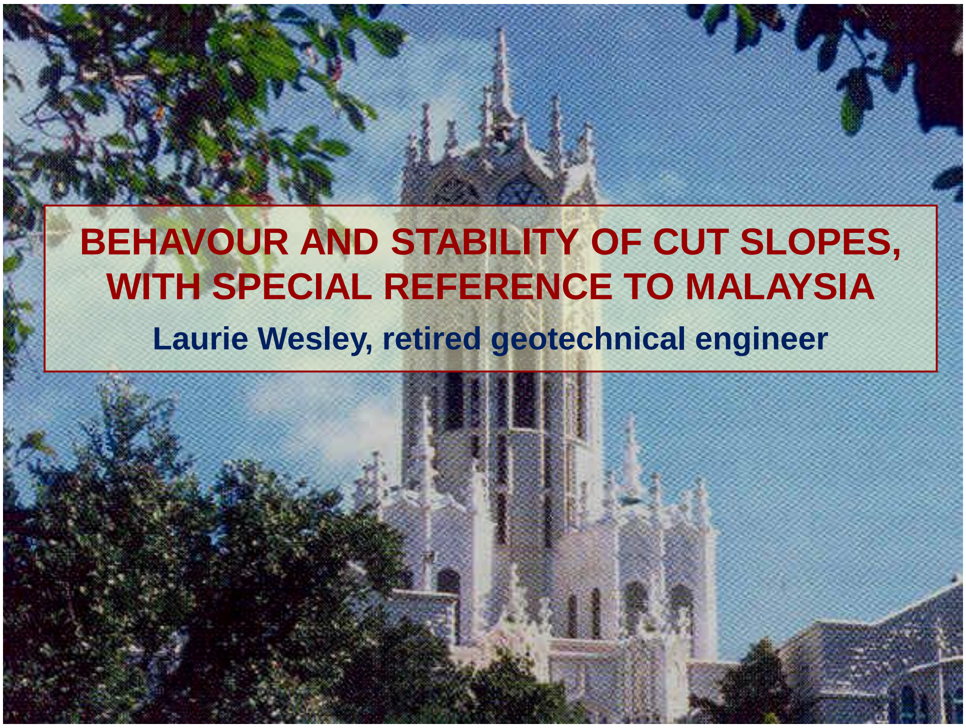
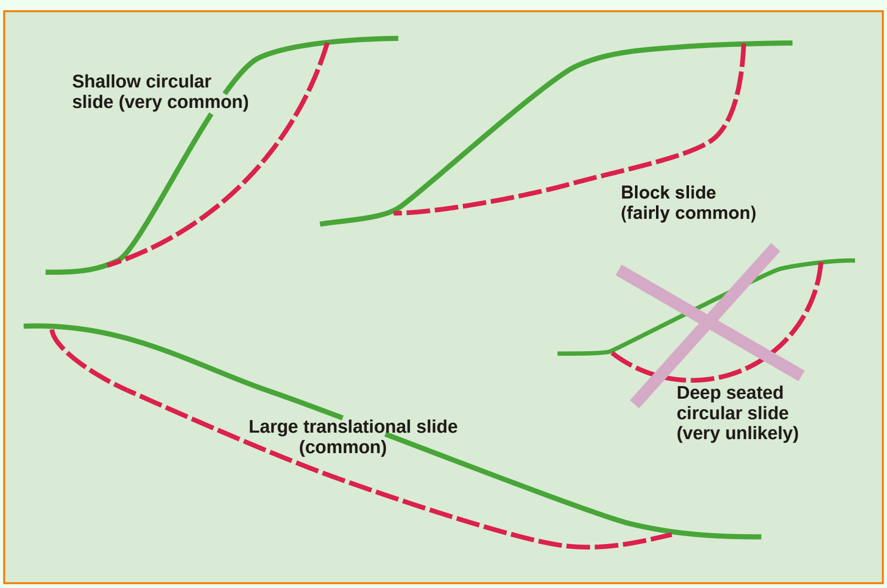


Residual soil behaviour, compared to sedimentary soils

1. Slopes are steeper – often stable at 45 degrees
2. Failures unlikely to be deep-seated
3. Value of c′ likely to be significant
4. Negative pore pressure above water table can play a significant role in maintaining stability.
5. Estimation of stability analytical methods is often very limited
6. Slips and landslides in residual soils often <u>triggered</u> by heavy rainfall or earthquakes.
7. However, the true <u>cause</u> of the failure is often human activity. Slopes have been steepened, or infiltration increased by removal of vegetation cover etc

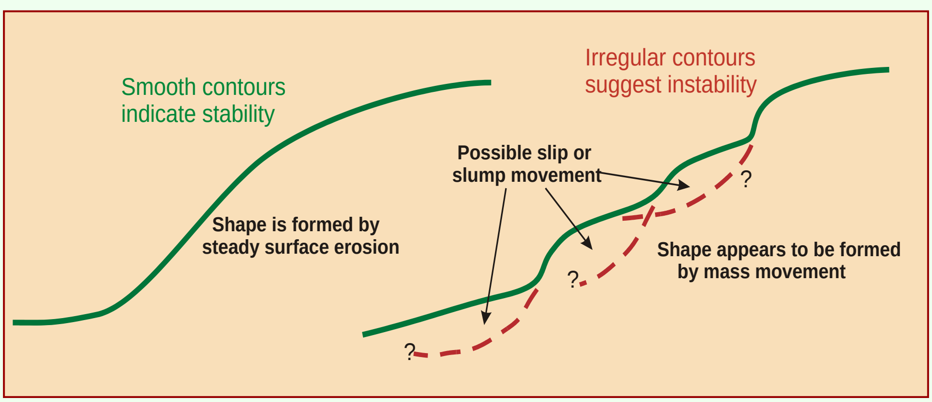
We cannot control rainfall or earthquakes, but we can control our own activities – if we want to minimise the risk of landslides, we need to control our own activities



Failure modes in residual soils

Assessing the stability of natural slopes is not primarily an analytical exercised. Other, non-analytical methods, are more important and should always be part of the process.

- **Visual inspection of the slope**
- **Geological appraisal – of slope and surrounding area, and of maps if available**
- **Examination of aerial photographs if available**
- **Inspection of existing slopes, especially cuts or excavations, in similar materials**



Visual inspection – the starting point for assessing the stability of a natural slope


Visual inspection shows very clear signs of instability


Darajat Geothermal Project, West Java, Indonesia
- Slip on access road to base camp (power station site)

Darajat Geothermal Project
slip on access road to base camp – soil conditions

Darajat Geothermal Project – slip on access road
Difficult soil conditions evident along the stream bank

Behaviour of Cuttings in Residual Soils in Malaysia

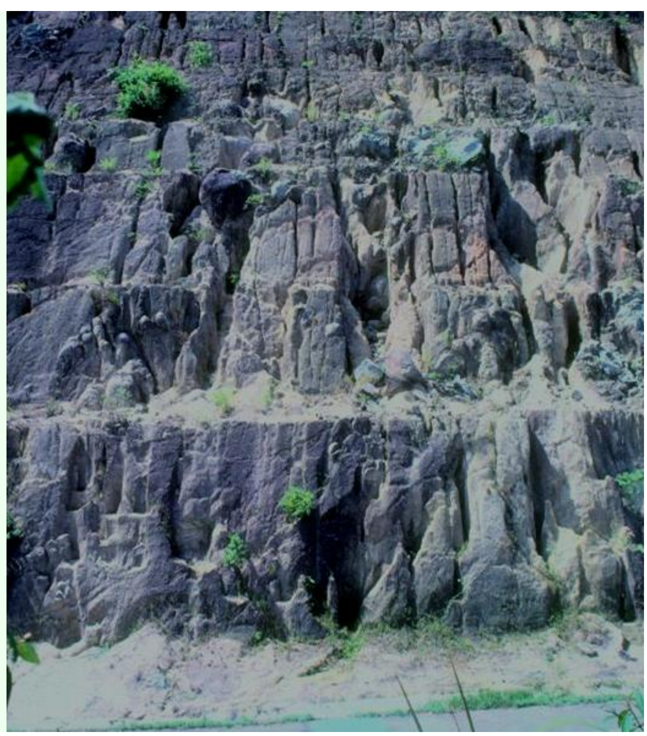
1. Kuala Lumpur – Karak Highway

2. Kuala Krai – Gua Musang Highway

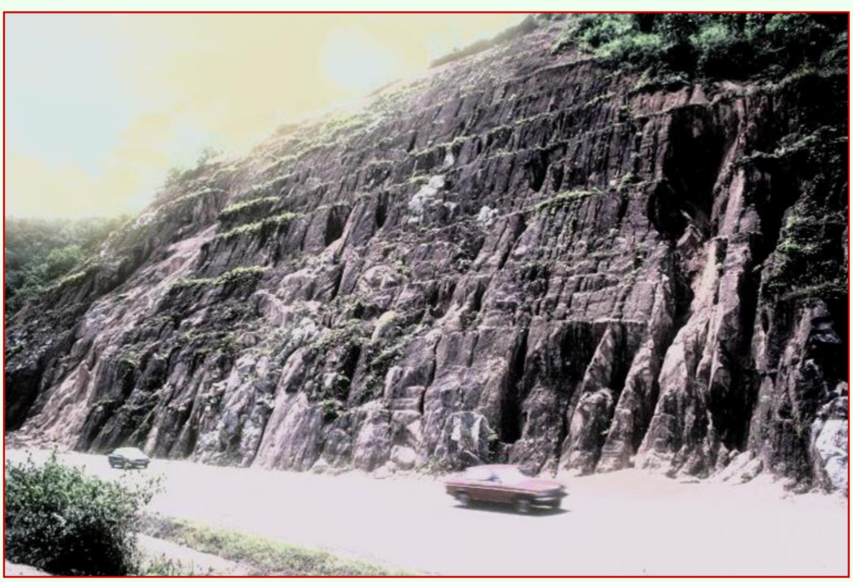
KL – Karak Highway

Erosion – a severe problem in weathered granite.

(but normally not in volcanics)

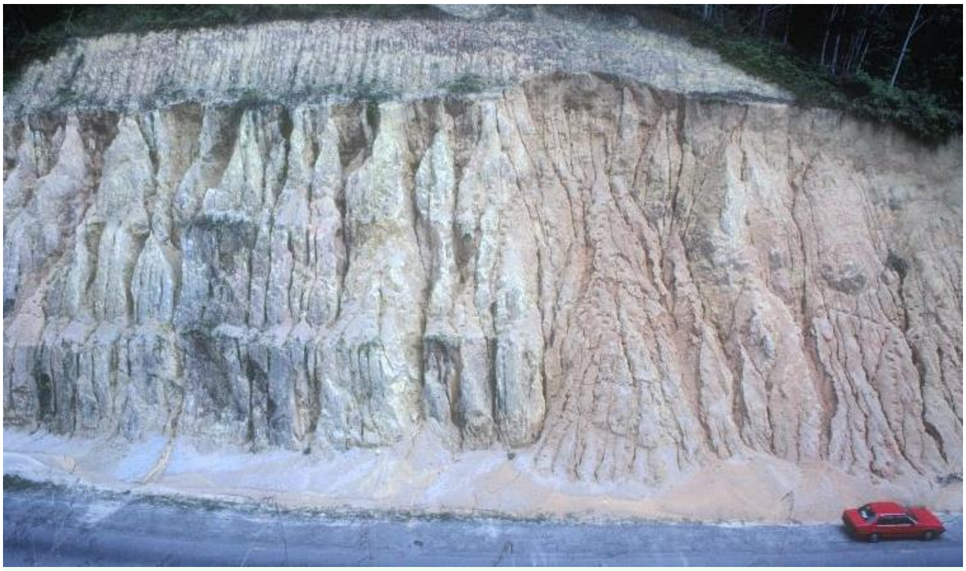


KL – Karak highway – erosion or slip?



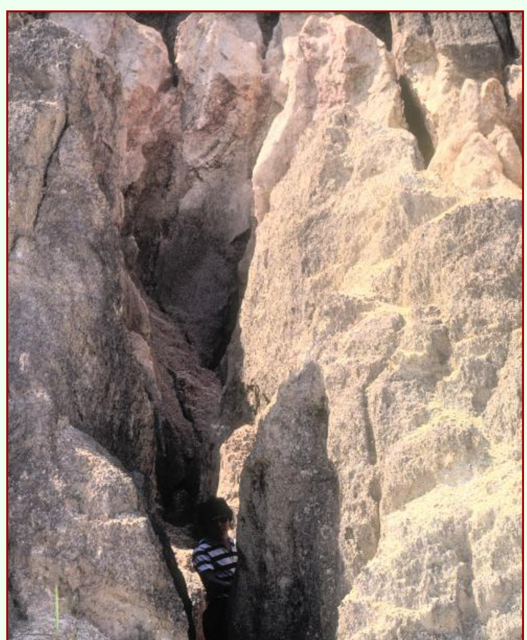
KL – Karak Highway (weathered granite)

KL – Karak Highway – erosion only from direct rainfall on the face – no catchment above the face

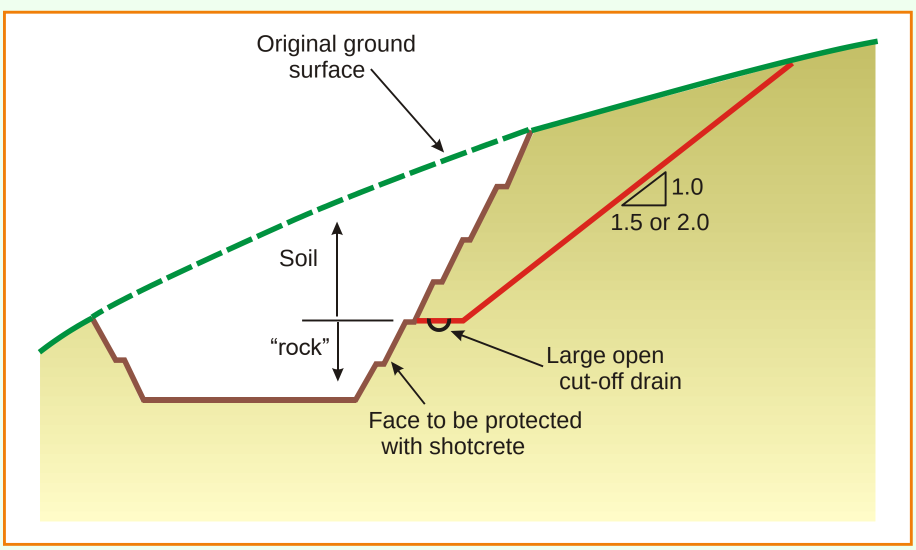


Erosion or slip failure ??

KL – Karak Highway - Erosion channel in cut slope



Weathered Schist

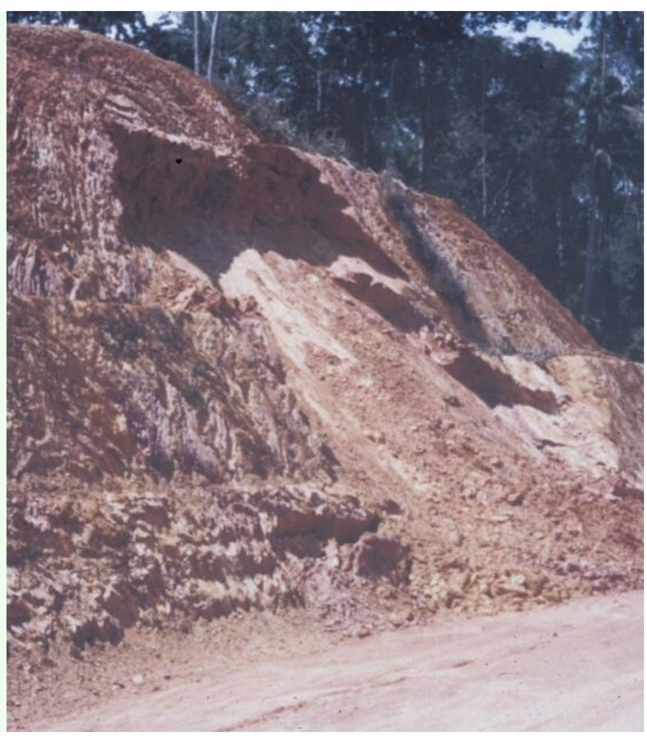


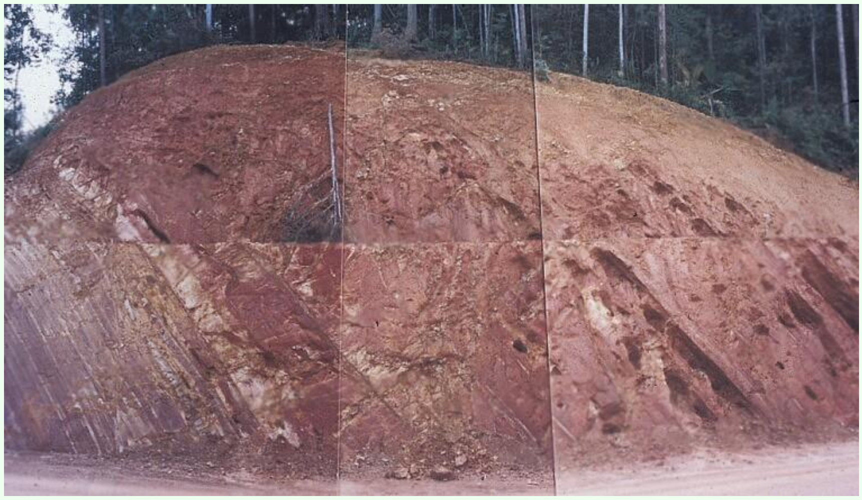
Proposed remedial work

Kuala Krai – Gua Musang Highway

Mostly in weathered sandstone and other sedimentary rocks

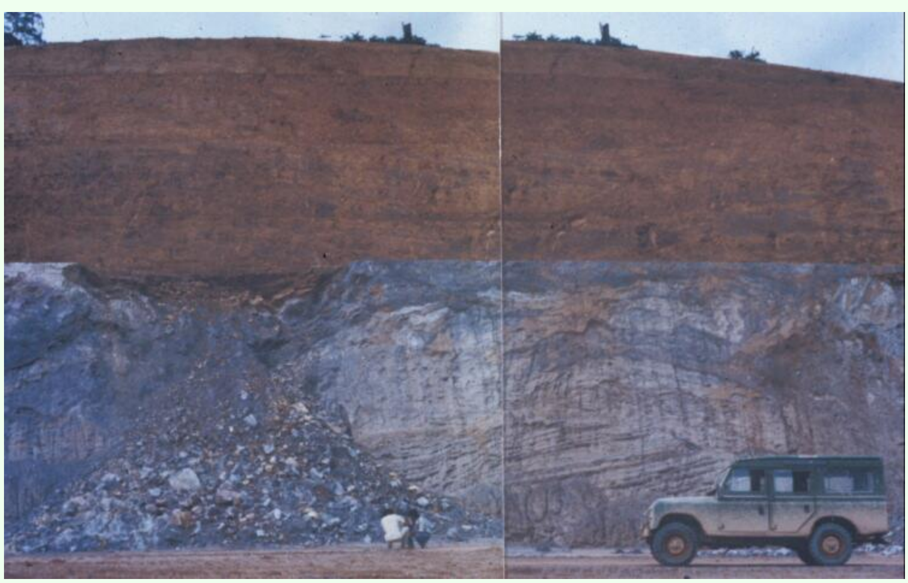
Slope containing distinct plane of weakness - unfortunately random





Bedding planes of original sandstone still clearly seen.

- some layers are more erodible than others



Reason for the change of colour is not known

A rather unusual failure - does not extend to the top of he cutting

Remedial Work

- the original design was seriously deficient. A literature study could have found the 1968 paper by Bullman that made sound recommendations based on a careful study of existing slopes

- the only option was to flatten the slopes, form 1:1 to 1.5:1.0 – a serious and embarassing mistake

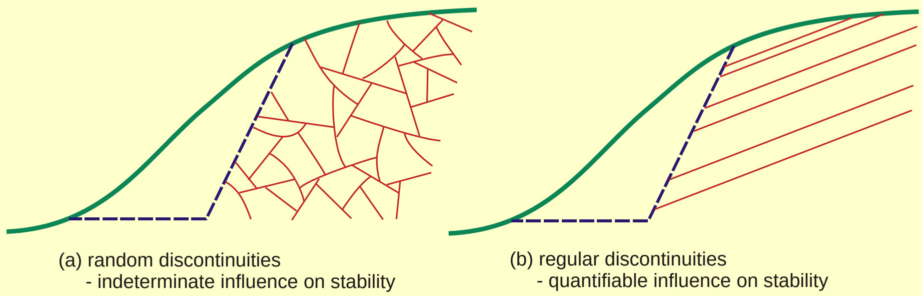
Limitations of Analytical Methods
- **Uncertainty regarding shear strength parameters**
- **Uncertainty regarding the pore pressures**

Three types of slopes, depending on material:

1. **Slopes of uniform, homogeneous, material**
2. **Slopes containing distinct, continuous, planes of weakness**
3. **Slopes of heterogeneous material, but without distinct planes of weakness (weathering profile of the "Little" kind)**

Slope of homogeneous soil – tropical red clay

- **analytical methods should give sensible results**



Slopes containing discontinuities

Influence of climate and weather

- the long term stability of natural slopes (or cuts in natural slopes) depends on the worst pore pressure condition

- normal stability may be partly due to negative pore pressure above the water table.

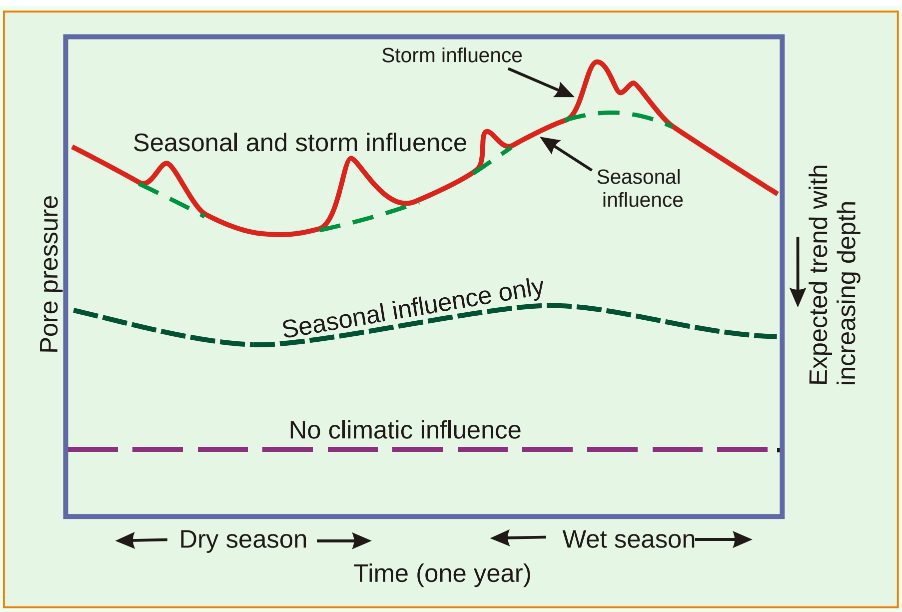
- intense rainfall may destroy this negative pore pressure and create positive pore pressures

Climate influences the pore pressure state in two ways:

(1) Regular seasonal influence – cyclical in nature and reasonably predictable.

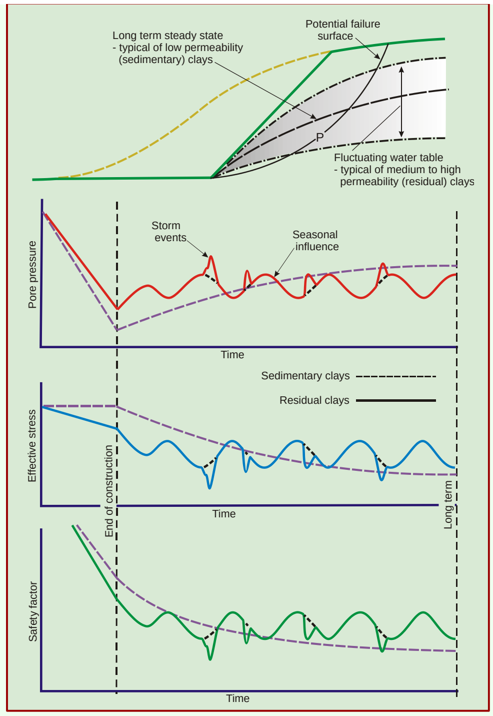
(2) Isolated storm events – generally unpredictable, both in timing and intensity.

The second are the more likely trigger of slips and landslides than regular seasonal effects.



Expected situation with clays

Short term, ("end of construction") and long term pore pressures and stability of cut slopes in low permeability soil (usually sedimentary clays) and moderate to high permeability soils (usually residual soils)



What can theoretical analysis or "modeling" do?

1. It cannot tell us with any certainty whether, or when, a particular slope will fail. This is partly because we cannot measure the soil properties sufficiently reliably , and partly because we cannot predict the weather.

2. It can help give us a better understanding of the way rainfall influences slopes, and be of assistance in our assessment of the stability of particular slopes

The challenge facing the engineer wishing to undertake a theoretical analysis of a slope (apart from uncertainty regarding geology and soil parameters) is to estimate the worst case pore pressure state.

The “worst case” pore pressure condition in a slope – can we estimate it???

The answer obviously is no, but we can make some (hopefully) intellegent guesses.

One possibility, which is not unreasonable is to assume that the water table rises to the ground surface.

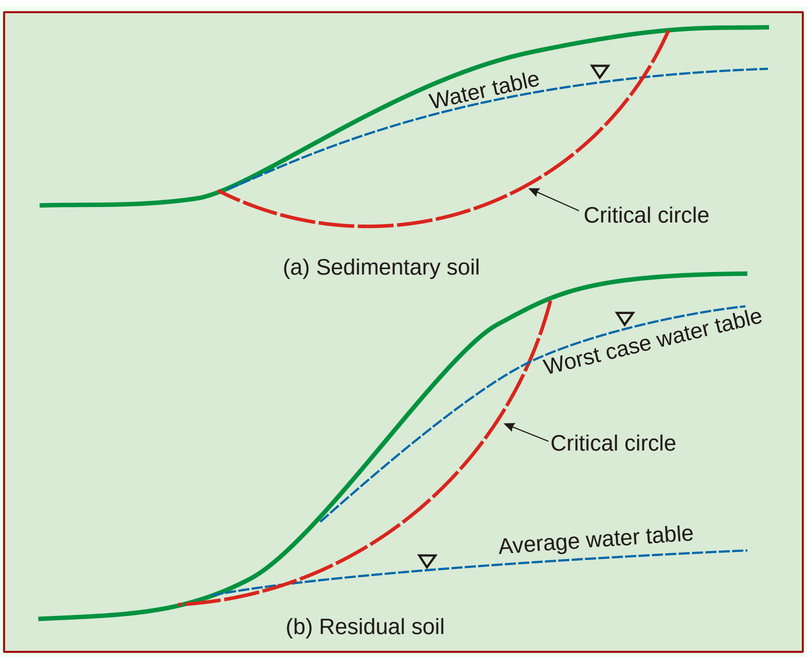
This assumes rainfall is continuous for a long period of time, which of course may not be the case.

This approach can be overly conservative, partly because the water table my not reach the surface, but also because of the way the analysis is carried out, in particular the calculation of pore pressure:

The pore pressure can be provided either in the form of the water table position (the phreatic surface), or the value of the pore pressure parameter r_u.

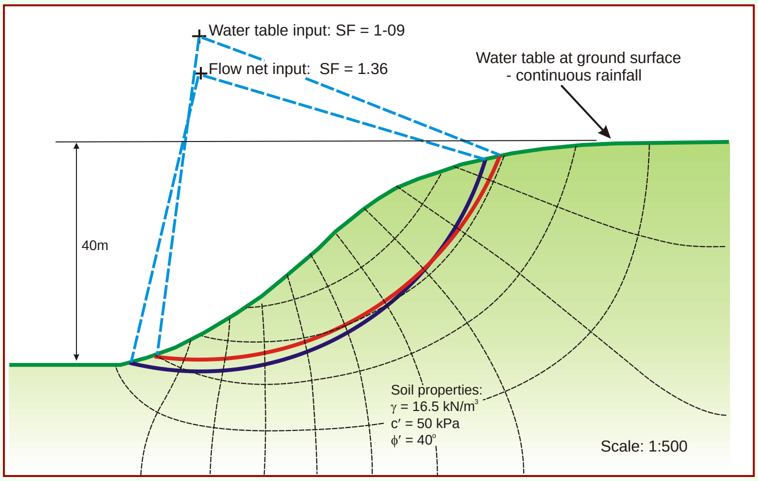
If the water table is provided, then the pore pressure is normally calculated using the vertical distance (depth) below the water table. This assumes horizontal seepage and vertical equipotential lines.

This can involve very significant errors in steep slopes



Typical slopes in sedimentary and residual soils

Computer programmes, given a water table (phreatic surface) almost invariably determine the pore pressure from the vertical intercept between the point on the slip surface and the water table.
In other words the assumption is made the equipotentials are vertical. This is a realistic approximation with gentle slopes (sedimentary soils), but can be grossly in error in steep slopes, such as those found in some residual soils

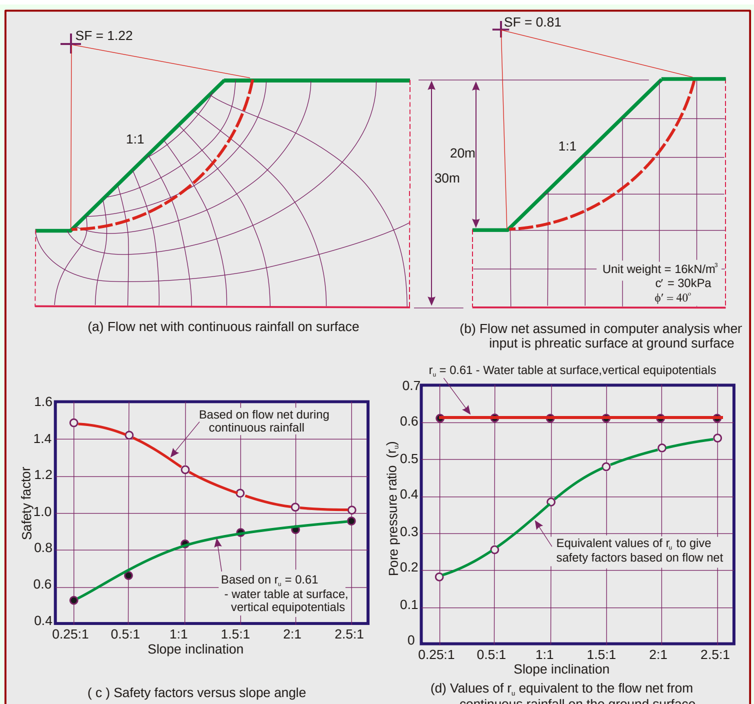


Analysis assuming water table is at the ground surface

Two seepage patterns based on this state are analysed

- one is the "vertical intercept" assumption

- the other is a flow net compatible with the assumption



The analysis shows that with steep slopes the common assumption of vertical equi-potentials can give very large errors in steep slopes.

For a slope of 0.25:1 the assumption gives a SF = 0.5 (approx) while that with a realistic flow pattern gives SF = 1.5 (approx).

The use of the "normal" assumption for the design of slopes would lead to totally unrealistic inclinations.

An example of a theoretical transient analysis:

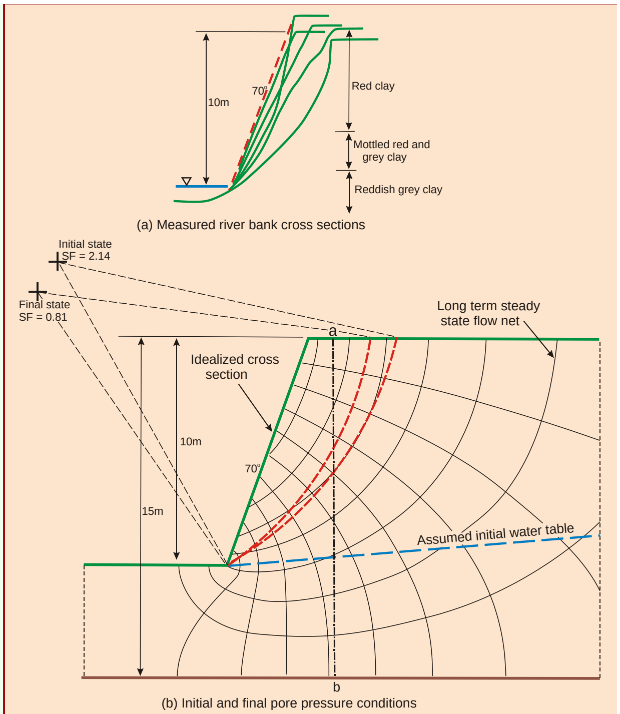
Assumptions:

1. Uniform soil conditions – fully saturated clay
2. Continuous steady rainfall on the ground surface
3. Initial water table is almost horizontal
4. The initial pore pressures above the water table are negative –hydrostatic with respect to the water table.
5. There is an impermeable layer not far below the bottom of the slope

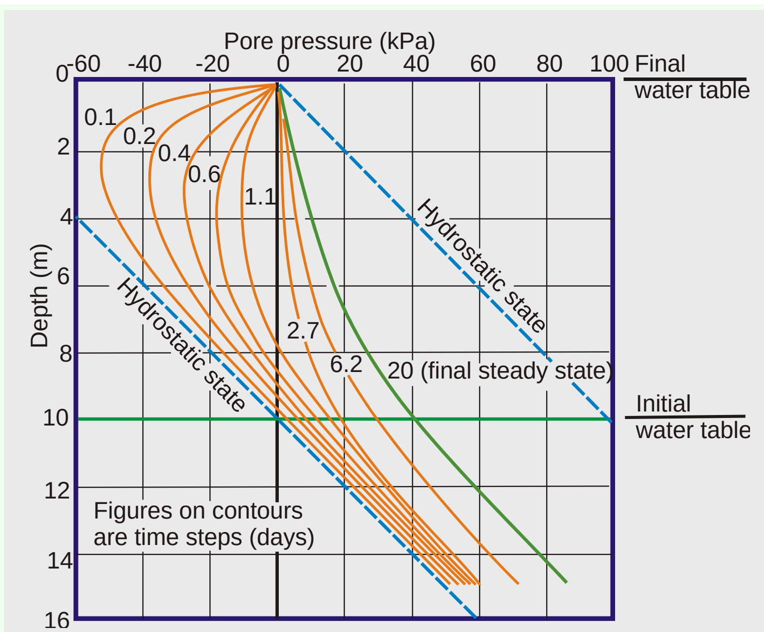
Case study - the red clay bank shown in the earlier slide

Analysis using Seep/W and Slope/W

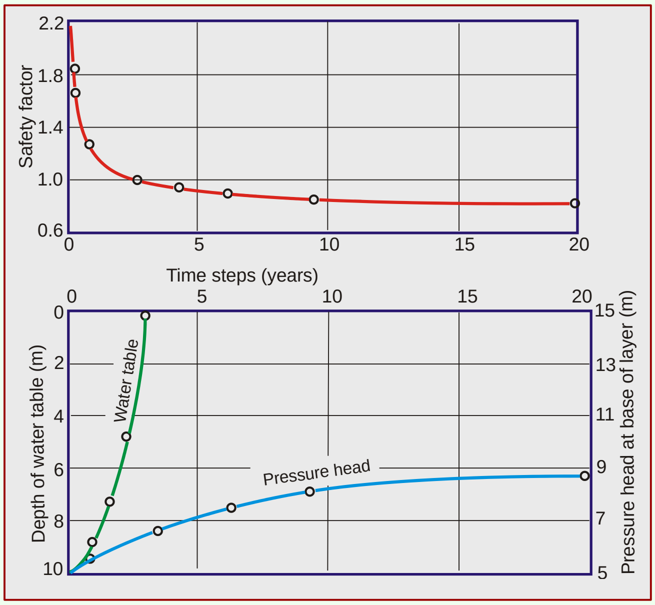
Unit Weight = 16.2 kN/m³
c′ = 14 kPa
ϕ′ = 37º
k = 0.01 m/day
m_v = 0.0001 kPa⁻¹



(a) Measured river bank cross sections
(b) Initial and final pore pressure conditions



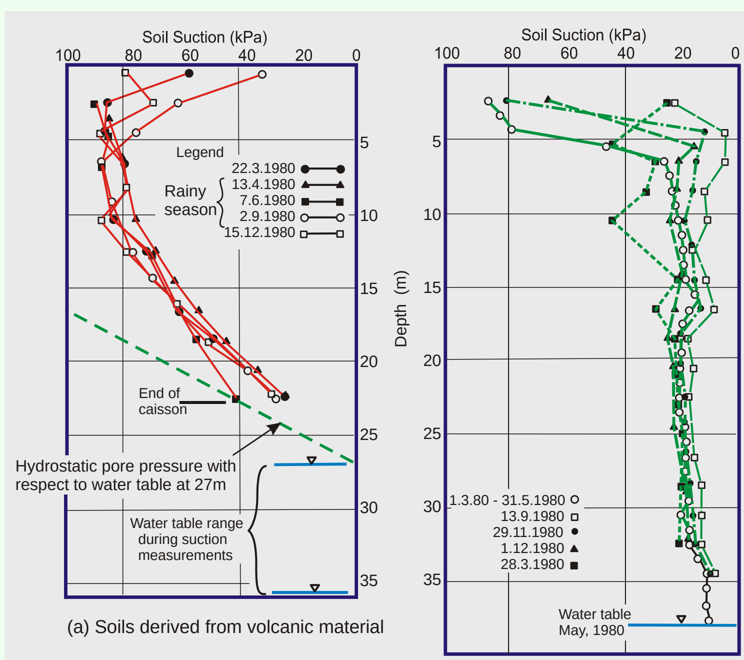
Pore pressure changes with time on line a-b of cross-section



Transient changes in water table depth, pore pressure at 15m, and safety factor - the safety factor would only fall below unity if rainfall continues for 2.5 days.

Soil suction measurements from two sites in Hong Kong

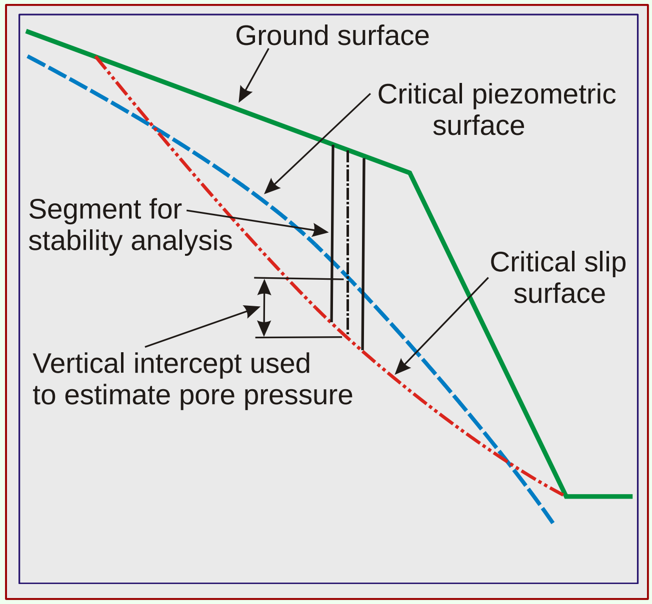
- measurements made in deep caissons



(a) Soils derived from volcanic material

(b) Soil derived from granite

Hong Kong slopes and influence of piezometric surface on pore pressure



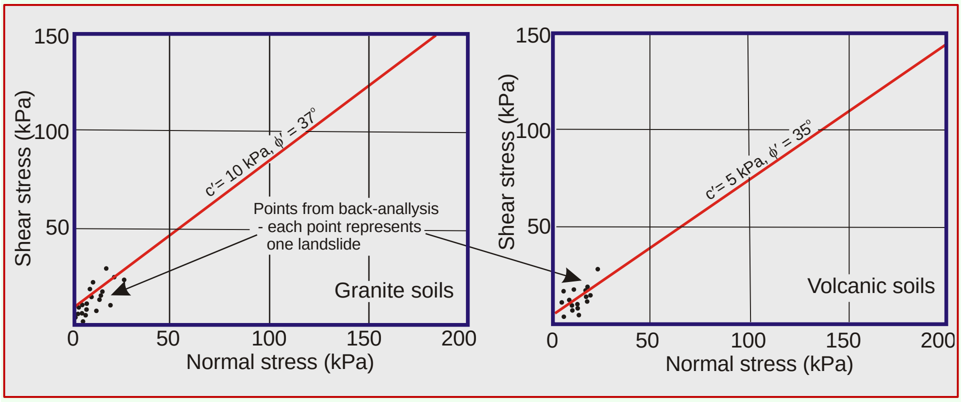
New slopes:

Risk to life / Economic risk		Recommended Factor of Safety against loss of life for a 10yr return period storm		
		Negligible	Low	High
Recommended Factor of Safety against economic loss for a 10yr return period storm	Negligible	> 1.0	1.2	1.4
	Low	1.2	1.2	1.4
	High	1.4	1.4	1.4

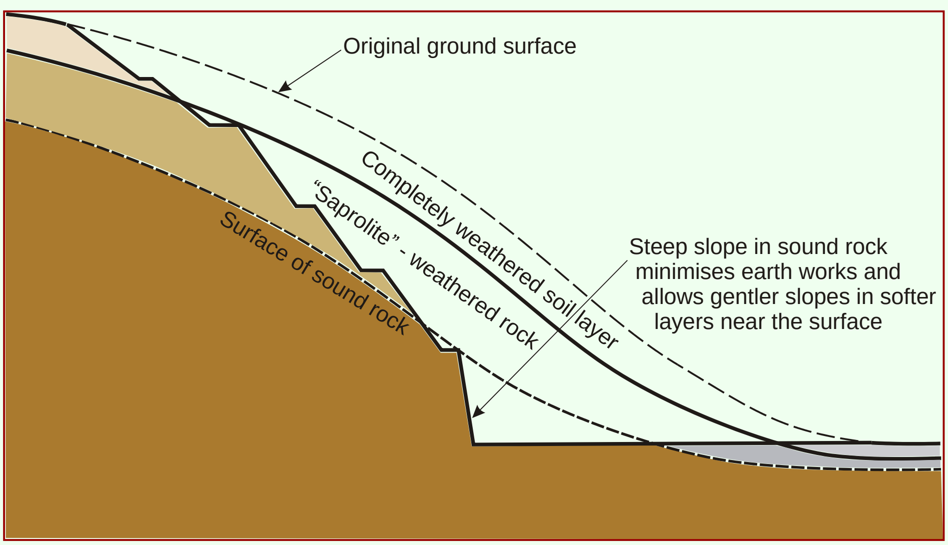
Note: (1) In addition to a factor of safety of 1.4 for a 10 year return period rainfall a slope in the high risk-to-life category should have a factor or safety of 1.1 for the predicted worst groundwater condition

(2) The factors of safety given in this Table are recommended values. Higher or lower factors of safety might be warranted in particular situations in respect of economic loss.

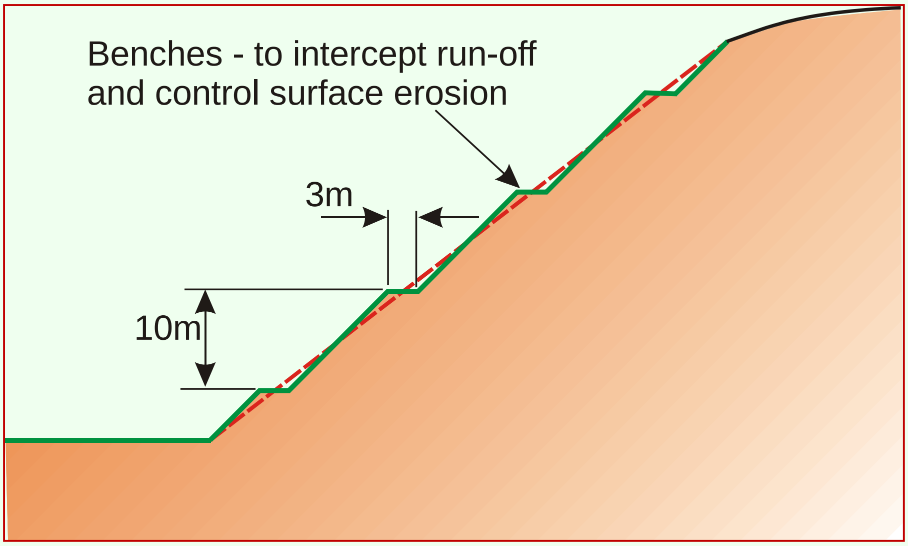
Recommended design safety factors for Hong Kong slopes



Results of back-analysis of landslides compared with triaxial tests on Hong Kong soils
- stress level of triaxial tests was well above actual stress levels in the field



Efficient cut slope profile in weathered rock of the "Little" type
- it is essential to determine the rock profile before starting excavation of the slope



To bench or not to bench, that is the question.....
- there are arguments for and against.
The answer depends on the soil type and the likelihood that once constructed the benches will be properly maintained

A very useful reference – in need of an update

"A Survey of Road Cuttings in Western Malaysia."
from
Proceedings, (First) Southeast Asian Regional Conference on Soil Engineering, Bangkok, 1968


The End
Thank you for your attention