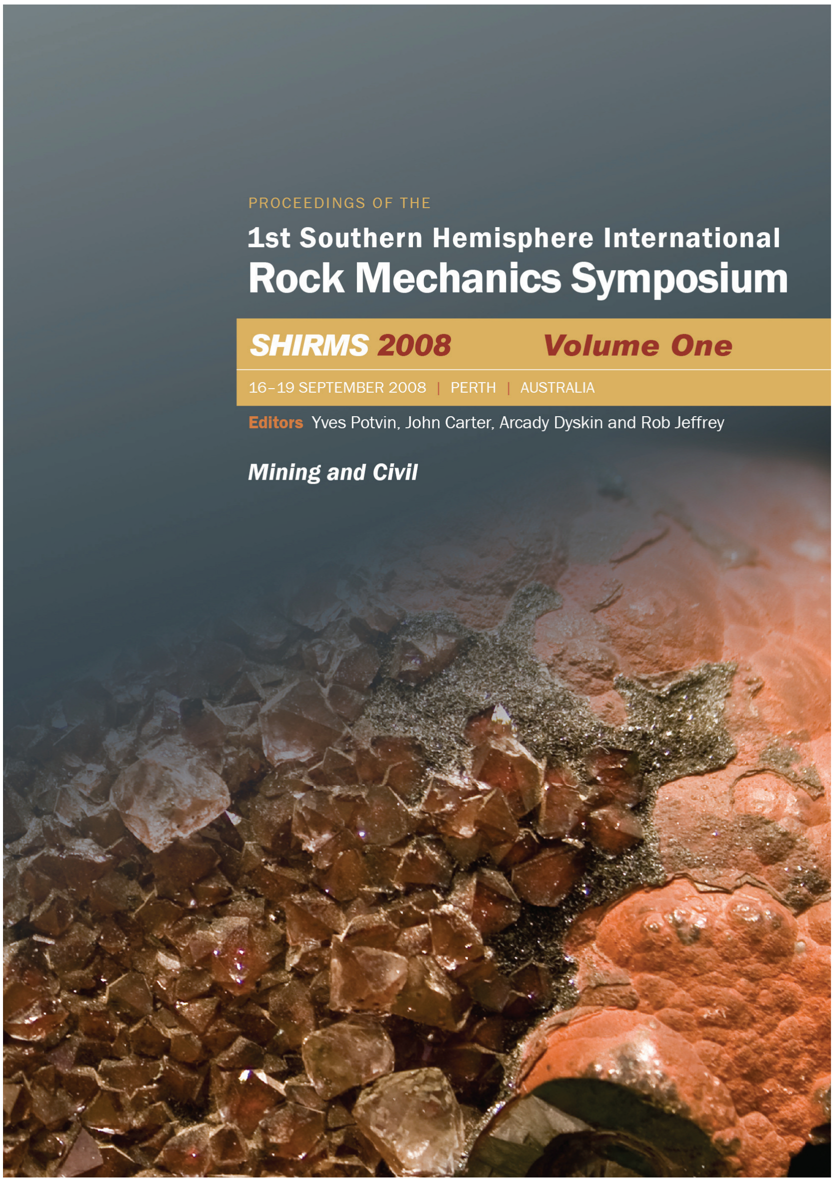
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Mining and Civil

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Low Wall Slope Monitoring by Robotic Theodolite System Likely to Contribute to Increased Production of Coal in PT Adaro Indonesia

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Abstract

Following the adoption of the plan of PT Adaro Indonesia to increase its coal production from 36 to 38 Mtpa in 2008, the pit wall slope stability will be one of the important factors to be monitored. The wall stability can be assessed, as mining proceeds, by high-quality displacement monitoring and sophisticated data analysis.

Robotic Theodolite is a system that is designed for automatic slope displacement monitoring. The system can produce displacement-versus-time graphs quickly and accurately and, compared to the manual system, fewer persons are required. The Robotic Theodolite system can also provide information of rock mass behaviour, as well as data for predicting the stability of the mining slopes. Furthermore, by applying the threshold limit value (THLV) to the system, an early warning system can be constructed. However, the THLV data available in PT Adaro Indonesia are derived from case histories from different rock masses and they cannot be directly imported into the Robotic Theodolite system. The data acquired by the Robotic Theodolite system at the Tutupan mine must therefore be validated by rheology modelling through laboratory creep shear tests, as the rheology model can be utilised to theoretically predict the failure time of the rock mass under a constant load.

1 Introduction

Maintaining the stability of steep slopes is an important geotechnical engineering component of any open pit mining operation. Monitoring the surface displacement of a rock mass slope makes available valuable information on the dynamics of any movements or changes within the rock mass structure. The magnitude, velocity and acceleration of displacements can then provide input data to assess the stability of the slope and rock mass behaviour. If the movements can be detected early, this will obviously help the geotechnical engineers to anticipate any worst-case scenario that could affect the slopes.

The authors' technique for monitoring slope displacements, especially in low wall applications, uses total station instruments. This method provides information such as slope angle and distance between prisms as well as prisms and reference point. As with any observational technique, total station system instruments have both, advantages and disadvantages associated with their use. The main advantage of using total station instruments is that it provides three-dimensional (3D) coordinate information of the points that are measured.

2 Background

Tutupan mine is one of the PT Adaro Indonesia open pit coal mines which currently consists of the Pama, Sis, Buma and RA pits (Figure 1). Pama pit is excavated in a better quality rock mass than that of RA pit. The Pama pit will be developed down to RL-204 mRL and will be the deepest pit in the Tutupan mine.

Having experienced minor slope failures of the low wall within the Pama, presumably associated with rock mass deformation, it can be concluded that this pit will need slope stability monitoring of its low wall.

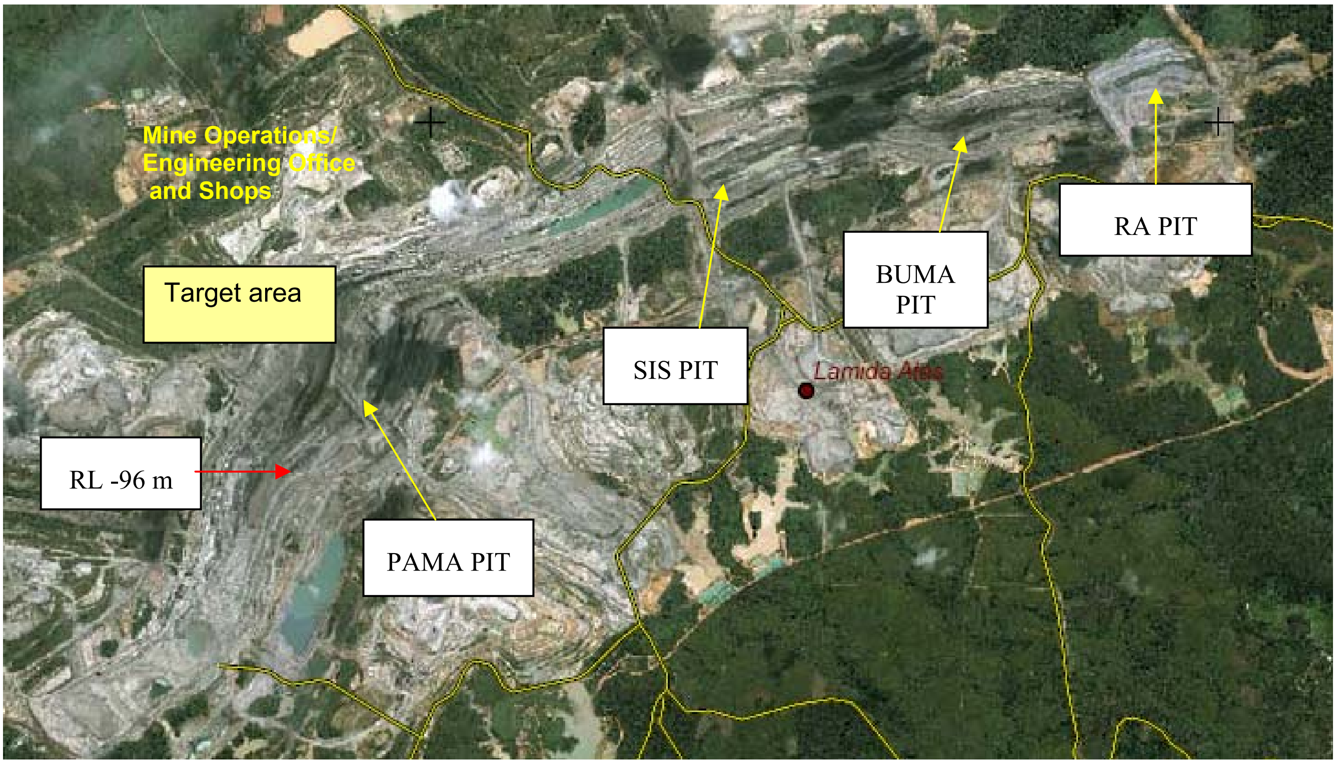

Figure 1 Tutupan coal mine site overview

Currently, there are over 42 km^2 of pit walls exposed within the four operational pits and they are equipped with approximately 70 slope monitoring prisms (SMPs) installed on low wall slopes which are deemed to be vulnerable to slope failure. The monitoring systems of these low wall movements employ a total station system consisting of digital theodolites and a data acquisition system. Information collected from the prism monitoring is used to track down the development and extent of any unstable conditions along the slopes and this enables the geotechnical department to define the magnitude of the problems and to determine subsequently, the potential failure mechanisms.

This kind of monitoring is undertaken in real time which then allows a rapid assessment of low wall stability to be carried out. This permits optimal coal production to be achieved whilst maintaining the safety of personnel and equipment operating at the floor of the slope.

On 20th March, 2008, a significant slope failure occurred at the Sis pit (Figure 2). Although no injuries were recorded, this event was considered to be a catastrophic failure. This has, again, made the management aware of the need for geotechnical monitoring to give early warning of the possible deterioration in slope stability over the lifetime of a slope.

Figure 2 Low wall failure in the SIS pit of Tutupan coal mine

3 Geology and hydrology

The coal deposits within this mine site have been tilted and folded due to the regional tectonics. Approximately
5 to 60 m thick lignite to sub-bituminous coal seams are exposed on the surface stretching for about 20 km along the Tutupan Hills. The dip of the coal seams varies from 20 to 70° towards the southeast. The coal bearing strata encompasses coal seams, sandstone and mudstone and individual thicknesses vary along the 20 km outcrop.

The sandstone is described as predominantly fine to medium sand, interspersed irregularly with pebbly layers. According to the ISRM (1978) classification, the strength (UCS) of weak sandstone is likely to be in the range of 2.44 to 22.4 MPa, whilst medium strong sandstone is in the range of 26.8 to 46.4 MPa. Minimal cementation can be observed within the sandstone layer (UCS = 0.13–0.27 MPa) so that the sandstone layer is defined as uncemented sand and very friable.

The mudstone exhibits varying contents of silt and organic constituents. The strength of the mudstone varies between weak rocks (1.38 to 22.4 MPa) to medium strong (27.8 to 28.8 MPa). In some places the mudstone also takes the form of soft clay (UCS = 0.013 MPa).

The sandstone in the area is an aquifer and the mudstone is aquiclude. Prior to the deep mining operation, the undisturbed groundwater table was around 75 to 95 mRL. As the mine gets deeper, the groundwater has been lowered to the level of the deepest excavation floor by a water drainage system using vertical and horizontal dewatering bores.

4 Deformation monitoring of slope

The simplest way to measure the displacement at a slope surface is by observing the evolution of slope failure and this enables the geotechnical engineers to observe and analyse the kinematics of the rock slope deformation. Ultimately, an engineer could develop appropriate corrective measures to control such slope movement.

As mentioned earlier, the slope displacement monitoring is based on the information obtained from recording of about 70 SMPs using the total station system. The latest total station instruments are equipped with servo-motors and automatic target recognition algorithms. Fewer personnel are required to retrieve the data recorded by the total station system. As this total station system works without involvement of many people, this system is called Robotic Theodolite. The essential parameters obtained from this measurement system are displacements of vertical, lateral and transversal directions (Dunnicliff and Green, 1993). In addition, by using this system any slope movements exceeding the previously specified threshold limit values (THLV), will be identified automatically and directly to the base station as an early warning alert.

The Tutupan mine slope monitoring system uses the total station instruments manufactured by Leica TCRP1203 and TCRA1201 and they are installed in high wall Pama pits namely Pondok Hijau and Pondok Biru respectively. Two Leica Theodolites each monitor 16 prisms at Pondok Hijau and 48 prisms at Pondok Biru (Figure 3).

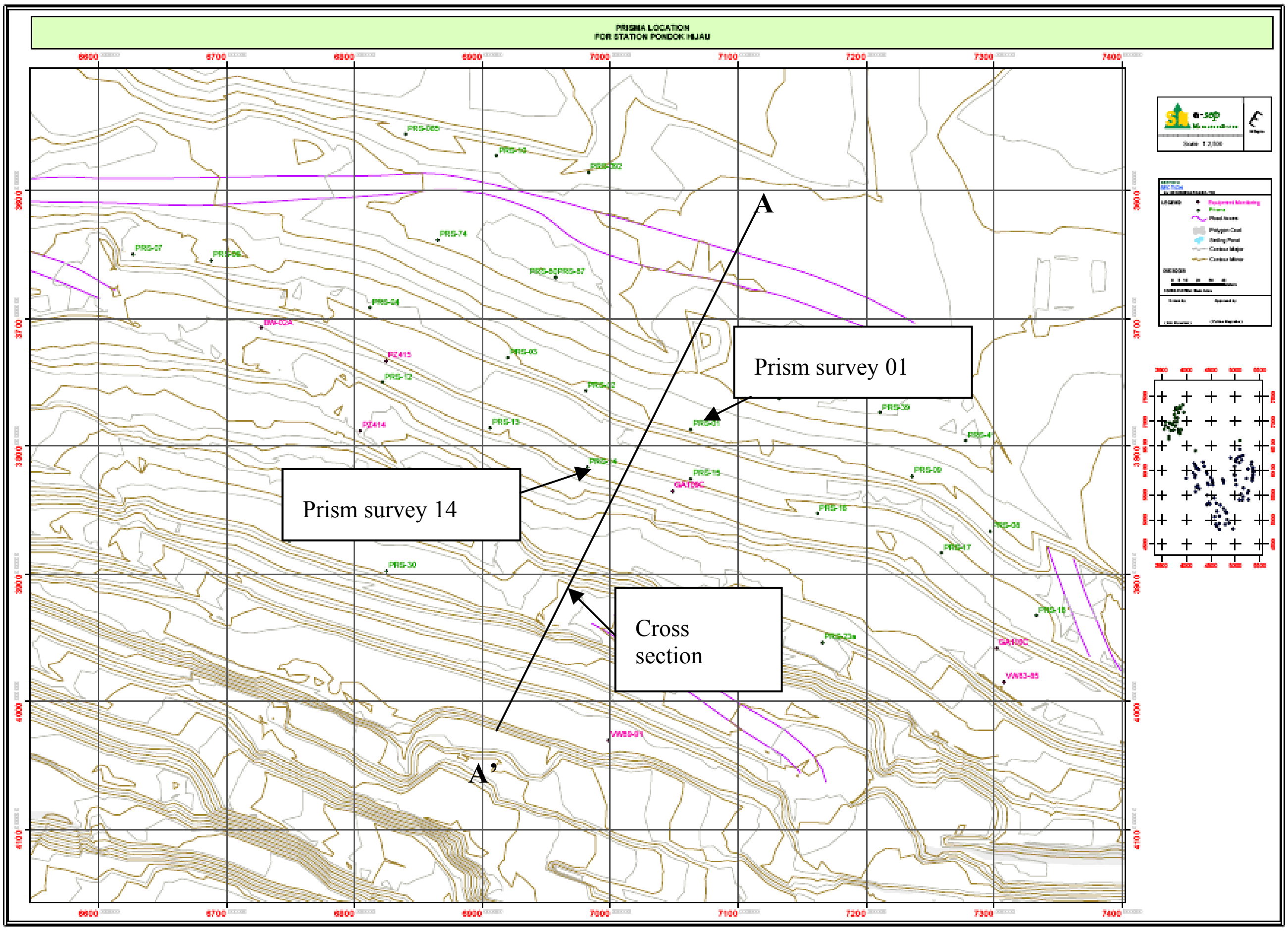

Figure 3 Low wall Pama pit showing prisms on Pondok Hijau groups

Due to the time frame limitation and practicality, this paper concentrates on the monitoring of two prism surveys within one section (north east 20° – south west 200°) at the Pondok Hijau, i.e. prisms numbered 01 and 14 which will then also represent the slope movements at the -204 mRL. The prisms numbered 01 and 14 represent the dumping slope and virgin slope, respectively. At the time of monitoring, the floor level on these slopes were -48 mRL, equivalent to slope height of 148 mRL with low wall slope of 14° (Figure 4).

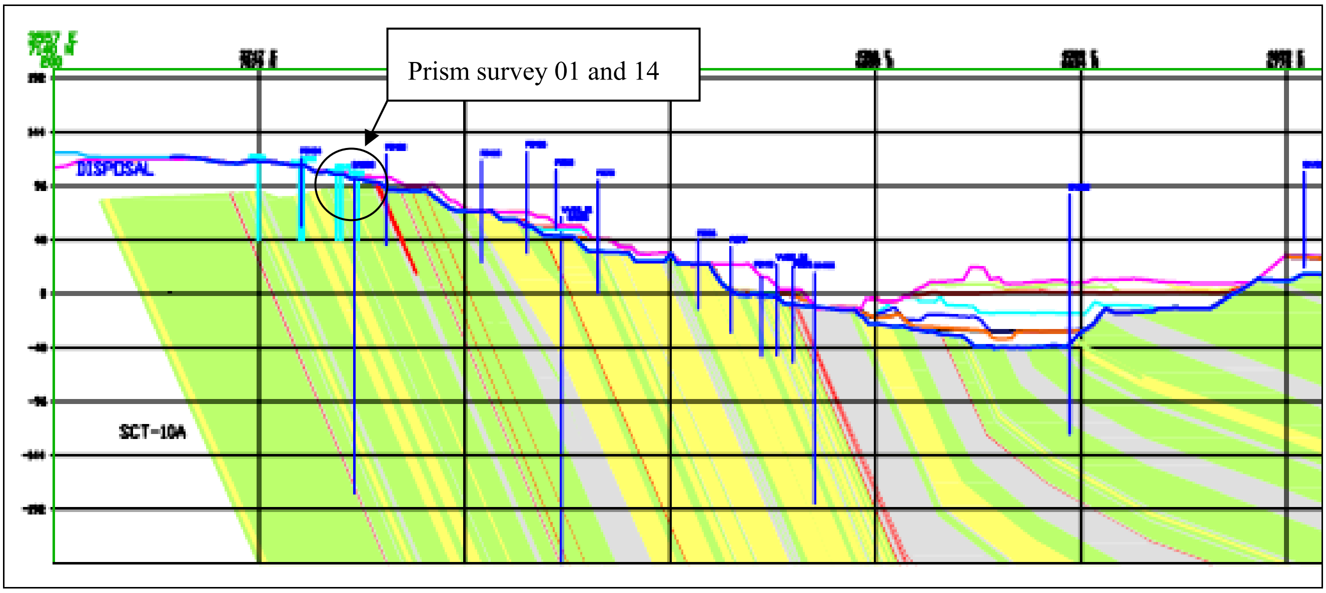

Figure 4 Cross section A – A' on survey prism No. 01 and 14 in low wall pit Pama

Figures 5 and 6 present curves of displacement versus time for prisms 01 and 14 respectively. Based on the monitoring of the Robotic Theodolite for the two prism survey lines the average lateral displacement rate over a seven month period (June 07 to December 07) was 10 mm/day. It is however, important to note that a rainfall event that yielded 106 mm in five hours, resulted in a significant increase of the lateral displacement rate, as indicated by the sudden rise in lateral displacement from 0.4706 to 0.6855 m and from 0.4879 to 0.6855 m, for the prism surveys of 01 and 14, respectively. On the other hand, ground settlements of 1.1 and 0.6 m were noted for the 01 and 14 prism surveys, respectively, during this same period of time.

As expected, Figures 5 and 6 show that the slope displacement (δ) increases with time (t). If the load above prism survey points remains constant and the displacement of these points increase with time, such displacement behaviour could then be regarded as a creep behaviour phenomenon. Constant load however, would only prevail on slopes in an inactive dumping area where the excavation process does not produce a load reduction. These arguments indicate that creep phenomenon applies for slope stability analysis purposes.

This information would not have been useful unless the data was manipulated to obtain the displacement rate per month or per period of a range of rainfalls. This should subsequently be validated with the rheology equation which can be derived from a series of shear creep tests in a laboratory (Kramadibrata et al., 2007).

The rheology equation actually describes the deterioration process of a geo-material which involves a reduction in both cohesion and angle of friction over a period of time. In order to be validated, the rheology equation obtained from the laboratory test and the displacement rate data obtained from field measurements, accuracy, time series, and consistency of slope displacement data can only be currently obtained by means of a Robotic Theodolite.

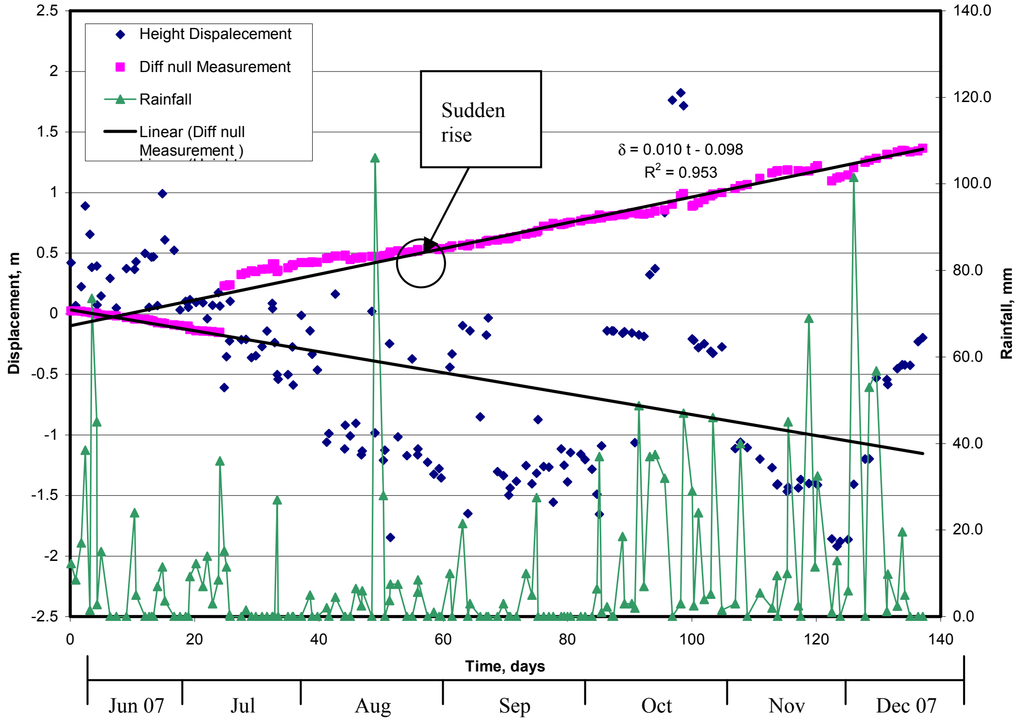

Figure 5 Displacement versus time on prism survey 01

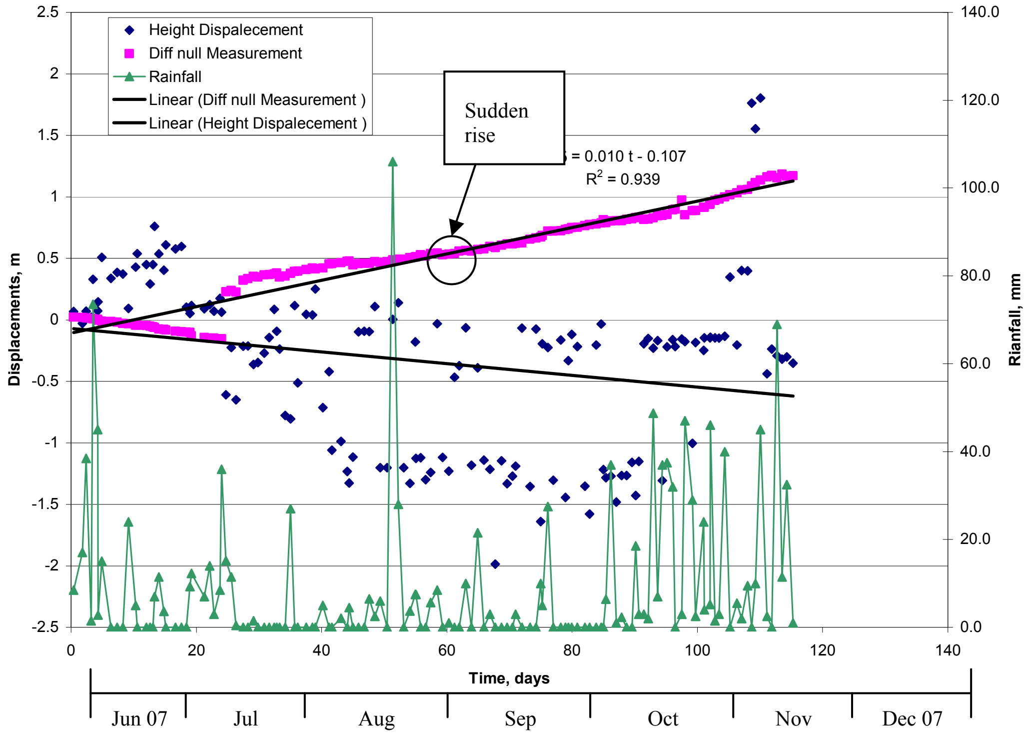

Figure 6 Displacement versus time on prism survey 14

5 Using threshold limit values (THLV) to detect the onset of slope failure

The intention of having THLV is that, if the displacement rate exceeds the THLV, the early warning system will be activated. Despite the fact that no geotechnical study associated with the displacement measurements using the Robotic Theodolite has been done in investigating the most appropriate standard to be applied, the THLV put forward by the Golder (2004) based on data obtained from Pama pit. It must be stated that, in the absence of slope movement data from the specific pit being monitored, it is acceptable to use data acquired from similar pits elsewhere as an interim measure, until sufficient local data and site-specific experience has been acquired.

The Golder (2004) THLVs are divided into four time conditions namely, (1) absolute check, (2) long time, (3) short time and (4) regression check as given in Table 1. For example, if we had an average displacement longitudinal of 15 mm/day the slope could be considered safe. On the other hand, when the displacement reaches 250 mm over 12 hours the activity should be stopped in order to release the load or mass of the slope.

Table 1 Limit values longitudinal displacement of different rate for different risk scheme proposed by Golder (2004)

	Interval (hours)	Limit 1 (m)	Limit 2 (m)	Limit 3 (m)
Absolute check		0.020	0.040	0.100
Short time check	24	0.015	0.020	0.075
Long time check	72	0.030	0.060	0.150
Regression check	12	0.050	0.100	0.250
Remarks		Safe	Caution	Stop

It appears that the displacement rate of 10 mm/day recorded by the Robotic Theodolite confirms the field observation that the slopes remain in safe condition. Nevertheless, displacement rate of 10 mm/day obtained from slope movement monitoring using crack-meter installed at the north east area within the Buma pit (Table 2) was noted prior to slope failure. This information actually contradicts the THLV of Table 1 suggesting that a displacement rate up 15 mm/day would be safe. In fact, the crack-meter data represented that the Buma pit, which is mostly dominated by mudstone, has slightly different bearing strata to that of the Pama pit. Consequently, the THLV from the Pama pit proposed by Golder (2004) could not continue to be used to analyse slope displacement at the Buma pit, once site-specific data had been obtained from that pit.

Table 2 Displacement rate of crack-meter monitoring on Buma pit

Date	CM 135				CM 136			
	Reading	Change	Cumulative	Daily	Reading	Change	Cumulative	Daily
12 October 2006	0	0	0	0.0	0	0	0	0.0
13 October 2006	37	37	37	0.0	49	49	49	0.0
14 October 2006	49	12	49	12.0	59	10	59	10.0
15 October 2006	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
16 October 2006	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
17 October 2006	Failure							

As noted earlier the slope displacement phenomenon recorded by prism surveys 01 and 14 indicated the trend of creep behaviour. Referring to Kramadibrata and Kushardanto (2002), Wattimena et al (2006), and Kramadibrata et al. (2007), it has become obvious that creep behaviour affects the stability of rock mass slope, especially within an area where weathering takes place over the year. In some instances, geotechnical engineers may have been able to predict the failure of certain slopes. Observation has also indicated that the failures apparently happened a few months or weeks prior to, or after, the failure time predicted or calculated by the most suitable rheology equation.

As soon as the ample data that has been recorded by the rheology system and field observations become available, a comprehensive and reliable failure prediction system is the likely result. If remediation is implemented immediately, when early warnings are given by the system, there is a good chance of minimising the impact of slope failures. This will obviously lead to the maintenance of the coal production.

From the foregoing analysis and, combined with the fact that the Buma and RA pits predominantly consist of mudstone which is known as even weaker than sandstone (the overburden of Pama pit), it is therefore appropriate to use the Robotic Theodolite monitoring system in these two pits further to its use in the Pama pit.

6 Conclusions

Coal production could increase the potential for slope failures. In order to anticipate this, comprehensive slope monitoring becomes essential and this can be performed by using the Robotic Theodolite. The monitoring system of the Robotic Theodolite is connected to a network with appropriate software that enables the geotechnical engineers to further process the data to give any desired kind of presentation.

By putting THLV into the data processing early warning system, early warnings can then be transmitted when the displacement rate exceeds the THLV, thus indicating that the slope is no longer safe. The current THLV developed by Golder (2004) from Pama pit cannot be generally applied to assess the stability of all slopes at the Tutupan coal mine because of the different regimes of rock mass. However, THLV suggested by Golder (2004) may be applicable to the Pama pit. Site-specific data is required in order to obtain appropriate THLV for the Buma and RA pits.

In order to develop the basis for comprehensive slope stability analyses applicable to the various rock masses at the Tutupan coal mine, shear testing to establish creep behaviour is recommended to be carried out on the different rock types that exist in the Adaro mine.

Acknowledgements

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References

Dunnicliff, J. and Green, E.G. (1993) Geotechnical Instrumentation For Monitoring Field Performance, John Wiley and Sons, Inc. New York, pp. 199–245.

Golder Associates (2004) Preliminary Results of First in Pit Well Trial and Review of Robotic Theodolith Trial.

ISRM (1978) Suggested Methods for the Quantitative Description of Discontinuities in Rock Mass, International Journal of Rock Mechanics and Mining Sciences and Geomechanics Abstracts, Vol. 15, No. 6, pp. 319–368.

Kramadibrata, S. and Kushardanto, H. (2002) The Role of Time Dependent Analysis to Improve Environmental Management System in Mine Closure Plan in Open Pit Mine, International Workshop of Life Cycle Assessment and Metals, Montreal.

Kramadibrata, S., Wattimena, R.K., Sulistianto, B., Simangunsong, G.M. and Tobing, A. (2007) Study on Shear Strength Characteristic of Coal Bearing Strata, Congress International Society of Rock Mechanic. Lisbon, Portugal.

Wattimena, R.K., Kramadibrata, S. and Damanik, B. (2006) Study on Shear Creep Behaviour and Long-Term Shear Strength at Laboratory, Internal Report of Department of Mining Engineering, Institut Teknologi Bandung.