</td>
<td>60.25</td>
</tr>
<tr>
<td>CI2</td>
<td>63.92</td>
</tr>
<tr>
<td>AI3</td>
<td>69.42</td>
</tr>
<tr>
<td>AI4</td>
<td>67.42</td>
</tr>
</tbody>
</table>

### Table 3: Load indicated by post mounted load cells – Mine 2 intersection support.

<table>
<thead>
<tr>
<th>Loading on posts (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load cell</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
</tbody>
</table>

Total load per intersection (tons): 12.8, 7.4, 10.3, 7.4
Mean load per post (tons): 3.2, 2.5, 2.6, 1.8

### Table 4: Crib mounted convergence point data – Mine 2 intersection support.

<table>
<thead>
<tr>
<th>Tons load (133 days – April 22 to Sept 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intersection</td>
</tr>
<tr>
<td>CI1</td>
</tr>
<tr>
<td>CI2</td>
</tr>
<tr>
<td>AI3</td>
</tr>
<tr>
<td>AI4</td>
</tr>
</tbody>
</table>
Table 5: Crib moisture content data – Mine 2 intersection support.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CI1</td>
<td>14.3</td>
<td>14.4</td>
<td>27.5</td>
</tr>
<tr>
<td>CI2</td>
<td>17.0</td>
<td>15.5</td>
<td>27.8</td>
</tr>
<tr>
<td>AI3</td>
<td>13.2</td>
<td>13.5</td>
<td>23.4</td>
</tr>
<tr>
<td>AI4</td>
<td>11.9</td>
<td>13.8</td>
<td>22.5</td>
</tr>
</tbody>
</table>

Table 6: QA/QC data.

<table>
<thead>
<tr>
<th>Range</th>
<th>Overall length</th>
<th>Center thickness</th>
<th>Overall height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Over tolerance</td>
<td>0</td>
<td>11.6</td>
<td>19.0</td>
</tr>
<tr>
<td>In tolerance</td>
<td>100</td>
<td>84.1</td>
<td>76.3</td>
</tr>
<tr>
<td>Under tolerance</td>
<td>0</td>
<td>4.3</td>
<td>4.7</td>
</tr>
</tbody>
</table>

Table 7: Stiffness comparison of ATLAS and conventional cribs.

<table>
<thead>
<tr>
<th>Crib</th>
<th>Crib age (days)</th>
<th>Deformation per ton (inch)</th>
<th>Peak load (tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.0249</td>
<td>60.8</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>0.0240</td>
<td>46.1</td>
<td></td>
</tr>
<tr>
<td>62</td>
<td>0.0471</td>
<td>88.6</td>
<td></td>
</tr>
<tr>
<td>114</td>
<td>0.0228</td>
<td>79.3</td>
<td></td>
</tr>
<tr>
<td>173</td>
<td>0.0143</td>
<td>80.3</td>
<td></td>
</tr>
<tr>
<td>ATLAS 100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.0190</td>
<td>79.3</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>0.0203</td>
<td>79.5</td>
<td></td>
</tr>
<tr>
<td>58</td>
<td>0.0163</td>
<td>97.3</td>
<td></td>
</tr>
<tr>
<td>98</td>
<td>0.0300</td>
<td>95.7</td>
<td></td>
</tr>
</tbody>
</table>
Table 8: Conventional cribs – shrinkage and moisture loss data over 178 days.

<table>
<thead>
<tr>
<th>Days</th>
<th>5</th>
<th>13</th>
<th>19</th>
<th>27</th>
<th>32</th>
<th>39</th>
<th>46</th>
<th>52</th>
<th>61</th>
<th>116</th>
<th>173</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cumulative shrinkage (in)</td>
<td>0.0339</td>
<td>0.0392</td>
<td>0.0372</td>
<td>0.0521</td>
<td>0.0544</td>
<td>0.0593</td>
<td>0.0687</td>
<td>0.0694</td>
<td>0.0796</td>
<td>0.1046</td>
<td>0.1450</td>
</tr>
<tr>
<td>% shrinkage</td>
<td>0.6</td>
<td>0.7</td>
<td>0.6</td>
<td>0.9</td>
<td>0.9</td>
<td>1.0</td>
<td>1.2</td>
<td>1.2</td>
<td>1.3</td>
<td>1.8</td>
<td>2.4</td>
</tr>
<tr>
<td>% moisture content</td>
<td>19.3</td>
<td>21.0</td>
<td>20.4</td>
<td>19.9</td>
<td>19.6</td>
<td>20.0</td>
<td>16.7</td>
<td>17.9</td>
<td>18.3</td>
<td>17.9</td>
<td>10.5</td>
</tr>
<tr>
<td>% moisture loss</td>
<td>30.5</td>
<td>24.2</td>
<td>26.3</td>
<td>28.1</td>
<td>29.5</td>
<td>27.9</td>
<td>39.6</td>
<td>35.5</td>
<td>34.0</td>
<td>35.5</td>
<td>62.1</td>
</tr>
<tr>
<td>Weight of element (lbs)</td>
<td>38.6</td>
<td>38.0</td>
<td>37.5</td>
<td>36.6</td>
<td>36.6</td>
<td>36.3</td>
<td>35.8</td>
<td>35.6</td>
<td>35.1</td>
<td>33.0</td>
<td>31.4</td>
</tr>
<tr>
<td>% weight loss</td>
<td>2.7</td>
<td>4.3</td>
<td>5.4</td>
<td>7.9</td>
<td>7.8</td>
<td>8.5</td>
<td>9.9</td>
<td>10.4</td>
<td>11.7</td>
<td>16.8</td>
<td>20.8</td>
</tr>
</tbody>
</table>

Table 9: ATLAS 100 cribs – shrinkage and moisture loss data over 178 days.

<table>
<thead>
<tr>
<th>Days</th>
<th>5</th>
<th>13</th>
<th>19</th>
<th>27</th>
<th>32</th>
<th>39</th>
<th>46</th>
<th>52</th>
<th>61</th>
<th>116</th>
<th>173</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cumulative shrinkage (in)</td>
<td>-0.0029</td>
<td>0.0284</td>
<td>0.0330</td>
<td>0.0453</td>
<td>0.0507</td>
<td>0.0586</td>
<td>0.0619</td>
<td>0.0719</td>
<td>0.0722</td>
<td>0.1072</td>
<td>0.1857</td>
</tr>
<tr>
<td>% shrinkage</td>
<td>0.0</td>
<td>0.4</td>
<td>0.5</td>
<td>0.7</td>
<td>0.8</td>
<td>0.9</td>
<td>1.0</td>
<td>1.1</td>
<td>1.1</td>
<td>1.7</td>
<td>2.9</td>
</tr>
<tr>
<td>% moisture content</td>
<td>12.3</td>
<td>19.3</td>
<td>17.4</td>
<td>17.1</td>
<td>17.4</td>
<td>16.7</td>
<td>13.2</td>
<td>14.8</td>
<td>14.1</td>
<td>16.0</td>
<td>9.3</td>
</tr>
<tr>
<td>% moisture loss</td>
<td>45.5</td>
<td>14.3</td>
<td>22.9</td>
<td>24.1</td>
<td>22.6</td>
<td>25.9</td>
<td>41.5</td>
<td>34.4</td>
<td>37.5</td>
<td>28.9</td>
<td>58.7</td>
</tr>
<tr>
<td>Weight of element (lbs)</td>
<td>23.8</td>
<td>23.4</td>
<td>23.0</td>
<td>22.6</td>
<td>22.4</td>
<td>22.3</td>
<td>22.3</td>
<td>21.8</td>
<td>21.3</td>
<td>20.3</td>
<td>19.6</td>
</tr>
<tr>
<td>% weight loss</td>
<td>4.3</td>
<td>5.6</td>
<td>7.2</td>
<td>9.1</td>
<td>9.8</td>
<td>10.1</td>
<td>10.3</td>
<td>12.2</td>
<td>14.1</td>
<td>18.2</td>
<td>20.9</td>
</tr>
</tbody>
</table>

FIGURES

Figure 1: Typical four-way intersection.
Figure 2: ATLAS crib element.

Figure 3: Typical crib location in a longwall tailgate return entry.

Figure 4: Cribs instrumented for monitoring in the Mine 1 demonstration area.
Figure 5: Location of ATLAS 300 cribs in Mine 1.

Figure 6: Location of intersection supports in Mine 2.

Figure 7: Intersection supplemental support layout – Mine 2.
Figure 8: Conventional and ATLAS dimensional data collection points.

Figure 9: Crib mounted monitoring station, bottom and top anchor points.

Figure 10: Roof-to-floor monitoring station, floor mount and roof mount.
Figure 11: Convergence point installation (not to scale).

Figure 12: SIUC load cell installation.
Figure 13: Load cell and crib compression calibration curves.

Figure 14: Crib mounted convergence point installation.

Figure 15: Crib compression calibration.
Figure 16: Automated load cell development – Design 1.

Figure 17: Automated load cell – Design 2.

Figure 18: Testing load cell in test frame.
Figure 19: Conventional cribs data – August 1 through December 3, 2010.

Figure 20: ATLAS cribs data – August 1 through December 3, 2009.
Figure 21: Conventional crib area data – December 3, 2009 to January 30, 2010.

Figure 22: ATLAS crib area data – December 3, 2009 to January 23, 2010.
Figure 23: Crib convergence as longwall advances from 900 feet away to 50 feet away.

Figure 24: Conventional cribs - laboratory load-deformation data.

Figure 25: Compressed contact points of conventional crib geometry after loading.
Figure 26: ATLAS 100 cribs - laboratory load-deformation data.

Figure 27: Dimensional shrinkage.

Figure 28: Weight loss.
Figure 29: Moisture loss.

Figure 30: Cumulative shrinkage.

Figure 31: Element weight versus time.
Figure 32: Moisture content versus time.

Figure 33: Load Cell Design 1 – Laboratory load-displacement data.

Figure 34: Load Cell Design 2 – Laboratory load-displacement data.
REFERENCES


DISCLAIMER STATEMENT

This report was prepared by Harrold Gurley of Southern Illinois University Carbondale, with support, in part, by grants made possible by the Illinois Department of Commerce and Economic Opportunity through the Office of Coal Development and the Illinois Clean Coal Institute. Neither Harrold Gurley and Southern Illinois University Carbondale, nor any of its subcontractors, nor the Illinois Department of Commerce and Economic Opportunity, Office of Coal Development, the Illinois Clean Coal Institute, nor any person acting on behalf of either:

(A) Makes any warranty of representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately-owned rights; or

(B) Assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method or process disclosed in this report.

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring; nor do the views and opinions of authors expressed herein necessarily state or reflect those of the Illinois Department of Commerce and Economic Opportunity, Office of Coal Development, or the Illinois Clean Coal Institute.

Notice to Journalists and Publishers: If you borrow information from any part of this report, you must include a statement about the state of Illinois’ support of the project.