IMPROVING THE CAPABILITY FOR REAL TIME ASSESSMENT OF ROOF CONDITIONS THROUGH INTELLIGENT ROOF BOLT DRILLING OPERATIONS

Robert Anderson, Design Engineer
J. H. Fletcher & Company
Huntington, WV

L. J. Prosser, Research Scientist
NIOSH - Pittsburgh Research Laboratory
Pittsburgh, PA, USA

ABSTRACT

Advance knowledge of roof conditions can lead to improvement in roof control strategies that will reduce roof falls and ultimately will reduce injuries to mine workers. J.H. Fletcher and Company, in cooperation with West Virginia University, has been developing a system to meet these needs by collecting torque, thrust, and rotation speed data during drilling operations. Recent improvements in analysis algorithms to detect anomalies in the roof structure as well as various display enhancements for real time mapping and evaluation of roof structures have been incorporated into current Fletcher Information Display system. The unit has also been housed in an explosion-proof container to allow use in coal mine applications. Recently, the system has undergone extensive field trials in several limestone mines and one coal mine. During these trials, the National Institute for Occupational Safety and Health assisted Fletcher in verifying the accuracy of the roof mapping capability of the system by comparing the display information to bore hole scoping observations and drill corings. It was concluded from this assessment that the intelligent drilling system can complement scoping and core analysis to provide a more complete picture of roof strata and is capable of seeing features or conditions that are not always obvious in these more traditional methods.

INTRODUCTION

The FLETCHER® information display system had its roots in a 1992 research and development project to use a Programmable Logic Controller (PLC) to monitor drilling operations. Later, a Drill Control Unit (DCU) was developed to automate the drilling and bolting cycle for improved safety and productivity. The DCU is connected to sensors that measure drill bit torque, thrust, rotation speed and position as well as vacuum or water pressure. It adjusts the drilling parameters to avoid stalling of the drill, breaking the bit, or bending the drill steel while maintaining optimum drilling speed. As the system evolved, various parameters from the DCU were recorded for analysis. It was realized that the data showed trends that could be useful to the mine engineer or geologist in evaluating the condition of the mine roof.

A software program was developed to analyze and interpret the data, graph the material hardness and display the location of voids or other discontinuities in the mine roof structure. The program presents a bar graph in shades of gray with lighter shades indicating softer material. A depth scale is shown beside the graph. Voids, rotation events and water events are marked with colored lines and letters. Rotation events are stalls or other sudden changes in rotation speed or torque. Water events are sudden changes in water pressure which may indicate that the drill steel is being plugged with soft material. Figure 1 shows a typical grayscale bar graph from the original software.

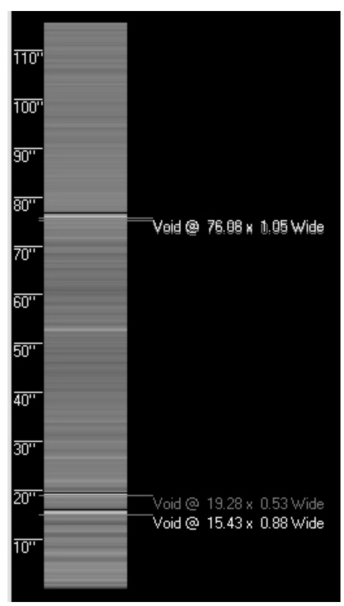

Figure 1. Grayscale bar graph from the original system.

The software was tested in the laboratory and in the mine and was refined to improve its accuracy. In a recent project with West Virginia University (WVU), the software was modified to communicate in real time with the drill control unit and display the information as the holes were being drilled. With this new system, graphs illustrating information from four separate drill holes were displayed side-by-side so that trends could be easily seen. The display and analysis can be activated through a rugged touch screen panel installed on the bolting machine to facilitate use underground by the roof bolter or other mine officials (see figure 2).

Figure 2. FLETCHER® Information Display

ADVANTAGES OF REAL-TIME ROOF MAPPING WITH THE FLETCHER® INFORMATION DISPLAY

An abundance of data is gathered and analyzed.

Core drilling, bore-scoping or scratch testing is done infrequently. With the Fletcher intelligent drill system and Information Display, every hole that is drilled in automatic mode has a graph displayed and corresponding data file recorded for analysis. Trends are visible as drill hole information from several holes are displayed side-by-side in real time during drilling or can be recalled from saved files for an historical perspective.

No additional work or equipment is required.

Core drilling and bore-scoping require additional equipment and personnel to perform these activities. Usually, they are done after drilling and bolting operations are complete. If problems are realized, then the bolter may have to return to the area to install additional bolts or longer bolts. Conversely, real-time roof mapping is achieved with the FLETCHER® intelligent drill system and Information Display during the normal drilling operation for bolting. Hole data is recorded automatically. No input from the operator or additional work is necessary and adjustments to the bolting strategy can be made in a more timely manner.

Consistent results are possible.

The drill data is interpreted by the computer and displayed in a manner that is easily read by the operator. No special training or expertise is required. Bore-scoping, scratch testing and core drilling require interpretation by skilled personnel. Results may vary depending on who is interpreting the data.

Historical records are created.

Data files can be backed up on a flash drive and carried above ground for later viewing and analysis by mine engineers or geologists. The files are automatically organized in folders by date and sequence number to facilitate historical record keeping. Optionally, at the start of work in a section, the operator can input a prefix which will be added to the beginning of each file name so that data files can be sorted by section identification. The grayscale hole graphs and line graphs can be printed out for reports and documentation as needed.

Trending shows what other methods may miss.

No single hole graph may be 100% accurate in predicting voids. Other factors in the drilling process may occasionally cause false indications in the graph. For example, any sudden change in hydraulic pressure, a broken drill bit or binding drill steel could show up as a change in the hole graph. Viewing several graphs from the same area will show trends, such as a light color for a softer band of material. Even though no open void is detected, this may indicate a location where a separation may later occur. These soft bands may not be visible with a bore-scope or a scratch tool especially with an inexperienced user.

The computer and display have other uses.

Parts books, operations manuals and maintenance manuals can be stored and displayed on the drilling machine. Image files can be viewed on the display. Video from a back-up camera or bore-scope can be viewed. Data collected by the computer can be used for machine diagnostics and event logging.

RECENT IMPROVEMENTS TO THE SYSTEM

Several improvements have been made to the original system, including:

- Based on experience in a limestone mine using a percussive (hammer) drill, algorithms were revised to detect mud seams by water events, where the drill control unit reacts to changes in water pressure and alters the drilling parameters to prevent the drill steel from plugging up.
- The computer's spinning hard drive was replaced with solid state flash memory for better durability.
- An uninterruptible power supply was added for soft shutdowns in case of power loss.
- A virtual keyboard was added to the program to allow the operator to enter a section number or other prefix to the file name.
- A back-up video display was added as a menu item for interfacing with a rear-facing video camera to facilitate backing up of the roof bolter in poor visibility conditions. The video image can be reversed as it would be seen in a rear view mirror.
- A print function was added to allow the user to make hard copies of the display information.
- An explosion proof housing was designed and built to house the Information Display so that it could be tested in an underground coal mine. In this application, an intrinsically safe infrared mouse was used to interact with the computer since the touch screen was not accessible.

- The software was revised to work with a new generation of Drill Control Unit and to read a different file format from the pendant recorder, a handheld data recording device which is connected to the DCU.

TESTING THE SYSTEM IN AN UNDERGROUND COAL MINE

In another joint project with WVU, a test machine was built for use in an underground coal mine. An older single-boom roof bolter was rebuilt with modern components including the latest generation of drill head and drill control unit. The FLETCHER® Information Display was installed in an explosion-proof housing on the machine. Figures 3 and 4 show the coal test machine and the information display.

Figure 3. Roof bolter used for testing in underground coal mine.

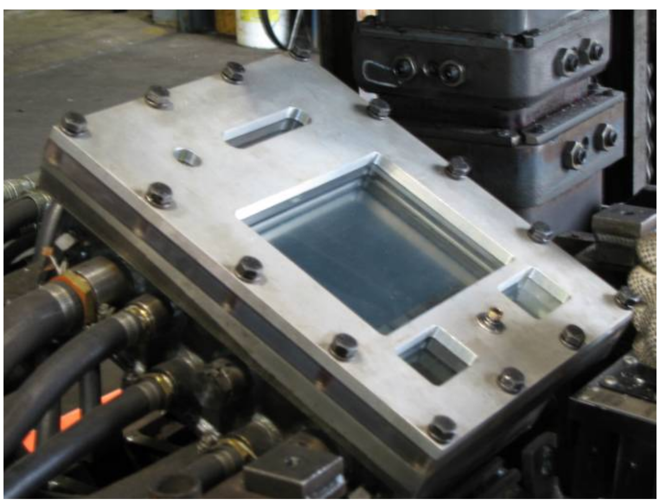

Figure 4. Information display in explosion proof housing.

The machine was first tested in the laboratory and then moved to a West Virginia coal mine. The first location where the system was tested was close to the mine opening and showed very little change in the roof structure throughout the drilling depth. Approximately 60 holes were drilled at different feed pressure and RPM combinations. Two core drill samples were taken from this area for analysis at WVU. The drill data files and core drill samples were unremarkable, showing a continuous homogenous material in the mine roof.

The test machine was moved to another section of the mine where there had previously been roof problems including a large roof fall. Figure 5 shows this area and gives a cross section of the roof strata in this area.

Figure 5. Section of roof adjacent to large roof fall.

In this area, thirty more holes were drilled and two more core samples were taken. Because of roof height limitations, the core drills had to be done some distance away from the group of drilled holes. There was some concern that the core drill results might not be a good representation of the other drilled holes. Nonetheless, the core samples had several discontinuities and the drill data files showed events as well. When viewing the hole graphs side-by-side, it was obvious that there was some change in roof strata at a depth of about 15 in (see figure 6).

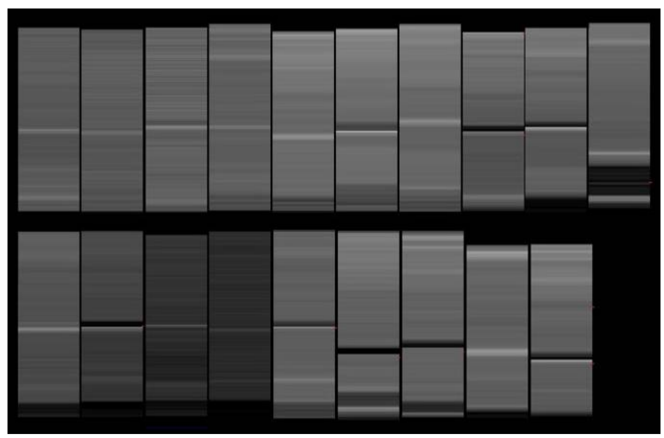

Figure 6. Several hole graphs showing discontinuity trends in the mine roof near the 15 in horizon as indicated by the breaks in the bar graphs.

Scoping holes were also analyzed using a small bore scope (less than 1 in diameter) as shown in figure 7. Video files were recorded for each hole. Initially, the bore-scope videos showed few discontinuities in the holes. Only two of the holes had obvious voids (see figure 8). The holes were flushed out with water, assuming that dust from the drilling might be obscuring the voids. The holes were bore-scoped a second time and again there were not clear voids at the locations indicated on the drill data files. A scratch tool was used to feel for soft bands or ledges in the holes. Discontinuities were found in almost every case at or near the locations indicated by the drill data files. Fifteen more holes were drilled in this area during another visit with similar results.

Figure 7. FLETCHER® Bore Scope.

Figure 8. Typical void, approximately ¾" high.

Even when no open voids were detected, the hole graphs showed trends such as the locations of soft bands relative to the bolting horizon. Figure 9 shows such a trend in one series of holes recorded at the coal mine.

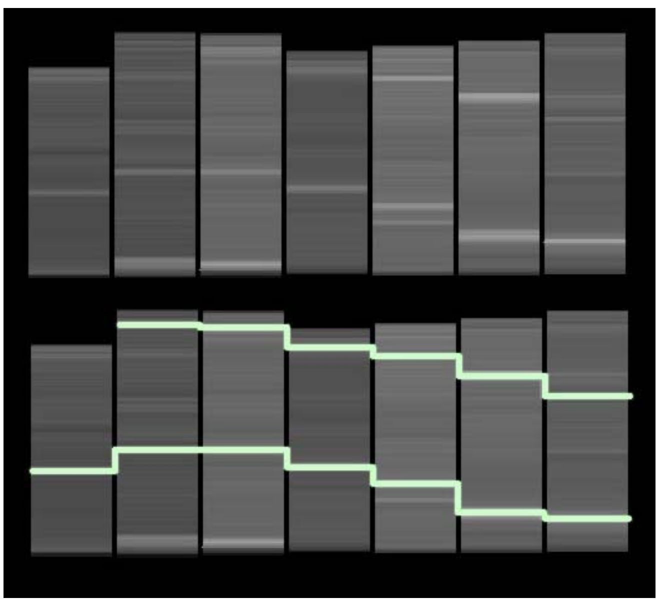

Figure 9. Location of soft bands within mine roof.

The core drilled holes were also bore-scoped. Both holes had three distinct voids. The first was at about 3 in depth. The second void was near the location of soft area detected in the other drilled holes. The last void was near the top of the holes at a depth greater than had been drilled in the other holes.

TESTING THE SYSTEM IN AN UNDERGROUND LIMESTONE MINE

A Maryland limestone mine elected to bolt a section of roof where there had been problems. This provided another opportunity to test the roof mapping system at a different limestone mine. NIOSH accompanied J. H. Fletcher in observing these tests and reviewing the results.

In this case, the roof bolter had the Drill Control Unit and a pendant recorder but no real-time display installed. A notebook computer was used instead to display and record the data. Four holes were drilled and bore-scoped at one location. Only one of the drill data files showed a possible void but no void was visible when bore-scoping the hole. The other holes in this area showed nothing remarkable in the data files or bore-scope videos.

Several holes were drilled and bolts were installed in another section of the mine where roof problems had occurred. One of the holes, which did not have a bolt installed, was bore-scoped and clearly showed a void at a depth of 39 Inches. There was no data file recorded for this hole. Another hole was drilled in the same area. Both the data file and the bore-scope video for this hole clearly showed a void at the same location. Figure 10 shows the hole graphs with the void marked. Figure 11 shows the void as seen by the bore-scope.

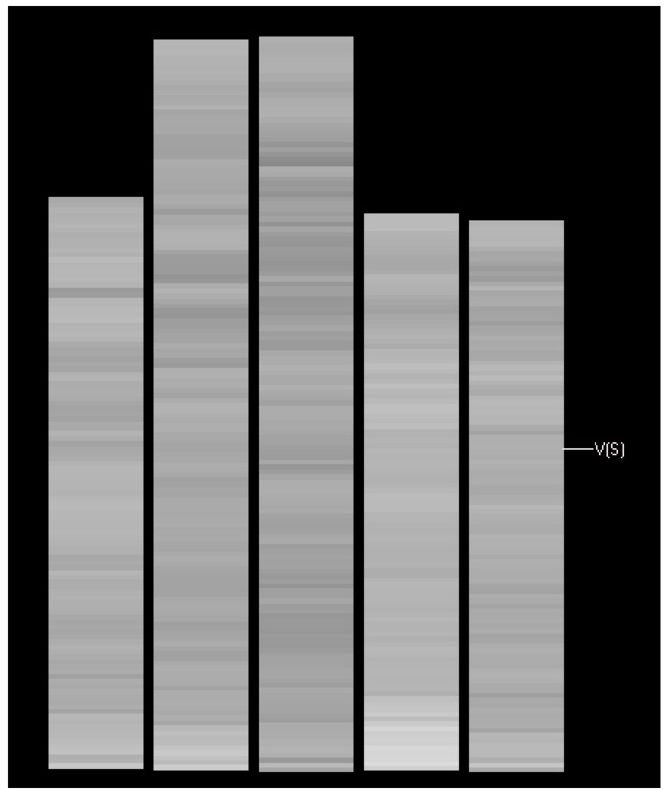

Figure 10. Hole graphs with void at 39-in depth marked.

Figure 11. Void as observed from bore-scope video.

A Missouri limestone mine has a percussive type roof drill and bolter with the FLETCHER® Information Display installed.. This system has been used successfully there for some time. Tests were performed recently with the latest version of the software and the new bore-scope for verification.

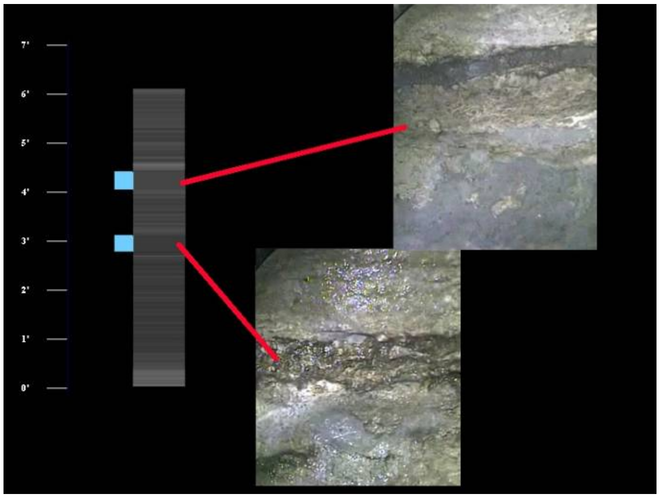

Figure 12. Mud seams at first location.

Three holes were drilled in one section and all three showed water events in the drill data files (see figure 12). These are events where the Drill Control Unit reacts to seams of mud which tend to plug the water flow through the drill. Mud seams were visible with the bore-scope at all three holes at locations consistent with the drill data. The mine engineer has been using the data from the Information Display to track these mud seams to set the roof elevation and make sure that bolts are not anchored in soft material.

Three more holes were drilled and scoped in another section of the mine. Only the first of these holes showed a water event in the drill data file. The bore-scope video for this hole shows a mud seam at that location. The video from the other two holes showed similar features that were small enough not to have plugged the drill. Figure 13 shows the hole graph along with bore-scope photos and a superimposed scale. The larger mud seam was approximately ¾ in thick and triggered a water event in the drill control unit.

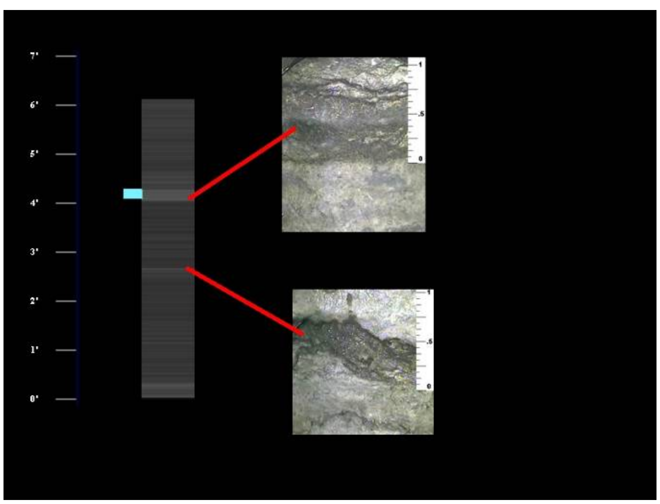

Figure 13. Mud seams at second location.

A Pennsylvania limestone mine which has the pendant recorder on a roof bolter offered another opportunity to record drill data files and compare them to bore-scope video. Again, NIOSH was present to observe these tests. Here, four holes were drilled in two different sections of the mine. Three of the holes showed large clay seams near the top of the hole. These were visible in the drill data files as lighter shades of gray. When the software sensitivity was adjusted they were marked as voids. The clay seams were clearly visible in the bore-scope videos. Figures 14 and 15 show the hole graphs and a bore-scope image.

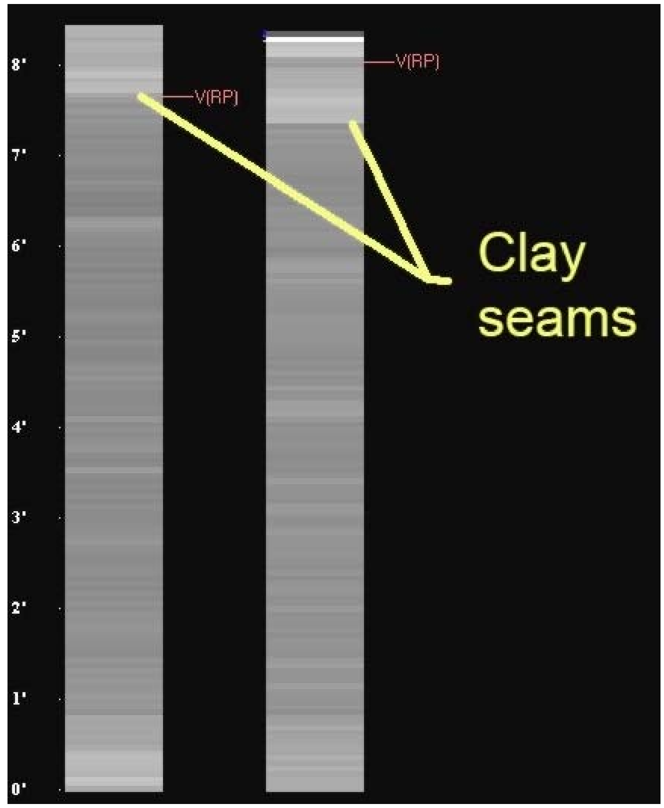

Figure 14. Hole graphs showing clay seams.

Figure 15. Bore-scope image of clay seam.

A photo from outside the mine opening shows the red clay above the limestone seam (see figure 16).

Figure 16. Red clay above limestone.

CONCLUSIONS

1. No one method shows everything.

Bore-scope video showed hairline and vertical cracks that did not show up with the intelligent drill system and Information Display. Rock layers which varied in color but had similar hardness were obvious in the bore-scope but not visible in the drill data files or with the scratch tool. Scratch testing found soft areas shown on the Information Display and some edges that were not obvious when using the bore-scope. The FLETCHER® Information Display will complement these other methods to provide a more complete picture of roof strata that is not dependent on personal interpretation.

2. The system needs to be adjusted for individual machines and mine conditions.

Many factors affect the thrust, torque and other parameters used to calculate material hardness and locate voids. These include drill size, bit type, bit sharpness, type of rock in the roof, style of drill (percussive vs. rotary) type of feed mechanism (rotary hydraulic motor vs. cylinder feed), settings for collaring and maximum feed pressures, RPM of the drill, and type of cutting removal (vacuum or water). An adjustment is provided in the software for rotation event and void detection sensitivity. As the knowledge base grows with different installations, a group of standard settings can be preprogrammed for each machine type and mine conditions.

3. Looking at trends gives a more accurate picture than individual data samples.

With all of these methods of determining roof strata, a single sample may not be an accurate representation of the area as a whole. Roof conditions may change drastically in a short distance. Voids that were clearly visible in one hole were not found in holes a few inches away. Core drilled holes which were closer to an intersection in the mine showed greater separation in voids than holes drilled just a few feet away. The FLETCHER® Information Display provides a way to view trends that may not be obvious using other methods alone. These trends are visible during the normal drilling cycle.

4. The FLETCHER® Information display is an ongoing research and development project that is still evolving.

More testing and improvements are scheduled.