Slope Monitoring Solution-SiteMonitor 4D
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Introduction

Slope monitoring forms an integral part of slope management in Open Pit mines. This is to provide information for; detecting potential unstable ground, assessing the performance of slope design which involves identifying any slope instability and/or failure mechanisms that develop. If the failure mechanisms are understood and the slopes are properly monitored, the risk of slope movement and the subsequent consequences can be considerably reduced. This allows for optimal mining conditions that are safe for mine personnel as well as working equipment.

In order to achieve this, one has to find the most adequate monitoring solution that meets all the necessary requirements, which is often a challenge. The main objectives for a slope monitoring strategy are:

- Maintaining safe operational systems and procedures to protect personnel and equipment.
- To provide notice of potentially unstable ground so that mine plans can be modified to minimise the impact of slope displacement.
- To provide geotechnical information for analysing any slope instability failure mechanisms that develop, designing appropriate remedial action plan and conducting future slope designs.
- Assessing the performance of implemented slope design.
- Building up a history of information to determine different rock behaviours over a long period of time of monitoring.

SiteMonitor is a state-of-the-art system that is designed to meet such objectives. This system is based on a laser measurement component (laser scanner) for monitoring the rock face. The principle behind the software is to establish a grid of measurement points and to re-measure the grid periodically to look for differences in the position of the grid nodes. This system was designed to provide simple-to-use, reliable solutions with flexibility and performance to function in a wide range of monitoring applications.

SiteMonitor can be used to measure and monitor:

- Stability of slopes and structures
- Changes in volumes
- Deformation
- Long term trend of rock behaviour
Laser scanner working principles

Terrestrial laser scanning offers new capabilities in deformation monitoring, mainly due to the high spatial resolution and speed of data capture, which enables repeat monitoring or data capture at high frequencies. A laser scanner measures points in 3D by combining laser range finder and high accuracy angle measurements in local coordinate (that is relative to the scanner). Thus combining the distance the pulse of light has travelled is achieved by using the formula: \[ r = \frac{c \times t}{2} \]

- \( r \) = the distance the pulse has travelled
- \( c \) = the known speed of light
- \( t \) = time taken for the pulse of light emitted by the range finder to be returned

and the angle encoders which measure the direction that the range finder is pointing during range measurements.

The laser scanner system can be used for monitoring of large open pits, small satellite pits and for volume measurements with ranges up to 4,000m. It is capable of recording a 150mm grid of measurements over a highwall every 10 minutes (at 1,000m range) (although a 30 minute interval is normal for long term monitoring). Rapid monitoring of thousands of points by the laser scanner rather than single prism locations enables complete coverage of visible surface. This a safe (Class 1 eye safe) reflector-less measurement system with waveform processing and small measurement footprint, allowing monitoring through wire mesh and vegetation. This is not possible with any other measurement technique.

Slope Monitoring Strategy

It is normal for a large open pit to have a strategy of using multiple measurement techniques, which all provide different types of information and measured in different ways. Listed here are the primary remote sensing techniques that are available to the Geotechnical Engineer:

**The Geodetic (prism) monitoring system** is used for identifying long term slope movement trends and indicating where slope failure is more likely to occur. This system provides highly accurate, and long term 3D displacement data, which is however, limited to that of the immediate area surrounding the installed prism as there is no data in-between prisms.

Even though prisms can be securely installed with protective casing fitted around the prism, many prisms are damaged or lost due to rockfall, slope failure and flyrock during blasts. The prism installation can be dangerous in certain areas, and also time consuming and expensive. Once a prism becomes defective or dusty, it affects the monitoring capability of the system and thus replacement or cleaning becomes critical. Prism monitoring is also limited by the fact that it measures movements of single widely-spaced points on a slope.

**Laser (SiteMonitor) monitoring** helps to fill the gaps where prism monitoring cannot monitor as it does not require prisms to measure points or face. This system allows the user to specify monitoring areas and frequency as well as group certain points that they want to monitor. It is therefore also used for long term monitoring trends and for identifying high risk areas. Whilst the laser may not be as accurate as the radar system, the set up (when using the fixed station) is very similar. Its main advantages are that; it is a simple automated operation which is easy to
configure, providing medium to long range operation. SiteMonitor has two modes of operation namely; periodic and continuous. The periodic mode enables the user to remove the scanner once the monitoring area has been measured. To measure the same area, the user re-mounts the scanner and continues with measurement (the position and orientation of the scanner have to be known). This allows the user to measure multiple setups for one scanner and is generally for long term monitoring. In continuous mode, the user can set a scheduler to automatically re-measure the monitoring areas or entire wall without any intervention. This is typically for critical monitoring.

Geological structural mapping features provided by the SiteMonitor alleviate the risk involved with direct face mapping, and this allows for mapping in areas of the pit whereby access is not possible. A detailed structural model allows for detailed risk assessments with regards to failure mode, and allows for refinement of the slope design.

There are two main types of radar systems that are used for monitoring. Radar systems are capable of accurate range measurements however the area footprint of each measurement is large compared to a laser system. The SSR (Real Aperture Radar) is a mobile monitoring system employing a radar dish. The scan time is dependent on the size of the slope area selected and the distance from the slope. Due to a lot of moving parts as it scans, the hardware components require high maintenance. The SAR (Synthetic Aperture Radar) system uses a radar antenna moving side to side along a rail. The system can have mobile, semi-permanent or permanent setups. The system requires little maintenance and has low power consumption. It also provides high accuracy as well as long range measurements.

**System Operation**

SiteMonitor is the first software product that has been designed specifically to apply 3D laser scanner technology to monitoring applications. This is intended to be used by Mine Surveyors and Geotechnical or Rock Engineers. The Surveyors are responsible for collecting and storing the data, ensuring that accuracy and reliability of measurements is maintained. The Geotechnical or Rock Engineers then analyse the data, looking for significant movement, and report any potential areas of slope failure to the mining personnel. They also use the system to conduct geotechnical structural mapping for potential failure mechanisms. For effective slope monitoring, the following parameters need to be considered:

**Repeatability**

This is often called ‘precision’ and is a measure of the noise in the measurements. It can be estimated by looking at the spread of multiple measurements of the same target. Random noise can be removed by taking the average of multiple measurements. This is the most important parameter for displacement monitoring.

**Accuracy**

This is a measure of how close the instrument measures to the true distance. This is important if we want to georeference the data to compare to other data or if we remove the instrument for a while then replace it and continue monitoring.

**Atmospheric correction**

Although laser scanners assume a constant speed of light while measuring range, meteorological conditions affect the speed of light and thus, the range measured. SiteMonitor uses control points with known locations that have been correctly measured in the site coordinate system. The true range from the scanner to the control point is then calculated since the location of the scanner is also known. Based on this, an atmospheric range correction factor can then be calculated by comparing the measured range from the scanner to the control point with the true range. This
is subsequently applied to the scan data of the monitoring area to provide a more accurate recording of the range of each node.

The SiteMonitor system is designed in accordance with the operating procedures of some of the major mining groups. These require the Mine Surveyor to be responsible for activities related to data acquisition and the Geotechnical Engineers to be responsible for the data analysis. Accordingly, the software is split into two parts, as follows:

**Acquisition**

Site Monitor Acquisition software is used by Surveyors to set up and run data acquisition in the field. Its main purpose is to acquire scans and change the acquisition parameters according to user’s discretion. The user can either scan the entire face, create one or multiple monitoring areas they are interested in scanning. Once the data has been acquired it is then sent and analysed on SiteMonitor Analysis Module. SiteMonitor has a wizard step by step setup that is easy to start or run a project.

**Data Analysis**

For any data analysis, it is important that the user is familiar with the site, the principles and the procedure of data capturing as well as the software itself. Once the data has been acquired and the integrity has not been affected or compromised, the data analysis becomes crucial in determining the value of the information provided by the system. The analysis part is customarily done by the Geotechnical Engineers as they are familiar with the Geotechnical conditions onsite. Based on the user’s preference, one is able to achieve and analyse data relating to the entire monitoring area or a particular area of interest or point.

**Typical Data Output**

To achieve the slope monitoring objectives, the system provides the user with the following information.

- **Range**
  - This refers to the absolute range to the selected data or measure distance to the points from the scanner (in meters).

![Figure 1: Typical Site Monitor Analysis output with the photograph as background, overlain by displacement map.](image)
• Displacement Rate
  This displays the rate at which displacement is occurring, which is mm/day. This can be viewed in incremental mode or averaged according time/scans. Displacement rate can give significant information about the acceleration of movement or failure.

• Volume
  The software provides the volume in cubic meters of selected areas of interest. This is significantly used in determining the volume of failed material.

• Vertical and horizontal sections
  The user is also able to extract vertical and horizontal sections of an area of interest. One can view the change in vertical section of any slope deformation over a number of scans or period of time.

• Report
  SiteMonitor can generate report on HTML format. The content of the report is user defined, and once the report has been exported the user is also able modify it.

• Rockfall
  It provided information on rockfall events and maintains history, as seen on the case study below.

• Stereonets
  Geological or Geotechnical structural information forms an integral part of slope management in determining the type of failure mechanism. Stereonet plot functionality provides this information for Rock Engineers to analyse.

• Displacement
  The displacement graph gives information about the relative range difference between the baseline survey (Reference Set) and the currently selected data. This aids to provide information on movement of ground for potentially unstable areas. The image below depicts evolution of potentially unstable area through cumulative displacement.
Figure 2: Image depicting significant displacement of an area (circled) over a period of nine days, where positive displacement represents movement towards the scanner.

Monitoring systems soon become “mission critical” to a mining operation as the safety of the staff rely on the output of the systems (either in real-time for critical monitoring or through better design using the results of long term monitoring). Technical support from the vendors becomes critical and is often delivered through a service level agreement. Laser scanners are reliable instruments with only a few moving parts so the service interval is typically every two years – which means the laser scanner typically requires less maintenance than the other monitoring techniques.
Case Study: Mogalakwena Mine

Mogalakwena mine is situated 35 km North of Mokopane in Limpopo Province, South Africa. SiteMonitor is currently used in Mogalakwena mine to monitor their pits for slope management. This has provided significant information on identifying geotechnical risks and hazards, as well as acting as a primary monitoring system providing long term data to understand the history of the rock masses and behaviour. The rockfall detection, stereonet (structural mapping) and displacement data aid in highlighting high risk and hazardous areas.

Use of Stereonet for Structural Mapping

Figure 3: Image of North pit showing stereonet plot of one of the plane surfaces, with dip and dip direction corresponding with joint set data from other sources.

The stereonet functionality is used to map structural features in order to ascertain the dip and dip direction as part of Mogalakwena mine’s slope management strategy. The information is then used to model potential failure mechanisms and also identify hotspots for safe working conditions. This is achieved using the stereonet functionality, which provides a quick overview of the dip and dip direction of structural features in relation to the pit slope, see image above. This allows the user to have an idea of possible sliding or daylighting structural planes. The stereonet provides accurate structural information comparable with most digital mapping packages currently used at the mine. The dip and dip direction provided by SiteMonitor (as seen on the image above) corresponded with a set of joint sets measured by other digital mining software.
Rockfall detection and history

Figure 4: Rockfall detected by SiteMonitor North pit, showing volume of the accumulated material from the rockfall event.

Mogalakwena mine is currently using Sitemonitor to detect rockfall hotspots in the open pit. This is achieved by identifying the displacement hotspots, measuring displacement rates, and rockfall volumes detached or accumulated on the highwall, as shown in the figure above. The failure mechanism is a combination of loss of cohesion on these planes and shearing as a result of blasting. These rockfalls are rapid, they can even occur within a few hours with various sizes.

Rockfall information obtained from Sit Monitor is complemented by ground truthing exercise to confirm the rockfall events detected on the system. Once a rockfall hotspot has been detected, remedial measures such as wire meshing, and rockfall catchment berms are implemented. The table below depicts history of rockfall events with information relating to each event, provided by SiteMonitor. The user can also export the data for further analysis.
Table 1: Rockfall history of the North pit at Mogalakwena, as seen on SiteMonitor.

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<th>Name</th>
<th>Date</th>
<th>Time</th>
<th>Age</th>
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Customer Reviews:

“In our current era we are employed within a demanding and dynamic mining environment where *mechanization* is a keyword used and applied. The SiteMonitor setup and Acquisition module has really catered for this in the sense that it simplified human interaction and increased safety and productivity within this arduous environment. SiteMonitor setup and Acquisition already enables the mine surveyor to smoothly and easily ensure validity of data captured for multiple setups within a short period of time on a daily basis or whenever there is an area of concern. This is important from a safety and legal standpoint.” - Frans Benadé, Section Surveyor at Mogalakwena Mine.

“Using the site monitor software has been a great experience for me. One of the major challenges faced by Geotechnical Engineers in open pit mines was the current lack of a system for rock fall risk management. The site monitor software provides a solution to this problem. It enables Geotechnical Engineers in open pit mines to detect rock fall hotspots, to quantify the number of rock falls, and to calculate volume of rock fall. This enables us to assess the risk and to ensure that appropriate rock fall risk mitigation is in place. There is no other system currently in the market that is capable of offering the same functionalities” - Ernest Rankhododo, Chief Rock Engineer at Mogalakwena Mine.

Conclusion

A combination of displacement information, rockfall detection and structural mapping by stereonet on SiteMonitor is significantly used in Mogalakwena mine to produce a pit hazard and monitoring plan.
Figure 5: Geotechnical hazard pit plan for Mogalakwena North Pit (courtesy of Anglo Platinum, Mogalakwena Mine).

As shown on the image below, the pit is categorised into different sections based on the geotechnical properties. Geotechnical risks and hazards identified help in putting the necessary mitigation measures according to each section’s risk level. Red being a very high risk, orange high and yellow medium.

SiteMonitor is applied as both critical and long term monitoring solution in open pit mines. This state-of-the-art technology continues to provide the essential information useful for optimum mining conditions.