EVALUATING HILLSLOPE STABILITY IN TROPICAL TOWER KARST

- Dave Gillieson

Hillslope stability is a serious topic for land managers and planners, especially in the light of recent tragic events in Australia. In January I had to carry out such a study in tower karst near Ipoh in Perak State, Malaysia. My job as consultant geomorphologist was to advise the developers on the stability of the limestone tower walls, prior to planning for residential and open space development. So this article is offered to provide some ideas on methods which might be applied elsewhere for rapid reconnaissance evaluation of larger areas. Where there is obvious risk to life or buildings then the services of a licensed geotechnical engineer familiar with karst terrains should always be sought for a specific evaluation of the stability of small areas.

Ipoh city lies in the Kinta valley of northern Malaya and has many limestone towers up to 600m high. Many of these towers have been mined for limestone and many of them have failed in the past, causing loss of life and damage to buildings. Most of the towers have undercut slopes with cliff-foot caves, many of which are used as temples, with associated dwellings. Traditional mining techniques involved removing the rock pillars that support the undercuts until they failed, producing a large slab failure. This involved blasting and hand piking. In the past this has often gone wrong leaving several pairs of feet sticking out from under a pile of debris. Today many developers are building housing estates and factories right up to the bases of the karst towers, and thus the stability of these towers is a major concern for local planners. So there is a need for rapid reconnaissance methods to identify stable hillslopes and more importantly those which are about to fail.

The evaluation of hillslope stability in relative and absolute terms can be made by a variety of techniques, each of which leads to positive results which can be interpreted individually or collectively. These techniques are:

- Direct geomorphological mapping of mass movement features (relative)
- Indirect mapping by correlation of factors to gain zoning (relative)
- Evaluation of stability for individual sites (absolute)

Of these three methods, the first two are appropriate for a reconnaissance study of a large area, such as the present one, while the third is more appropriate for detailed site investigations, over a small area, using geotechnical engineering methods.

My study was conducted along the following lines:

1. geomorphological mapping around the base of the tower to identify areas of potential rockfall and toppling failure, former mass movement deposits (according to Varnes 1978 classification) and subsidence depressions;
2. detailed study of identified areas where joint and bedding orientation is conducive to slab failure and toppling failure;
3. from the above, zoning of the towers and identification of buffer zones according to landslide risk and known dispersal of landslide debris.

The tower was divided into a sequence of sectors, each of which was evaluated and for each of which the following ratings were obtained: hillslope type, landslide activity and rock mass stability. The hillslope type was defined according to a scheme initially used by Jennings (1965) for studies in the Bukit Batu area of Malaya and modified for the Kinta valley. The landslide activity was assessed using the method of Crozier (1987). The rock mass stability was defined using the rating method of Selby (1980). This method was modified to take account of evidence of karst water movement gained from carbonate deposition in the footslope zone. The entire perimeter of the limestone tower, about 25km, was surveyed on foot and by vehicle. Wherever possible an inspection of individual rockfaces and mass movement deposits was made, and sections of the cliff base were traversed on foot. Access to the cliff base was not possible in some sectors due to the presence of the following:

- residual tin mining pits filled with thixotropic clays like porridge;
- freshwater swamps too deep to wade through (even for Steve Reilly);
- thick secondary scrub and forest through which tracks would have to be cut for longer than 60 minutes.

In such cases the hillslopes or cliffs were inspected from the nearest road or track with binoculars, their position recorded using GPS, photographs taken and notes made on the observable features. In addition, examination of geological maps, radar imagery and some aerial photographs was possible. However the available aerial photography was panchromatic at a scale of 1:20,000 and suffered from severe radial distortion and limited side overlap.

Hillslopes were classified into one of four classes as follows:

- Type 1: Tower wall without cliff-foot caves, abrupt vertical contact with marginal plain
- Type 2: Tower wall with cliff-foot caves, abrupt vertical contact with marginal plain
- Type 3: Tower wall with short colluvial footslope, angle 5-20 degrees.
- Type 4: Tower wall with steep colluvial footslope, angle 20-45 degrees.

The relative stability rating follows the following scheme:

… Class I: Slopes with active landslides. Material is continually moving, and landslide forms are fresh and well defined. Movement may be continuous or seasonal.
… Class II: Slopes frequently subject to new or renewed landslide activity. Movement is not a regular, seasonal phenomenon. Triggering of landslides results from events with recurrence intervals of up to five years.
… Class III: Slopes infrequently subject to new or renewed landslide activity. Triggering of landslides results from events with recurrence intervals greater than five years.
… Class IV: Slopes with evidence of previous landslide activity but which have not undergone movement in the preceding 100 years. Sub-class IVA: Erosional form still evident; Sub-class IVB: erosion forms no longer present, but previous activity indicated by landslide deposits.
… Class V: Slopes which show no evidence of previous landslide activity but which are considered likely to develop landslides in the future, landslide potential indicated by joint analysis and cliff morphology.
… Class VI: Slopes which show no evidence of previous landslide activity and which by joint analysis and cliff morphology are considered stable.
(Modified from Crozier, 1987).

In addition, a rock mass rating was developed for each sector according to the following factors:
Table 1: Rock mass rating factors (modified from Selby, 1980)

Factor Very strong Strong Moderate Weak Very weak
Intact rock strength (Schmidt hammer R) 100-60
very strong
r=20 60-50
strong
r=18 50-40
moderate
r=14 40-35
weak
r=10 35-10
very weak
r=5
Weathering unweathered

r=10 slightly weathered
r=9 moderately weathered
r=7 highly weathered
r=5 completely weathered
r=3
Spacing of discontinuities >3m solid
r=30 3-1m massive
r=28 1-0.3m blocky
r=21 300-50mm fractured
r=15 <50mm shattered
r=8
Joint orientations very favourable steep dips into slope
r=20 favourable
moderate dips into slope
r=18 fair
horizontal dips or nearly vertical
r=14 unfavourable
moderate dips out of slope
r=9 very unfavourable steep dips out of slope
r=5
Width of joints <0.1mm
r=7 0.1mm
r=6 1-5mm
r=5 5-20mm
r=4 >20mm
r=2
Fracture continuity none continuous
r=7 few continuous
r=6 continuous, no infill
r=5 continuous, thin infill
r=4 continuous, thick infill
r=1
Groundwater outflow none
r=6 trace
r=5 slight (<25L/min)
r=3 moderate
(25-125L/min)
r=3 great
(>125L/min)
r=1
Total rating 100-91 90-71 70-51 50-26
<26

Mapping and recording proofs of stability of the hillslopes is an important positive aspect of this study. According to Crozier (1987), the following proofs of stability can be evaluated for any hillslope:

- convex hillslope shape or low slope gradients
- absence of standing or seepage water
- low joint density or dip angles of discontinuities greater than slope angle
- absence of collapse debris
- development of soil cover on landslide debris
- lack of recent alteration to vegetative biomass on cliff faces
- stable perennial vegetation on landslide debris
- in the case of karst, massive carbonate formations such as stalactites and tufas
- well developed algal stains or cryptogams (mosses, lichens) on rock surfaces

All sites were located using GPS. Shadowing by the tower was a problem, in such cases I took an offset out on to the surrounding plain, recorded the location and back calculated the correct position. I used a Schmidt type N test hammer for rock strength and found it very useful for a ^{3}quick and dirty^{2} assessment. Good solid limestone rings like a bell when struck while in cruddy weathered limestone the probe penetrated the surface with a dull thud. Most of the limestone was quite strong (Figure 1), except near old quarries where transferred blast shock had shattered the rock. Structural data were recorded using compass and clinometer.

There were no class V and VI slopes in the survey (Figure 2), most of the tower perimeter falling into types II and III. Thus the tower walls are maintained by frequent landslides which are triggered by intense rainfall events. The heaviest recorded rainfall ever - 631mm in 24 hours - was at nearby Jeram. Probably many of the old stabilised scars relate to this event. But a rainfall of

250mm/day occurs every 20 years and can trigger minor landslides. There is little or no seismic activity in this part of Malaysia.

Once I had the three ratings for each sector I mapped them onto a base plan which also showed the roads, old mining ponds, drainage and cliffs. I worked out the width of a buffer zone using a regression (Figure 3) derived from existing landslides and their debris in the Kinta Valley. A minimum 100m buffer width from the base of the tower was chosen to conform with local planning regulations. In many places old mining ponds and fish farms separated the alluvial plain from the karst towers. These were indicated for retention as amenity zones which have potential to absorb the mass and energy of any debris which is released as a result of landslide or rockfall activity. This landslide hazard map is now being used in the development of the detailed planning for residential, recreational and aquaculture uses around the base of the limestone tower.

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