Investigations into the applications of microseismic sensing to slope stability monitoring in open-cut mining

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Background

Unexpected high wall failure brings with it the highest potential impact in open cut coal mining operations and current methods of risk management rely on slope stability monitoring.

Early identification of a ground failure will ensure the safety of workers but would also be of provide a window of opportunity to take corrective action depending on the nature and cause of the problem.

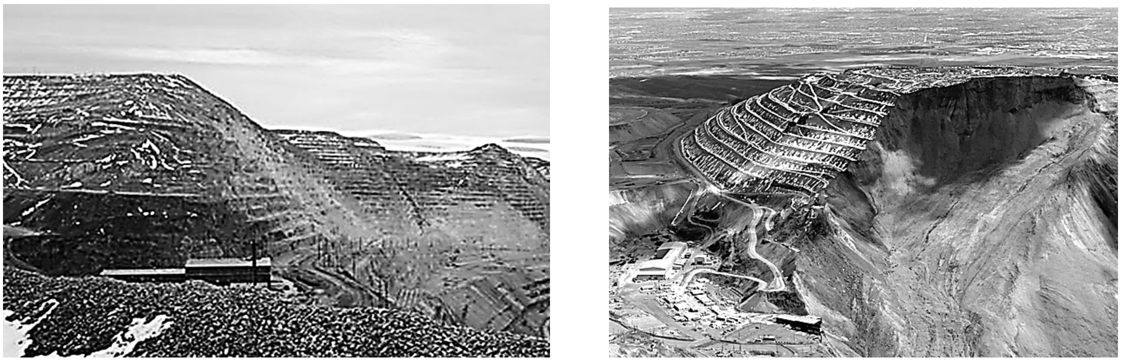


Figure 1 Before and after the 10 April 2013 landslide

In 2012 the Kennecott mine near Utah in the USA produced about 163,000 metric tons of refined copper metal plus 279,000 ounces of gold and 9,400 tons of molybdenum. On 10th April 2013 a land slip took place that saw 165 million tonnes of ground slide into the 450m-deep excavation (Figure 1). In the weeks leading up to the dramatic events of that day, the mine wall had been monitored by every technique available. The mine had been completely evacuated by the time the pit wall failed.

It was clear to all concerned that once 165 million tonnes of material started to move, there was nothing more that could be done to prevent it progressing ; all efforts had been focussed on ensuring the safety of personnel and minimising damage to infrastructure and loss of equipment.

Highwall stability is a critical issue for open cut mines in terms of safety and production efficiencies. In today’s economic climate it is essential that the cost benefit analysis and business case for adopting new technologies or methodologies is unambiguous .It is the OCE’s responsibility to continually assess the condition of rock faces and make a judgement regarding the likelihood of failure and to have procedures in place that define operating standards that minimize the risk to personnel, equipment and reserves. Information from monitoring can inform training in best practice, slope design or defining the components of the Trigger Action Response Plan

The significance of each mode of ground failure depends on the potential impact of that event and its likelihood of occurring: highwall failures resulting in a release of rock-mass; low-wall failure; dragline bench failure; dump failure; each bring their own risks to the operation.

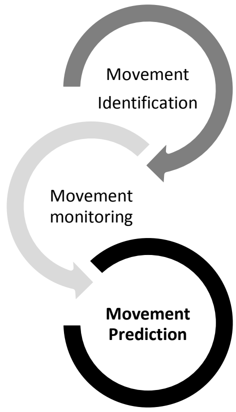


Figure 2 Ground control hierarchy

The true structural condition of a highwall can be difficult to judge but indications can be derived from a number of methods: in 2009 a major mining firm in Australia listed the techniques open to them to monitor ground movement as:

- ☐ Visual monitoring
- ☐ 3D visualisation/ assessment
- ☐ Use of Tell Tales
- ☐ Measuring between pins
- ☐ Wire line extensometers
- ☐ Prism monitoring of the high wall
- ☐ Inclinometers
- ☐ Piezometers
- ☐ Photogrammetry
- ☐ Slope Monitoring Radar

All of the techniques above indicate whether there has been, or ongoing ground movement and the rate of change of that movement can be indicative of the future behaviour of the ground.

Some of these methods give localised warning and others, such as radar and photogrammetry, have application to monitor wider areas of the rock face. The use of ground monitoring radar is another example of a reliable, real-time technique which is considered by many as the most effective system available to provide reliable advanced warning of an impending event. Detection of outward movement of rock of less than 1mm is possible.

Microseismic Monitoring

Microseismic detection has always held promise to give advanced warning a rock failure. Miners have listened to their mines for centuries hoping to interpret the sounds they were hearing . Seismic monitoring remains the only means available to remotely monitor how the rock mass is responding to mining activity.

In addition to major slope failures, rock fall can present a significant hazard to personnel and equipment. Even when exclusion zones are in place some mining activities will periodically require personnel to work within these specified, primary standoff distances.

Recent developments in microseismic sensing technologies and the associated signal processing techniques offer the possibility of using seismic sensors *without the need to drill bore holes.* The new systems will allow the precursors of slope movement to be detected in real time, localised and mapped, delivering insight into how the high wall is responding to mining activity.

During 2014/15 Simtars is intending to initiate its own trials of this surface-deployable technology in Queensland with the specific aim of identifying if and how microseismic systems could contribute to safety and productivity in open cut mines. Other investigations will focus on underground mining applications where similar microseismic systems have been successfully demonstrated to detect and locate trapped miners.

An ACARP supported study by CSIRO (King. A, 2009) investigated the benefits of automated real-time microseismic sensing in underground coal to understand roof-weighting; fracturing between adjacent seams; wind blast; caving issues; fault monitoring and gas flow. They achieved their goal to specify and develop a distributed wireless seismic sensor network with real-time signal processing that would meet the needs of underground coal mining.

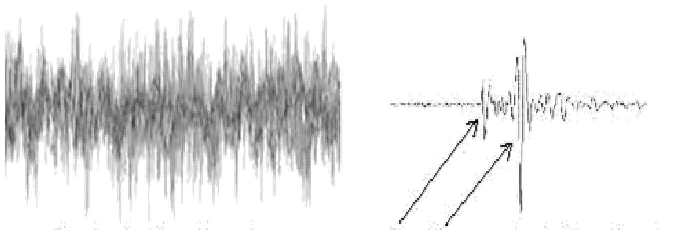
(Wesseloo.J, 2008) addressed the specific application of microseismic monitoring to the needs of open pit mining. The increasing need to develop ever deeper mines creates increasingly stressed environments and consequent uncertainty regarding the mechanical behaviour of slopes. Slope heights greater than 500m are more common and depths of greater than 800m have already been realised.

(Kable, 2005) references one of the first seismic installations of a seismic array in an open pit mine in 1996. Wesseloo cites earlier work by (Stacey, 2007), (Eberhardt et al, 2004) and (Stead et al, 2007) and their work on stability of rock slopes and fracture initiation, and brittle fracture failure on slope behaviour. It is acknowledged that hardware limitations have played a role in preventing the technique from becoming mainstream.

As recently as 2009 microseismic sensing was not automatically included in the repertoire of the slope stability monitoring technologies despite there being an estimated 25 open pit slopes being monitored to date (Lynch R.A, 2006). Wesseloo (and Sweby) conclude that current seismic monitoring systems are rigid compared to the dynamically changing mining environment.

As outlined here, this technology has the theoretical ability to detect and spatially locate the point of origin of a seismic event. By logging these events in real-time and mapping them with respect to the mine plan, it is reasonable to expect that some level of insight into impending ground failures to be identified.

Contemporary microseismic system designs exploit the ability to measure the time difference of arrival the 'P-wave' and 'S-wave' that are generated by a seismic event together with their vector and magnitude.



Raw signal with working noise   P and S waves extracted from the noise

Historically there were a number of good reasons that this technology hadn't been widely adopted in Queensland, namely:

- Installation was costly as the sensors needed to be installed in bore holes to get them as close to the expected zone of interest as possible. This meant that boreholes were necessary to physically get the sensors near the highwall.
- Some systems required an arrangement of sensors on the surface and underground in an attempt to 'surround' an event.
- As mining progressed, the sensors had to be extracted from their positions, and transplanted into a new set, without damaging them in the process.
- Some systems on offer cannot function if the mine is still in production, as the background levels of vibration were too high from vehicle movements, operating plant, pumps, generators and conveyors.
- The magnitude of the seismic events was too low a level to be identified by the system
- System capital cost was upwards of $400,000.

Why is the timing right to revisit microseismic monitoring?

Simtars has been looking at sourcing appropriate microseismic systems for some time and the Surewave system stands out in one key respect, namely that it is designed for installation at the surface, without the need for boreholes. In this respect the Surewave Technology system is a game changer.

Surewave UK has been working on microseismic monitoring since the early 1990s and their latest offering, the SP2, appears to deliver benefits that neatly compliments the needs of the open cut mining industry.

In absolute terms the SP2 can isolate seismic events with signal levels in the order of 10^{-15}mm/s. This astonishing sensitivity is supported by equally impressive signal processing that can isolate the seismic signal at 10^6 times lower than the background mine noise.

Case Studies

The SP2 has been used to monitor ground response in deep underground coal; open cut coal; slate mines; deep potash mines; hard rock; gypsum underground mines; border surveillance operations to detect movement of people and contraband in shallow tunnels and as part of emergency response measures to detect and locate trapped miners.

A trial of the Surewave system was supported by the University of Liverpool in 1996 (Styles. P, 1998) at the underground coal mine at Asfordby in the UK. The system identified a pattern of seismic events that were the precursors to a major mine collapse, nearly 18 weeks ahead of the collapse.

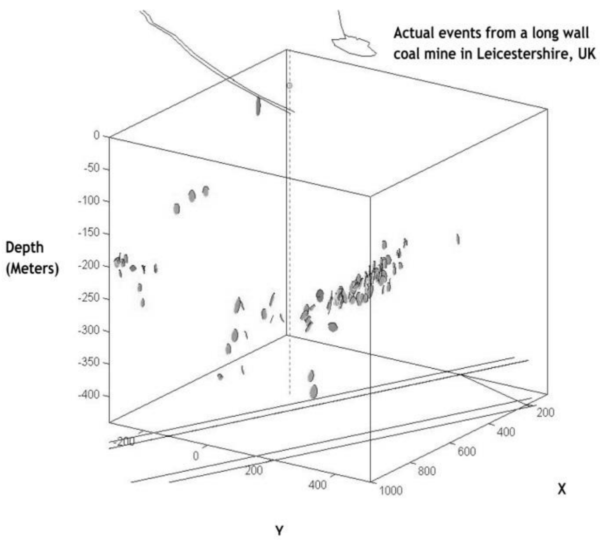


Figure 3 3D Display of microseismic events superimposed on the mine plan

Expert geotechnical support from the University of Liverpool was responsible for the interpretation of the raw seismic data and they reached the conclusion that there was an impending mine collapse.

In 2013 the SP2 system was deployed to map the seismic activity in a potash mine 800m deep. With the system established at the surface in shallow excavations of <1m, the system could detect the movement of water surrounding the mine workings.

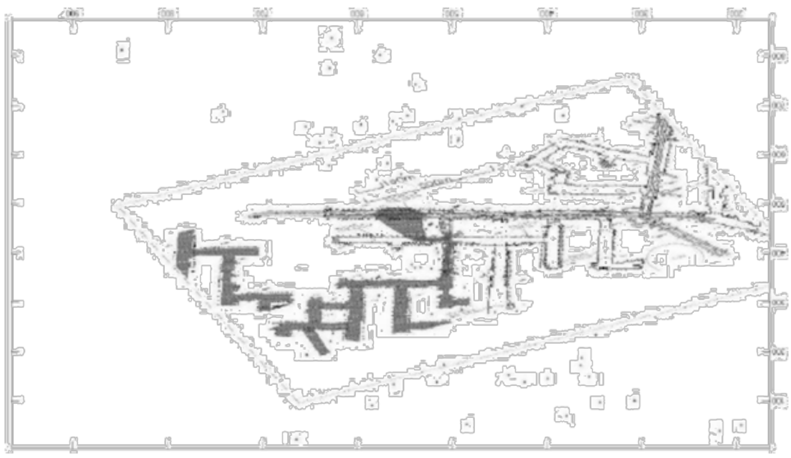


Figure 4 Areas of water movement (shaded dark gray)

In a 2014 open cut case study, the SP2 system identified the precise location of impending rock falls. The rock in questions were approximately $0.5m^3$. One benefit for this open cut coal mine operator was to allow an increase in slope angle. The seismic monitoring was a requirement to manage the potential increased risk. The operators have stated that for every degree of increase of the high wall angle they can save $ 1 million/ month in avoided over burden removal.

Surewave participated in two open competitions to supply seismic monitoring systems for border protection installations. In both cases, major international providers were also competing to prove that their systems could perform within the specified parameters.

These trials were conducted under the scrupulous supervision of the USA's Department of Homeland Security at the Yuma Proving Ground in Arizona. Other systems tested were supplied from Boeing, Lockheed Martin, ESG and MSHA. The outcome showed that Surewave was the only supplier to achieve 100% success rate with zero % false alarms. Their system was able to 'see through the noise' of surface transport movement to identify movement in elicit tunnels.

Further trials of the system took place in the USA in the context of a 'Trapped Miner Detection" at depths of 200-300m. The mine trials in the USA were conducted under the supervision of Prof Keith Heasley of the University of West Virginia. (Heasley, 2014). Trials in the USA were conducted at Consol Energy's Macelroy Portal, West Virginia, Federal #2 Mine, Alpha Natural Resources. Each participated in a 'trapped miner' exercise and in all cases the system proved successful to detect the miners pounding on a roof bolt.

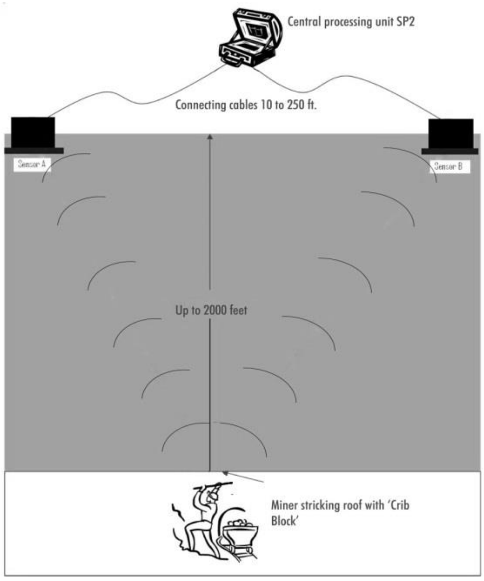


Figure 5 Test setup to detect trapped miners

During these trials the aim was to detect the signals in real time. Significantly the MSHA-designed, intrinsically safe geophone-based system failed to detect the pounding by the miners.

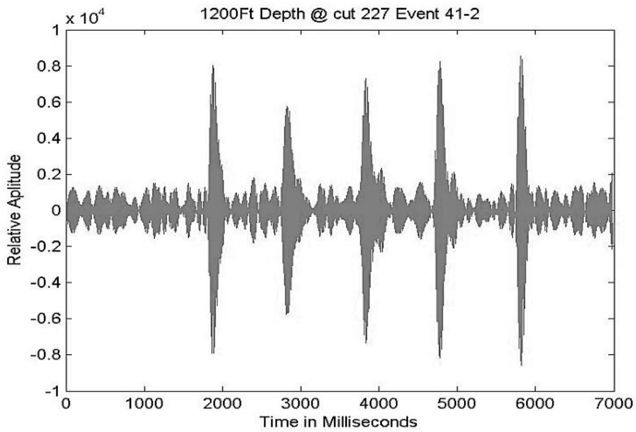


Figure 6 Impulse response to hammer blows on a roof bolt underground

By contrast, National Institute for Occupational Safety and Health (NIOSH) conducted an independent trial of the Surewave technology in 2013, but the results were inconclusive and remain disputed.

The most recent endorsements of Surewave comes from two national defence agencies that have approved the SP2 system to be deployed for wide-area security to detect incursions into sensitive areas and for tunnel detection.

Simtars Planned Investigation

As a safety organisation it is Simtars' primary aim to improve the safety and wellbeing of the mining community in Australia and further afield. These investigations are important as they could establish a new option to inform safety decision making and to improve productivity.

During the coming year Simtars plans to conduct a series of trials on the SP2 system in open cut mines. The trial aims to identify the detection limits, and identify the infrastructure requirements and operational risks arising from its operation. The system itself comprises of three tri-axial geophones established at positions 100m apart on a rough line 50m behind the crest with a remote power supply and communications. The sensors are mounted onto rock, or in shallow holes deep enough to have the best chance of coupling to the seismic signals. All three geophone signals are collected at a local data acquisition device (the SP2). Monitoring can take place while the mine is fully operational.

Theoretically, microseismic monitoring detects the precursors to movement, however it needs to be demonstrated that the information obtained from the system will be unambiguous and be capable of interpretation such that safe and consistent operational decisions could be made. We are aiming to determine whether the system would truly provide sufficient quality of data that the mine site OCE could include the insight derived from this system into the formation of the mine TARPs.

For the purposes of this trial, the data will be collected via a satellite link to a remote server.

Simtars has an SP2 system ready for deployment. At this stage we believe that the benefits of the system are:

- It is sufficiently sensitive to detect microseismic events
- Location accuracy can be tuned by generating events at known locations and calibrating the system
- The manufacturer has offered their support to optimise the signal processing to the ground conditions
- Ability to monitor a high wall face over 1km in length with one 3-sensor system.
- No bore holes are required (although ideally the sensors should be mounted into solid ground or below the top soil)
- The mine operators should benefit from real-time alerts if seismic activity rises in frequency or the magnitude of the events increases
- Observe how the pit reacts to normal mine activities and to drill and blast operations over time and range from the blast area.
- Gain an understanding of whether changing mining processes in some circumstances would reverse an impending slope failure.

We are actively seeking partners in the industry to participate in the trial by permitting the system deployment on site for a number of months.

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