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EARLY WARNING OF LONGWALL ROOF CAVITIES USING LVA SOFTWARE

David Hoyer

ABSTRACT: It is shown that by monitoring longwall leg pressures in real time, warning can be given for significant weighting events and the formation of roof instabilities, such as roof cavities, several hours in advance.

Longwall Visual Analysis (LVA) is a software package that continuously monitors shield pressures and shearer position in longwall mines. LVA has been running on 22 Australian longwalls for up to five years, and as a result a very substantial database of shield pressure trends in a wide range of longwall situations has been collected. This database has been analysed to develop indicators that will give operators and geotechnical engineers advance warnings of developing conditions such as weighting events and difficult roof conditions.

LVA displays live charts of data, such as shield leg pressures, loading rates, and yield frequencies. Data analysis techniques were applied to historical data records from multiple longwall sites in order to develop a “Cavity Risk Index” (CRI). The CRI indicates the relative risk of roof cavities developing, and it is based on pressure trends that indicate significant yielding and loading rates spanning a region of relatively low support.

Case studies from two different longwalls are given, showing how the CRI can give real-time advance warning of the formation of roof cavities.

INTRODUCTION

Longwall Visual Analysis (LVA) is a software package that continuously monitors, analyses, and displays shield pressures and shearer position in longwall mines. The first version of LVA was installed on an operating longwall in 2006, and the latest version is currently running on 22 Australian longwalls. As a result, a substantial database of shield pressures in a wide range of longwall situations has been collected. These data have been used to develop and test indicators that will give operators and geotechnical engineers advance warnings of developing conditions, such as significant weighting and the formation of roof cavities.

Other researchers have used roof geology in conjunction with leg pressure data to predict areas at risk of experiencing difficult roof conditions (Trueman, 2011; Wiklund, 2011). This paper uses leg pressure data only, which is easier to implement in practice.

LVA MONITORING OF LEG PRESSURES

The LVA software typically connects to the longwall face data via an OPC server (OPC is an industry standard for communication between machines). LVA reads leg pressures and shearer position every 20 to 30 seconds and creates an independent database of these values in a compressed format that allows fast access over networks. This provides sufficient resolution for LVA’s data analysis methods to identify individual set-to-release cycles on each shield, from which individual shears across the face can be identified. Various statistics can then be calculated for each leg during each set-release cycle or during each shear. These include time-weighted average pressure (TWAP), set pressures, loading rates, and leaking and calibration issues. Individual users (“clients”) can connect to the database via the network to view and analyse the data.

Figure 1 shows a typical LVA screenshot of pressures across the face and back in time over a period of 18 h. The black line over the leg pressure data is the shearer path.

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Figure 1 - LVA screenshot showing a 3D image of leg pressures across the face and back in time, with shearer path overlaid

The 3D image in Figure 1 is very efficient for real-time monitoring of a longwall face by operators, but other visualisation techniques can be more effective for reviewing larger amounts of data, such as a whole panel or major portion of a panel. LVA can identify individual shears across the face by analysing patterns of supports setting to the roof, which allows data to be displayed on a shear-by-shear basis. Figure 2 is a “Load Cycle Map” in which each horizontal row of pixels represents the average pressure of each leg across the face during a specific shear.

Figure 2 clearly shows areas of weighting events (horizontal bands of “hot” or red colours), and areas of difficult roof conditions and low-pressure roof cavities (areas of “cool” or blue/green colours). This paper describes a method for determining indicators to show operators in real time when there is a higher than normal risk of these roof cavities forming. This would allow the operators to take preventive action to reduce downtime and safety hazards; these actions could include double-chocking (advancing the shields more frequently and in smaller steps) and not stopping for maintenance.

ALERTS FOR “WEIGHTING DEVELOPING”

The LVA software has an Alert system that logs messages and sends emails when certain events are triggered. One such Alert trigger is called “Weighting Developing.” This is currently being used successfully by several mines to provide early warning of the start of unusually high weighting on a portion of the face. According to Moodie and Anderson, “The use of LVA has enabled earlier detection of an oncoming weighting event (several hours) and also a better indication of the potential severity of the event via triggers based around the support average pressure in combination with loading rate and yield counts in a cycle”.

Figure 3 shows how loading rates and yield counts can be calculated by LVA from the leg pressure trending data for each support. The “Weighting Developing” alert system has the following algorithm. LVA calculates the loading rate during the initial 5 to 10-minute period after the start of each set-to-roof cycle for each shield. During the cycle, LVA also counts yield events by identifying the characteristic rising/falling pattern of leg pressures when yielding. Every few minutes LVA determines which shields have the following properties, where numbers in square brackets are configurable by the user:

- The loading rate is at least two bar/min during the period five to ten minutes after the shield is set to the roof;
- The number of yields is at least three during the set-to-roof cycle;
- The time-weighted average pressure (TWAP) is at least 380 bar;
- A “Weighting Developing” alert is issued when at least ten shields simultaneously satisfy the three conditions above.
An Alert triggered by this algorithm indicates that a significant number of shields across the face are experiencing both high loading rates and substantial yielding. The Alert event is displayed on screen as a text message and optionally emailed to a list of recipients so that appropriate action can be taken.

![Figure 2 - LVA load cycle map showing time-weighted average pressure (TWAP) on individual legs across the longwall face for 989 individual shears over about 12 months. Weighting events show as horizontal bands of “hot” or red colours. Areas of difficult roof conditions and roof cavities show as “cool” or blue/green colours.](image)

![Figure 3 - Leg pressure trend showing start and end of a set-to-roof cycle, and illustrating the calculation of loading rate and number of yields in a cycle. This cycle had five yields on the maingate leg (red) and three on the tailgate leg (blue).](image)
ANALYSIS OF PRESSURES, YIELDS AND LOADING RATES

Figure 1 showed how instantaneous leg pressures can be displayed across the face and back in time using 3D graphics. Note, however, that these data are often quite noisy and the signal noise can mask longer-term trends such as periodic weighting and cavity formation. LVA provides a signal filter that smoothes the data. For example, Figure 4 shows similar data to Figure 1, though over 36 h instead of 18, with smoothing applied. Both the weighting and cavity events are much clearer when smoothed.

![Figure 1](image1.png)

Figure 1 - Screenshot of a 3D graphical representation of leg pressures across the face and back, showing the instantaneous data across time.

![Figure 2](image2.png)

Figure 2 - Screenshot of a 3D graphical representation with LVA signal filter applied, showing clearer data with smoothing.

The same smoothing and 3D presentation methods can be applied to yield count and loading rates, as shown in Figures 5 and 6. These are the data formats that will be used in the next section to develop a cavity risk alert system. In particular, compare Figures 4 and 5. Note how in Figure 5 showing Yields in a Cycle, there are two “mountain peak” areas that form on each side of where the cavity formed in Figure 4. Note also that these peaks can be identified several hours before the cavity forms.

![Figure 3](image3.png)

Figure 3 - Screenshot of yield count for each shield across the face and back in time, with formation of a significant “bridge” to each side where the cavity formed.

![Figure 4](image4.png)

Figure 4 - Similar data to Figure 1, but with the shearer path removed and with a smoothing filter applied. Note the appearance of a substantial roof cavity near the middle of the face (blue area at front of image).

![Figure 5](image5.png)

Figure 5 - Smoothed image of yield count for each shield across the face and back in time. Note the formation of a significant “bridge” to each side where the cavity formed (cf. Figure 4). This bridge was prominent for several hours prior to the cavity forming.
The “Weighting Developing” Alert system described above has proved useful at several longwall sites. The primary concern when responding to weighting alerts is to try to reduce the occurrence of actual roof cavity events, namely complete loss of support pressure over a portion of the face and a section of the roof collapsing. This situation often results in loss of production and increased safety hazards. However, if an operator gets a Weighting Developing alert, they still do not know if the situation may develop into a cavity, which is a much worse condition. It was speculated that it should be possible to develop a “Cavity Risk” indicator by modifying the weighting alert algorithm. Additionally it was considered that a real-time display system with continuous visual feedback would be more useful to operators than a text-based Alert system when heading into potentially difficult roof conditions.

Cavity risk index algorithm

Several different algorithm types were trialled on historical roof cavity events from different longwalls across Australia. Roof cavity events can be clearly identified from the Load Cycle Maps of TWAP, like the example shown in Figure 2. The LVA databases from each longwall site were used to replay conditions leading to cavity events, in order to test the effectiveness of various algorithms. It was found that cavity events are frequently preceded by the type of Yield bridging shown in Figure 5, and this was used as the basis of the Cavity Risk algorithm in conjunction with loading rates. Note that the bridge is neither a physical bridge nor a pressure bridge, it is a conceptual “yield and loading rate” bridge, which begins forming several hours before the pressure bridge of a roof cavity.

The algorithm finally selected to quantify cavity risk is as follows:

- Each individual shield is considered a “cavity risk trigger” if
  - its loading rate is at least two bar/min five minutes after setting the shield to the roof;
  - the number of yields is at least three during the set-to-roof cycle.

- The pattern of cavity risk triggers across the longwall is analysed to determine whether a bridge exists somewhere on the longwall. A bridge in this context is a region of non-triggered shields (low yielding and loading rate) straddled on each side by a region of triggered shields (high yielding and loading rate). For example, a bridge may be said to exist when a region at least ten shields wide has no triggers, and the region is straddled by regions on each side that have at least four out of 12 shields in a trigger state. The numbers given here (10, 4 and 12) have proven satisfactory in the cases studied so far. Further work is required to see whether these may need to be tuned specifically for different sites.

- A “Cavity Risk Index” (CRI) is calculated from the size of the bridge, from 0% when no bridge exists to 100% when four or more out of 12 shields on each side of the bridge are triggered.

- The calculated CRI can actually decrease before a cavity event as the roof begins to weaken. For this reason, the displayed CRI is taken to be the peak CRI value over the previous 12 h when implemented in a real-time warning system.
• Filtering is applied to the CRI trending, to reduce the effect of anomalies such as isolated spikes.

CAVITY RISK - CASE STUDY A

This case study was taken from an Australian longwall mine with 170 shields of capacity 875 t, with a yield pressure of 430 bar (the same data shown above in Figures 3 to 6). The immediate roof is sandstone conglomerate, with thick massive sandstone conglomerate channels from 60 m above the seam. The case study shows how the CRI changed from low to moderate about seven hours before a roof cavity formed, and to extreme about three hours before the cavity formed.

Figure 7 shows how the calculated CRI varies between close to 0% and 100% over a period of 36 h. The CRI went into the “high” range, above 80-percent at 3:28 am, and reached 100-percent at 7:26 am.

Figure 8 shows a sequence leading to the roof cavity forming at 10:40 and becoming more pronounced by 13:55. The sequence of seven snapshots, labelled A to G, shows the state of the longwall leg pressures at different times. The x-axis shows shield number, in this case from 1 to 170. The blue dots along the bottom edge mark those shields that satisfy the trigger conditions of high yielding and high loading rate. The CRI is calculated from the pattern of these dots as described earlier. The sequence progresses as follows:

• 28 May at 13:04. Leg pressures across the face are within the low to normal operating range. The thick black line is a smoothed profile drawn through the leg pressures. The blue dots along the bottom section of the graph mark those individual shields that are in a “cavity risk trigger” state, meaning they have experienced high loading rates and multiple yields. The Cavity Risk Index (CRI), shown in the gauges to the right, is calculated from the pattern of individual shields in the cavity risk trigger state - specifically identifying when the longwall face is in a bridging state. At this stage the CRI is low, as the algorithm applied to the pattern of blue dots indicates a weak degree of bridging.

• Four hours later, 17:02. Leg pressures across the face are still within the low to normal operating range. The CRI is low but just touching on yellow (moderate). Note that the black gauge needle represents the peak CRI value over the previous 12 h, not necessarily the value from the exact pattern of dots shown in this image.

• Eight hours later, 29 May 03:28. Leg pressures across the face are still within the normal operating range, but the CRI is high, just touching on red.

• Four hours later, 07:26. Leg pressures across the face are still within the normal operating range, but the CRI has just jumped to extreme.

• 10:19. The CRI has been extreme for three hours, while leg pressures across the face remain within the normal operating range.

• 10:40. After the CRI has been high for seven hours and extreme for three hours, major loss of roof pressure occurs between shields 65 to 95, indicating formation of a roof cavity.

• Three hours later at 13:55 the cavity is more pronounced. Mining stops for two days.
Figure 8 - A sequence of seven snapshots (A to G) of the state of the longwall leg pressures, leading to the cavity formation. The CRI becomes high several hours before the cavity forms.

CAVITY RISK - CASE STUDY B

This case study was taken from an Australian longwall mine with 181 shields of capacity 913 t and yield pressure 420 bar. The case study shows how the CRI changed from low to moderate about three hours before a roof cavity formed, and to extreme about two hours before the cavity formed. Figure 9 shows the smoothed leg pressures across the face and back in time, developing to a cavity at the front of the image.

Figure 9 - Case Study B. Smoothed leg pressures across the face and back in time. Note the appearance of a substantial roof cavity near the middle of the face (blue area at front of image)
Figure 10 shows how the calculated CRI varies between 0% and 93% over a period of 18 h. The CRI was in the “high” range of 60 to 80-percent at 2:46 am, and reached the “extreme” range of 80 to 100-percent at 3:30 am. Figure 11 shows a sequence of smoothed face pressure profiles and CRI readouts leading to the roof cavity forming at 5:28.

Figure 10 - Case Study B. The trending graph over 18 h of the Cavity Risk Index, rising from low at 0:48 to high at 2:46 and extreme at 3:30. A roof cavity began forming at 5:28

Figure 11 - Case Study B. 21 Aug at 14:00 to 22 Aug at 5:28. Showing how the CRI varies from low to extreme as leg pressures across the face change, leading to the roof cavity at 5:28

IMPLEMENTATION OF REAL-TIME CAVITY RISK INDICATOR INTO LVA

Figure 12 shows a prototype of how the CRI has been integrated into the LVA software for continuous real-time feedback on the future risk of roof cavities forming.
CONCLUSIONS

The LVA shield monitoring software calculates a Cavity Risk Index (CRI) from patterns of yielding and loading rates across a longwall face. This CRI warns of developing poor roof conditions including roof cavities - often giving several hours more warning than might be gained from looking at leg pressure trends alone. This advance warning allows operators to take preventive action such as double-chocking and not stopping for maintenance, which in turn can reduce downtime and safety hazards.

The CRI has been implemented in the LVA software program to provide real-time warnings of cavity risk to longwall operators. Two case studies were presented in this paper. Approximately ten additional roof cavity events have been identified and studied to date. In all but one the CRI was triggered several hours before the cavity formed. The confidence that a cavity can be predicted with several hours notice is therefore high, though additional work is needed to quantify the incidence of false cavity predictions.

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REFERENCES

