Effective Use of the Slope Stability Radar for Mine Slope Monitoring – Reference to the Movement and Surveying Radar (MSR)

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Abstract

Effective surface mine slope monitoring is an integral part of a safe and profitable mining operation. The invention of the slope stability radar for monitoring of surface mine slopes has transformed the science of mine slope monitoring. Monitoring which has hitherto been done with a combination of two or three techniques such as the Electronic Distance Measurement (EDM), Piezometer, crack meter, Laser, Inclinometers and Scanner now has the monitoring radar as a state-of-the-art compliment to the whole process of slope monitoring. The Slope Stability Radar (SSR) manufactured by ground probe, Australia and the Movement and Surveying Radar (MSR) by Reutech, South Africa are available in the market. For the radar to be effective in slope monitoring, a number of measures need to be implemented and adhered to by the mining companies and particularly by the users of the equipment. This study was conducted on the use of the MSR in open cast mines, although, the findings are applicable to other surface mines as well as the SSR. It was discovered that to monitor the high-wall in an open cast coal mine, good space needs to be created between the high-wall and low-wall for the radar to scan and this is quite a challenge. Also, the selection of user defined time window in the MSR is in most cases arbitrarily done by the users. Selection of threshold value at which evacuation of personnel should be made is equally done arbitrarily. With proper documentation of displacement records and adherence to suggestions made in this paper, the radar will add great value to mine slope monitoring.

1 Introduction

1.1 Slope Stability Radar (SSR)

A scanning radar system was designed by researchers at the University of Queensland, Australia in 2002 specifically for monitoring mine slopes using differential interferometry (Figure 1). The system, known as the Slope Stability Radar (SSR), uses real aperture 2° beam-width radar to scan a slope in both vertical (height) and horizontal (azimuth) directions. Scanning at a rate of 10°/second over a range of ±60° vertically and 340° horizontally, the system continuously monitors the slope face for deformations (University of Queensland 2002). The return signal phase is recorded for each pixel in the resulting image and phase unwrapping is used to remove the $2\pi$ ambiguity (Reeves et al. 1997). The SSR is a trailer-mounted unit that features a 0.92 m diameter scanning parabolic dish antenna, controlling/data collecting computer, remote area power supply, warning siren and lights, CCD camera, communication links, and internet compatibility. Typical scan repeat time is 15 minutes. (McHugh et al. 2006)

The SSR-X model can operate at a maximum range of 2800m from the target slope. (GroundProbe 2011). Line of sight displacement can be measured to ±0.2 mm without the use of reflectors. In operation, the system scans a region of the wall and compares the phase measurement in each region with the previous scan to determine the amount of movement of the slope. It then produces an image showing spatial deformation relative to a reference image for the entire slope scanned. The displacement history of each point in the image can be plotted. (McHugh et al. 2006)

Data from the SSR is usually presented in two formats. Firstly, a colour rainbow plot of the slope representing total movement which quickly enables the user to determine the extent of the failure and the area where the
greatest movement is occurring. Secondly, time/displacement graphs can be selected at any location to evaluate displacement rates (Ground Probe 2003). Additional software is also installed to allow the data to be viewed live at locations remote to the SSR site such as offices of relevant geotechnical personnel.

The 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 have been monitored and on every occasion precursor “warning” movements were recorded by the SSR (Harries et al.2006). Cahill and Lee (2006) reported that the SSR has been in use since 2002 at Leinster nickel mine, Australia for monitoring mine walls in areas with low confidence level on the ability of prisms and visual inspection to predict failure. Phelps Dodge Sierrita Mine, is the first mine in the United State of America to use the SSR. At the time, he SSR was the only system in the world that provides continuous sub-millimeter measurements of rock wall movements across the entire face of a wall (Ground Probe 2003)

![Slope stability radar](image)

Figure 1. Slope stability radar (Ground Probe 2003).

### 1.2 Movement and Surveying Radar (MSR)

A contemporary of the Slope Stability Radar called Movement and Surveying Radar (MSR 200) was introduced into the market in January, 2006 by Reutech Mining a division of Reutech Ltd. South Africa. The MSR 200 (Figure 2) works in the same manner as the SSR with all slope measurements fully geo-referenced but an additional feature separates the MSR from the SSR is that it provides fully geo-referenced surveying information thus allowing areas that are not hitherto accessible to be surveyed. This is made possible because the system incorporates a fully integrated total station which is a surveying instrument that allows the MSR200 to be accurately geo-referenced. The survey measurement of the MSR is capable of measuring 3-D information of the slope surface and can also be used to determine the amount of materials removed (Reutech 2006)

According to Reutech (2008), another model, MSR 300 was introduced in June, 2008 as an improvement on the MSR200. Like the SSR, the MSR300 is capable of detecting sub-millimetre movement of the rock face. The MSR 300 offers continuous slope monitoring and surveying of rock surfaces up to a slant range of 2500m under all weather conditions. The MSR 300 offers a high level of immunity to false alarms during sudden environmental changes such as rain, dust storms or mist formations. It equally offers significant improvement in the system’s surveying capability.
Conventional Slope Monitoring System versus Radar Monitoring

Bye (2009), using fault tree analysis (Table 1) gives the success rate of different monitoring types. While the other monitoring methods without the radar have success rates of below 90%, monitoring with radar alone gives a success rate of 93%, when it is combined with other methods of monitoring; the success rate is almost 100%. This is a pointer to the capability of this invention. However, the error in this analysis based on the author’s experience, is that it is impossible to monitor with the radar alone or any other method for that matter. Visual monitoring always precedes any monitoring method. In addition, while monitoring is going on, visual monitoring never ceases, it is an integral part of any monitoring process.

The MSR is currently utilised in Africa, South America, United States of America, Europe, Indonesia, Papua New Guinea and Australia. Specifically, it’s been used by Anglogold Ashanti in its Navachab open-pit mines in Namibia, Sadiola Gold mine in Mali and Sunrise Dam gold mine in Australia. Six MSR are in use at different mines operated by Anglocoal in South Africa. Like the SSR, the MSR is gaining popularity in managing and monitoring sub-millimetre movements in mine slopes around the world.

<table>
<thead>
<tr>
<th>Monitoring Type</th>
<th>Success Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual Monitoring only</td>
<td>32%</td>
</tr>
<tr>
<td>Prism/Crack Meters only</td>
<td>45%</td>
</tr>
<tr>
<td>Visual + Prism/Crack monitors</td>
<td>63%</td>
</tr>
<tr>
<td>Visual + Prism/Crack + Laser</td>
<td>86%</td>
</tr>
<tr>
<td>Radar Only</td>
<td>93%</td>
</tr>
<tr>
<td>Visual + Prism/Crack + Radar</td>
<td>97.5%</td>
</tr>
<tr>
<td>Visual + prism/crack + laser + radar</td>
<td>99%</td>
</tr>
</tbody>
</table>
3 Factors militating against the effectiveness of MSR

The following factors have been observed to affect the effective performance of the radar for mine slope monitoring. These observations were made during a study on the use of the MSR in some open cast mines:

- Inconsistency in Selection of Time Window
- Incorrect Selection of Threshold Values.
- Lack of Proper Documentation (Database) of Slope Displacement History and Failure
- Poor Usage and/or Poor Understanding from the User of the MSR
- Apathy among Users
- Frequent Relocation of the Monitoring Radar due to Frequent Mining Operations
- Inadequate Space for Monitoring the High-wall Within the Coal Mine Strip.

3.1 Inconsistency in selection of time window

With the MSR, the user has the option of choosing from among 1hr, 2hr, 4hr, 6hr, 12hr, 24hr and the “all data” time window. The displacement measurements during the selected period of time are used to determine the velocity at the end of that period. These many time windows as good as they are, create problems for the users, as an understanding of the difference and significance of each time window is lacking. Thus, a user may use 1hr window today and another one the next day. There is no consistency in the use of the time window. For example, the values of velocity (cumulative rate in the MSR) vary with time window, although, the time of failure remains the same. One way out of this is, after recording failure using one of the time windows, the user should determine the corresponding values at failure for the other time windows. These values can then be used as reference when required.

3.2 Incorrect selection of threshold values

During the course of this study, it was observed that threshold values were arbitrarily selected by the operators of the MSR. The implication of this is that:

1) There is no proper database of the displacement behaviour of the slope from which threshold values can be determined.

2) The significance of the threshold is not well understood.

3) There is no empirical method in place for threshold selection.

3.3 Lack of proper documentation (database) of slope displacement history and failure

For a thorough understanding of the behaviours of slopes in mines, a comprehensive database of the displacement behaviours of the slope extracted from the radar must be kept. This should include amongst other things, the type of slope, the name of the section of the mine, the displacement and velocity at regressive, progressive behaviour as well as at failure. Unless this is properly done, it will be difficult to understand the slope and select correct threshold values.

3.4 Poor usage and/or poor understanding from the user

One of the major factors affecting the effectiveness of the radar is lack of concentration on the critical area of instability when users review the movement trends and set alarms. In most cases, the users of the radar select too large a region of the mine slope for movement trends and alarms. This will affect the displacement data used since the computation is based on the average movement of all pixels within the region. The larger the area the lower the displacement velocities obtained. With low velocities, slope failure in small areas may occur without
notice. This point is illustrated in Figure 3. The Relative Range (displacement) and Cumulative Rate (a measure of velocity) at failure for scan region ABCD in Figure 3 are 8.85mm and 0.40mm/hr respectively while it is 52.75mm and 3.40mm/hr for the exact area EFGH where failure occurred. Focusing monitoring only on region ABCD will underestimate the slope displacement behaviour and thus affects accurate threshold estimation. This is further illustrated in Figures 4 and 5 representing plots of the behaviour of section ABCD which shows that the slope is stable. This is different from the behaviour obtained in the failing section EFGH (Figure 3). Figures 6 and 7 show the displacement and cumulative rate of section EFGH which clearly indicate a failing slope. Note that the noise in this data is largely due to the fact that no reference areas for atmospheric correction were used.

Figure 3. Monitored mine slope.

Figure 4. Relative range (displacement, mm) for region ABCD.
According to Joubert (2011), to solve this problem, it is not necessary for the user of the MSR to monitor a smaller area of the slope rather, he suggested the following:

1) For larger regions use an area threshold and specify the size of the area, in pixels, which may fail. The MSR software will then check all possible areas of the specified size within the larger region. If the average movement of any of these smaller areas exceeds the alarm thresholds, then an alarm will be triggered and the user will be shown where the excessive movement is.

2) The average of a complete region is only useful for small areas, and should only be considered in such cases.
3.5 Apathy among users

The apathy towards the radar in open cast mines is not as a result of the inability of the radar to perform its function of slope monitoring but of other factors. At a weight of about 1.5 tonnes (1,500kg) and a length of 3.5m, it’s quite a task moving the MSR around the mines frequently. Mining activities such as drilling and blasting are always going on in open cast mine strip which requires the MSR being moved regularly. Relocating the machine creates excessive stress for the user, considering the effort and time in setting it up. This represents the major frustration to the users of the radar in open cast coal mines.

3.6 Frequent relocation of the monitoring radar due to frequent mining operations

One of the biggest challenges to the effectiveness of the radar in open cast mines is frequent re-location. The lifespan of the high-wall in most active open cast mines is less than 6 months, the implication of this is that one mining operation or the other is always going on in the mine. These operations such as coaling, drilling and blasting can impede the operation of the radar. This frequent movement of the radar leads to inconsistent and incomplete displacement records, consequently resulting in lack of proper understanding of the slope failure mechanisms.

3.7 Inadequate space for monitoring the high-wall within the coal mine strip

Monitoring the high-wall in an open cast mine with the radar requires the placement of the machine in the mine strip on the low-wall. The best option is to locate the machine in the mine strip, the other option of placing it on the low-wall is almost impossible. For the radar to monitor the high-wall effectively when it is located in the mine strip, it has to be at a distance of 50 metres away from the monitored high-wall. In most cases, finding a distance of 50m to locate the radar is an arduous task considering the width of the strip in open cast mines. Therefore, lack of space results in monitoring being done at a distance of less than 50 metres from the high-wall, which is the minimum distance for effective monitoring. The low-wall on the other hand can be monitored effectively by locating the radar on the high-wall.
4 Conclusions

- The radar can be very effective in open cast mines, particular if it is not being moved around always. Otherwise, it is more suitable for mine slope monitoring in open pit mines where it can be positioned at a location without disturbance for a long period.

- Without proper documentation and familiarization with the displacement patterns obtained from the radar, failure may likely occur unnoticed.

5 Recommendations

- Beginning from the mine planning stage, provision (in terms of space) must be made for the radar to operate by designing the mine strips wide enough to accommodate the radar during mining operations. This is of particular importance in areas of high slope instabilities.

- The use of pixel monitoring within the larger region should be emphasised as this will prevent failure in any part of the slope from going unnoticed.

- Preliminary monitoring should be carried out to determine the critical areas of instability which the author refers to as reconnaissance monitoring.

- Comprehensive database of slope displacement behaviour should be kept from which empirical methods of threshold determination should be developed.

- Arbitrary use of time windows must be avoided for the MSR to be effective.

- Users of the MSR must be extensively trained on the in-depth capabilities of the equipment.

6 References


