SURVEY SLOPE STABILITY MONITORING: LESSONS FROM VENETIA DIAMOND MINE

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ABSTRACT

This paper describes the survey monitoring processes at Venetia, which are discussed under visual inspections, *ad hoc* investigations, system monitoring and slope stability radar monitoring. This is followed by a description of the main survey monitoring methods. The next section briefly states typical problems, i.e. the atmospheric corrections required to adjust total station distances, maintenance of the system and management of the monitoring process. The paper ends with some important lessons that could be applied to similar monitoring programmes. These lessons are firstly, communication is most important, process a vital part of the system, a champion must take responsibility for the programme and system planning ensures that the monitoring results are needs driven.

INTRODUCTION

Mining regulations¹ today place major emphasis on the proactive identification and reduction of risk to employees and the operation. Reducing operational and safety risk through an approved survey monitoring program is the focus of this paper. The governance and compliance of the program is highlighted in the operational Code of Practice (CoP) and standard operating procedure documents which are site specific and updated on a regular basis to include the changes in the way that monitoring is performed. These documents become legal evidence in the case of an accident at the operation and could, in the event of non-compliance, point to negligence by the responsible person(s) appointed in terms of the Mine Health and Safety Act (MHSA)². The monitoring program depends on the operational requirements and factors such as costs, system capabilities, mining methods and environmental factors. The skilled responsible person heading up the program requires a sound knowledge of the mining method, planning schedules and surrounding geology. The program should range from various stages of maturity in managing potential failures from regular visual inspections to systematic automated measuring of faces. The intensity of the program is related to the impact of the activity and focus can change on a regular basis. Accurate and timely communication is essential between the monitoring and production teams to ensure that all stakeholders are aware of potentially dangerous areas. The program also requires an early warning system at the point of potential failure in order to achieve proactive risk management. Imperative to the success of managing the recorded data is to ensure that the analysis of raw data is conducted by a suitably qualified person.

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SURVEY MONITORING PROCESSES AT VENETIA

This section describes survey monitoring processes at Venetia. The reader should understand that this process is dynamic, mine-specific and because it is audited on a quarterly basis, one can expect regular adjustments thereto. The process starts with visual inspections done once per week covering all production areas at Venetia. Additional inspections may be required following heavy rains and blasting close to the high wall (e.g. pre-split and trim blasting). An experienced senior surveyor is responsible for doing these inspections. The outcome is a report indicating the date and area comprising the inspection, findings and recommended actions required. This report is signed by the Manager Survey acknowledging the content thereof. The Manager Survey in consultation with the geotechnical department then assesses the potential risk impact and possible action. Such actions could either be maintaining the status quo or implementing an ad hoc investigation.

Ad hoc investigations may be the subject of either medium or low risk areas. The investigation method is determined jointly by the Manager Survey, Geotechnical Engineer and planning department. Issues to consider include the mine plan, potential impact of incident and monitoring requirements such as density of prisms, frequency of monitoring, accuracy and reporting. The outcome is determined by the monitoring results and applied to the standard operating procedures for monitoring, which give guidance on action(s) required. The geotechnical department then assesses the potential risk or impact and possible action following the ad hoc investigation. Such actions are either a reversion to visual inspections or require system monitoring for high risk areas.

System monitoring requires GeoMos analysis of monitoring data from high risk areas. As is the case with ad hoc investigations, the Manager Survey in consultation with the Geotechnical Engineer establishes monitoring requirements such as density of prisms, frequency of monitoring, accuracy and reporting. The prism density could be less than 5m for critical areas e.g. ramps but is generally based on a 30m to 50m grid. The Venetia guideline makes use of the following required frequency of measurement, which is increased proportionally to the actual cumulative movement:

- Points undergoing movement of 0mm to 2mm per day are monitored once per month;
- Points undergoing movements of 2mm to 5mm per day are monitored once per week;
- Points undergoing movements of 5mm to 10mm per day are monitored once every 2 days;
- Points undergoing movements of 10mm to 50mm per day are monitored once per day; and
- Points undergoing movements of greater than 50mm per day require continuous observation.

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Exponential cumulative movement is investigated by the survey and geotechnical departments in order to assess the impact of movement and establish beyond doubt that movement is related to slope instability. The findings are distributed to the Mine Manager, Geotechnical Engineer, Manager Mining, Pit Superintendent, MRM department and Control and Instrumentation (C & I), who installs the early warning (alarm) system for critical areas, which classification requires slope stability radar (SSR) monitoring to be implemented.

Groundprobe SSR monitoring at Venetia is primarily used in order to monitor highly critical areas. The system remains stationary until failure and has its own on-board alarm system with radio links to the offices of the Manager Survey, Geotechnical Engineer, Geotechnical Assistant and the main control room, which has a dedicated computer for this purpose. Movement occurring after normal working hours, which is indicated by means of a flashing red signal on screen, requires contacting of the Shift Foreman, who must investigate the situation and report to the geotechnical personnel on stand-by. Required actions are recorded in the standard operating procedures, which are available in the control room at all times. Empirical evidence at Venetia shows that failure seldom occurs before the cumulative movement reaches 0.1m. This observation requires that monitoring efforts are intensified beyond a cumulative movement of 50mm and an instruction to evacuate becomes a definite possibility.

SURVEY MONITORING METHODS

There are various ways to conduct survey monitoring, which methods are related to the amount of expected movement and possible impact of failure. The process explained in the previous paragraph usually follows the sequence of monitoring methods explained in this paragraph. These methods are visual inspections, systems monitoring and finally, SSR.

Visual Inspections

This method consists of walking the perimeter of the pit, inspecting all access ways, high walls and crests, which are close to potentially dangerous working areas with the emphasis on identifying any new, visible movement or cracks that may have occurred. At Venetia these inspections are undertaken at a minimum rate of weekly intervals unless otherwise specified by verbal instruction, e.g. during rainy periods when inspections are done more frequently. All inspections and related actions are noted on an inspection sheet and signed off by the Manager Survey. This serves as notification on the status of pit conditions. In the case of excessive movement, appropriate action is taken and interested and effected parties are informed. Best practice includes taking pictures of the event as changes occur and also serve as proof for future reference to actions taken.

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When the crack is identified as a possible risk, Venetia installs a simple device to record both width of crack and ground sagging simultaneously. This practical device could be used by anyone and is shown in Figure 1 below. It works on the principle of two separate tapes, one vertical and the other horizontal, where the magnitude of movements on this ‘grid’ is identified by tick markings on the tapes. The ease and practicality of the method allow shift supervisors to use the system and identify movement whenever the need arises.

**Figure 1: Device used as part of manual inspections to record relative movement over time**

Survey system monitoring

System monitoring is the action that follows from the visual inspections performed. Suitable monitoring measures are in place to ensure that the slightest movement is measured by appropriate technology, recorded and reported timeously. In addition, all monitoring positions are surveyed and noted on the mine plans. The system at Venetia consists of total station measurements done at prescribed intervals, transfer of data to the survey office and processing and interpretation by means of GeoMos software. Conventional theodolite measurements are time consuming, labour intensive and have the potential for human error. Although conventional systems are very accurate and adequate for *ad hoc* monitoring, continuous monitoring requires more advanced systems to cope with the intensity of the program at Venetia. Implementing automated technology has
become popular due to its flexibility, speed and continuous monitoring ability. The measuring intervals can be set according to monitoring program requirements and high risk areas can be set according to priority, providing for flexibility of monitoring higher risk areas more frequently without human intervention.

Practical considerations during installation are system protection, power supply and system communication. Figure 2 below illustrates how these problems were addressed at Venetia. The housing itself is unusual because it does not give protection against theft.

The system at Venetia is situated within a security area and protection against theft is therefore not an issue. In order to ensure natural ventilation it was regarded necessary to provide an open environment but protection against direct sunlight. The canopy-designed housing provides for these criteria, in addition to 360 degree visibility. A TCM2003 Leica automated total station is mounted permanently on a free-standing survey station. Maintenance is performed according to the following schedule:

- Weekly cleaning and calibration; and
- Annual servicing by the authorized vendor.

The system operates by means of a 12 volt battery, which is charged with solar paneling attached to the back of canopy roof in order to minimise damage from flying rock during blasting. Communication is via a radio modem connected with a cable to the total station. Data is transferred from the radio modem to the office modem and then relayed via cable to the computer network in the survey office.

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Figure 2 Instrument housing at Venetia Mine

The positioning of targets plays an integral part in the success of the monitoring program. Targets are placed according to a geotechnically designed grid, at sufficiently representative intervals to confidently monitor the high risk areas. Initial targets at Venetia were installed in the high walls as indicated in Figure 3 (left picture). The purpose was to monitor for potential bulging movement across the high wall benches. Subsequent to this practice, targets are placed along the peripherals of the pit and along the ramps (Figure 3, right picture). The reason for this decision is mainly due to safety. Installation and maintenance of targets in the high wall become a problem when access routes to the benches are mined out, resulting in targets potentially lost to long term monitoring.

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Figure 3 Targets installed in the high wall and along ramps at Venetia

Access to targets is important for maintenance purposes as targets may be broken due to blasts and fall of loose rocks. Targets also swivel away from the total station line of sight due to air blasts. Dust becomes an issue in the pit affecting the ability to track a point. Ideally targets should be placed such that the constellation provides near direct measurement to points. Acute measurements to the target add to the difficulty in detecting slight movements.

Temperature and atmospheric pressure measurements are obtained by means of a MeteoSat measuring device situated outside the survey office (Figure 4) which applies these corrections to the field measurements at the base station. It automatically overwrites the settings on the total station. Although the location is not ideal, for the mean time it is the most practical solution for Venetia. This is an area already identified for further investigation and research.

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One of the solutions available to end users for analysing and interpreting survey monitoring data is GeoMos software. GeoMos operates as follows:
  o It calculates direction from survey stations to orientation beacons;
  o It instructs the instrument to search, track and measure strategically placed targets along the high wall according to a user-defined sequence; and
  o It collects the raw survey data, applies error propagation and calculates spatial positions on the survey datum

Analysis is done through GeoMos Analyser, which is an add-on module to the monitoring software. GeoMos Analyser provides for visualization and interpretation using the following charts:
  o Horizontal displacement, calculated from movements influenced by changes in the horizontal angle measurements;
  o Velocity, calculated as horizontal displacement over time;
  o Vector, calculated from total displacement indicating distance and direction in three-dimensional space;
  o Height displacement, calculated as elevation difference; and
  o Transverse displacement, calculated from movements influenced by changes in the horizontal distance measurements.

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The calculated spatial positions are compared with absolute coordinates in order to establish which points have moved. Variances in excess of allowable tolerances (which can be user-defined) are calculated and e-mails are sent to relevant personnel stating movements. A shortcoming of the e-mail system is that the software generates too many and unnecessary notifications and because there is no separate alarm system, there will be no warning when the recipient is out of office. The management of failures and the timeous evacuation of employees are critical to the safety of employees and the prevention of production losses. The GeoMos system also provides the ability to send an SMS to a cell phone. However, in most instances, workers in the pit rely on the end-user to inform them of hazardous conditions and for timeous evacuation. The Venetia experience shows that the most effective method is the installation of a separate alarm system which is triggered when the ground moves beyond the set tolerance. This is illustrated in Figure 5. Because the alarm sounds in the pit and therefore warns the workers of the movement, it allows people and machines to be removed from the critical areas until the area has been inspected and declared safe. The alarm system can also be connected to the radio communication system, sounding a background noise identifiable by all. The responsible team will automatically be informed and dispatched to the affected area.

**Figure 5 Alarm sounding system at Venetia**

![Figure 5 Alarm sounding system at Venetia](image)

**GroundProbe**

One of the most advanced systems available today is the SSR system\(^4\). It provides for high density, high precision measurements of up to 0.2mm accuracy. The SSR has the ability to cover a broad area simultaneously (approximately 170° horizontal view and 120° vertical at ranges between 30m and 850m, potentially 1400m at a reduced resolution). Early tests at Venetia indicate that there is no measurable loss of accuracy over distance. The system has the ability to monitor continuously and depending on the scan range it completes a scan area after about five to seven minutes. The data is

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automatically updated in the database and graphs indicate the rate of movement. The system is not affected by atmospheric conditions because measurements are relative over time independent of the coordinates of the radar. It operates off custom software and provides alarms for areas that indicate movement beyond user-defined tolerances.

A shortcoming of the SSR system is that when the system is moved, the historical data collected loses its value as the system cannot be replaced in the exact position from where the data had been originally collected. The suppliers are currently working on the ability to co-ordinate the positions of the data within the software and therefore correlate points and areas with historical data. This would provide the user with the ability to analyze and understand the characteristics and movement behaviour of the material monitored. To summarize, the system does not calculate spatial positions but rather the relative rate of movement between points, as illustrated in Figure 6 below.

Figure 6 Graphs indicating relative movements and velocity at Venetia

Figure 6 indicates the real time visual data provided by the SSR system after an area was identified for scanning. The related measured data for the area is plotted on a graph and

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the trend is monitored. Once the movement and velocity increase beyond the user-defined parameters the alarm triggers and notifies the user of the potential hazard. The statistics are based on a third line defence strategy; the critical risk areas are identified by first (visual and *ad hoc* investigations) and second line (systems monitoring) defence methods, after which SSR monitoring commences.

**SURVEY PROBLEMS ENCOUNTERED AT VENETIA**

The survey monitoring problems encountered at Venetia can be divided into two main categories, namely system maintenance and process management. The first issue regarding maintenance of system deals with total station measurements. Atmospheric corrections on total station distances are problematic when measuring over long distances across voids where the temperature variations along the line of measurement vary significantly. These variations cause spikes in monitoring charts and errors in elevation. Vertical measurements are more prone to error than measurements for position. These errors make interpretation of continuous monitoring difficult. The result is that a decision was made not to monitor 24 hours a day and not to use elevations for interpretation of movement. The current timetable, which takes cognisance of the large temperature variation during day time (20°C to 45°C) at Venetia allows for continuous monitoring from 17H00 until 07H00 during which time best results are obtained. Continuous monitoring during day times requires fundamental research before better integrity and accuracy of data could be achieved.

Other system concerns include housing of equipment, robustness, compensator malfunction and remoteness of mine for vendor support. This makes the initial installation, calibration and maintenance of the system of vital importance. System failure usually occurs because of battery (power) failures, loss of radio contact, dust on target and target movements. Movement of targets is a result of damage caused by moving equipment and tilting of targets as a result of wildlife interference.

A major concern related to management of the process is the inclusion of the quarterly audit to form part of the overall mining auditing process in order to sustain the credibility of system output. Such audit results could be used to update the CoP and standard operating procedure documents. This will result in improved communication of risk management strategies to all production personnel through improved induction and refresher training programmes ensuring continuous risk awareness in the work place.

**LESSONS FROM VENETIA**

This paper ends with some of the lessons coming from Venetia’s survey monitoring programme. The first lesson is that communication is a vital part of the system’s success. Such communication is contained in the survey CoP and documented standard operating procedures. Section 9 of the MHSA provides for the preparation and implementation of a

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CoP on ‘any matter affecting the health and safety of employees and other persons’ should the Chief Inspector of Mines (CIM) requires it. For this purpose the CIM has provided guidelines on the internet, an *Aide Memoire* and clarifying documentation (available from www.dme.gov.za). Although a CoP on rock falls is not mandatory without an instruction from the CIM, best practice suggests that an approved monitoring programme as part of the CoP is an essential document on surface mines operating on a scale similar to Venetia. Such survey monitoring CoP must link to that of the geotechnical and other affected departments, be regularly updated and allow for accurate and timely communication. In order to ensure effective management and communication of localities in the pit Venetia implemented a pit monitoring plan indicating target positions and identification number on the local grid system for easy reference.

The second lesson is that process is similarly important. Process is the backbone of the system which ensures the sustainability of the programme and ultimately ensures the future of the mine and the safety of employees. Fundamental to having a successful process is to designate a champion to manage and drive the process. This is an area where there is considerable overlap between the technical disciplines on a mine. This paper focuses on survey monitoring and therefore considers survey competence in the analysis of monitoring data. Section 7 of MHSA requires that the employer appoints persons ‘with appropriate qualifications and trained to understand the hazards associated with the work’. There are several questions that arise from this requirement, which are:

- Who is this person and what specific competencies should this person have?
- Is this monitoring responsibility stipulated in his/her letter of appointment or job description?
- Did this person sign a letter of accepting this responsibility?
- How does this appointment affect the competent person in charge of mine surveying appointed in terms of Section 17 of the MHSA?

The third lesson from Venetia deals with system planning, which starts with a proper needs analysis. The needs analysis must consider extent of automation, reliability, accuracy, consistency, flexibility and cost efficiency. Monitoring in its own right is a monotonous and time consuming process. The automation process provides for the ability to monitor during any time of the day and under strenuous weather conditions on a continuous basis. It aids in freeing up the labour complement and removes the potential of human error. The automation process is not without its own system inaccuracies that need to be considered. The need for implementing a reliable monitoring system is based on the existing potential for slope failures to occur. The system implemented is expected to be robust in order to withstand the mining and atmospheric conditions and the reliability of the system for continuous data capture and analysis of trends are important.

Systems are purchased based on their operational and accuracy specifications. Therefore, it is necessary to understand the system capabilities and match them with the operational

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restrictions. A single second accuracy theodolite does not imply that the measurement of a monitoring point will be within one second of accuracy to the absolute position of the target. It merely implies that the instrument is capable of measuring down to single seconds of arc. Ideally, measured displacements should not vary more than 4mm from the absolute co-ordinates under stable conditions. Precise monitoring requires fourth-decimal accuracies. Consistency requires for the system to reproduce the same results under similar conditions provided that movement has not taken place. As the monitoring program matures, it may become necessary to be flexible in the measuring approach. The rate or impact of movement may require monitoring time periods to be extended or performed at more regular intervals. Ideally, the system should adapt to the changing requirements. Finally, the system should provide adequate and cost-effective monitoring coverage of the area, sufficiently representative to make informed decisions about the stability or the movement of the workings. The cost of technology is directly related to the complexity of the system, the amount of research and development invested in the system and the demand in the industry for the type of solution which the technology provides.

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