CASE STUDIES OF SLOPE STABILITY RADAR USED IN OPEN CUT MINES

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ABSTRACT

The management of risks associated with slope instability is an essential process in the safe and economic operation of open cut mines. The 'slope stability radar' (SSR) has been developed to better manage those risks. The SSR remotely scans rock slopes to continuously measure any surface movement and can be used to detect and alert users of wall movements with sub-millimetre precision. The high level of movement precision and broad area coverage of the rock face can allow for a better understanding of the geomechanics of slope deformation, including magnitude of potential failures and additional warning time of impending instability. Additionally, radar waves adequately penetrate through rain, dust and smoke to give reliable measurements, 24 hours a day.

SSR systems have been deployed in many mines in Australia, Indonesia, South Africa, Zambia, Chile and the United States. Greater than 70 rock falls and waste dump failures (from several to millions of tonnes) have been monitored, and on every occasion precursor 'warning' movements were recorded by the SSR. This technology enables a radical change in the management of risks in open cut mining. This paper will present recent case studies of the SSR operation in coal and metalliferous mines.

1. INTRODUCTION

The management of risk to personnel, equipment and continued production associated with slope instability is one of the key roles of geotechnical and mining engineers in open cut mines. The importance of slope angles, slope instability and striping ratios on the economics of open pit operations is well recognised, and it can be quickly appreciated that eliminating all probability of slope instability by reducing slope angles is usually economically prohibitive. Therefore, some degree of risk is usually accepted during the mine design process.

The rock slope design role often incorporates some degree of risk management, either explicitly or implicitly in the design of pit slopes. Nevertheless, unexpected failures have occurred in the past and continue to do so today. These slope failures motivated the development of the slope stability radar (SSR). The SSR system can detect and alert movements of a wall with sub-millimetre precision, with continuity and broad area coverage. This monitoring occurs without the need for mounted reflectors or equipment on the wall and the radar waves adequately penetrate through rain, dust and smoke, 24 hours a day (see Noon, 2003; for more details about the SSR technology).
The SSR system produces data for interpretation usually within minutes. The data from the slope stability radar is presented in two formats. Firstly, as a coloured "rainbow plot" of total movement which quickly enables the user to determine the extent of the

failure and where the greatest movements are occurring (which is useful to characterise the type of failure). Secondly, any number of time/displacement graphs can be created at any locations within the scan area to evaluate displacement rates and aid in the creation of alarm triggers for action response plans.

To date, SSR units have detected and recorded warning movements in over 70 rock falls and slope failures ranging from just a few tonnes to many millions of tonnes. The SSR units have operated within highly variable geotechnical conditions including massive hard rock, intensely fractured, foliated ultramafics, weathered oxide pits, coal strata and waste dumps of variable characteristics. This paper presents several case studies of the SSR providing improved operational risk management by characterising the slope instability, and providing sufficient warning time prior to failure.

2. COAL MINING (MOUNT OWEN MINE, AUSTRALIA)

2.1 Introduction

The Mount Owen Coal Mine is located in the Hunter Valley, Australia and is owned by XSTRATA Coal. The North Pit of the Mount Owen Complex of coal mines is the deepest open cut coal operation in Australia with depths in excess of 270 m and has extreme and unusual geological conditions. It is located between two regional thrust faults, with the coal intensely faulted and folded with the dip of bedding between 10-45 degrees. This results in some challenging geotechnical conditions, both in the high wall and in the low wall floor conditions.

2.2 Overview of SSR Positioning and General Conditions

Mount Owen was monitoring an unstable low wall using traditional methods for over twelve months. When the movement rates became excessive, the mine utilised the SSR which commenced on 13th January 2005. The monitored wall is concave, with the SSR positioned to the extreme left hand side (see Figure 1).

2.3 Radar Parameter Setup

The SSR permits users to enter parameters that define the conditions for alarm generation. One urgent alarm (red alert) was set for the scanned area using a 70 mm movement threshold over a time period of 45 minutes. This alarm could be triggered within a scanned, pixelled area of 1029m^2.

2.4 Failure Characteristics

1. The slump was a multi-bench, day lighted circular failure.
2. The material that slumped was spoil that formed part of the mine dump and access roads to the dump area.
3. The low wall slumped as a single entity and caused 10-15 metres of floor heave.
4. The official estimated failure size was 15,000,000 to 30,000,000 m^3.
5. The slump occurred at approx 7.40 am 29/01/2005.

6. Deformation up to 1000 mm in the area of the slip was recorded at the time of failure. The deformation data in Figure 1 is colour coded and clearly shows movement over the whole slump area. Note the absence of detectable movement around the well defined slump area. The two graphs show points within the moving mass which show characteristic acceleration (progressive failure response) prior to failure.

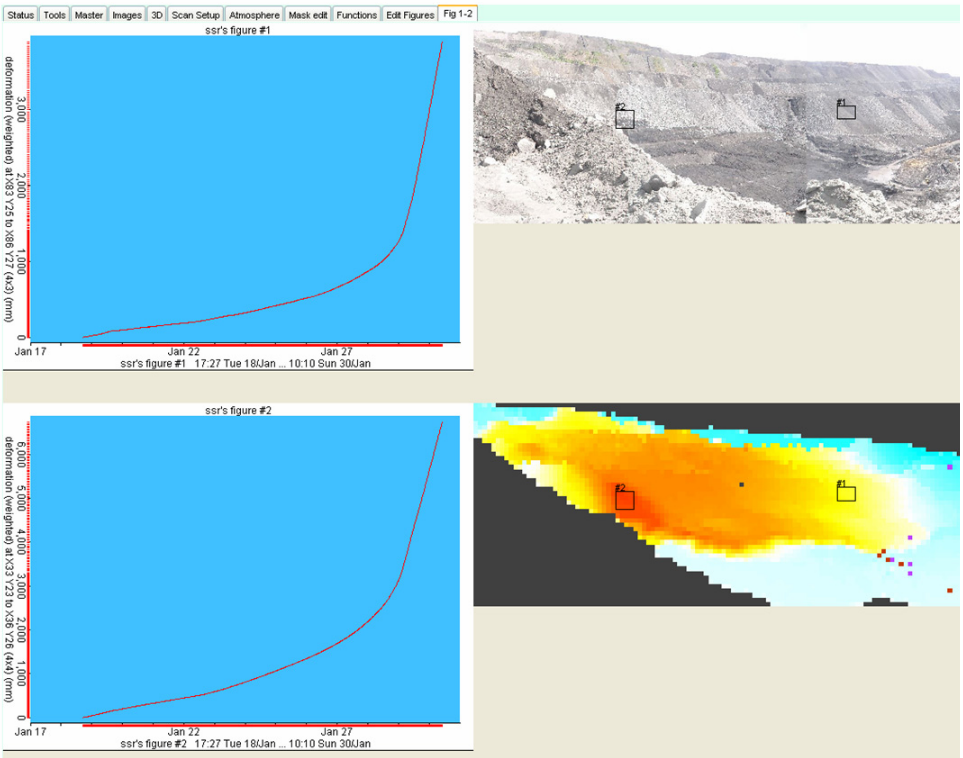

Figure 1: SSR Visual of the Mt Owen Wall Failure (with Selected Displacement Plots)

Figure 2: Visual of Alarm Trigger and Failure Surface

2.5 Operational Aspects

1. The red alert was first sounded at 03:43 on 29/01/05 (see Figure 2).
2. The alarm procedures were followed by the control room staff.
3. The slump occurred at approx 07:40 on 29/01/05.
4. The movement detected was consistent with that set in the alarm parameters.
5. Using the alarm settings discussed, approximately 4 hours of warning was received prior to the impending slump.

Management plans developed on site incorporating the SSR enabled operations to continue up until approximately 5 am that morning. At this point overburden haulage over the low wall dump ceased. Comments from members of the inspection team that witnessed the failure unfold include: "There were few tell-tale signs when it failed, no rilling of material over the dump, no rapid opening of cracks, no dust, no noise, only minor trickling of material along the day-lighting surface of the surface" and "…Strange silence prior to failure...then I saw the ramp just raise 10m in the air at a rate of about 1m/second…" (Pisters, 2005).

The combination of the SSR and a well developed trigger action response plan (TARP) at Mt Owen was the key to the success in managing the risks associated with the low wall instability.

3. METALLIFEROUS MINING

3.1 Introduction

Although initially developed in the coal mining environment, SSR systems have obtained far greater acceptance throughout the metalliferous mines of Australia and Africa. The first SSR unit to be deployed in Africa was in Novemeber 2003 on a 3 month trial (described in Poggiolini, 2005) but due to it's effectiveness in managing slope instability risk has remained on-site to this day. There are currently 8 SSR units in Africa with 5 SSR units currently on long term deployments at operating diamond, iron and copper mines. The rock mass conditions, geometry, operation and risk exposure of metalliferous mines can be significantly different to that in coal mines. A number of smaller, slope failures (rock falls) are described in the following section, which although much smaller in magnitude to the Mt Owen low wall failure also carry a significant risk due to the speed at which the failures develop and the higher exposure of workers (and infrastructure) to potential slope failures in metalliferous mines.

3.2 Radar Parameter Setup and Alarming

The SSR is often used in localised critical monitoring such as where active mining is occurring in the pit or along the main haul roads. Unlike the case in Mt Owen where the SSR was used to monitor an ongoing (but relatively low velocity) slope failure, the SSR systems in metalliferous mines are mostly being used to identify smaller failures that may develop quite rapidly following excavation, blasting or other change in loading conditions. To this aim, four alarms are often used at an operation:

- Red Alarm – critical alarm situation where an emergency situation is announced and the pit superintendent is notified to evacuate the area of concern as well as calling the geotechnical department.

- Orange Alarm – so called "geotech alarm" where movements indicate a developing situation that the geotechnical department should be made aware of and provide guidance on.

- Yellow Alarm – system failure in the radar which results in the pit superintendent being notified that the radar is unavailable and geotechnical department notified to assess the SSR (with GroundProbe support).

- Green Alarm – a minor system failure where the SSR is shutdown and SSR viewer program restarted as per procedure.

The selection of alarm triggers is done on a custom basis by the mine geotechnical personnel as alarms can be set up on threshold displacement, time (using time and displacement to get a velocity trigger) and size of failure. The SSR data is continuously dispatched to the control room and screened. When an alarm is triggered, on screen instructions with the alarm ensures that the appropriate target action response plan is undertaken.

3.3 SSR Monitored Rock Fall Number 1

The SSR response from the first rock fall captured by a SSR at an African Mining Operation is shown below in Figure 3.

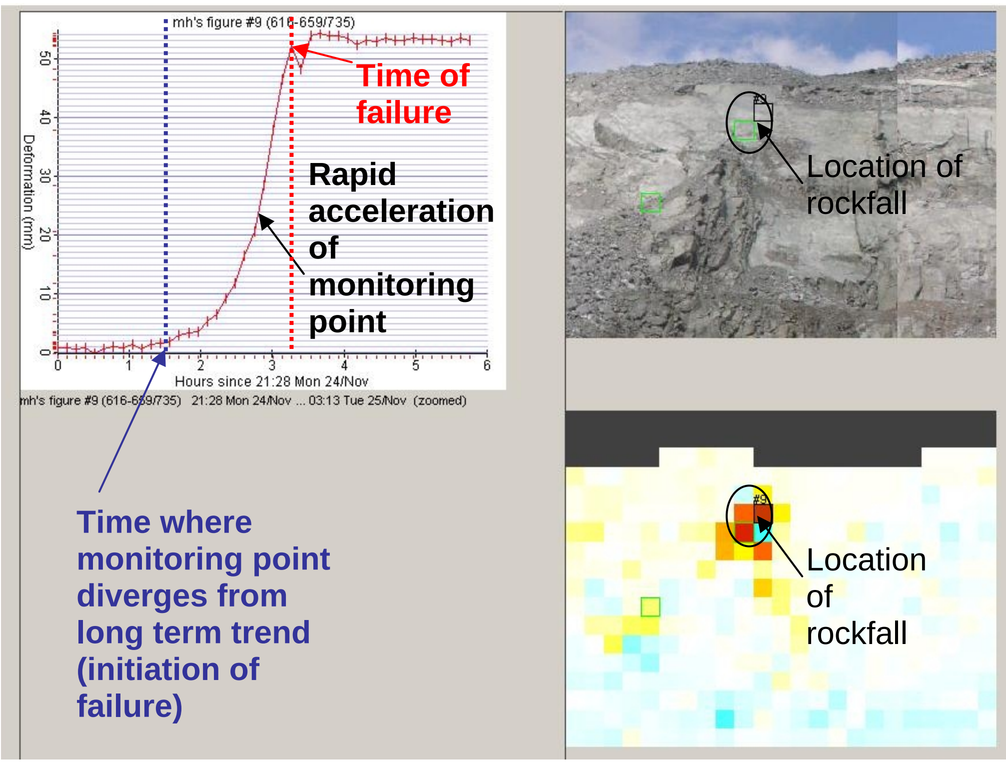

Figure 3: SSR visual of the Rock Fall (with Selected Displacement Plot)

It occurred two weeks into the initial field trial and was a small 300 t failure. The failure can be seen to develop on the SSR deformation plot, where 54 mm of movement was seen over 240 minutes prior to actual rock fall event (when the failed rock detaches itself from the face). Even with a small failure in a brittle rock mass, the SSR did provide over an hour of warning which would allow the area of concern to be cleared of personnel and equipment.

The small size of the failure that was monitored is such that it may 'fall in the gaps' between conventional prism monitoring programs (typically on a 50 by 50 m grid or more) and use of the SSR allowed real time monitoring and alarming. This resolution of failure detection and speed of alarming resulted in adoption of the technology as part of the slope instability risk management process and there has constantly been a SSR unit at the operation since the initial trial.

3.4 SSR Monitored Rock Fall Number 2

The second example highlights failure associated with active mining (excavation). In this example a small (less than bench height) rock slab failed due to excavation at the toe of the slope. The small size of the rock slab can be seen in Figure 4.

Figure 4: Small Rock Slab Failure

The SSR response to this failure can be seen in Figure 5. The large pixel size of the SSR image is due to the small size of the failure and distance (approx 400 m) from the radar to the slope. The monitoring point located to the left of the failure (the upper displacement graph) shows a maximum movement of 3 mm. At the actual site of the failure the deformation (lower displacement graph) shows up to 250 mm of movement. Rather than a typical acceleration profile, the figure shows a stepped profile with steps relating to actual excavation events. Shovel digging and removing of rock from the rock slab occurred up to 17:30. The slab finally detached from the face at 18:20.

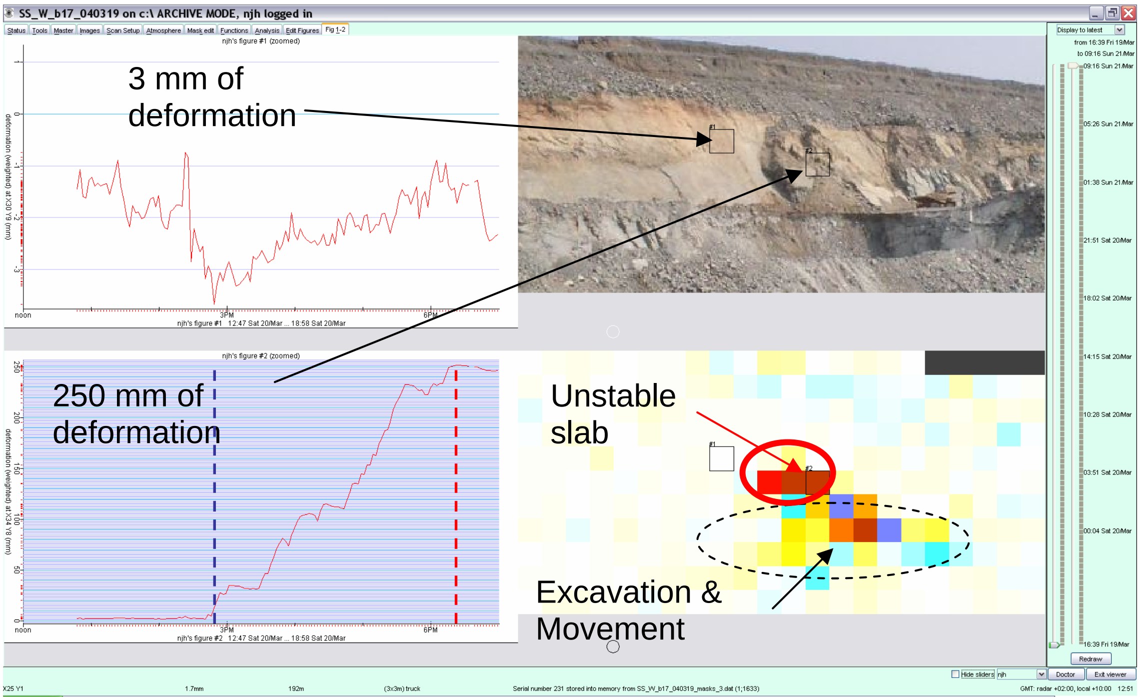

Figure 5: SSR Visual of the Rock Slab Failure Caused by Undermining the Toe

The situation discussed above is a relatively common occurrence in mining where walls have to be "cleaned" to make them safer. The benefit that the SSR system provides is that it allows the dimensions of any potential failure to be ascertained and can help control the risk to the shovel operation. The sensitivity of the SSR unit means that the system can be a huge improvement on the traditional use of spotters in such operations.

4. CONCLUSIONS

The SSR is a state-of-the-art development for monitoring slope movement in open pit mines. It offers unprecedented sub-millimetre precision and broad area coverage of wall movements through rain, dust and smoke. The real-time display of the movement of mine walls has allowed continuous management of the risk of slope instability at a mine operations level. There are two key roles where mines are now using the slope stability radar:

1. *Safety Critical Monitoring*: The radar is used during mining production as a primary monitoring tool of a designated unstable slope.

2. *Campaign Monitoring*: The radar is moved around the mine in a repeatable manner to compare movements at each site over an extended time, and determine problematic areas. Campaign monitoring in this manner is often used in metalliferous mines until determination of developing failure is observed.

In the case studies discussed in this paper, the SSR was utilised in the safety critical role. The SSR technology has enabled a radical change in the management of risks in open cut mining operations, which has resulted in a rapid take-up of the technology throughout the world to date. At a number of mines, the SSR is now an integral part of the mine providing major contributions to the mine's future plans (Naismith, 2005). It is also believed that the SSR will contribute significantly to safety and mine design by providing accurate, reliable deformation data that may be later reviewed to further develop our understanding and analysis of failure mechanisms in open pit mines; eventually leading to improved slope design.

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