SLOPE FAILURES IN TROPICAL RESIDUAL SOILS

Presented by:
Ir. Liew Shaw Shong

Contents

A. Creep Movement of Slope, Sabah

Ground Movements

- Damage of road pavement and drains.
- Tension cracks, settlement and lateral movement.
- Investigation of root causes.

Ground Movements

Road Settlement

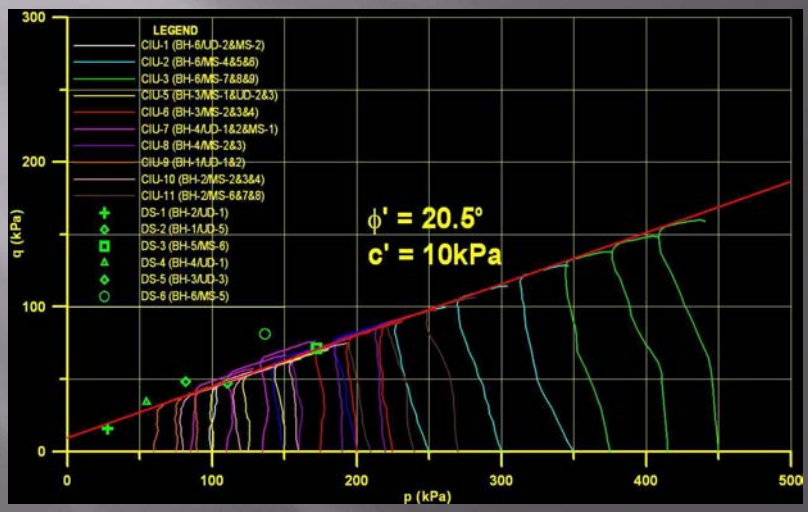
Site Background

- RL1335m to RL1500m.
- Terrain : Undulating/Sloping.
- Outcrops: Granitic boulder/ Grey Shale/ Sandstones.
- Deposits of Pinosuk Gravel from Mt. Kinabalu.
- Glaciation & Ancient Mudflow.

SI & Laboratory Testing

- Six Boreholes & Inclinometers
- Six Piezometers (GWT : 1.5~2.5m)
- C.I.U. Tests & Direct Shear Box Tests (ϕ'=21°, c' = 10kPa).
- Others Properties : w_n = 7% to 13%, γ_{bulk}= 21~23.7kN/m^3
- Normally Consolidated

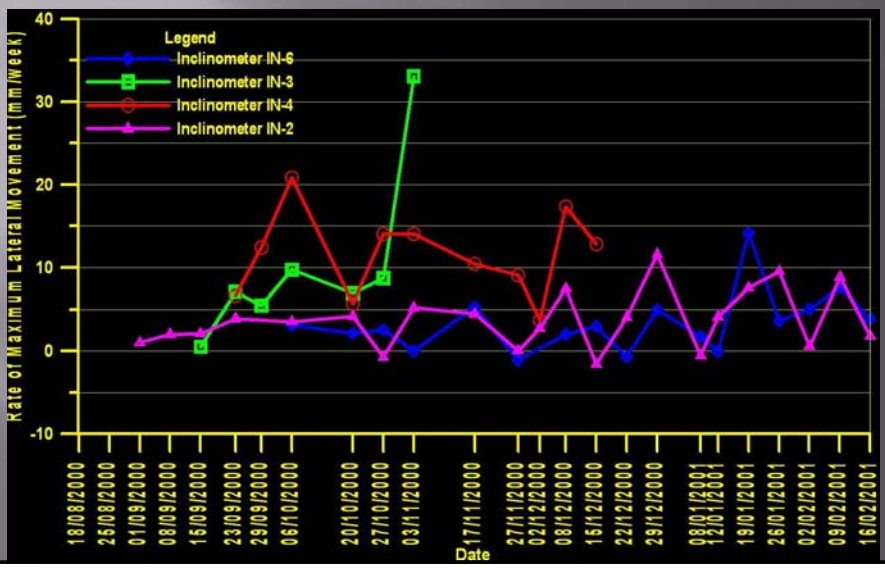
Shear Strength Test Results



Monitoring Results

- Inclinometers detected slip surface.
- Lateral Movement:
- Direction :225°~250°
- Max. Movement : 140mm (IN-4)
- Rate of Movement : 2~14mm/week (Max. 21mm/week)

Inclinometer Movement Rate



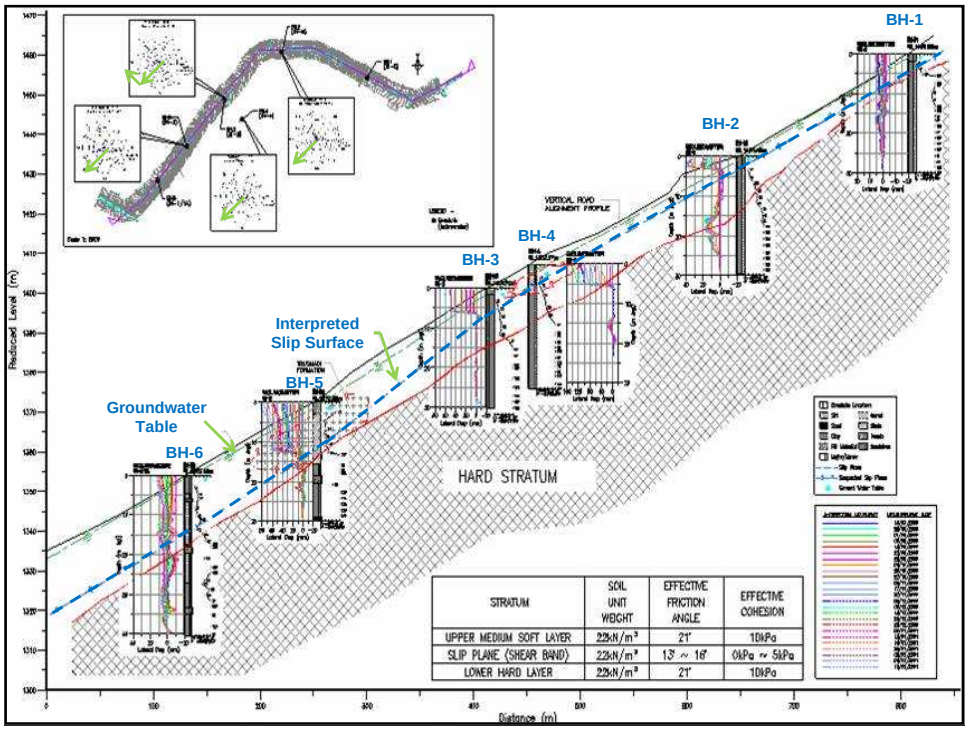
Engineering Assessment

- Interpreted laboratory shear strength parameters are too high to cause instability.
- Back-analysis shear strength parameters:

  $\phi' = 13^{o} \sim 16^{o}$, $c' = 0 \sim 5$kPa

Findings

- Slip Surface : 6m (higher ground) to 15m (lower ground).
- Movement Direction: almost parallel to road alignment, towards river.
- Back-analysed shear strength < Interpreted laboratory test results.



Recommendations

- Carry out continuous sampling at identified shear surface for observing slicken-sided surface and direct shear testing.
- Carry out ring shear test and/or multiple reversal direct shear box test to determine residual strength.

B. Cut Slope Failure in Johor

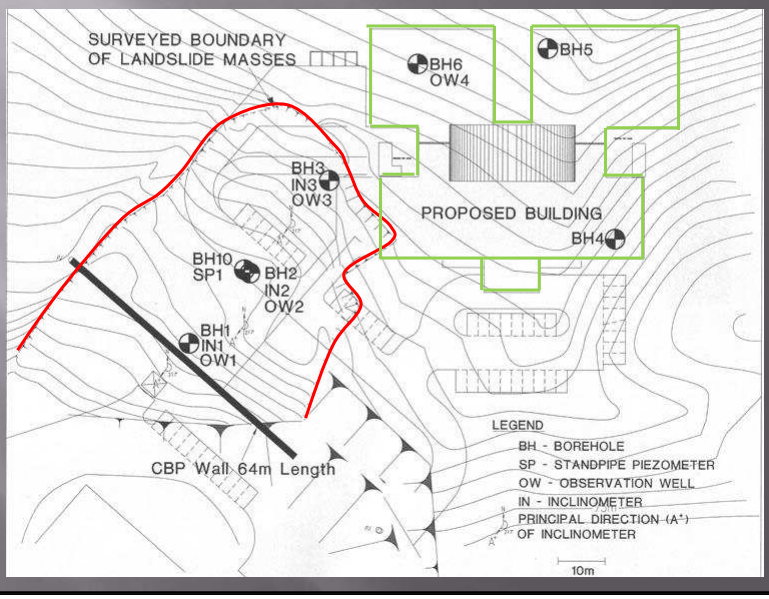
Site Background

- RL54m to RL106m.
- Terrain : Sloping.
- Geology: Mainly basic intrusive gabbro and intermediate intrusive.
- Two berms cut slope 1V:1.5H.
- Slope collapsed after heavy downpour.

SI and Instrumentations

- SI and instrumentation for failure investigations:
- 4 boreholes within failed mass area.
- 3 inclinometers.
- 3 observation wells and 1 standpipe piezometer.

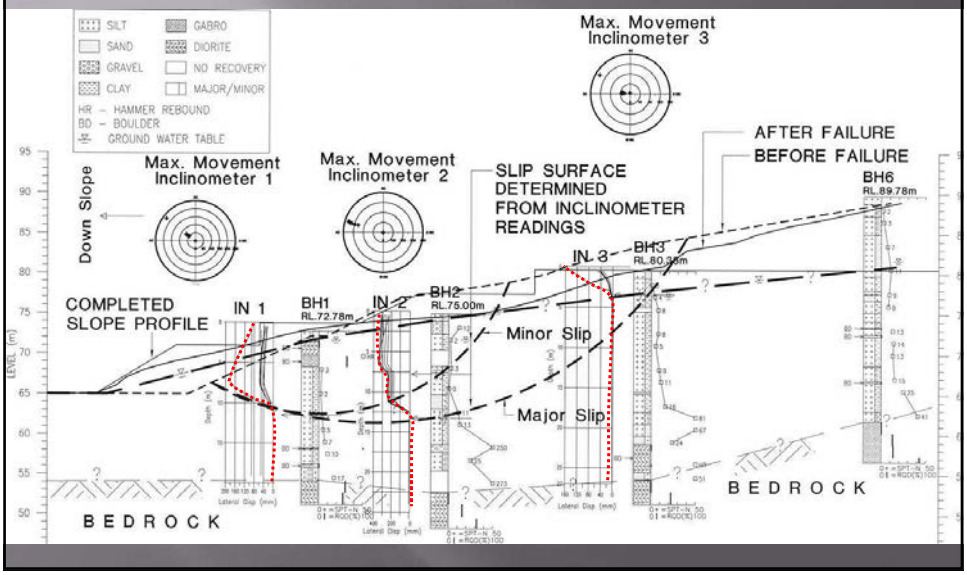
SI Layout Plan



Instrumentation Results

- IN-1 and IN-2 were sheared off at 10.5m and 12.0m below ground.
- IN-3 sheared off at 2.5m below ground.
- Observation wells were also sheared off.

Interpreted Slip Surfaces



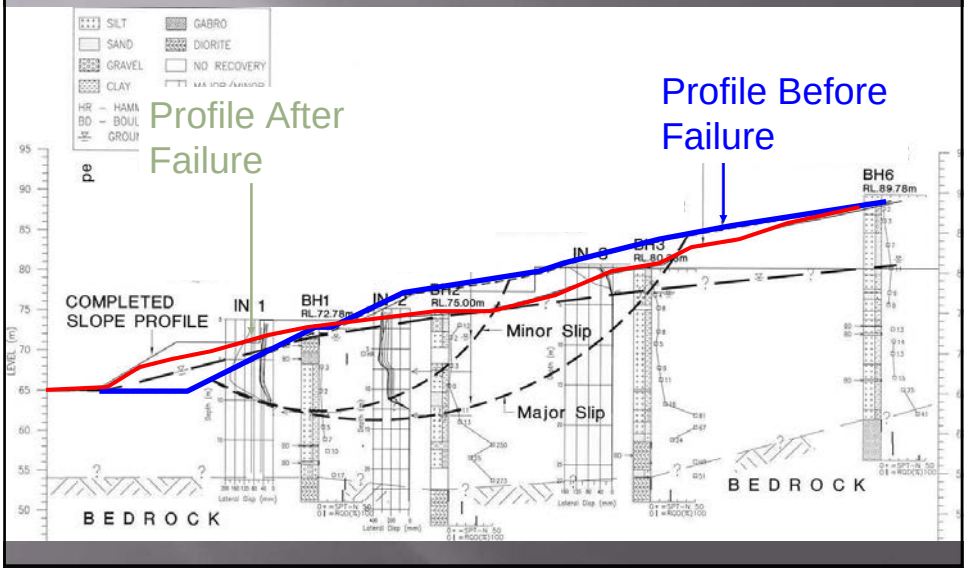
Laboratory Test Results

- **CIU test :**
  a. Peak strength – c'=3.5kPa, ϕ'=32^o
  b. Critical state strength – c'=0kPa, ϕ'=29^o
- **Direct Shear Box test : (fairly scattered)**
  a. Peak strength – c'=15.7kPa, ϕ'=24^o
  b. Residual strength – c'=5.9kPa, ϕ'=20^o

Back-Analysis

- Back-analyses were performed for 2 conditions:
  a. Slope profile after cutting, before failure (critical state strength)
  b. Slope profile after failure. (residual strength)
- The interpreted slip surface & monitored groundwater level is used for back-analysis.

Slope Profile for Back Analysis



Back-Analysis Results

- Back-analyses using PC-Stabl6 and Plaxis.
- Back-analyses results :

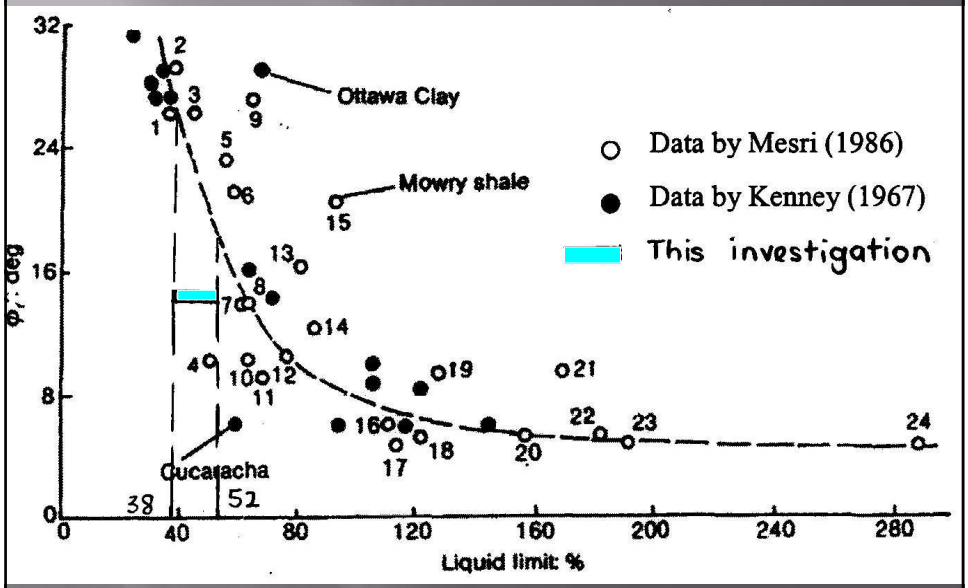
  a. Mobilised shear strength : $c'=0$ kPa, $\phi'=24^o - 25.9^o$

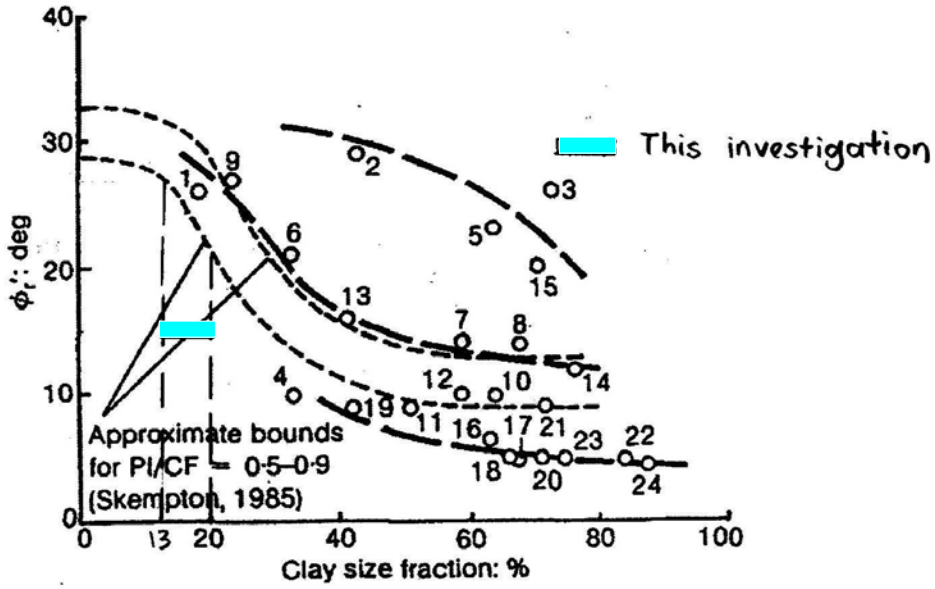
  b. Residual strength : $c'=0 - 0.5$ kPa, $\phi'= 14.4^o - 15^o$

Residual Strength

- Comparisons with literature:
  a. Residual friction angle – **Liquid Limit.**
  b. Residual friction angle – **Clay size fraction**

- Back analysed residual friction angle are **lower** as compared to literatures.





Findings and Recommendations

- The investigation deduced that there is likely an unidentified thin weak layer at the slip surface with low shear strength.
- Boreholes are not able to capture the thin layer and could only be detected by inclinometers.
- **Residual shear strength** should be used for remedial design works.

C. Cut Slope Failure at Gua Musang, Kelantan

Site Observations

Collapsed Shotcrete Wall

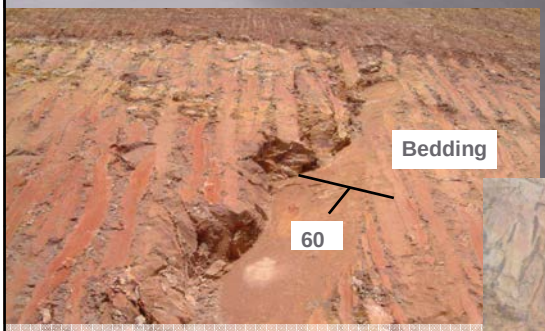
Site Background

- RL210m to RL330m.
- 7 Upper berms of 1V:1H Cut Slope & 5 Lower berms of 4V:1H Soil Nailed Slope
- Soil Nail : 12m with spacing of 1m(V):1m (H)
- Geology : Shale Facies in Gua Musang Formation (mainly consists of Mudstone & Sandstone)
- A massive slope failure occurred before soil nails were installed at the lowest berm.

Geological Mapping

- 'Line Mapping' Method
  - To measure & record discontinuity along the exposed slope face
  - To detect anomalous features
  - Schmidt Rebound Hammer to give indication on weathering condition

Site Observations



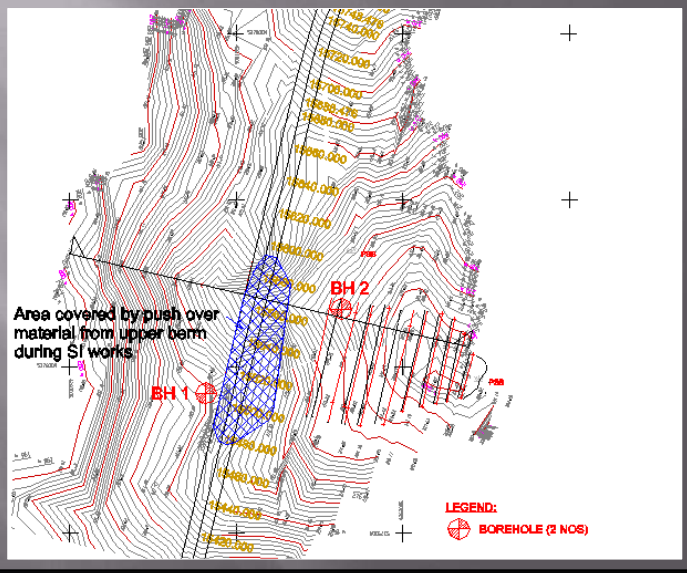
Day-lighting Relict Bedding at Cut Slope towards Main Road

Joints with Infilling Materials

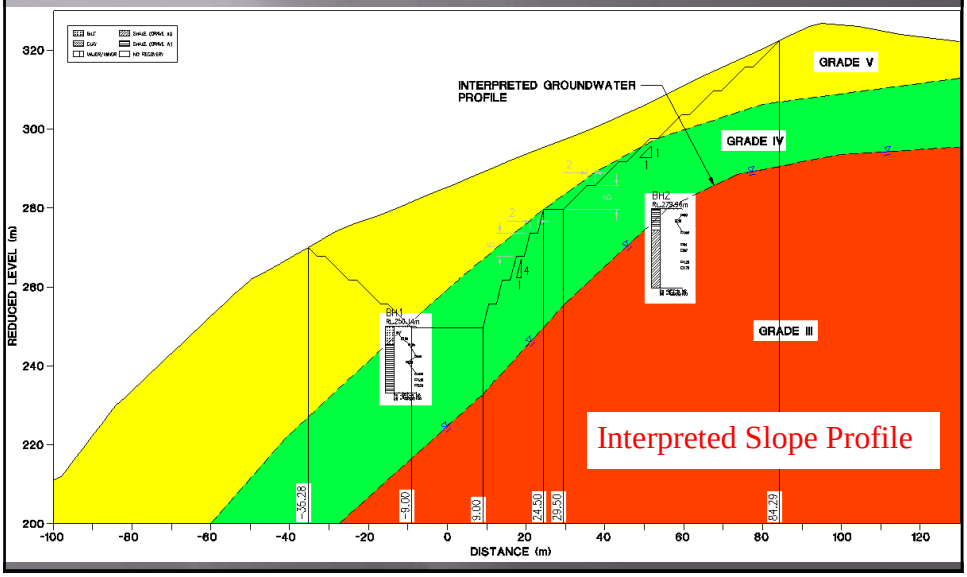
SI & Laboratory Works

- 2 boreholes
- 3 C.I.U. Tests
- 2 Multiple Reversal Direct Shear Box Tests
- Grade IV Material
  a. Peak strength – c'=30kPa, ϕ'=33^o
  b. Residual strength – c'=0kPa, ϕ'=33^o
- Grade III Material
  a. Peak strength – c'=30kPa, ϕ'=39^o
  b. Residual strength – c'=0kPa, ϕ'=33^o

SI Layout Plan



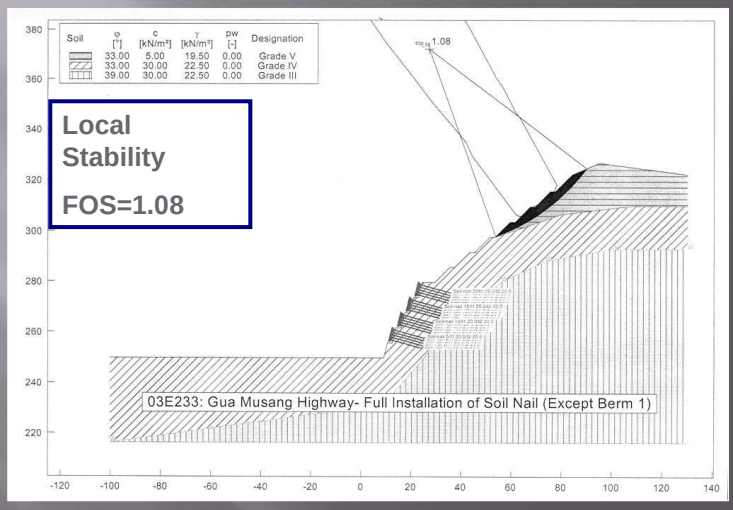
Slope Profile



Interpreted Slope Profile

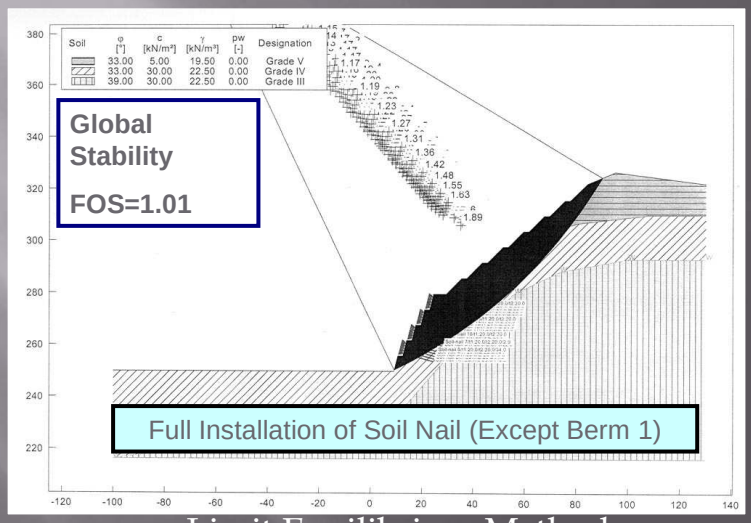
Engineering Assessment

Slope Stability Analyses



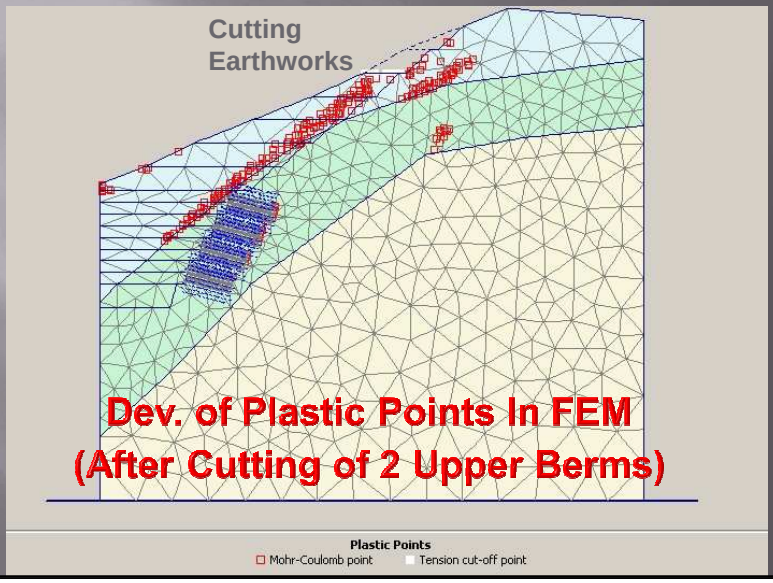
Limit Equilibrium Method

Slope Stability Analyses

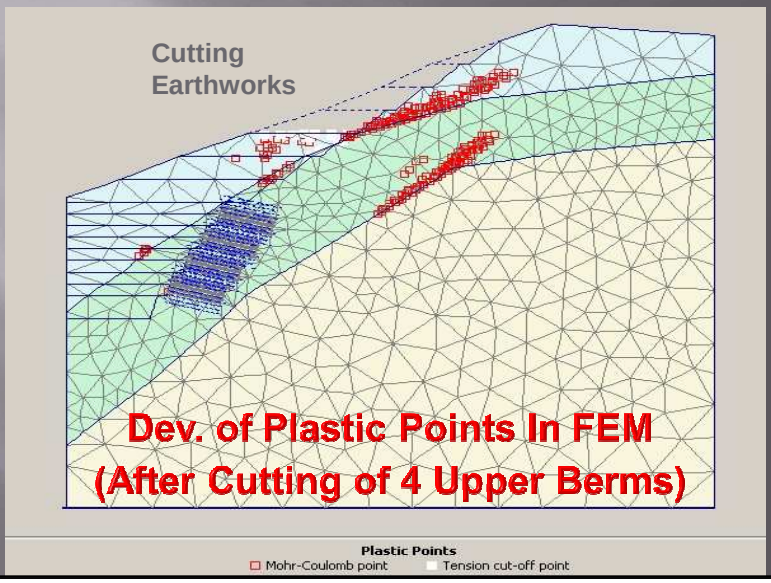


Limit Equilibrium Method

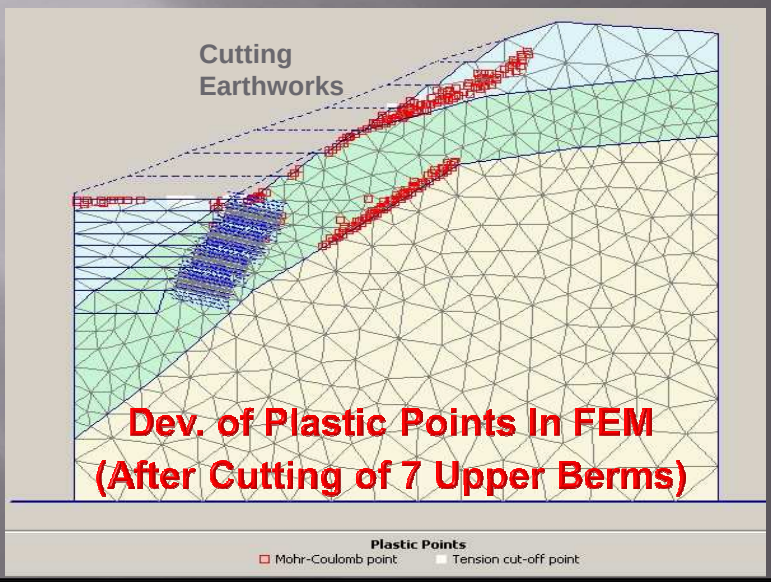
Finite Element Analyses



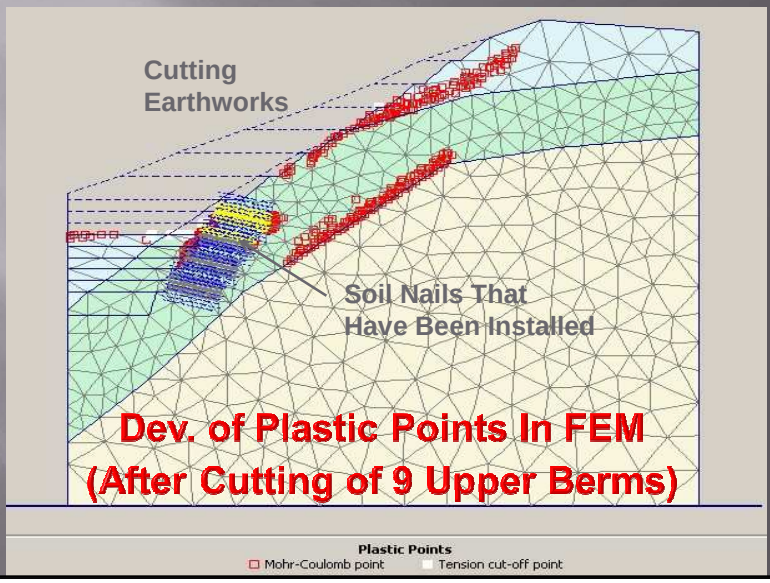
Finite Element Analyses



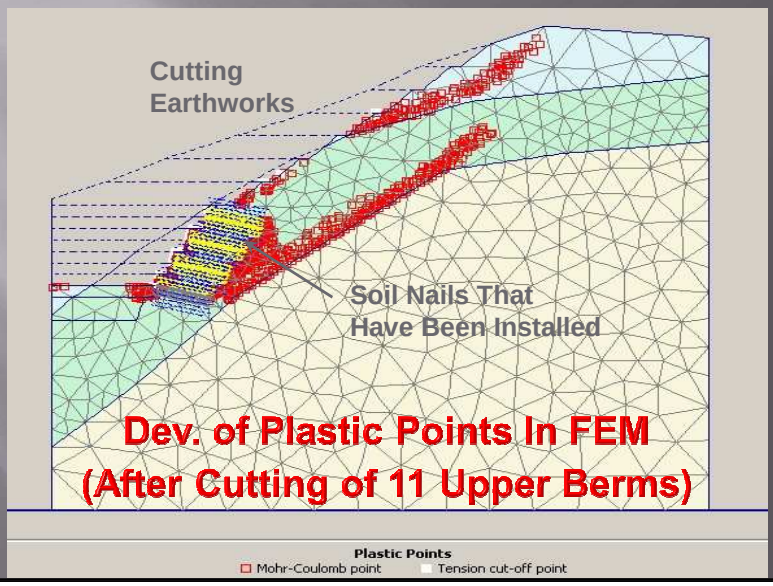
Finite Element Analyses



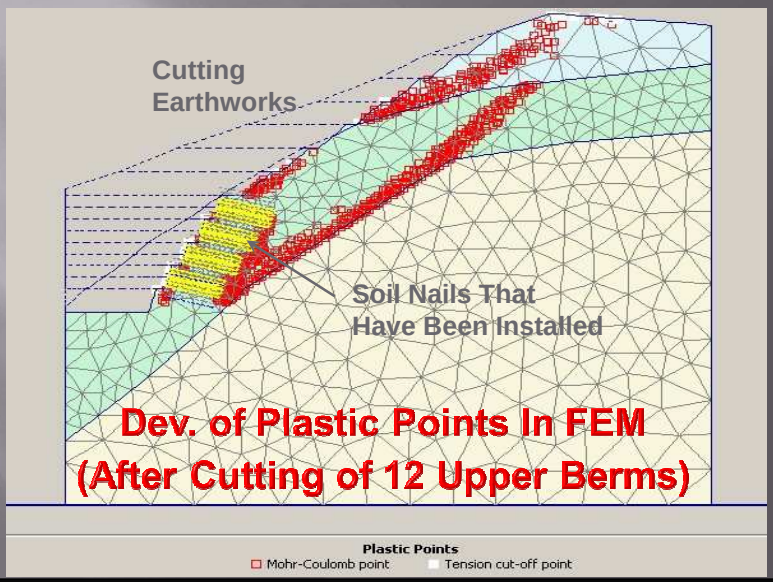
Finite Element Analyses



Finite Element Analyses



Finite Element Analyses



Findings

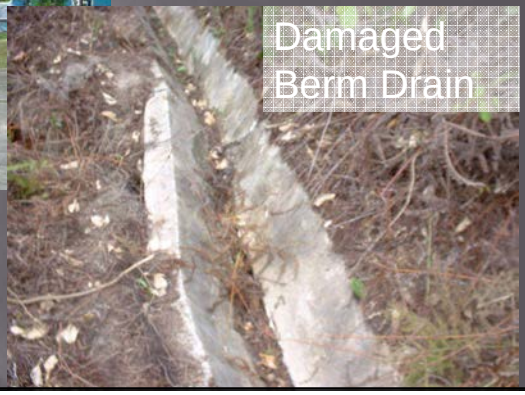
Possible Causes of Failure

- Steep upper cut slope of 1V:1H.
- Inadequate soil nail length (12m).
- Day-lighting relict geological structures of Grade III to V materials at the upper cut slope.
- Progressive failure have leaded to develop of a continuous shear surface.

D. Cut Slope Failure at Kuala Lumpur

Site Observations

Closed Drain at Toe of Slope



Damaged Berm Drain

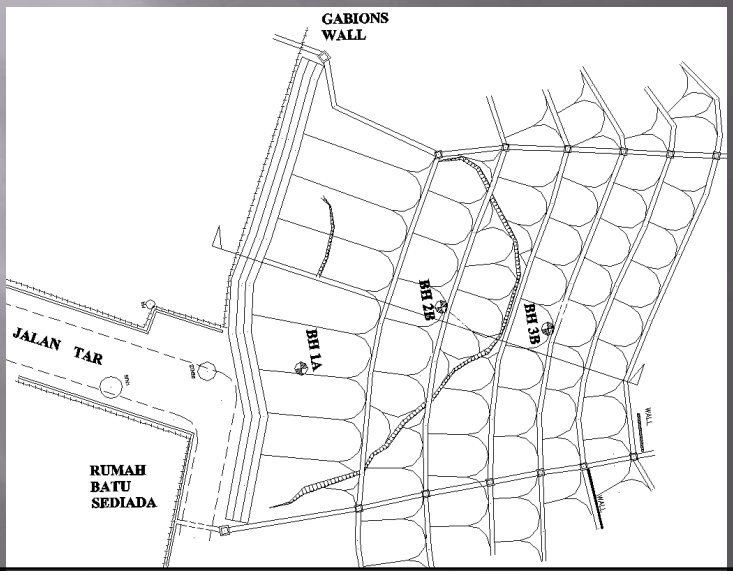
Site Background

- The cut slope with 6 berms was formed in 90s
- Slope gradient varies from 1V:1.72H (lowest berm) to 1V:1H (highest berm)
- RL75m to RL110m.
- Geology: Granite formation.
- Slope movement was detected in Nov 2002 and obvious tension cracks were found at the lowest three berms.

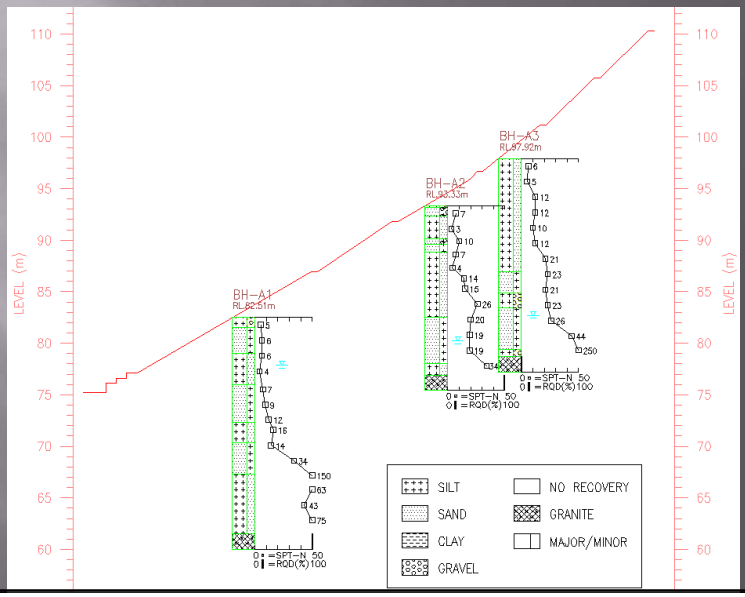
SI & Instrumentation

- SI and instrumentation for failure investigations:
- 3 boreholes
- 22 Mackintosh Probes
- 2 inclinometers
- 3 observation wells

SI & Instrumentation Layout Plan



Slope Profile



Laboratory Test Results

- 8 C.I.U. tests
- 2 Multiple Reversal Direct Shear Box Tests
- Interpreted Moderate conservative soil parameters:

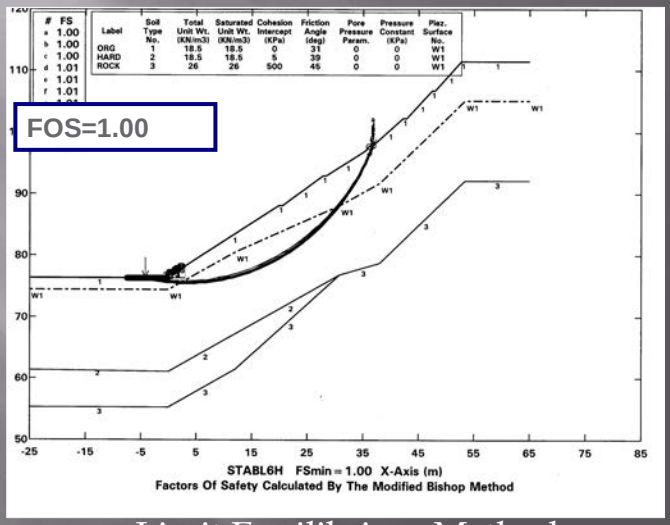
  $c' = 2kPa$, $\phi' = 31^o$

Instrumentation Results

- Max lateral movement (IN. 1)

  ~ 8mm with the depth of shear surface of about 7m tallies with stability analyses.

Slope Stability Analyses

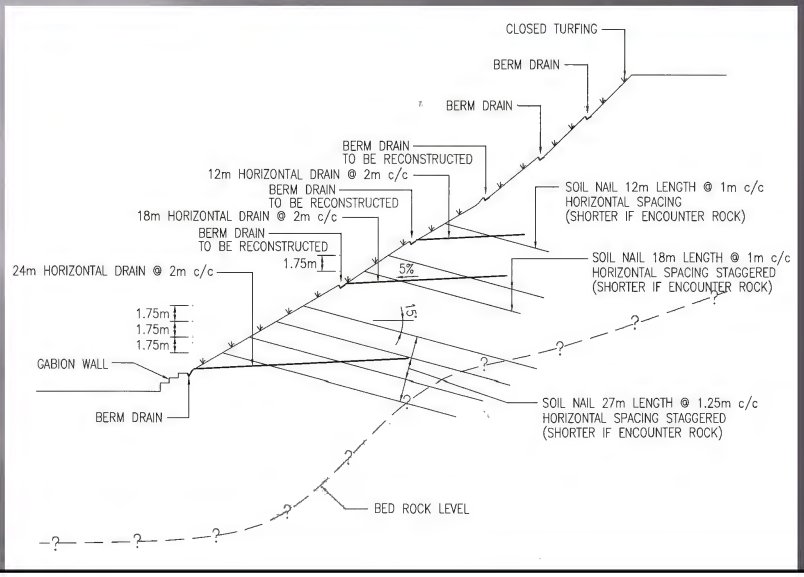


Limit Equilibrium Method

Proposed Remedial Works

- Installation of Soil Nails (12m,18m and 27m).
- Installation of horizontal drains.
- Repairing and re-construction of berm drains.

Proposed Remedial Works



Completed Soil Nailed Slope

Findings

Possible Causes of Failure

- The gradient of the cut slope is steep and is not stable in long term
- Slope strengthening works with installation of soil nails and subsoil drainage system have proven an effective solution to stabilise the distressed slope.

E. Fill Slope Failure at Salak Tinggi

Site Background

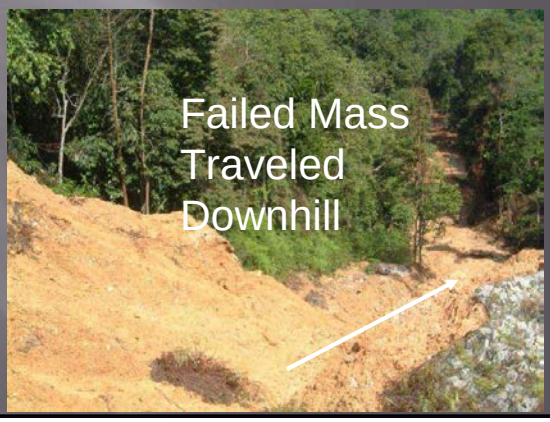
- Fill slope over a natural valley to form pipeline platform.
- Three berms slope : 20m height.
- Another three slopes on top of platform.
- Geology: Kenny Hill formation with interbedded sandstone and siltstone.
- Slope collapsed after heavy downpour.

Site Observations

- The platform of pipeline was saturated.
- Concrete drains were clogged.
- Debris, tree trunks and vegetations indicated surface runoff overflowed the platform and traveled downslope to valley.
- Failed mass traveled more than 120m downhill along valley.

Site Observations

- Bedrock was observed at certain parts, indicating the failure resembles a slide along the bedrock surface.



SI and Laboratory Tests

- 3 boreholes were sunk.
- Sandy material – weathering from sandstone.
- CIU tests.
- Interpreted shear strength: $c' = 2kPa$, $\phi' = 32^{o}$.

Probable Causes of Failure

- Valley terrain (Channelised runoff).
- Steep fill slope gradient – steepest gradient of 1V:1H.
- Marginal FOS when groundwater level rises near to ground surface.
- Poor drainage system lead to saturation and erosion.

Remedial Works

- Fill embankment over valley.
- Fill embankment comprises of :
  rock toe and seven berm slope (1V:2H).
- Provision of extensive subsoil drainage :
  French drain and drainage blanket.
- Upgrading and construction of new drainage system.


Failure Area
Construction of
Fill Embankment
Drainage
Blanket
Rock Toe
Rock Mattress
25 8 2003


25 11 2004

F. Soil Nailed Slope Failure at Pahang

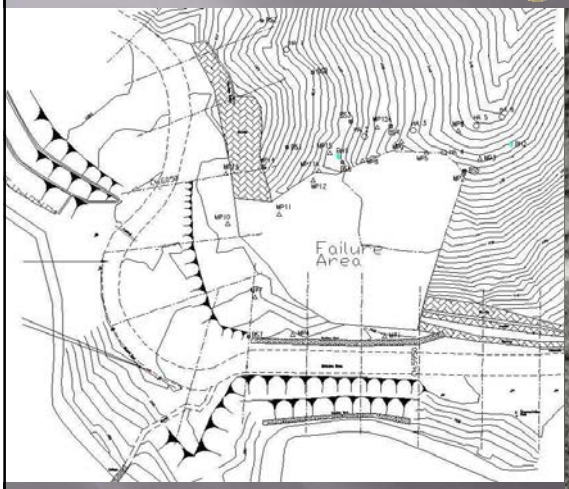
Site Observations

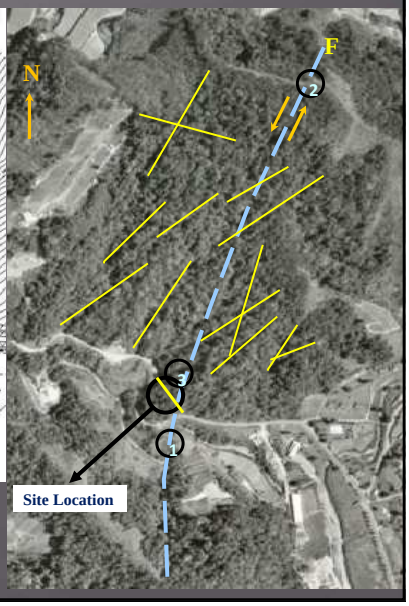
Soil nails hanging on failed slope

Site Background

- Geology: Granite and metamorphic rocks
- Slope with varying degrees of weathering: rock to soil.
- 7.5 berms of 4V:1H Soil Nailed Slope
- Maximum height = 45m
- 12m soil nail length at 1.5m c/c

Site Plan showing Failure Area



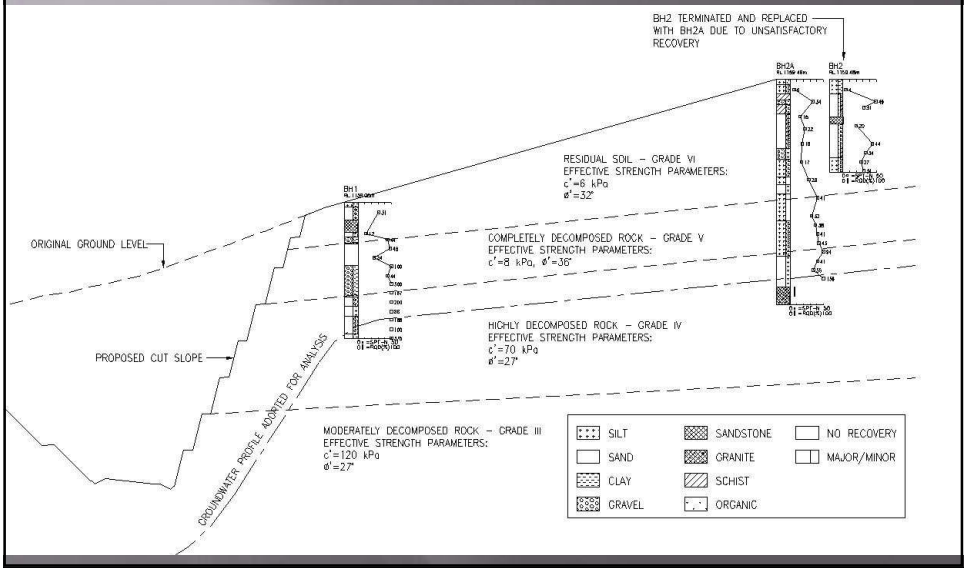


Interpretation of Lineament from Aerial Photograph
1-River running straight along fault line
2-dislodged ridge
3-site location

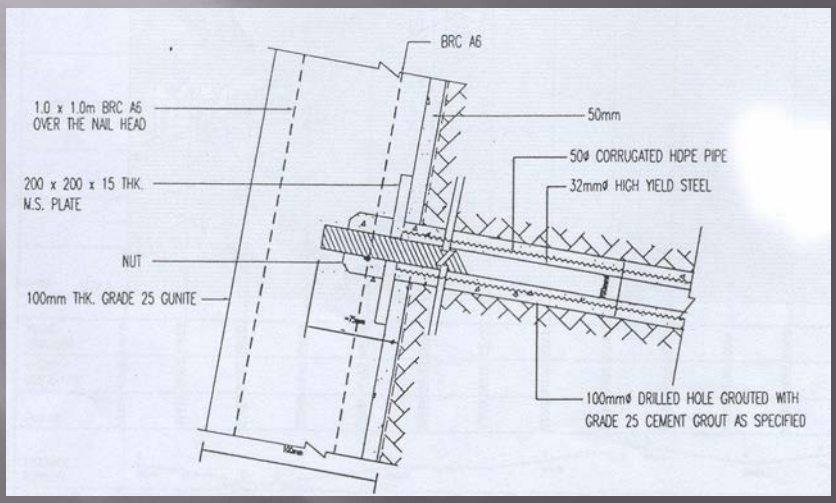
SI & Laboratory Works

- 2 boreholes at the slope.
- 3 Consolidated Isotropically Undrained Triaxial (C.I.U.) tests.
- 6 Direct Shear Box Tests.
- Hoek-Brown failure criteria for weathered rock mass.

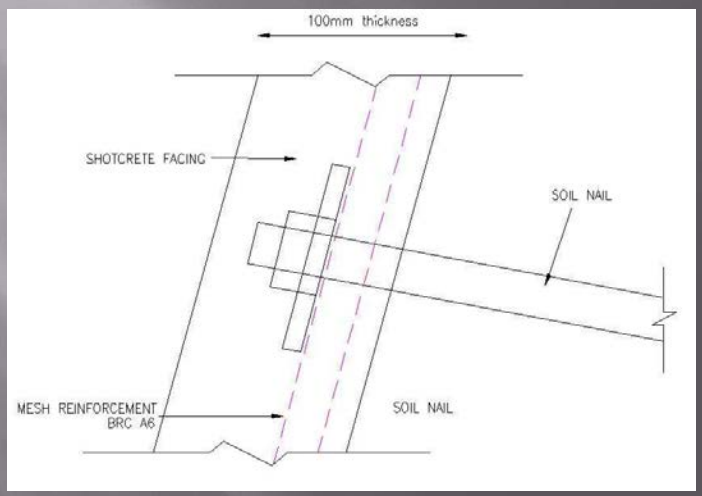
Interpreted Subsoil Profile



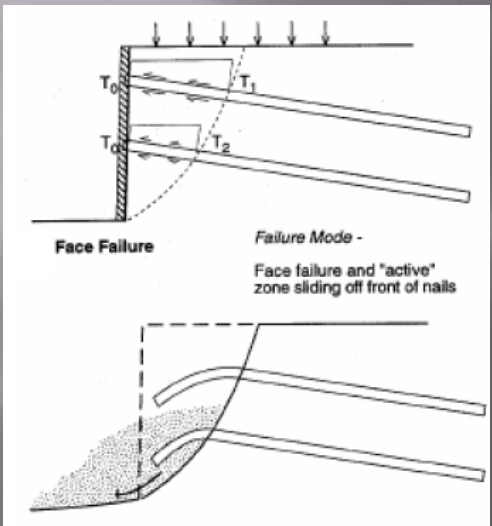
Shotcrete Facing as per Construction Drawing



Shotcrete Facing as Constructed at Site



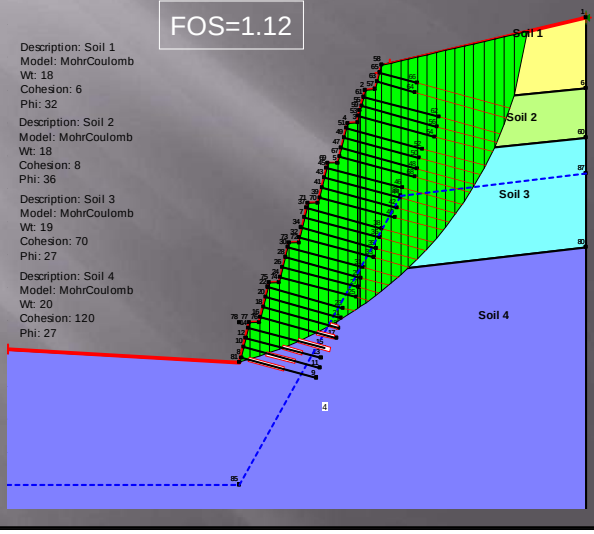
Facing Failure Mode for Soil Nailed Wall



Note: Figure extracted from "The Manual for Design and Construction of Soil Nail Walls" FHWA

Slope Stability Analysis

FOS=1.12



Findings

Possible causes of failure:

- Inadequate design of shotcrete facing of soil nailed slope.
- FOS against overall failure is inadequate and marginally stable.
- Rainfall/groundwater is not a triggering cause to failure.

Recommendation & Conclusion

- SI and geological mapping for slope are essential for slope design especially for soil nailed slopes.
- Design shall be reviewed during construction to verify the design assumptions especially subsoil profile.
- Progressive failure mechanism is prominent in high cut slope.

Recommendation & Conclusion

- 4 Failure modes (nail tendon failure, nail pull-out failure, facing failure) & overall failure shall be checked. Facing failure check is usually neglected.
- Facing design is critical especially when soil nailed slope is steep and high.
- Hoek-Brown failure criterion is appropriate for establishing engineering parameters of weathered rock mass of different formation in Malaysia.

G. Cut Slope Failure at Kedah

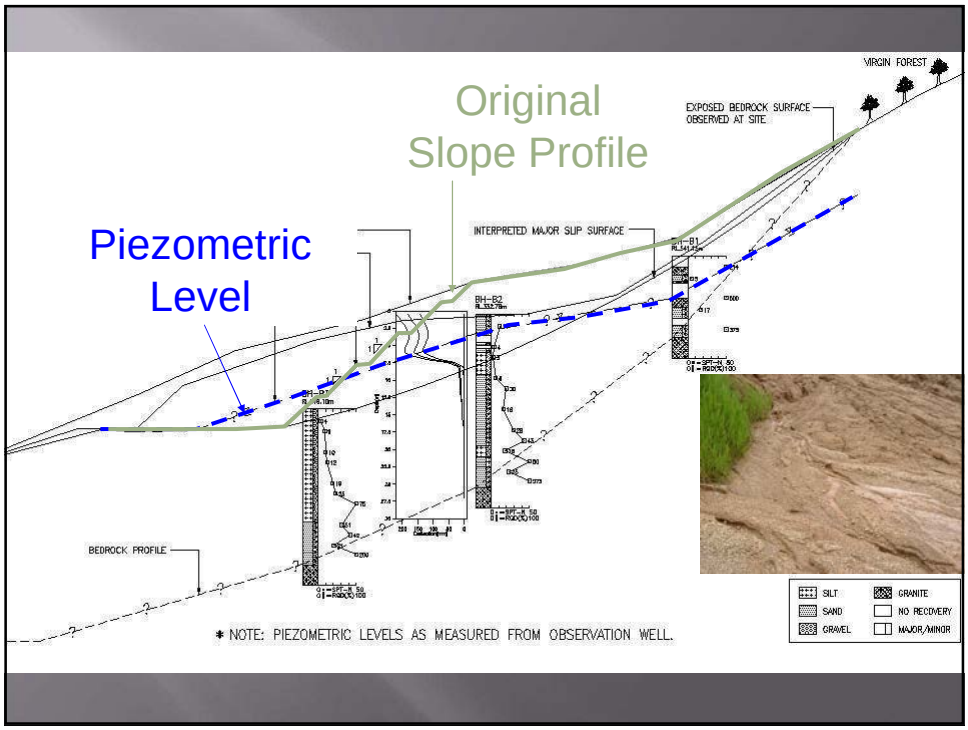
Site Background

- High ground RL300m – RL350m.
- Bedrock : Intact granite bedrock with prismatic feldspar phenocrysts.
- 5 to 6 berms : 27m height.
- Slope gradient 1V:1H.
- Two failure incidents:

  a. Localised stretch (50m).

  b. Major slope failure (250m) after 1 month following heavy rainfall.


Phenocryst


Original
Slope Profile
Piezometric
Level
VIRGIN FOREST
EXPOSED BEDROCK SURFACE
OBSERVED AT SITE
INTERPRETED MAJOR SLIP SURFACE
BEDROCK PROFILE
SILT
SAND
GRAVEL
GRANITE
NO RECOVERY
MAJOR/MINOR
* NOTE: PIEZOMETRIC LEVELS AS MEASURED FROM OBSERVATION WELL.

Laboratory Test Results

- Sandy material within failed mass.
- CIU test :
  a. $c_p' = 2kPa$, $\phi_p' = 30^o$
  b. $c'_{cr} = 0kPa$, $\phi'_{cr} = 28^o$
- Back Analysis :
  a. $c_m' = 0kPa$, $\phi_m' = 30^o$

Findings

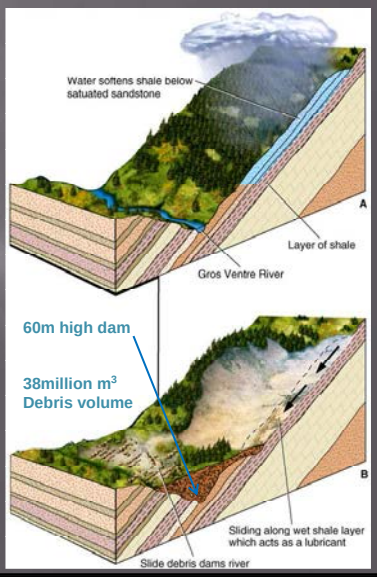
Possible causes of failure:

- FOS against overall failure indicates the slope is at the verge of failure for the water level measured during investigation.
- Rainfall leading to rise of groundwater is the triggering cause to failure.

H. Natural Slope Failure at Miri

Gros Vantre Slide, USA (23 June 1925)

- Sandstone and debris on Impermeable shale
- Saturation of sandstone and lubrication of shale
- Both reduced shear strength (added to shear force)
- Shear force overcomes shear strength
- Sandstone and debris slide

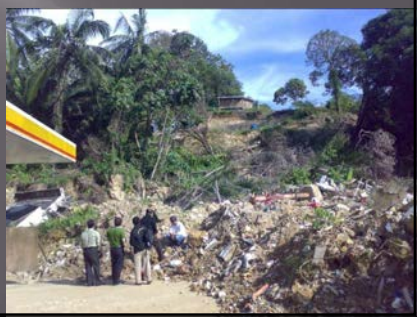


Canada Hill at Miri

Published: Friday January 16, 2009 MYT 3:54:00 PM

Two Indonesian workers killed in Miri landslide

MIRI: Two Indonesian workers were buried alive when tonnes of rocks and earth on Canada Hill collapsed on their housing quarters located at the foot of the hill fronting the city early Friday morning. The tragedy happened following several days of continuous heavy downpour that apparently loosened the earth on the 200-metre hill. The two men working in a petrol station in Miri were identified the name Endy and Kiong, in their early 20s, were living in a small concrete hut at the foot of the hill at the back of the Shell petrol station located along Jalan Bintang just near the city centre. The hut was completely buried during the landslide. The petrol station sustained serious structural damages.



Thank You