Slope Monitoring using Total Station: What are the Challenges and How Should These be Mitigated?

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Abstract

The purpose of this study is first, to provide a mine survey perspective on the typical problems that can be expected during slope monitoring using total station (also known as prism monitoring) and second, to suggest ways of mitigating such problems. The aim is to create awareness of the implications of incorrect use or negligence during slope monitoring surveys utilising a total station.

1. Introduction

Slope instability can be expected at any surface mining operation, but the unpredicted movement of ground endangers lives and destroys property. Unstable slopes are unsafe for miners who work on or beneath them, and large-scale failures have the potential to cause loss of life (McHugh *et al*, 2006). A typical example of this is slope failure in phosphate mine Southwest China's Guizhou on 28th July 2012 as reported in Xinhua on 28th July 2012. Therefore, it is necessary to implement an effective monitoring program to oversee and predict the occurrence of such events. Monitoring success, be it slope monitoring or structural monitoring is performed to detect movement that could lead to collapse and to allow for sufficient warning to successfully evacuate the area or structure. In mine surveying, slope stability monitoring is one of the routine events during mining operations. Slope stability is based on the interaction between two types of forces, namely driving forces and resisting forces. The driving forces cause downslope movement of material, whereas resisting forces prevent such movement. Consequently, when driving forces overcome resisting forces, the slope is unstable and movement occurs. Diligent monitoring of structures and slopes for early warning signs are, thus, imperative for protecting life and equipment (Osasan and Afeni, 2010).

Wyllie and Mah (2004) declared that: "because of the unpredictability of slope behaviour, slope monitoring programs can be of value in managing slope hazards, and they provide information that is useful for the design of remedial work". Slope movement is most common in open pit mines, and many mines continue to operate safely for years with moving slopes that are carefully monitored to give warning of deteriorating stability conditions.

The use of total station surveying instruments for monitoring structures movement with good results were reported by many authors, such as Radovanovic and Teskey (2001); Hill and Sippel (2002); Kuhlmann and Glaser (2002); Zahariadis and Tsakiri (2006). Continuous monitoring, as an important operation in an open pit mine to ensure safety and predicting the stability of the mine wall, was also described by Palazzo *et al,* (2006). The use of total station to monitor mine slope stability is still widely used.

2. Slope Monitoring using Total Station

Usually, slope monitoring using total station comprises of three components. Firstly, a network of reference beacons is required on stable ground that can be observed from the transfer (i.e. instrument) station. Secondly, a number of transfer stations are established on stable ground at locations from which the slope surface is visible. If the positions of the monitoring points are to be measured, then the transfer stations should be arranged so that they form a suitable survey network for optimal line-of-sight and a robust network . The third component involves installation of monitoring prisms at the suspected likely unstable slope zone or area of interest. It is preferable that the measurement direction is in the likely direction of movement so that the distance readings approximate the actual slope movement. The monitoring points on the slope can be reflectors or survey prisms, depending on the distance and the accuracy required (Wyllie and Mah, 2004). The monitoring frequency depends on the nature of the rock type, operations around the slope and the objectives of the monitoring programme in place. For slow-moving slopes, the measurements may be taken every few weeks or even months. For a potentially rapidly-moving slope, an automated system should be set up to take more frequent readings at pre-set intervals as determined by the geotechnical engineer. Also, quick checks of stability can be made by making distance measurements only. When slope movement is detected, there is need for check surveys (using other methods such as triangulation, GPS etc.) to determine the coordinates of each station at less frequent intervals to re-confirm measurements and ensure they are not "outliers".

This paper is concerned with the typical challenges expected during such prism monitoring. These challenges include staffing, budgeting, establishment of the survey control network, construction of the monitoring shelter (observation house) at the transfer beacon, installation of prisms on the bench faces, planning or consideration for weather influence and transfer of data to the control room.

3. Steps in Slope Monitoring using Total Station

According to Cawood and Stacey (2006), the main considerations for effective monitoring have to do with correct design, legal compliance, monitoring requirements and systems design that provide for both geotechnical and survey monitoring instrumentation. Steps in slope monitoring using total station start with staffing and budget, in addition to systems design and implementation. Data collection, processing and the presentation of results in a concise format that allow for efficient analysis, interpretation and decision making complete these steps.

3.1 Staffing and Budget

The survey monitoring operation requires a significant investment in resources. Staffing during survey monitoring has two considerations: the appointment of an expert to carry out the design upon which the entire monitoring programme will be based and personnel (suitably qualified surveyors and assistants) who will implement the design and operate the survey monitoring system on a daily basis.

Slope monitoring is an auxiliary operation, since it does not contribute directly to mine production but has definite economic benefit when it gives early warnings to prevent loss of life, damage to equipment, loss of production and possibly the closure of the mine (Cawood and Stacey, 2006). It is also required by law as part of health and safety measures at mines. Therefore, relevant persons (e.g. the heads of the mine surveying and geotechnical departments) must motivate the safety critical aspect and expected cost-benefit of the monitoring programme that will convince management to release adequate budget for slope monitoring. The success of any slope monitoring exercise depends on the budget provided for the procurement of appropriate equipment and hiring of competent or suitably qualified personnel. Inadequate personnel and budgeting would lead to operational failure. Table 1 summarises the likely challenges that could be encountered during staffing and budgeting. The table also gives possible ways to solve these problems.

Table 2: Staffing and Budget

Problem		**Mitigation**
Staffing:	Design	Secure the services of an expert (part-time or on contract basis) to help in the design of the monitoring programme
	Survey monitoring	Employ suitably qualified surveyors to perform the day-to-day monitoring survey
		Employ able assistants to assist the surveyors in their daily routine.
		Ensure competency through continuous professional development of staff.
Budget:	Salaries Procurement of instruments	Prepare a motivation that can accommodate suitably qualified personnel, procure necessary instruments and other running cost.
		Explain the requirements (health and safety and statutory reasons) for a monitoring programme and highlight the overall benefits.
		Present and motivate the budget plan.

3.2 Survey System Design and Implementation

Slope monitoring system design must be a thorough process that takes into account adequate information and provides a design aimed at mitigating risk. During system design, the objective of the monitoring system must be clearly stated, coupled with the geological and geotechnical history of the area under consideration. Detailed reconnaissance entails the examination of published geological maps and reports, study of aerial photographs, gathering of local experience, field visits to examine, if possible, the performance of existing slopes in similar geological conditions, and geophysical studies if data is limited. The reconnaissance will assist in establishing the project requirement. The findings will suggest probability of failure and the variables that will most likely contribute to such failure. These variables must be considered when designing the monitoring system, investigating appropriate instrumentation and implementing the monitoring system (Ding *et al*, 2000). Wyllie and Mah (2004) also affirm that the system design should be able to predict accurately the type of movement that is likely to occur in a particular area of interest. This information can be used to select appropriate instrumentation for the site and assist in interpretation of the results. Above all, the system design should state clearly the frequency of monitoring, accuracy required and reporting method to be used.

Design specifications are carried out in consultation with a geotechnical engineer (i.e. expected magnitude of movement, parameters to measure, type and scale of deformation to be monitored, purposes of various instruments, locations of equipment, desired accuracy/precision, checks using different survey methods and equipment) have great influence in selection of slope monitoring equipment. Cawood and Stacey (2006), emphasised that the survey monitoring equipment selection depends on economic value-added as a result of the system, required level of confidence in the results, ease of interface (i.e. compatibility with other monitoring technologies), GIS adaptability, environmental conditions, survey budget and survey training necessary for optimal use. Equipment required for prism monitoring surveys include a robotic total station (RTS), total station shelter, equipment for measuring atmospheric conditions, pillar beacons (for transfer and reference beacons) and prism for monitoring points (Thomas, 2011). The procedure of prism installation must also be considered, this includes:

- bench crest beacon (in case of bench crest prism installation); and
- drilling and grouting (in the case of bench face prism installation).

Sourcing external energy to power the total station and other auxiliary equipment is a further consideration. The implementation of the slope monitoring survey is discussed below:

3.2.1 Setting up control points

A control point is a point at which the coordinates (X, Y) and the elevation (Z) are known and from which survey measurements to a number of reference points can be made. Prism monitoring survey requires three types of points namely: transfer, reference and monitoring points. The transfer and reference points is part of the survey control network.

Both the transfer and reference beacons must be positioned to ensure unobstructed line-of-sight between beacons but not located in a position that is unstable and hazardous, i.e. too close to crest/highwall (Thomas, 2011). For accurate monitoring, the survey control network must have a minimum grouping of four intervisible forced-centring pillar beacons (that can form a quadrilateral) and spatially fixed by a least squares adjustment. It is recommended to construct additional transfer and reference beacons for redundancy purposes. Figure 1 shows a typical transfer beacon and reference beacon respectively.

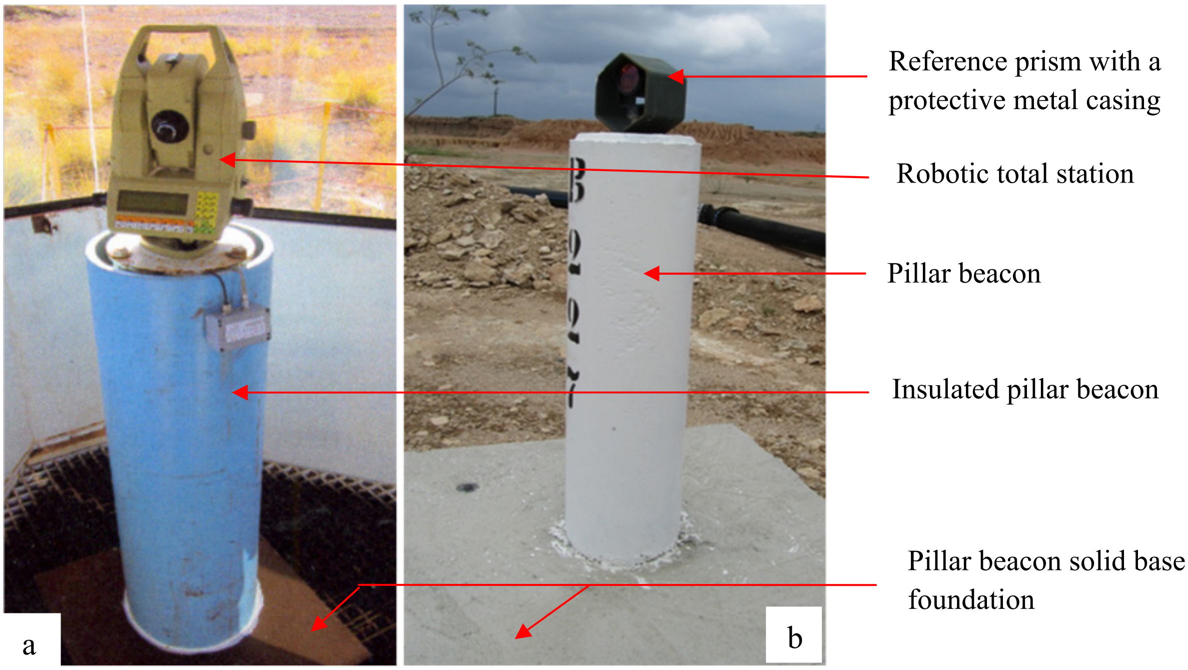

Figure 1: Typical example of (a) transfer beacon and (b) reference beacon (source: Thomas, 2011)

The location of monitoring points must be determined in consultation with the geotechnical engineer. Monitoring points are usually located on the crest and the bench faces. Their position must be intervisible from the transfer pillar beacon and some (if not all) of the reference pillar beacons. Figure 2 shows typical example of a crest mounted monitoring point. Figure 3 shows typical example of a bench face monitoring point.

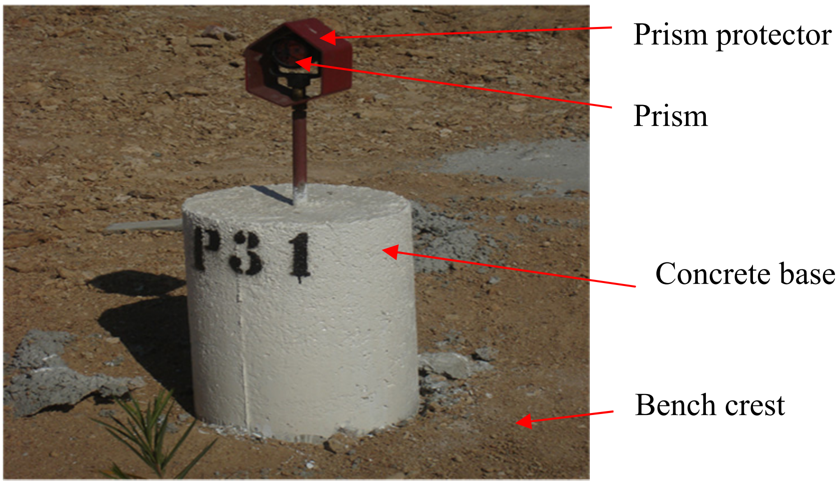

Figure 2: A typical example of a crest mounted monitoring point at Anglo Platinum, Mogalakwena operation, South Africa (source: personal photographs taken during two days visit to Anglo Platinum, Mogalakwena operation).

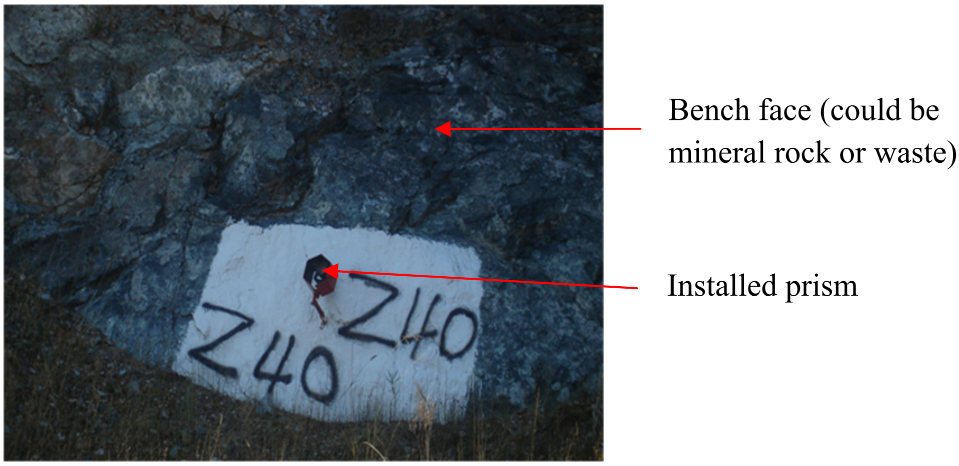

Figure 3: A typical example of a bench face mounted monitoring point at Anglo PlatinumMogalakwena operation, South Africa (source: personal photographs taken during two days visit to Anglo Platinum, Mogalakwena operation).

3.2.2 Construction of shelter at transfer beacon

A protective shelter must be constructed on the transfer beacon on which the RTS will be setup as shown in figure 4. If the transfer beacon protective shelter is made from metal sheet, the inner part must be insulated to reduce heat generation from sunlight. The outer part should also be painted white to reduce the effect of heat from sunlight. Air conditioning may also be installed, but such air conditioning may have its own effects on the RTS readings as reported by Rueger *et al* (1994). Due to the high cost and sensitive nature of the RTS, they are usually housed in a protective shelter for the following reasons:

- protection from fly rock resulting from blasting operation;
- protection against dust resulting from drilling, blasting and haulage operation at the mines;
- protection against excessive sunlight and rain; and
- theft.

The power source, i.e. battery, that is supplied with RTS can only work for a limited period before it has to be recharged. To overcome this problem, the RTS can be powered using an external energy source, for example, a solar energy (as shown in figure 4a) or a standby generator.

The monitoring is usually carried out through glass as shown in figure 4b. The properties of the glass such as shape, thickness and colour (tint level) must be borne in mind during the selection process. The importance of the glass properties has been explained by Afeni and Cawood (2010). The distance between the window glass and the robotic total station must also be kept to a minimum. Figure 4 a and b shows a typical total station shelter constructed on a transfer beacon at a mine site.

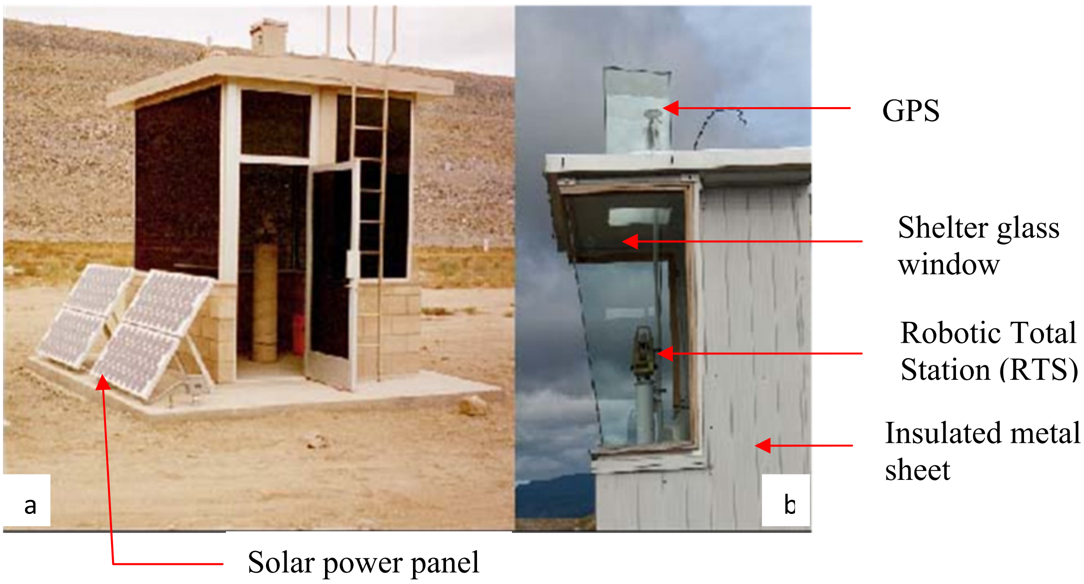

Figure 4: a - RTS shelter with solar power panels, b – Typical RTS/GPS shelter (source: Chrzanowski and Chrzanowski, 2008)

3.2.3 Installation of monitoring point prisms

Installation of the prisms into the area of interest in the open pit is another task to be carried out for slope monitoring. The installation of the prisms must be performed when the bench is still accessible. It is compulsory that the installation of the prisms is done at the early stage of the mining operations in areas where there are faults and there is likelihood of slope failure. Holes are drilled into the bench face and then cleaned to remove all dust in the hole before grouting in a prism rod. Injected grouting material can be used to seal the drilled hole after inserting the metal rod that holds the prism and its protective (metal) hood. The moveable plastic arms (U-shaped) that hold the prism can be made rigid by applying silicon sealant (or an adhesive to keep the prism in place) before installation. In terms of consistency and uniformity of error propagation, all prisms (or reflectors) must be identical (Cawood and Stacey, 2006). A typical example of installed prism on a bench faces is shown in Figure 3.

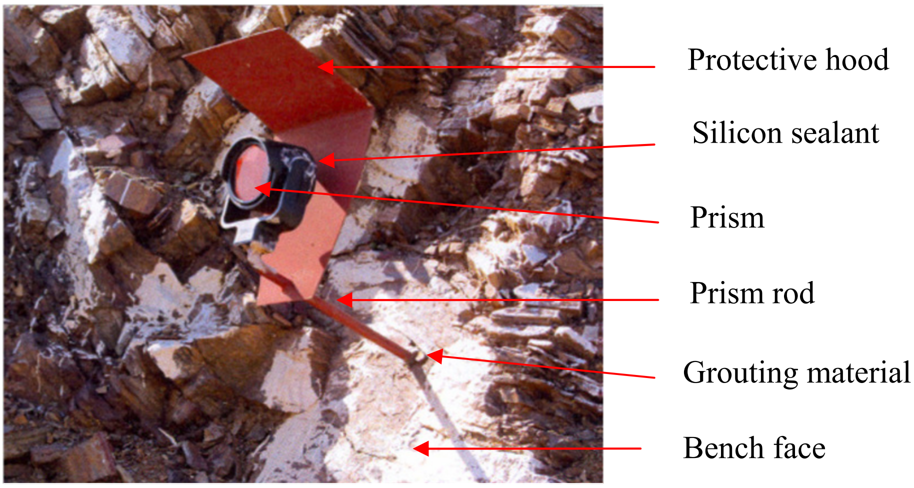

Figure 5: A typical example of prism installed to the bench face for monitoring purposes (source: Thomas, 2011).

As a result of mining operations the RTS may not be able to measure to the monitoring point prism because of dust covering the face of the prism. This dust emanates from drilling, blasting and haulage operations. This problem is more common in winter (South Africa) when there is little or no rainfall. If the point is not too high for a hydraulic water hose to reach, the prism can be cleaned with a water jet. The problem of dust settling on the prism face can be problematic to the monitoring programme. Measurement can be interrupted until rainfall assists in cleaning the prism; only then can the RTS measure to the point again. Figure 6 shows a prism covered with dust. Improper design and poor implementation mean no slope monitoring. Table 2 summarises the problem and mitigation on system design and implementation.

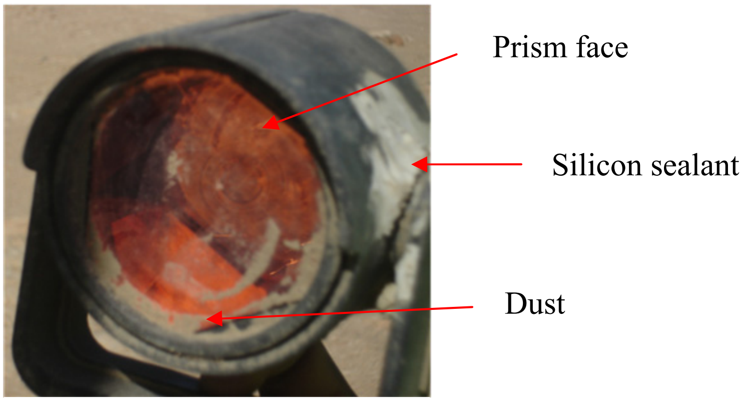

Figure 6: Typical example of Prism covered with dust at Anglo Platinum, Mogalakwena operation, South Africa (source: personal photographs taken during two days visit to Anglo Platinum, Mogalakwena operation).

Table 2: System Design and Implementation

Problems		Mitigations
System Design	System installation	Design system that is commensurate with the objective of the monitoring program.
		System designed must be simple and flexible, i.e. not onerous.
		State clearly the frequency of monitoring, accuracy required and reporting method.
		System installed must be accurate to satisfy requirements stated in the system design.
	Equipment selection	Use fit for purpose equipment (vendor selection is important).
	Equipment maintenance and replacement	Calibrate the total station frequently, especially when errors in data are suspected to be instrumental.
		Maintain, repair or replace any faulty equipment.
	Power source	Ensure frequent/adequate supply of continuous power.
Design of survey control	Beacon design	Use appropriate method to establish reference points.
		Ensure that the beacons are stable.
	Prism selection and geometry	Select appropriate prism for job at hand (i.e. use genuine manufacturers prism for slope monitoring).
		Install selected prism properly at the crest or bench face
		Use identical prisms.
	Prism maintenance	Clean the prism glass when covered with dust. Check stability.

3.3 Data Collection and Processing thereof

The use of RTS for monitoring work is a common practise at most open pit mines and dams because it can provide continuous 24 hours remote data collection for analysis and warning alarms to alert personnel with regard to ground stability problems (Afeni 2011). Manual total station observations are time consuming, labour intensive and have the potential for human error when recording survey data. Although conventional systems are suitable for *ad hoc* monitoring, continuous monitoring requires more advanced systems to cope with the amount of data recorded (Jooste and Cawood, 2006) . The use of robotic total stations has become popular due to their flexibility, high speed, high efficiency and accuracy. When referring to flexibility in this case, it means the ability of the instrument to find the prism, take a reading and store the data. The measurement intervals can be set according to monitoring programme requirements, and high risk areas measurement intervals can be set according to priority, providing for the monitoring of such areas more frequently. Monitoring surveys make use of two data sources, namely data that is measured by the RTS (e.g. distances and angles) and data that is external to the total station (e.g. meteorological sensor). Data that is external to the total station is complementary data (i.e. atmospheric condition measurements i.e. ambient temperature and atmospheric pressure, for atmospheric corrections). The two types of data are summarized below:

- Total station measurements: horizontal, slope and vertical distances readings, and angular (horizontal angle, Hz and vertical angle, V) readings.

- Data external to total station: Atmospheric conditions (i.e. ambient temperature, atmospheric pressure and humidity), observation glass properties, etc..

Data from these two sources must be integrated and processed before a meaningful survey result can be achieved. Such data is processed using suitable computer software. A control centre for automated data collection and processing thereof must be established. Data transfer to the survey/geotechnical office is usually done by radio link (Cawood and Stacey, 2006). However, care must be taken to ensure that the communication network does have a limitation from frequency interference when the radio link is used.

Error propagation and data processing are the next tasks after data transfer to the surveyor's office. There are several software packages on the market for total station error propagation, processing and analysis of monitoring data. Such software allows for error propagation and network analysis (i.e. least square analysis for near errorless measurements, and entails reduction of standard deviation of measurements to a minimum). The error propagation and network analysis use separate software (e.g. Surpac). Unlike monitoring software (e.g. GeoMos) which involves atmospheric corrections to adjust total station measured distances (Bannister *et al*, 1998). The software also calculates coordinates (XYZ), compares final coordinates for different surveys and presents these results using graphs showing movement trends over time.

The final step in slope monitoring is to present the data in a manner that facilitates interpretation and decision-making. The presentation of the monitoring data can be in form of graphs, tables, photographs and charts (e.g. movement according to time, rainfall and temperature variations). What is important at this stage is for the surveyor to record and document all relevant events that may affect the slope monitoring data (e.g. drilling blasting and rainfall). Also survey decisions and design changes with supporting evidence (i.e. planned versus mined) when communicating results to management must be recorded. Wrong data collection and processing thereof would lead to erroneous alert or no slope failure warning. The summary of problems and mitigations on data collection and processing thereof is presented in Table 3.

Table 3: Data Collection and Processing thereof

Problems		**Mitigations**
Data collection	Onboard the total station	Ensure that all necessary settings required are set correctly.
	Data external to total station	Use quality instruments to acquire atmospheric measurements and apply corrections.
	Integration of different data	Use software and good network linkage between the transfer station (observation house) and the survey office.
Data processing	Error propagation	Always bear in mind that no survey is free from error..
		Accurately describe spatial data accuracy without ambiguity.
	Data presentation for decision making	Process all collected data by close-of-business each day and disseminate the results as soon as possible, if it is not done on a real-time system.
		Present the outcome of monitoring data in a manner that will facilitate efficient interpretation and decision-making.
		Document all events, decisions and design changes with supporting evidence.

The influence of atmospheric conditions pose great challenges on prism monitoring. The refraction effects of atmospheric conditions (ambient temperature, atmospheric pressure and humidity) on light wave have been modelled by many researchers in the past (Barrel and Sears, 1939; Edlen, 1966; Fraser, 1981 and Ciddor, 1996), many effects of atmospheric conditions still needed to be modelled.

Changes in weather conditions, such as heavy rainfall and mist, greatly hinder prism monitoring. To overcome this, the instrument could be sheltered resulting in measurements to be taken through a glass surface. Experience by the authors during measurements to check the impact of glass on total station distance measurements revealed that both rainfall and mist have a significant impact on the results as revealed in Figures 7 to 8 and Tables 4 to 5.

Figures 7 and 8 show horizontal distance (HD) measurements to a prism without glass and with glass (5.0 mm clear float glass) at different angles (45°, 60° and 90°). In Figure 7 the HD measurements to the prism were corrected for prism constant and scale factor but not atmospheric corrections. Figure 8 shows the graph of HD measurements to prism corrected for prism constant, scale factor and atmospheric corrections. Tables 4 and 5 show HD readings during monitoring to prism in early morning misty weather condition. Figure 9 shows a photograph taken during the misty weather condition.

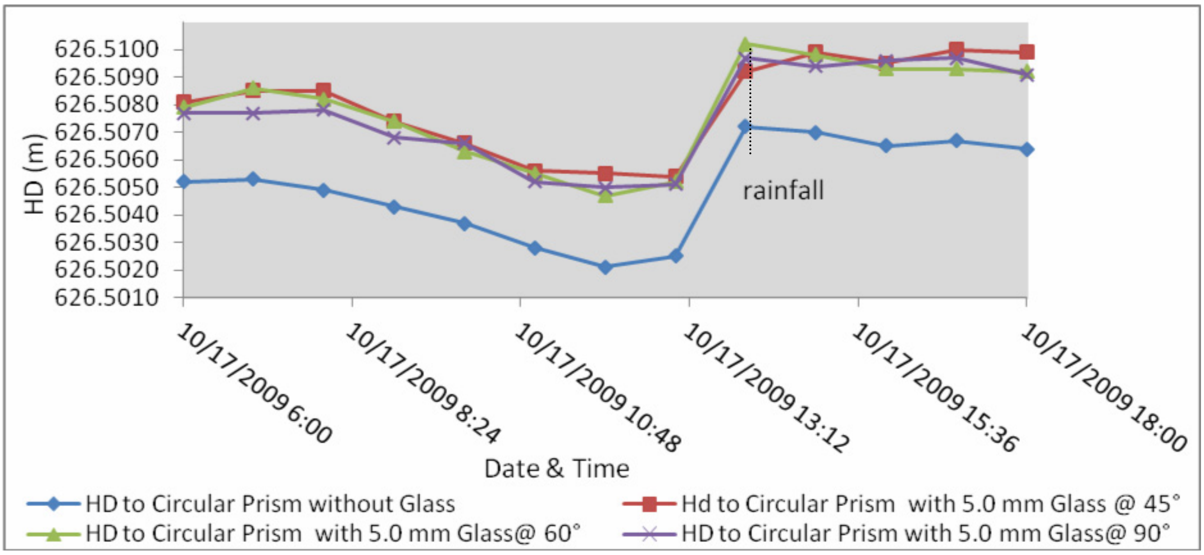

Figure 7: Graph of HD measurement to prism, corrected for prism constant and scale factor only.

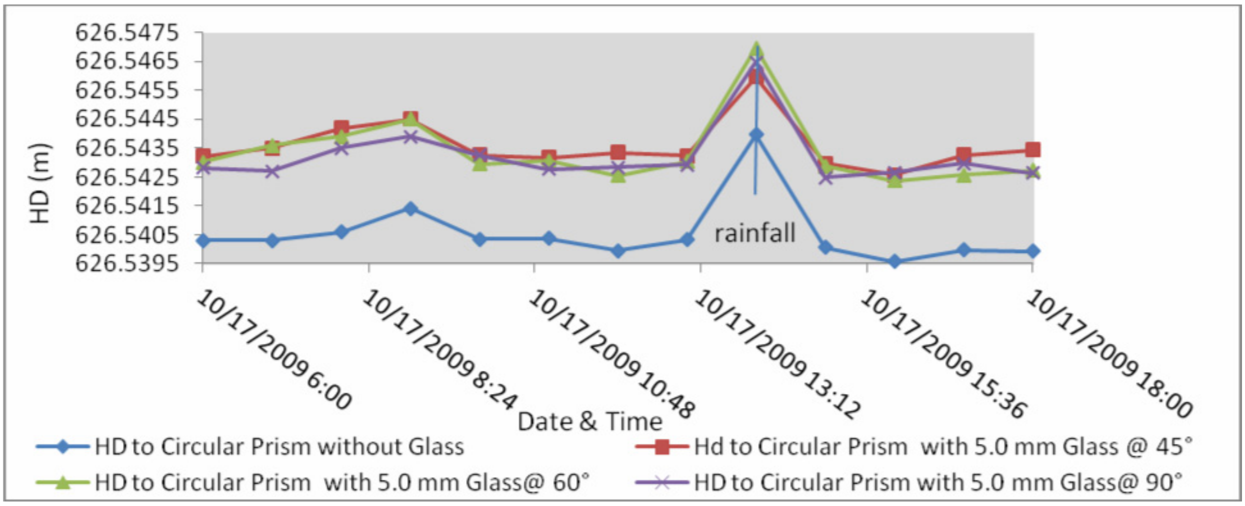

Figure 8: Graph of HD measurement to prism after all corrections.

In Figure 7, the trend in the HD path changes when the light shower began, even after atmospheric correction formulae are applied as revealed in Figure 8. The impact of the rain on HD (without and with glass) is about 4.1mm at 13h00. If the rain continued on that day, the impact may have risen and may have affected any alarm limit set by the monitoring group. (i.e. if the light shower had continued, it may have given rise to a false alarm). Figure 8 revealed that the trend returned back to the normal after the rain had stopped (i.e. beginning from 15h00 to 18h00).

Table 4: HD readings to Circular prism

Date with Time	**HD to Circular Prism without glass**	**HD to Circular Prism with glass @ 30°**	**HD to Circular Prism with glass @45°**	**HD to Circular Prism with glass @60°**	**HD to Circular Prism with glass @90°**
2010/05/13 06:00	Misty weather with visibility below 100 m				
2010/05/13 07:00	Misty weather with visibility below 120 m				
2010/05/13 08:00	Misty weather with visibility below 150 m				
2010/05/13 09:00	Misty weather with visibility slightly above 200 m				
2010/05/13 10:00	626.5093	626.5118	626.5112	626.5112	626.5110
2010/05/13 11:00	626.5091	626.5112	626.5118	626.5114	626.5109
2010/05/13 12:00	626.5084	626.5106	626.5099	626.5104	626.5097
2010/05/13 13:00	626.5082	626.5097	626.5091	626.5098	626.5097
2010/05/13 14:00	626.5070	626.5082	626.5087	626.5089	626.5085
2010/05/13 15:00	626.5070	626.5087	626.5083	626.5084	626.5085
2010/05/13 16:00	626.5063	626.508	626.5085	626.5083	626.5087
2010/05/13 17:00	626.5067	626.5078	626.5085	626.5088	626.5080
2010/05/13 18:00	626.5075	626.5084	626.5087	626.5092	626.5091

Table 5: HD readings to Circular prism

Date with Time	**HD to Circular Prism without glass**	**HD to Circular Prism with glass @ 30°**	**HD to Circular Prism with glass @45°**	**HD to Circular Prism with glass @60°**	**HD to Circular Prism with glass @90°**
2010/05/14 06:00	Poor visibility and misty weather condition; visibility limited to 150 m				
2010/05/14 07:00	Poor visibility and misty weather condition; visibility limited to 500 m				
2010/05/14 08:00	626.5085	626.5103	626.5101	626.5101	626.5101
2010/05/14 09:00	626.5081	626.5095	626.5093	626.5104	626.5093
2010/05/14 10:00	626.5069	626.5082	626.5088	626.5088	626.5087
2010/05/14 11:00	626.5069	626.5082	626.5080	626.5077	626.5081
2010/05/14 12:00	626.5057	626.5070	626.5073	626.5074	626.5071
2010/05/14 13:00	626.5060	626.5069	626.5073	626.5069	626.5070
2010/05/14 14:00	626.5051	626.5068	626.5065	626.5068	626.5062
2010/05/14 15:00	626.5045	626.5060	626.5063	626.5061	626.5065
2010/05/14 16:00	626.5047	626.5057	626.5061	626.5061	626.5060
2010/05/14 17:00	626.5052	626.5069	626.5073	626.5072	626.5067
2010/05/14 18:00	626.5055	626.5071	626.5070	626.5071	626.5067

Figure 9: Picture of misty conditions

Monitoring to a prism during misty weather conditions as presented in Tables 4 and 5 revealed that the total station cannot capture any data during poor visibility, the instrument can only capture data as weather visibility improves. Figure 9 shows the misty condition during one of the monitoring exercises. Since rainfall and misty weather conditions have temporary effects (as shown in Figures 7 to 8 and Tables 4 to 5 above) on the total station monitoring data their effect is temporary. A combination of more than one monitoring technique (multiple monitoring tools) to complement total station monitoring during these two adverse conditions might be suggested but the performance of other monitoring tools under heavy rainfall and misty conditions remain doubtful (radar does penetrate mists but its performance under heavy rainfall is uncertain). Atmospheric influence can mar the outcome of the whole monitoring operation if not well catered for. Table 6 summarizes the problem and mitigation on weather influence.

Table 6: Atmospheric Influence

Problems		**Mitigations**
Atmospheric conditions/weather variations	Atmospheric conditions	Use good meteorological sensor and software for atmospheric corrections.
	Heavy rainfall	Use suitable instrumentation that can work under extreme conditions
	Misty conditions	Stop operations temporarily till weather improves

4. Conclusion and Recommendation

This paper discusses various challenges likely to be encountered during slope stability monitoring using a total station and possible ways to overcome them. The challenges discussed, if not handled properly, can affect the integrity of prism monitoring. Therefore, a RTS system should be complemented by other monitoring techniques such as GPS (for spatial control), radar and/or laser scanning and geotechnical instrumentation e.g. piezometer and extensometer.

5. Acknowledgement

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6. References

Afeni, T.B., 2011, An Approach to Eradicate the Effects of Atmospheric Variations on Total Station Distance Measurement in a Surface Mine Environment. The impact of taking measurement through a glass medium. PhD Thesis, University of the Witwatersrand, Johannesburg.

Afeni, T.B. and Cawood, F.T., 2010, 'Do the properties of glass matter when taking total station distance measurements through an observation window?' Proceedings of International Society for Mine Surveying (ISM) XIV international Congress held in Sun City, South Africa, pp. 109 – 120.

Bannister, A., Raymond, S. And Baker, R., 1998, *Surveying*. Pearson Education Ltd. Edinburgh Gate, England.

Barrel, H. and Sears, J.E., 1939,' The refraction and dispersion of air for the visible spectrum', *Philosophical Transaction of the Royal Society, Series A, vol. 238, pp 1 – 64.*

Cawood, F.T. and Stacey, T.R. 2006, 'Survey and geotechnical slope monitoring considerations', *South African Institute of Mining and Metallurgy (SAIMM) vol. 106, no. 7, pp. 495 – 501.*

Chrzanowski, A.S. and Chrzanowski, A., 2008, 'Interdisciplinary approach to monitoring analysis and modelling of deformations', *Electronic Journal of Polish Agricultural University (EJPAU), vol. 11 no. 2, viewed 30 January 2011* <http://www.ejpau.media.pl/volume11/issue2/art-29.html>.

Ciddor, P.E., 1996, 'Refractive index of air: new equations for the visible and near infrared', *Applied Optic, vol. 35, no. 9, pp.1566-1573.*

Ding, X., Ren, D., Montgomery, B. and Swindells, C., 2000, 'Automatic monitoring of slope deformations using geotechnical instruments'. *Journal of Surveying Engineering, vol. 126, no. 2, pp. 57 – 68.*

Edlen, B., 1966, 'The refractive index of air'. *Metrologia, vol. 2,* 1966. *pp. 71 – 80.*

Fraser, C.F., 1981, 'A simple atmospheric model for electro-optical EDM reduction'. *The Australian Surveyor, vol.30, no.6, pp. 352 – 362.*

Hill, C.D. and Sippel, K.D., 2002, ' Modern deformation monitoring: A multi sensor approach'. FIG XXII International Congress, Washington DC, USA, 2002. 12pp.

Jooste, M.A. and Cawood, F.T., 2006, 'Survey slope stability monitoring: Lessons from Venetia Diamond Mine'. Proceedings of the International Symposium on Stability of Rock Slopes in Open Pit Mining and Civil Engineering, The South African Institute of Mining and Metallurgy, Symposium Series 44, pp 361 – 374.

Kuhlmann, H. and Glaser, A., 2002, 'Investigation of new measurement techniques for bridge monitoring'. 2nd Symposium on Geodesy for Geotechnical and Structural Engineering, Berlin, Germany.

McHugh, E.L., Dwyer, J., David G. Long, D.G. and Sabine, C., 2006, 'Applications of ground-based radar to mine slope monitoring'. Report of Investigations 9666; Centers for Disease Control and Prevention National Institute for Occupational Safety and Health, 39pp.

Osasan, S.K. and Afeni, T.B., 2010, 'Review of slope monitoring techniques'. *Journal of Mining Science, vol. 46, No. 2, pp. 177 – 186.*

Palazzo, D., Friedmann, R., Nadal, C., Santos-Filho, M., Veiga, L., and Faggion, P., 2006, 'Dynamic monitoring of structures using a Robotic Total Station'. XXIII FIG Congress, Munich, Germany, Oct. 8-13, 10pp.

Rueger, J.M., Alanko, G. and Snow, T.J., 1994, 'Monitoring of an open cut mine with a surveying robot'. *The Australian Surveyor, vol. 39, no. 4,* 1994. *pp. 252 – 266.*

Thomas, H.G., 2011, Slope stability prism monitoring: A guide for practising mine surveyors. Unpublished M.Sc dissertation, University of the Witwatersrand, Johannesburg, South Africa.

Wyllie, D.C. and Mah, C.W., 2004, Rock slope engineering civil and mining. Spon Press, Taylor and Francis e-library, 456pp.

Xinhua News Agency, 2012, Slope failure kills 4 in SW China mine. Reported online by Xinhua web editor: Liuyuanhui.

Zahariadis, H. And Tsakiri, M., 2006, 'Low cost monitoring system in the Open Pit Lignite Mines of Megalopoli, Greece'. *3rd International* Association of Geodesy (*IAG)/12th FIG Symposium, Baden, 10pp.*