Landslide Types & Processes

By :

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Mohd Asbi & Associates

Course contents

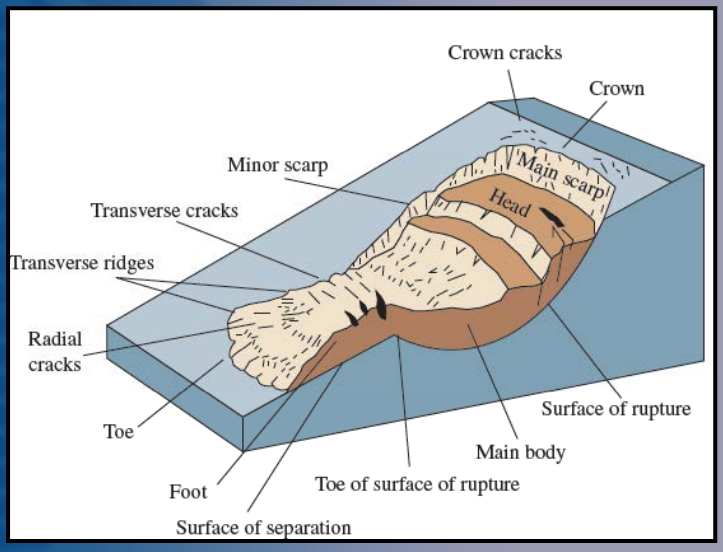
- What is landslide?
- Parts of landslide (common nomenclature)
- Landslide classification and identification
- Common landslide types
- Causes of landslide
- Landslides outside Malaysia
- Case studies

What is landslide ?

The term "landslide" describes a wide variety of processes that result in the downward and outward movement of slope-forming materials including rock, soil, artificial fill, or a combination of these.

(USGS, Fact Sheet 2004–3072)

Parts of a landslide



Commonly used nomenclature for labeling the parts of landslide

Landslide classification and identification

- Landslides or slope movements can be classified in many ways. There are many attributes used as criteria for identification and classification including:

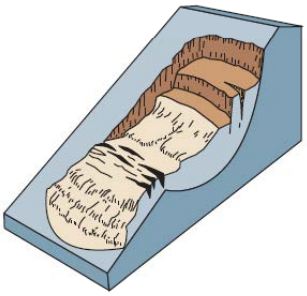
  - Rate of movement:
  This ranges from very slow creep (mm/yr) to extremely rapid (m/sec).

  -Type of material:
  Landslides are composed of bedrock, unconsolidated sediment and/or organic debris.

  - Nature of movement:
  The materials may move by falling, toppling, sliding, spreading, or flowing.

Common landslide types - rotational landslide

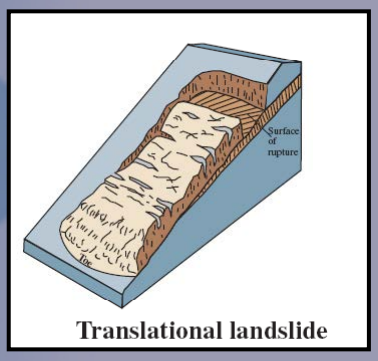
This is a slide in which the surface of rupture is curved concavely upward and the slide movement is roughly rotational about an axis that is parallel to the ground surface and transverse across the slide



Rotational landslide

Common landslide types - translational landslide

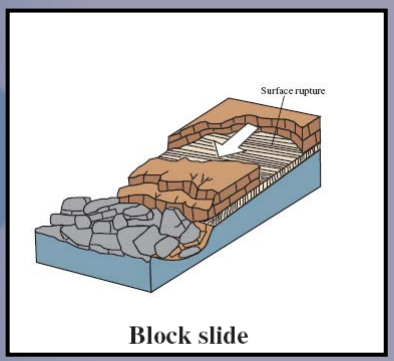
In this type of slide, the landslide mass moves along a roughly planar surface with little rotation or backward tilting



Translational landslide

Common landslide types - block landslide

A block slide is a translational slide in which the moving mass consists of a single unit or a few closely related units that move downslope as a relatively coherent mass



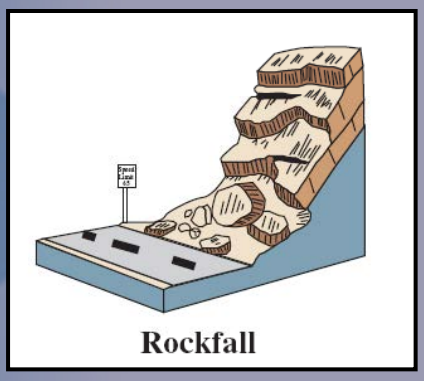
Block slide

Common landslide types - rockfall

Falls are abrupt movements of masses of geologic materials, such as rocks and boulders, that become detached from steep slopes or cliffs .

Separation occurs along discontinuities such as fractures, joints, and bedding planes, and movement occurs by free-fall, bouncing, and rolling.

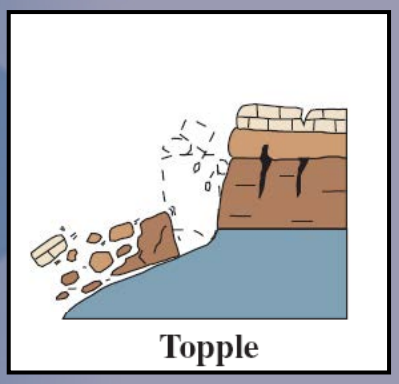
Falls are strongly influenced by gravity, mechanical weathering, and the presence of interstitial water.



Rockfall

Common landslide types - topple

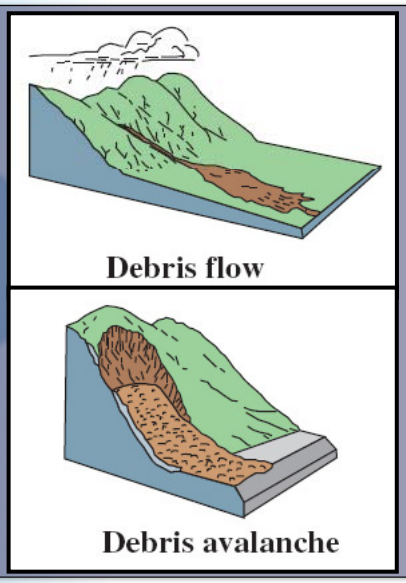
Toppling failures are distinguished by the forward rotation of a unit or units about some pivotal point, below or low in the unit, under the actions of gravity and forces exerted by adjacent units or by fluids in cracks



Topple

Common landslide types – debris flow

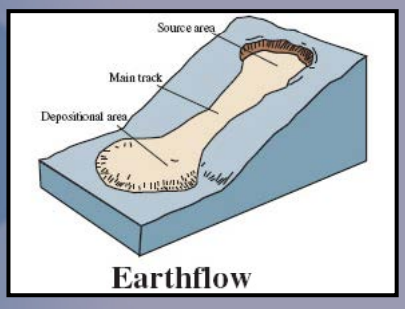
A debris flow is a form of rapid mass movement in which a combination of loose soil, rock, organic matter, air, and water mobilize as a slurry that flows downslope.



Common landslide types - earthflow

Earthflows have a characteristic "hourglass" shape .

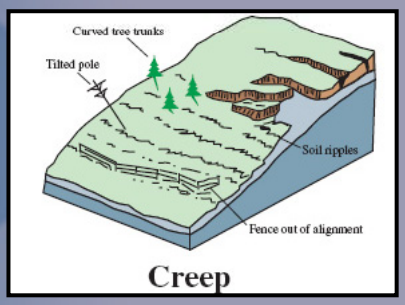
The slope material liquefies and runs out, forming a bowl or depression at the head. The flow itself is elongate and usually occurs in fine-grained materials or clay-bearing rocks on moderate slopes and under saturated conditions. However, dry flows of granular material are also possible



Common landslide types - creep

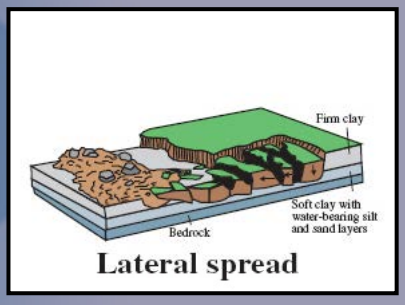
Creep is the imperceptibly slow, steady, downward movement of slope-forming soil or rock. There are generally three types of creep:

- Seasonal, where movement is within the depth of soil affected by seasonal changes in soil moisture and soil temperature
- Continuous, where shear stress continuously exceeds the strength of the material
- Progressive, where slopes are reaching the point of failure as other types of mass movements.



Common landslide types – lateral spread

Lateral spreads are distinctive because they usually occur on very gentle slopes or flat terrain. The dominant mode of movement is lateral extension accompanied by shear or tensile fractures.



TYPE OF MOVEMENT		TYPE OF MATERIAL		
		BEDROCK	ENGINEERING SOILS	
			Predominantly coarse	Predominantly fine
FALLS		Rock fall	Debris fall	Earth fall
TOPPLES		Rock topple	Debris topple	Earth topple
SLIDES	ROTATIONAL	Rock slide	Debris slide	Earth slide
	TRANSLATIONAL			
LATERAL SPREADS		Rock spread	Debris spread	Earth spread
FLOWS		Rock flow (deep creep)	Debris flow (soil creep)	Earth flow
COMPLEX		Combination of two or more principal types of movement		

Causes of Landslides

There are three major factors that can cause the landslide:

- Hydrogeological factor
- Morphological factor
- Human factor

Causes of Landslides

Hydrogeological causes

- Weak or sensitive materials
- Weathered materials
- Sheared, jointed, or fissured materials
- Adversely oriented discontinuity (bedding, schistosity, fault, unconformity, contact, and so forth)
- Contrast in permeability and/or stiffness of materials
- INTENSE AND PROLONGED RAINFALL

Causes of Landslides

Morphological causes

- Tectonic or volcanic uplift
- Glacial rebound
- Fluvial, wave, or glacial erosion of slope toe or lateral margins
- Subterranean erosion (solution, piping)
- Deposition loading slope or its crest
- Vegetation removal (by fire, drought)
- Thawing
- Freeze-and-thaw weathering
- Shrink-and-swell weathering

Causes of Landslides

Human causes

- Excavation of slope or its toe
- Loading of slope or its crest
- Drawdown (of reservoirs)
- Deforestation
- Irrigation
- Mining
- Artificial vibration
- Water leakage from utilities

Brand E.W., (1981) pointed out that:

"The majority of failures in the residual soil cut slopes are due to the rainfall"

Hencher, S. et. al. (1984) cited that:

"In predicting the stability of Hong Kong slopes, the groundwater conditions are poorly understood"

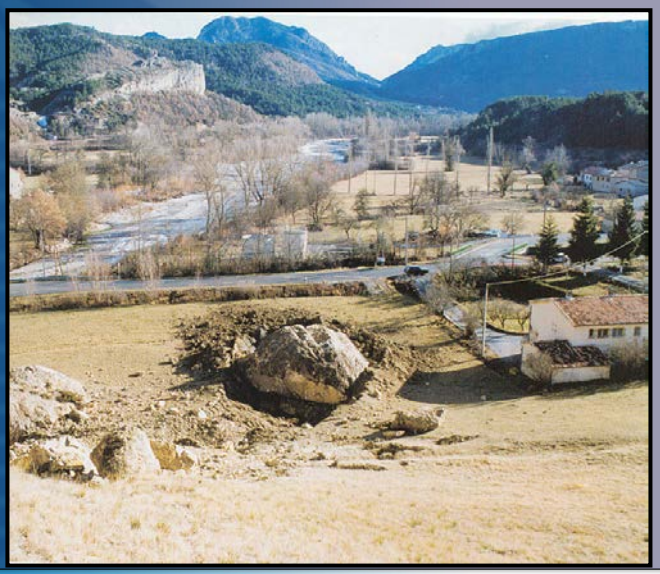
Prof. Dr Steve Hencher
Hong Kong University

Landslides Outside Malaysia

The Sarno landslide southern Italy in May 1998 which resulted in the loss of 244 lives

The Vajont landslide in Italy, caused by the collapse of a valley-side into a reservoir.

One of the most famous examples of a toppling failure occurred on the 26 July 1928 at Niton Underclift, Isle of Wight



A massive rock fall in the Commune of Sennoz, France with debris impacting close to residential development

Rock fall at Ancona, Adriatic coast of Italy

The landslide extends for 2.5km through the southern slopes of Mount Teverone and the major mudslide was activated after intense rainfall in October 1960.

Coastal landsliding at Overstrand, Norfolk , UK – part of this frontage has now been protected.

CASE STUDIES

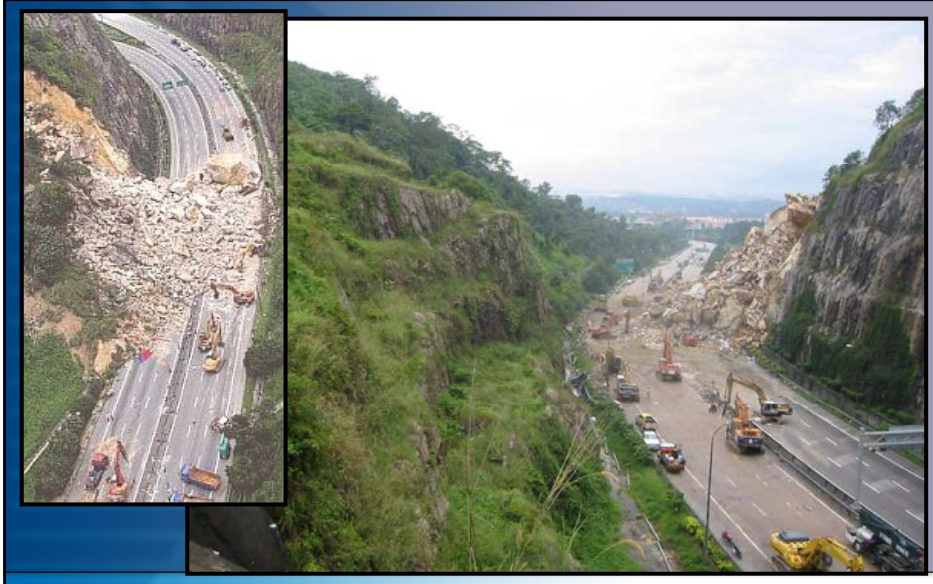
CASE STUDY 1
BUKIT LANJAN ROCK SLOPE FAILURE

Case Study 1: Bukit Lanjan Rock Slope Failure

- On the 26 November 2003 at about 07:16 a very large rock slope failure occurred at kilometer 21.8 of the Bukit Lanjan Interchange on the New Klang Valley Expressway (NKVE).

- The rock slope failure involved an estimated 35,000 m^3 of rock debris, mainly angular blocks of various sizes, which came to rest on the expressway. The failure materials blocked the entire expressway forcing the closure of the road to the public

Case Study 1: Bukit Lanjan Rock Slope Failure



Case Study 1: Bukit Lanjan Rock Slope Failure

Case Study 1: Bukit Lanjan Rock Slope Failure

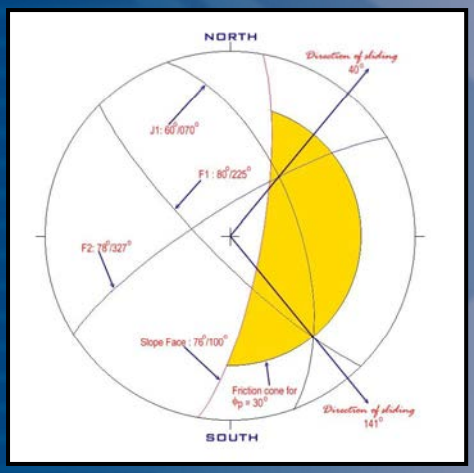
Analysis of Failure

- The stability of the rock slope in Bukit Lanjan is controlled by the characteristics and orientations of the discontinuity planes present in the rock mass

- A kinematic rock slope stability analysis was conducted using a stereo graphic projection technique. This method is extremely useful, particularly to project three dimensional discontinuity planes onto two-dimensional presentation

- Three measured major discontinuity planes were plotted on a Schmidt lower hemisphere equal angle stereonet together with the orientation of the failed slope face

Case Study 1: Bukit Lanjan Rock Slope Failure



Discontinuity	Dip/Dip direction	Type
J1	60/070	Joint plane A
F1	80/225	Fault plane B
F2	78/327	Fault plane C (Release plane)

Case Study 1: Bukit Lanjan Rock Slope Failure

- The rock slope failure at Bukit Lanjan was due to a huge wedge block which was formed along the intersection between a steeply dipping fault plane F1 (dip/dip direction: 80°/225°), and a more gently dipping major joint plane J1 (dip/dip direction: 60%70°), with a fault plane F2 (dip/dip direction: 78°/327°) as a release plane.
- The line of intersection plunged at an angle of 33° with the direction of sliding toward 140°.
- The development of groundwater pressure within this release plane could have reduced the resisting force, subsequently promoting failure.

Case Study 1: Bukit Lanjan Rock Slope Failure

- Since the analysis indicated that unfavorable discontinuity orientations and built-up water pressure along these discontinuities were two most importance causal factors, one might still ask ***why did the failure occur several years after the construction of the slope.***
- A more straight forward answer to this question is related to the unusual condition for ***the triggering factor.***
- Rainfall analysis based on the data collected by the Malaysian Meteorological Service at Petaling Jaya and Old Subang Airport indicated that rainfall in November 2003 for both stations was extremely high. In fact, the monthly rainfall of 472mm at the Old Subang Airport station was ***the highest monthly rainfall since 1966.***

Case Study 1: Bukit Lanjan Rock Slope Failure

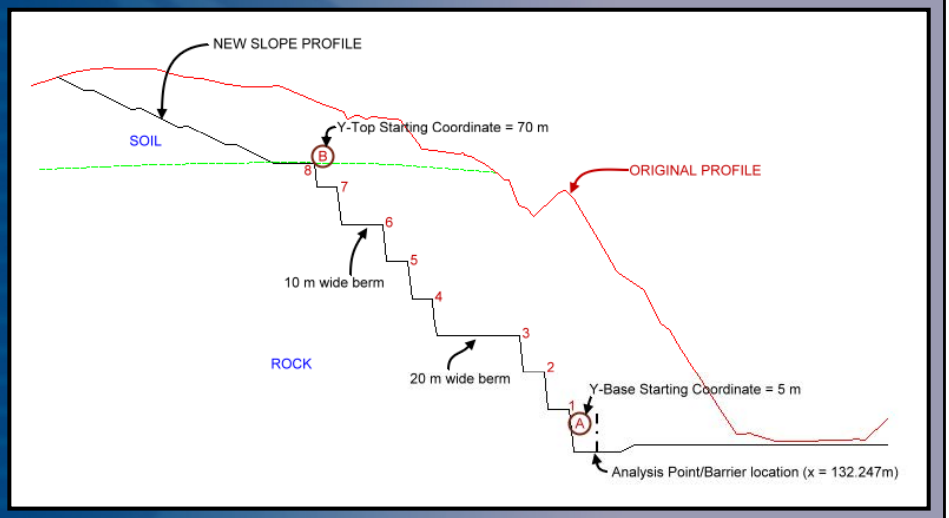
Rehabilitation Scheme

- The rehabilitation scheme chosen was rock slope re-profiling because the construction was quick, simple and most cost compared to other options.
- An overall rock slope profile of 48° was considered appropriate for the anticipated *in situ* instability condition

Case Study 1: Bukit Lanjan Rock Slope Failure

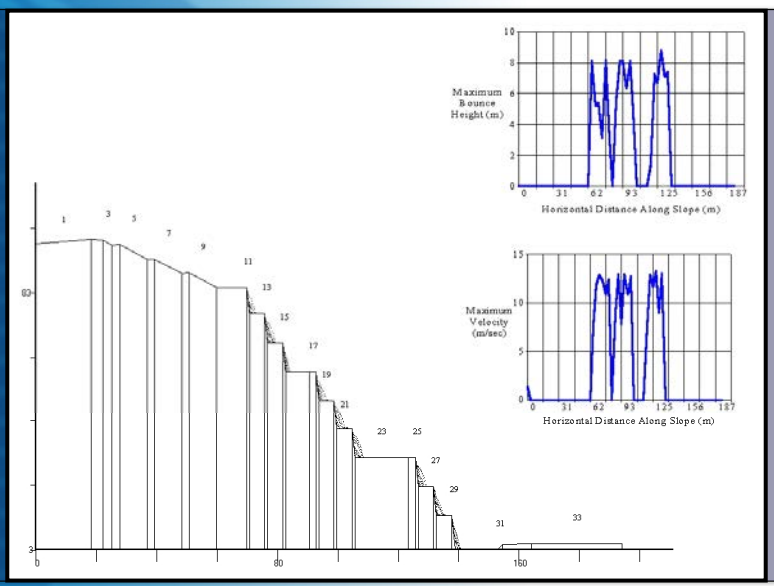
- Slope re-profiling usually reduces the possibility of large scale wedge and/or planar type failure.
- To contain localized minor rock and debris falls, the design would have to incorporate appropriately designed catch berms, rock bolts, rockfill buttress, protection screens, rock trap ditches and fencing.
- Localized stabilization measures such as rock bolts, rock anchors, dowels, shotcrete and concrete buttress were also anticipated to support kinematically unstable blocks that would become exposed during the construction works.
- Drainage works were also incorporated in the form of surface and horizontal drains; the latter were designed in excess of 20 metres to 30 meters in depth

Case Study 1: Bukit Lanjan Rock Slope Failure



Trajectory analysis – Cross section

Case Study 1: Bukit Lanjan Rock Slope Failure



Trajectory analysis – Rock fall travel distance & bounce height

Case Study 1: Bukit Lanjan Rock Slope Failure

CASE STUDIES

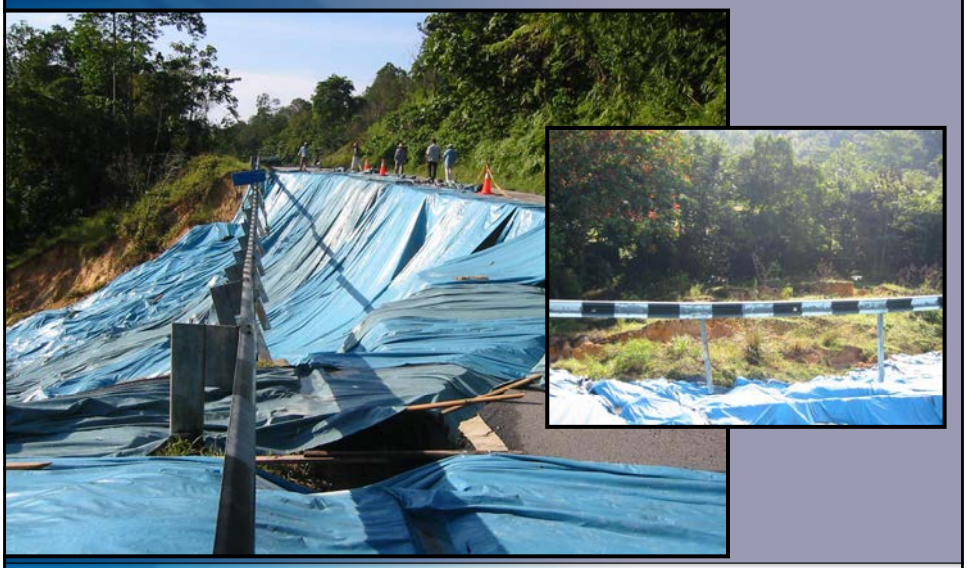
CASE STUDY 2

EMBANKMENT FAILURE AT ULU YAM ROAD

Case Study 2: Embankment Failure at Ulu Yam Road

- A major landslide occurred at KM 12, Jalan Ulu Gombak - Ulu Yam Baru (B23) located in Daerah Gombak on 22 Nov 2002.
- The landslide was triggered by intense and prolonged rainfall brought down tonnes of earth and damaged almost three-quarters of the width of the road. No fatalities were reported in the incident.
- The ***rotational landslide*** measured approximately 70m wide and 10m high. The crown and surface of rupture were circular.
- The toe of the slope was seen to have heaved indicating a very high pore water pressure build up prior to the failure.
- This is common for areas where large catchment is found upslope.

Case Study 2: Embankment Failure at Ulu Yam Road



Case Study 2: Embankment Failure at Ulu Yam Road

Case Study 2: Embankment Failure at Ulu Yam Road

Rehabilitation Scheme

- In order not to sacrifice the geometric standard of the section (vertical and horizontal alignment), it was proposed that the original alignment was maintained.
- This required a reconstruction of the embankment. Given the limited Right of Way (forest reserved), it was proposed that a geogrid reinforced wall (approximately 5m in height) was designed to act as a gravity structure to the embankment.

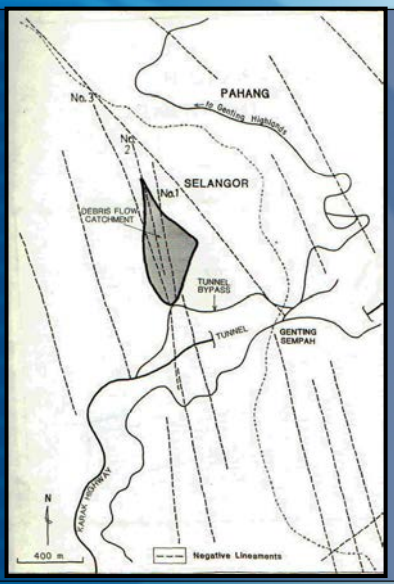
Case Study 2: Embankment Failure at Ulu Yam Road

CASE STUDIES

CASE STUDY 3

DEBRIS FLOW AT THE TUNNEL BYPASS ROAD, GENTING SEMPAH

Case Study 3: Debris flow at the tunnel bypass Road, Genting Sempah



- The tragic site is located in Genting Sempah at a curved turning at the tunnel bypass road which is approximately 425 metres from its Junction at the Kuala Lumpur-Karak Highway.

Case Study 3: Debris flow at the tunnel bypass Road, Genting Sempah

- **The debris flow tragedy at the tunnel bypass road to the Genting Highlands occurred at about 5.20 p.m. on the 30th June 1995.**
- **The incident took 21 lives (one body missing) and injured another 22 persons.**
- **Most of the victims were buried under tonnes of mud, some 200 metres from the point where the debris flow crossed the bypass road**

Case Study 3: Debris flow at the tunnel bypass Road, Genting Sempah

Case Study 3: Debris flow at the tunnel bypass Road, Genting Sempah

- A very intense and heavy rainfall occurred over the Genting Sempah area covering the debris flow catchment from about 3.40 p.m. to about 5.30 p.m. on the 30th June 1995.
- As a consequence, flash floods were reported at the highway tunnel and the surrounding Genting Sempah area resulting in a massive traffic jam in the area.
- The debris flow, consisting essentially of large volume of water carrying mud, stone, cobbles, boulders and tree trunks flowed down a stream course at great velocity and force sweeping across the tunnel bypass road at the curved turning where heavy traffic was lined up.

Case Study 3: Debris flow at the tunnel bypass Road, Genting Sempah

Case Study 3: Debris flow at the tunnel bypass Road, Genting Sempah

The aftermath at the main stream

Case Study 3: Debris flow at the tunnel bypass Road, Genting Sempah

- The debris flow was initiated by the impounding of the main stream within a valley followed by subsequent breaching which resulted in massive flow sweeping across the tunnel bypass road with great force and velocity.
- The impounding was caused by a debris avalanche involving some 5100 cubic metres of earth, measuring 120 metres and 75 metres in length and height respectively from the main stream.

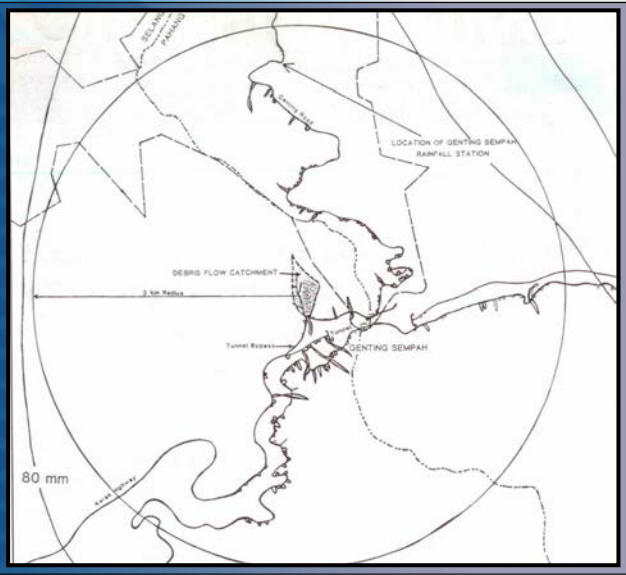
Case Study 3: Debris flow at the tunnel bypass Road, Genting Sempah

Debris avalanche responsible for the impounding

Case Study 3: Debris flow at the tunnel bypass Road, Genting Sempah

Evidence of impounding was clearly seen as mud stains on the bark of trees along the main stream.

Case Study 3: Debris flow at the tunnel bypass Road, Genting Sempah



The 3-kilometer radius from the debris flow site where other debris flow and other forms of instability were recorded

Case Study 3: Debris flow at the tunnel bypass Road, Genting Sempah

- Rainfall analysis was undertaken based on the rainfall records of Department of Irrigation and Drainage's (DID) Genting Sempah rainfall recording station No. 3317004 located at about *3 km north of the tragic site*.
- The frequency analysis of annual maximum 2-hour rainfall records indicated that the 30th June 1995 storm with a total rainfall of 96.5 mm had a probability of recurrence of about 16 years.

Case Study 3: Debris flow at the tunnel bypass Road, Genting Sempah

- Characterization of the storm using a total of 10 rainfall stations around the Genting Sempah area showed that the debris flow catchment was located within the centre or core of the storm.

Case Study 3: Debris flow at the tunnel bypass Road, Genting Sempah

- The month of June 1995 was abnormally wet over the Genting Sempah area.
- A total rainfall of 428.5 mm recorded for the month of June 1995 was the highest in 20 years, approximately 2.6 times the long-term average rainfall of 163.2 mm.
- The 6-day accumulated rainfall ending on 30th June 1995 was recorded at 2075 mm, constituting approximately 50% of the monthly total and exceeding the June long term average of 163.2 mm by 27%.
- Such high antecedent rainfall which occurred within the debris flow catchment was responsible for extreme wetting of the soil prior to the 30th June storm.

Case Study 3: Debris flow at the tunnel bypass Road, Genting Sempah

- The flood discharge hydro graph for the debris flow catchment indicated that storm flow would have started at 4.00 p.m. and reached its peak between 5.00 pm. and 5.15 p.m. where the discharge rate was greater than 2.5 cubic metres per second which was at least 1000 times that of the normal flow.
- The total volume produced by the 2-hour storm at the debris flow catchment was estimated to be about 10,600 cubic metres.

CASE STUDIES

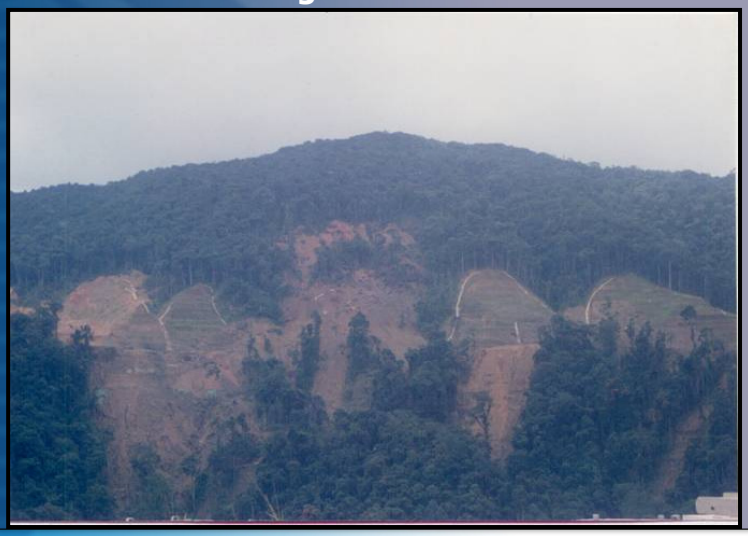
CASE STUDY 4
LANDSLIDE AT POS SELIM-CAMERON HIGHLAND HIGHWAY

Case Study 4: Landslide at Pos Selim-Cameron Highland Highway

- The Pos Selim-Cameron Highland is one (package 2) of the 8 packages of road that link Simpang Pulai in Perak & Kuala Berang in Terengganu; the 3rd E-W Highway in Peninsular Malaysia, after the KL-Karak & Gerik-Jeli Highway.
- The construction of the 35 km highway was started in 1997 and was scheduled to be completed on Apr 2000, but having confronted with slope failures, the opening of the highway to the public had been delayed to 2004.
- One of the major failures was the deep-seated, structurally-controlled massive cut slope failure between CH23000 – CH24500.

Case Study 4: Landslide at Pos Selim-Cameron Highland Highway

August 2000



After completion of a few berms, the slope started to fail. A series of failures on this slope was first reported in April 2000 after a long period of intense and heavy rainfall which triggered further retrogressive slips in the upper catchment .

Case Study 4: Landslide at Pos Selim-Cameron Highland Highway

October 2001

Case Study 4: Landslide at Pos Selim-Cameron Highland Highway

2002

The deep-seated failure mode exhibited by these failures had prohibited the adoption of stabilization measures using active anchors, passive soil nails, sprayed concrete etc. Eventually, the Main Contractor had no alternative but to adopt the rehabilitation scheme involving slope re-profiling.

Case Study 4: Landslide at Pos Selim-Cameron Highland Highway

August 2003

Despite the efforts by the Main Contractor to stabilize the slope by re-profiling , the high cut slope at between CH23000-CH24560 is still experiencing deep-seated slope movement

Case Study 3: Landslide at Pos Selim-Cameron Highland Highway

June 2004

Further Re-profiling were then undertaken

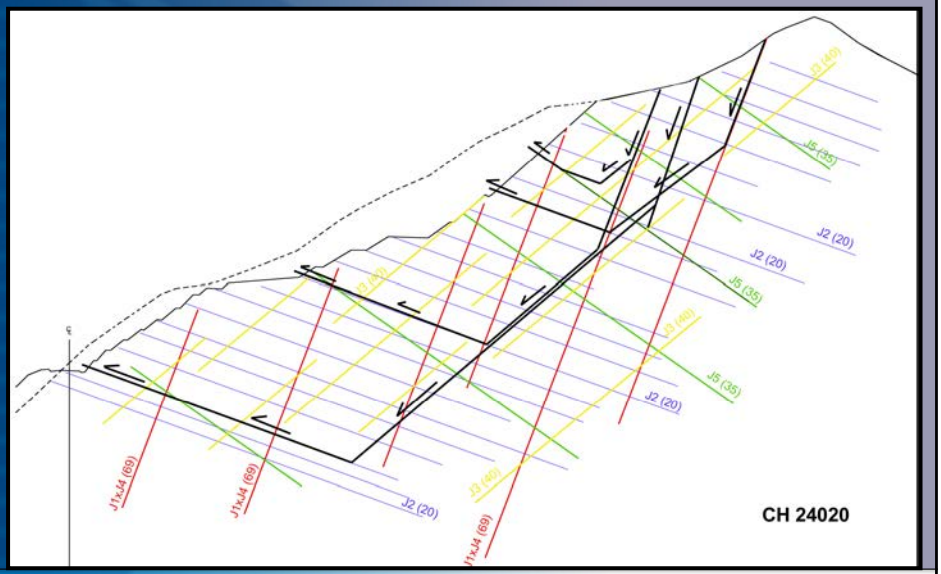
Case Study 4: Landslide at Pos Selim-Cameron Highland Highway

2005

Case Study 4: Landslide at Pos Selim-Cameron Highland Highway

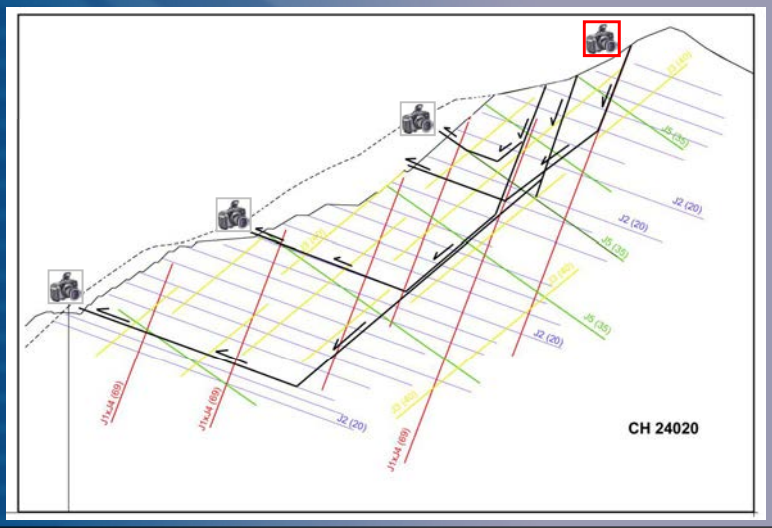
Field-sketch to show the approximate extend of the moving blocks within the major failure

Case Study 4: Landslide at Pos Selim-Cameron Highland Highway



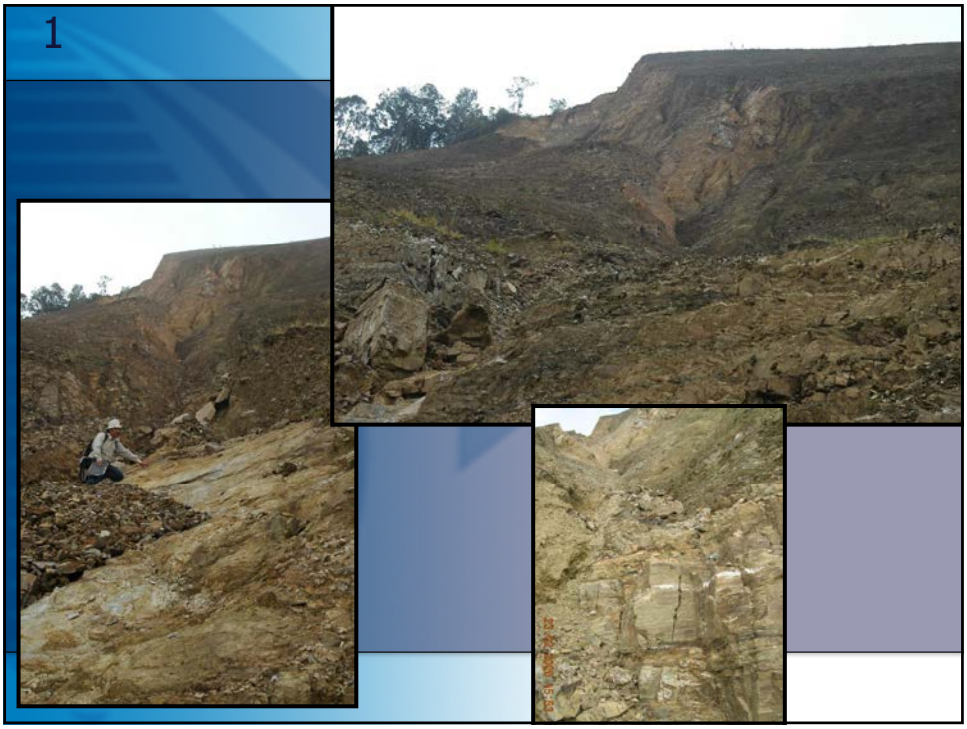
Interpretative cross section of the slope based on the kinematic stability analysis and field data, showing the likely structural orientation and mechanism of the slope failure in the form of a "passive wedge".

CH 23+900 – CH24+400
(The major failure)

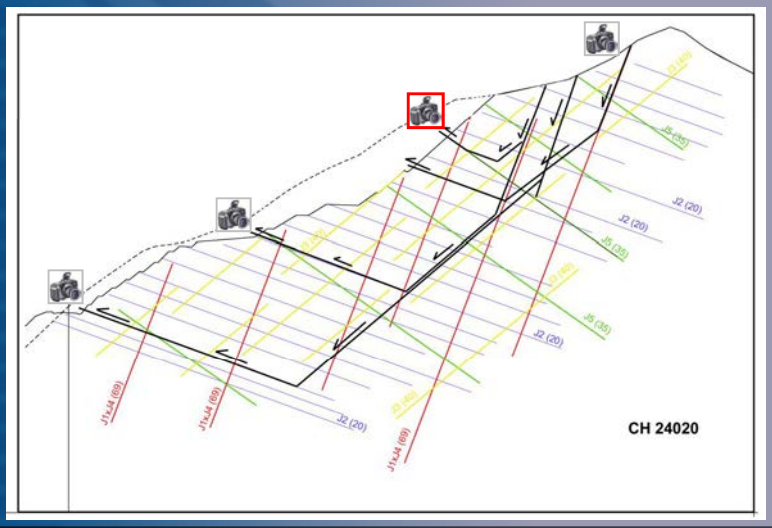


CROSS SECTION SHOWING THE LIKELY MECHANISME OF THE MAJOR FAILURE BETWEEN CH 23900 – CH 24400

1



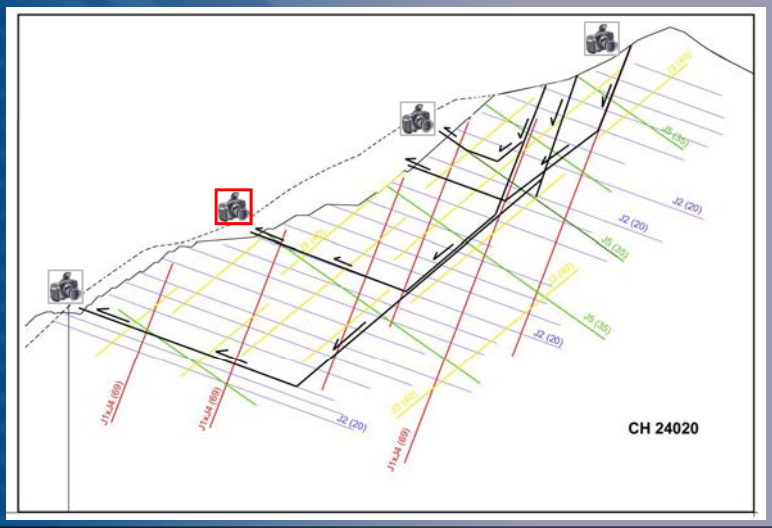
CH 23+900 – CH24+400
(The major failure)



CROSS SECTION SHOWING THE LIKELY MECHANISME OF THE MAJOR FAILURE BETWEEN CH 23900 – CH 24400

2

CH 23+900 – CH24+400
(The major failure)

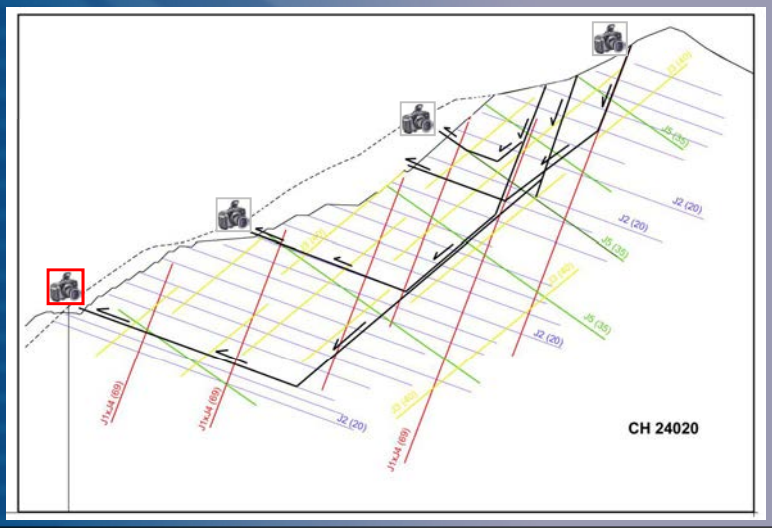


CROSS SECTION SHOWING THE LIKELY MECHANISME OF THE MAJOR FAILURE BETWEEN CH 23900 – CH 24400

3

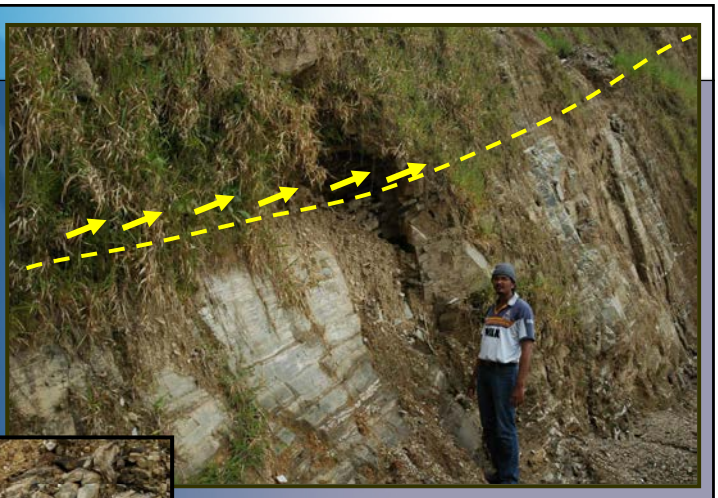
Basal Sliding Plane

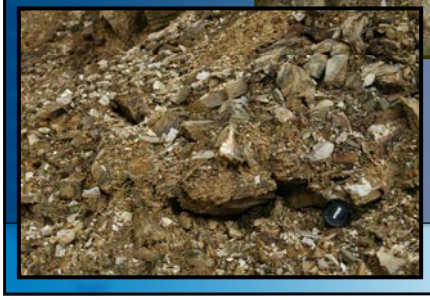
CH 23+900 – CH24+400
(The major failure)



CROSS SECTION SHOWING THE LIKELY MECHANISME OF THE MAJOR FAILURE BETWEEN CH 23900 – CH 24400

4





Basal Sliding Plane

- Ground water conditions and rainfall contributed significantly towards reducing the shearing resistance along discontinuities.
- The slope movement is reported to be still active, notably during and after prolonged rainfalls.

Case Study 4: Landslide at Pos Selim-Cameron Highland Highway

- The large-scale landslide is mainly attributed to unfavourable orientation of major discontinuities with respect to the cut slope orientation.
- The failure is a deep seated failure and still active, notably during heavy and prolonged rainfalls.
- Based on findings in the field and results of kinematic analysis, elements of instability still exists even though the slope is cut further inwards.

THANK YOU