# Post-failure movements of a large slow rock slide in schist near Pos Selim, Malaysia

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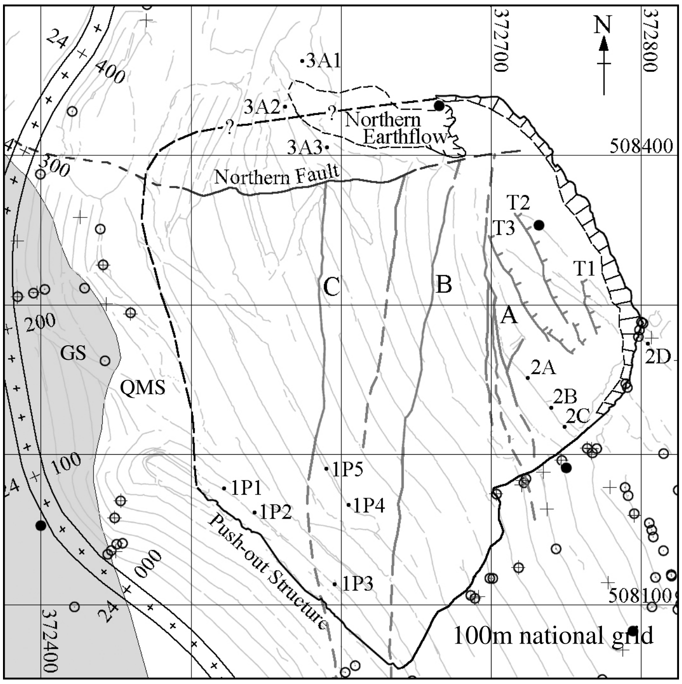
ABSTRACT: This paper describes the results of the monitoring, by total station and photogrammetric surveys, of the movements of a slow compound rock slide from failure in 2003 to December 2006. During this period the head moved downwards more than 21m. Whilst the rate of displacement is declining slightly year on year, for much of the time the landslide mass is accelerating and then decelerating in surges. Evidence is presented of some correspondence between the timing of the surges and the seasonal rainfall pattern. It is inferred from surface observations that the failure involves sliding at the head and in the upper main body of the landslide on joints roughly orthogonal to the foliation, which dips at a shallow angle into the slope. In the central toe zone the landslide slides up and out on the foliation. The failure, which occupies an area of about 8.5ha, has reactivated major pre-existing faults which run obliquely through the landslide mass.

## 1 INTRODUCTION

A landslide occurred in September 2003 during hillside excavation for a new strategic road in mountainous terrain near the Cameron Highlands hill resort in northern Peninsular Malaysia. The site is on the Simpang Pulai - Lojing Highway, close to Longitude 101° 20' 43" Latitude 4° 35' 27" (Figure 1). Roadworks commenced in 1997 and movements occurred in roadside cut in the vicinity of chainage 23+900. The slope was cut back to a flatter angle but instability persisted. Progressively more extensive slope flattening was undertaken in response to continuing failure until the works reached the ridgeline, 200m to 260m above the road. Gross movements occurred in the cut in September 2003 with the formation of a main scarp and associated disruption and the displaced mass has since moved continuously. A study of the landslide was carried out by the authors in 2005 and 2006 (Andrew Malone Ltd, 2007).

## 2 TOPOGRAPHY, GEOLOGY AND THE LANDSLIDE

The site is on the western hillside of the Gunung Pass ridge which reaches an elevation of 1587m above sea level. Prior to cutting, the valley sides were densely forested and generally steeper than 30°, with ravines leading down to the deeply-incised River Penoh some 600m below the ridge.




QMS *Quartz Mica Schist Unit* GS *Graphite Schist Unit*
ABC geological faults; T1 T2 T3 transverse cracks
1P1, 2A etc total station survey markers
○ points used in the photogrammetric adjustment
+ survey check points ● survey targets

Figure 1 Outline of the landslide superimposed on a simplified geological map of the site; and survey points.

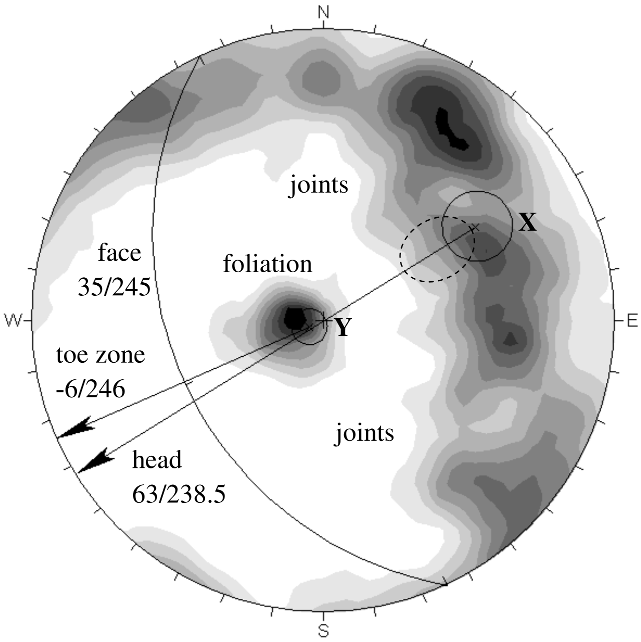
The cuts were formed largely in nominally 12m high 1:1 batters and 2m berms to produce an excavation up to 260m high and inclined about 33°-35° overall.

The geology of the Gunung Pass area consists of a sequence of sedimentary rocks, probably of Paleozoic age, which have undergone low- to medium-grade dynamic metamorphism. The metasedimentary rocks outcrop in a 4 km-wide shear zone contained within Mesozoic granites. The landslide has taken place in quartz mica schists (Figures 1 & 2) which at the base contain impersistent graphite schist layers less than 30cm thick. The foliation strikes generally north and the orientation of the excavated face of the hillside is NNW-SSE (Figure 3). The foliation dips at shallow angles towards the east, i.e. into the slope.

The rock sequence at site is cut by sets of pre-existing faults. The most prominent fault set dips steeply towards the E to ESE and three of these faults can be traced across the landslide (Figure 1, faults A, B & C). The fault planes form counterscarps at outcrop on the landslide and have oblique and vertical striations, suggesting distinct phases of slip. The faults also show signs of recent but pre-landslide movement and have been reactivated during landslide movements. The schists at outcrop are highly jointed with typical joint spacing less than 0.5m (Figure 2). The poles of the joints form a girdle that is roughly orthogonal to the low-dipping foliation (Figure 3). Where unweathered, the schist is generally strong to very strong and most of the rock material currently exposed across the site can be classified as 'slightly' to 'moderately weathered' (British Standards Institution, 1999: Figure 19).

The main surface features of the landslide are the main scarp, the head graben, the north and south flanks, the counterscarps of the oblique faults (A, B & C etc) and a low-angle push-out structure at the toe zone (Figure 1). Neither the northern flank, which is partly concealed beneath an earthflow, nor the toe of the basal slip surface can yet be fully delineated. The term 'toe zone' is therefore used here in preference to the word 'toe'.


Figure 2 Several joint sets cutting the low-dipping foliation within the *Quartz Mica Schist Unit.*




equal angle, lower hemisphere, 541 poles
Shading represents concentration of poles (5% maximum).
The circles X & Y are centred on the mean disposition of vectors within 100m wide blocks of ground (on the centre line) at the highest part of the head (X) and at the toe zone (Y) and enclose >80% of the vector data points.

Figure 3 Stereographic projection of poles to joint planes and foliation and surface displacement vectors.

The head graben is crossed by multiple high-angle internal shears with counterscarps at outcrop (T1, T2 & T3 etc).

## 3 DEFORMATION MONITORING BY TOTAL STATION

Monitoring of the landslide has been carried out by the road contractor since October 2003. The work involves nominally weekly measurement, by total station (Sokkia SET5E), of distances and horizontal and vertical angles from base stations west of the road to reflective markers installed on the landslide. The plan co-ordinates and reduced levels of the markers are computed from these data. The magnitude, dip and dip direction of the displacement of each survey marker have been calculated and velocities of movement have been determined. Some of the monitoring data are presented in Figure 4.

Uncertainty in the data may be assessed by examining the reported movements of a marker located above the crown of the landslide (Marker 2D). In contrast to the markers within the landslide, the reported changes in the position of Marker 2D are very small (save for an unexplained excursion in September and October 2006) and no systematic pattern is evident. The variance in horizontal position data to August 2006 (standard deviation of data = 45mm) is about three times that expected from equipment

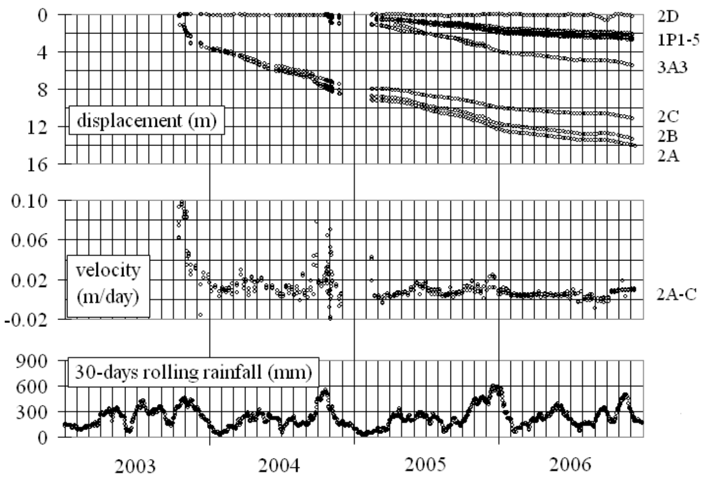



Figure 4 Displacements and velocities from total station monitoring; and rainfall at Stesen Kajicuaca Cameron Highlands.

error alone. The variance in height determination is as expected from equipment error alone.

## 4 TOPOGRAPHIC SURVEY AND PHOTOGRAMMETRIC MEASUREMENTS

A digital elevation model had been created from topographic survey in November 2003 and another was made photogrammetrically from aerial photographs taken from a helicopter in September 2005. Displacement vectors were constructed from the differences between the two digital elevation models at identifiable features such as the ends of drainage channels and berm edges.

Many of the 150 displacement vectors are shown in Figure 5.

Uncertainty in these measurements is associated with the coordinates of the ground control points used for photogrammetric adjustment and errors in the digital camera system. The photogrammetric survey was compared to the November 2003 survey at 56 survey check points in areas thought not to have moved between 2003 and 2005 (see Figure 1). The error standard deviation is 0.2m. Uncertainty in the dip and dip direction of the vectors is less than 1º for the longest vector (24.3m), a possible maximum of 13º for the shortest vector (1.6m), and an average of 2.7º for the mean vector (8.0m).

## 5 POST- FAILURE LANDSLIDE MOVEMENTS

The surface displacement vector data (2003-5) advance our understanding of landslide behaviour. Viewed in plan the vectors are seen to be normal to the slope face contours with lateral extension revealed by radial divergence (north-south spreading), conforming to topography, which takes the form of a subdued ridge. Movements are greater at the head than in the toe zone (compression) and, on any slope face contour, displacements are greater in the north than in the south (rotation). Viewed in cross-section the vectors are seen to plunge at the head of the landslide, to generally lie sub-parallel to the slope in the upper main body and to emerge in the toe zone.

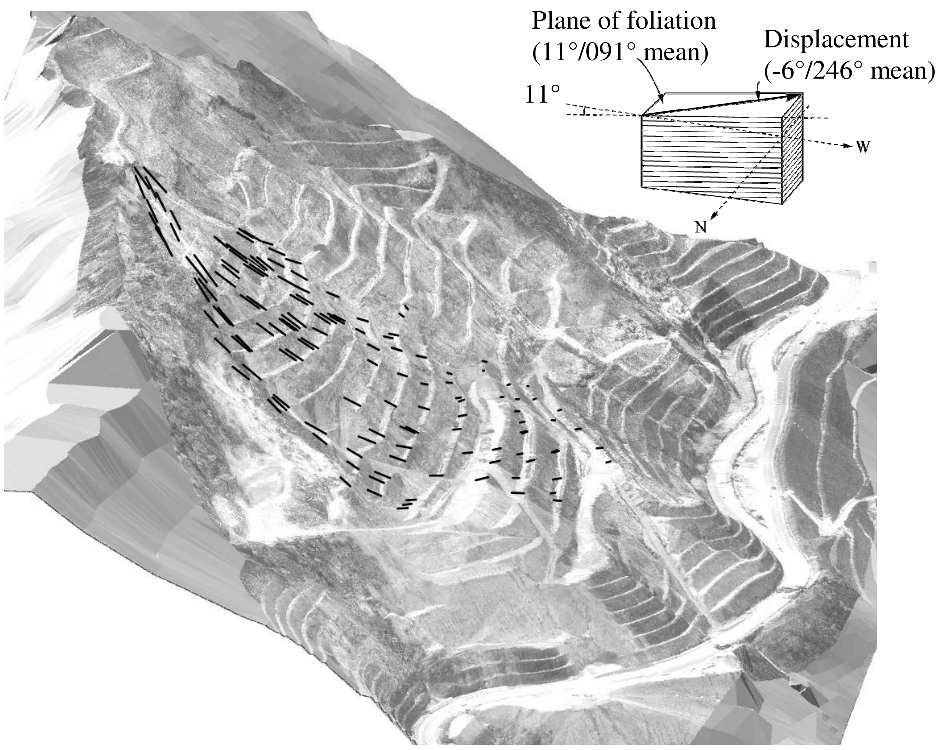



Figure 5 3D visualisation of the excavated hillside showing the surface displacement vectors (2003-5) to scale. Inset: surface movement of the central toe zone block relative to foliation.

It is instructive to examine the disposition of vectors along the centreline of the displaced mass by means of stereographic projection (Figure 3). The directions of vectors within 100m wide blocks of ground at the highest part of the head (mean 238.5°) and at the toe zone (mean 246°) closely correspond to the dip direction of the face (mean 245°). The disposition of vectors at the highest part of the head coincides with a concentration of joint planes (Figure 3 - X) and at the central toe zone block corresponds to the attitude of the foliation (Figure 3 – Y and Figure 5 inset).

The vectors reveal significant downslope compression. Compressive strain (defined as the displacement normalized against downslope length) measured on centreline between upper main body (at the elevation of Markers 2A-2C) and the toe zone is about 5% (2003-5). Such compression is evident in small-scale sliding on foliation seen as shear offsetting ('kicking out'), especially in the southern part of the landslide, and by slip on the reactivated faults A, B & C etc. Observed fault slip movements are dextral, increase to the south and are greatest on fault B, where slip at the centreline is 3.5m.

The total station data give further insights into landslide behaviour. Whilst the overall rate of displacement is declining slightly year on year, for much of the time the displaced mass appears to be either accelerating or decelerating. Five surges are apparent (Figure 4) and comprise an accelerating phase (six to eight weeks) and a decelerating phase (two to three months). The velocity reached during surges at markers 2A-C is generally about 20mm/day (greater in late 2004).

## 6 DISCUSSION

The nature of the basal sliding surface(s) is of interest. Evidence is given above of movement at surface stations which is parallel to joint planes at the highest part of the head and to foliation in the central toe zone; slip on foliation is also visible on the ground. It may be inferred, if the effects of non-parallel internal shear and change in landslide thickness are assumed insignificant, that the landslide is sliding on joint planes at the highest part of the head (i.e. at the main scarp 'normal fault') and sliding upwards on foliation in the central toe zone (but oblique to dip, Figure 5 inset).

The vectors plunge steeply at the head and emerge sharply in the toe zone, the profile suggesting a non-circular basal slip surface (Figure 5). The presence of multiple counterscarps in the head graben (T1, T2, T3 etc. Figure 1) may signify curvature of the basal slip surface (Hutchinson, 1988). There are joints disposed to facilitate slip on such a curved surface (Figure 3 – dashed oval). The landslide is probably a compound slide. An educated guess was made about the geometry of the basal slip surface, using the surface station movements and crack patterns, and estimates were made of landslide volume. It appears that the volume of the landslide is about 2million $m^3$.

After failure the landslide decelerated until March 2004 and it has since continued to move, for much of the time accelerating and then decelerating in surges. The timing of the surges generally coincides with peaking in the 30-day rolling rainfall (Figure 3), rainfall being measured at the Stesen Kajicuaca Cameron Highlands raingauge of the Malaysian Metrorological Service, 13km SSE of the site. The bimodal rainfall pattern shown in Figure 4 is characteristic of an inland climatic regime in peninsular Malaysia. It may be that the landslide is responding to rainfall-induced seasonal rise and fall of groundwater levels. Such fluctuation is manifest by intermittent seepage from the southern toe zone. Other causal factors may have contributed to surges: a surge in late 2004 concurred with the removal of 100,000$m^3$ of ground from the northern toe zone of the landslide.

## 7 CONCLUSIONS

The landslide is a slow rock slide in schist. Failure occurred in September 2003 and by December 2006 the head had moved downwards more than 21m. The rate of displacement is declining slightly year on year, but for much of the time the landslide mass is accelerating and then decelerating in surges. There is some correspondence between the timing of the surges and the seasonal rainfall pattern. It is likely that the surges are induced by groundwater fluctuations. It may be inferred from surface observations that the failure involves sliding at the head and in the upper main body of the landslide on joints roughly orthogonal to the foliation, which dips at a shallow angle into the slope; in the central toe zone the landslide is sliding up and out on the foliation. The failure, which is probably a compound slide of volume about 2million $m^3$, has reactivated major pre-existing faults that run obliquely through the landslide mass.

Acknowledgements
The study of the Pos Selim landslide was carried out on behalf of the Slope Engineering Branch of the Public Works Department of Malaysia and facilitated by the road contractor, MTD Construction Sdn Bhd., who supplied the total station data. Prof YQ Chen of the Department of Land Surveying and Geo-informatics, Hong Kong Polytechnic University checked the displacement and velocity calculations and assessed the errors in the total station surveying.

## REFERENCES


Andrew Malone Ltd 2007. *Landslide study at Ch 23+800 Simpang Pulai-Lojing Highway, Malaysia*. Report to Minister of Works of Malaysia.

British Standards Institution, 1999. *Code of Practice for Site Investigations BS5930:1999*.

Hansen, A. 2007. *Semi-automated geomorphological mapping applied to landslide hazard analysis.* Ph.D. Thesis, Department of Spatial Sciences, Curtin Univer sity of Technology, 281p.

Hutchinson, J.N. 1988. General Report: Morphological and geotechnical parameters of landslides in relation to geology and hydrogeology. In *Proc Fifth Interna tional Symposium on Landslides* (C Bonnard ed.) Balkema Rotterdam v1 3-35.