Slope Stability Radar Monitoring of a Drape Meshed Pit Slope at Mogalakwena Platinum Mine, Limpopo Province, South Africa

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Abstract

Mogalakwena Platinum mine is Anglo American’s only open pit platinum operation. A 40 000m² passive rockfall netting protection system has been installed on a brittle hard rock highwall that was being monitored by a GroundProbe slope stability radar system. This paper presents the results of a study to determine the effectiveness of the continued monitoring of the highwall, using radar.

1 Introduction

Mogalakwena Platinum mine is Anglo American’s only platinum open pit operation. It is located on the northern limb of the Bushveld Igneous Complex, approximately 300 km north of Johannesburg in the Limpopo Province.
Rockfall protection systems are an important element in the design and maintenance of infrastructure networks and have a direct impact on safety. Although they have been extensively used in the civil engineering environment, they have applicability in the open pit mining environment as well. A slope remediation project was completed in December 2010 on the eastern highwall of Mogalakwena Platinum’s central pit. This highwall, which is prone to rockfall, was covered with 40 000m² of Maccaferri double twist hexagonal woven, zinc coated wire mesh with an aperture of 80mm.

Mogalakwena has a comprehensive slope monitoring strategy in place, which includes the use of prisms, laser and radar monitoring. The eastern highwall is monitored using a GroundProbe SSR T-Series radar unit. After the project had been completed, a study to assess the impact of the rockfall mesh on the radar monitoring was started at the beginning of January 2011. This paper forms the subject of this study and reports on findings.

2 Use of a high wall mesh system

The mesh system is typically applied to highwalls whose rockmass is highly jointed and where the rockmass breaks down into fairly small fragments. This system allows for loose rocks ravelling from highwalls which are subject to time-dependant deterioration, to be guided, collected and piled up at the highwall toe. A mesh system can be either active or passive.

Active systems are designed to prevent rock detachments. Different kinds of steel wire and cables form an armoured mesh which is anchored at the crest and toe of the slope, and at various points on the highwall. These installations are referred to as pinned mesh installations and result in surficial support to the rock surface of the slope.

Passive systems do not prevent the process of rock detachment from the highwall, but focus rather on containing falling debris behind the mesh curtain. These installations are referred to as drape mesh installations. Anchoring is done only at the crest and toe of the highwall. A passive system was installed at Central pit.

3 Project background

Radar monitoring of the pit slopes at Mogalakwena mine is an essential part of the mine’s overall safety strategy. The main aim of this project was to determine if a drape meshed pit slope can successfully be monitored by radar and whether slope movements behind the mesh can be detected. The success or failure of this project will determine the type/s of rockfall protection system that can be employed at Mogalakwena mine in the future.

The radar was set up on the pit floor approximately 300m from the eastern highwall. Data was collected 24 hours a day, 7 days a week. Besides radar data, additional data was collected by the on-board weather station. This included wind speed and direction, air temperature, and rainfall amount and intensity.

4 Slope stability radar technology

The GroundProbe slope stability radar is a technique for monitoring mine walls based on differential interferometry using radar waves. The system scans a pre-selected 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. An advantage of radar over other slope monitoring techniques is that it provides full area coverage of a rock slope without the need for reflectors mounted on the rock face. The system offers sub-millimetre precision of wall movements without being adversely affected by rain, smoke, dust, fog and haze. The scan area is set using a digital camera image and can scan 270 degrees horizontally and 90 degrees vertically.

The system provides immediate monitoring of slope movement without calibration and prior history. Scan times are typically every 1-10 minutes. Data is uploaded to the office via a dedicated radio link. Custom software enables the user to set movement thresholds to warn of unstable conditions. Data from the slope stability radar is
usually presented in two formats. Firstly, a colour ‘rainbow’ plot of the slope representing total movement 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.

5  Radar data interpretation

The first round of data interpretation took place in May and the wall folder below was typical of the data collected.


5.1.1  The performance of the catchment berms

The dimensions of the highwall covered by the mesh (Fig. 2) were 450 m along the crest and between 60-90 m high. It is a passive system anchored at the crest and the toe only. The berms are originally designed to be 8m wide but due to mining induced crest damage, adversely orientated structures and weathering, the berms have been significantly degraded and are in places only 1m wide. A significant amount of loose rock has accumulated on, and filled the berms. The preparation of the crest area for the mesh anchor points included the use of a mechanical grader to level the ground, and rounding off the uppermost crest edge. A large proportion of the accumulated rock on the berms originated from the ground levelling exercise.

Figure 2.  The meshed area on the eastern highwall of Central pit.
5.1.2 The identification of the meshed and unmeshed area of the highwall by scan response

The bottom scan (Fig. 3) shows that there is a significant amount of deformation movement over the meshed area compared with the unmeshed area. The question is, how much of this detected movement is due to movement of the mesh, and how much is due to movement of the rockmass on the highwall?

- The meshed area is shown above.
- It can be seen that there is a significant amount of deformation movement within the meshed area.

Figure 3. Photograph and scan showing unmeshed area on the left and meshed area on the right.
5.1.3 **Areas of interest**

Analysis of the data from this wall folder has revealed four main areas of interest (Fig. 4) which are annotated on the photograph. The other areas of movement appear to expand and contract correlating with daily temperature changes. Many of these appear to occur between the edges of the berms where the mesh is not in direct contact with the highwall. This can be seen in the scan above where the pixels are arranged as horizontal linear traces. The combination of loose rock and the daily expansion and contraction of the mesh may be the cause of these linear deformation traces. There are small amounts of vegetation on the highwall, and the movement associated with the vegetation has also resulted in movement being detected.

The four main areas of interest will be examined more closely.

![Figure 4. The four main areas of interest.](image)
5.1.4  Area 1

There is a large amount of loose rock in this region (Fig. 5). A fall of ground totalling 243 tonnes occurred here on the 6th April 2011. Mode of failure was toppling failure. The movement of the rock mass prior to failure and the failure event itself, was not detected by the radar, as this area of the scan was masked. Masking was necessary as loading equipment was working in the area at the time. If masking on the alarms was done, instead of masking on the mask tab, then the alarm that was initiated due to movement on the highwall would have allowed back analysis to be done, thus allowing the failure progression to be studied. This oversight has been noted and the masking procedures amended. Daily visual inspections have revealed that small amounts of rock material are still ravelling off the highwall from this area. This is reflected in the deformation scan.

Figure 5.  Location of Area 1.
5.1.5 Area 2

Area 2 (Fig. 6) is characterised by a sloping region where the catchment berm has been degraded by the weathering of the crest zone exacerbated by the presence of an oblique steeply dipping fault zone, resulting in a large amount of loose rock being present. The movement of this loose rock is evident in the scan. Pixel (123,26) below this region appears to demonstrate a change in deformation, although the coherence is questionable. The change in deformation suggests that there is loose rock in Area 2 which is moving.

Figure 6. Location of Area 2.
5.1.6 **Areas 3 and 4**

Areas 3 and 4 (Fig. 7) both have accumulation of loose rock. Most of the pixels in these areas demonstrated cyclic changes. A few pixels however exhibit changes in deformation that differ to those of the surrounding pixels. The coherence may suggest that there may be loose rock accumulating in both areas.

Further data interpretation took place in July after more data had been received and the two wall folders below are typical of the data collected.

![Figure 7. Location of Areas 3 and 4.](image-url)
5.2 Wall Folder: SSR127_110603_Mog C E Wall_Mog central_b6tob23
Examination of the data from this wall folder over the period 4-6 June, shows a cyclic pattern of thermal expansion and contraction corresponding with negative (daytime) and positive (nightime) deformation (Fig. 8).

![Deformation graphs showing positive (nightime), and negative (daytime) deformation, 4-6 June.](image)

5.3 Wall Folder: SSR127_110617_Mogalakwena_Central_Eastwall_b6tob23
The data from this wall folder (Fig. 9) shows a similar pattern of deformation with the delta range image at the bottom also showing horizontal linear patterns.

6 Discussion
The passive drape mesh system installed at Mogalakwena was designed to contain falling rock material behind the mesh curtain and allow loose rocks to be guided, collected and piled up at the highwall toe. It is anchored at the crest and toe only (Fig. 10). Analysis of the radar data has revealed that the mesh is subject to thermal expansion and contraction as a result of the differing day and night temperatures. During May and June temperatures can range between 4º C-23º C. Figure 10 illustrates the mesh layout. The mesh is in contact with only the berm crest edges, these edges effectively acting as “fixed” points. Between the berm edges, the mesh is able to expand or contract in response to changes in temperature.
The mesh comes into contact with the highwall at the berm edges which act as fixed supports for the mesh. Thermal expansion and contraction does not affect the mesh at these points.

Figure 9. Deformation graphs showing positive (nighttime), and negative (daytime) deformation, 18-19 June.

Figure 10. Drape mesh layout showing the “fixed” points.
During daylight hours thermal expansion of the mesh causes the mesh between the berm edges to sag, resulting in the mesh moving away from the radar. The deformation image records this as negative deformation characterised by the cold blue and purple colours, Figure 11.

During the night thermal contraction of the mesh causes the mesh between the berm edges to be pulled taught, resulting in the mesh moving closer to the radar. The deformation image records this as positive deformation characterised by the warm colours. Maximum deformation represented by the red colours occurs around 4:00 am, Figure 12.

7 Conclusions

- The radar is picking up significant noise from the meshed section of the highwall.
- Large positive deformations can be expected when large rock blocks are trapped behind the wire mesh displacing the mesh towards the radar.
- A cyclic pattern of mesh contraction during the night and expansion during the day was noted.
- Theoretically, thermal expansions and contractions should be larger in the areas between the berm edges, compared to the berm edges themselves.
- During daylight hours the mesh expands with the resulting deformation image recording this as negative deformation characterised by cold blue and purple colours.
During the night the mesh contracts with the resulting deformation image recording this as positive deformation characterised by warm colours.

It is unclear whether the radar is measuring the mesh only or a combination of wall plus mesh.

Pinning the mesh to the highwall will reduce the cyclic deformation patterns, but as it has been designed as a passive drape mesh system, this is not feasible.

Further work still needs to be done to determine the efficacy of monitoring of a drape meshed slope using radar.

8 Acknowledgments

The author would like to thank Mr Albert Cabrejo and Dr. Richard Wiltshire of GroundProbe for data interpretation and to the Management of Mogalakwena Platinum mine for permission to publish this paper.