Slope Failures in Tropical Residual Soils

Presented by:

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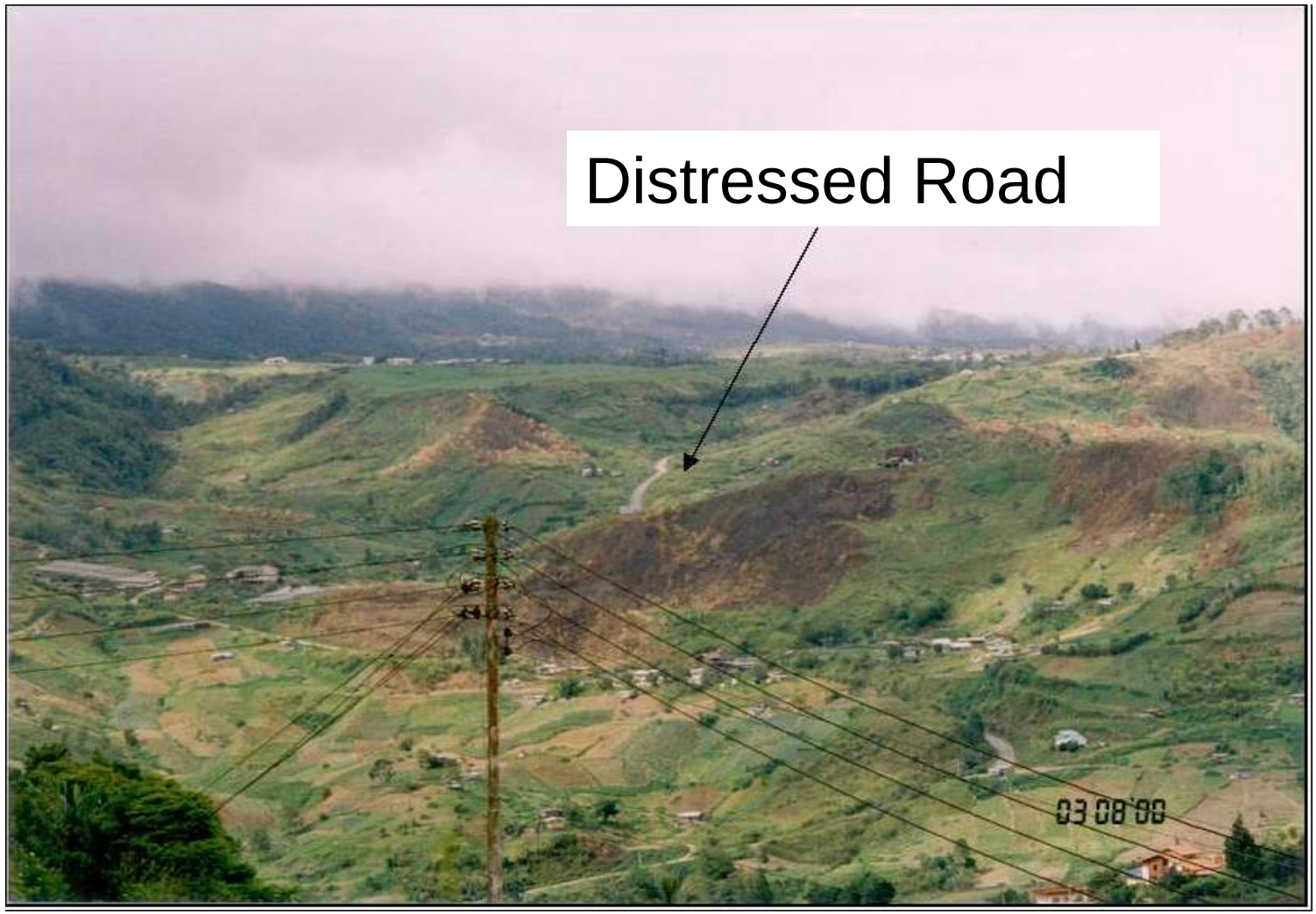
Highland Tower
1993

Debris Flow 2004

Contents

- Creep Movement of Slopes, Sabah.
- Cut Slope Failure in Skudai, Johor.
- Cut Slope Failure at Gua Musang, Kelantan.
- Cut Slope Failure at Kuala Lumpur.
- Filled Slope Failure at Salak Tinggi.

Creep Movement of Slope, Sabah



Ground Movements

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

Road Settlement

Site Background

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

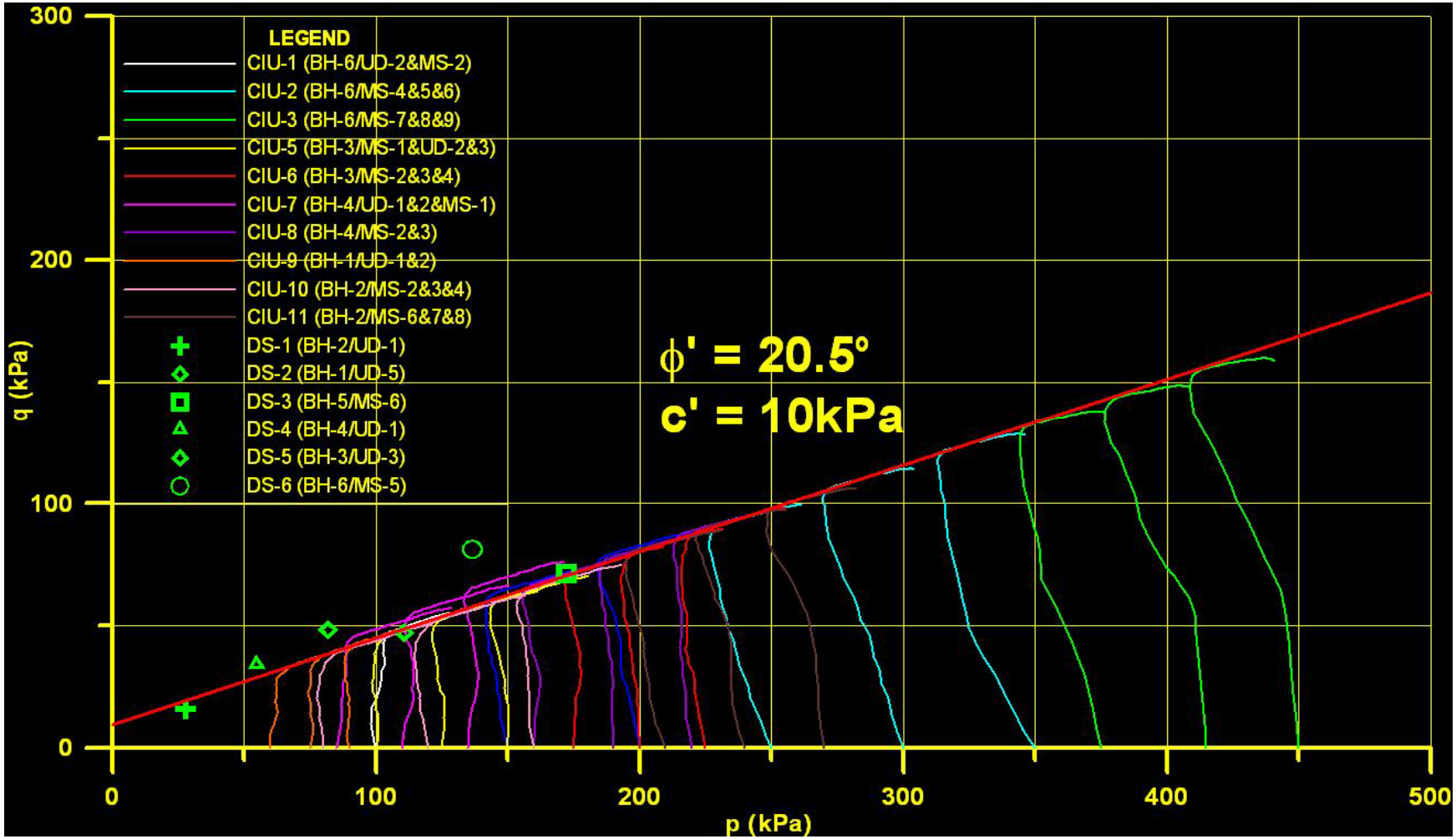

Granitic Boulder


Outcrop of Pinosuk Gravel

SI & Laboratory Testing

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

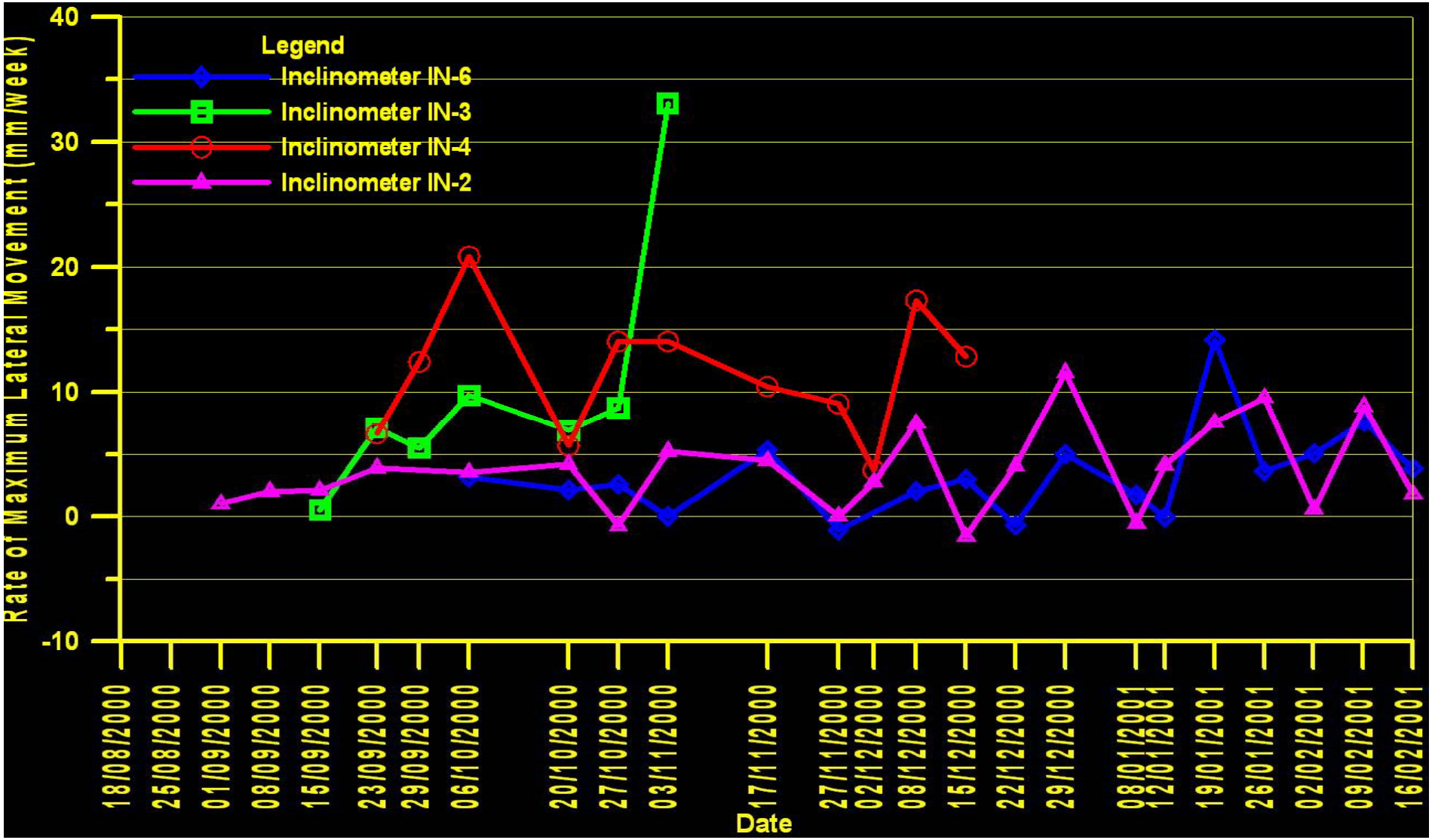
Shear Strength Test Results



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



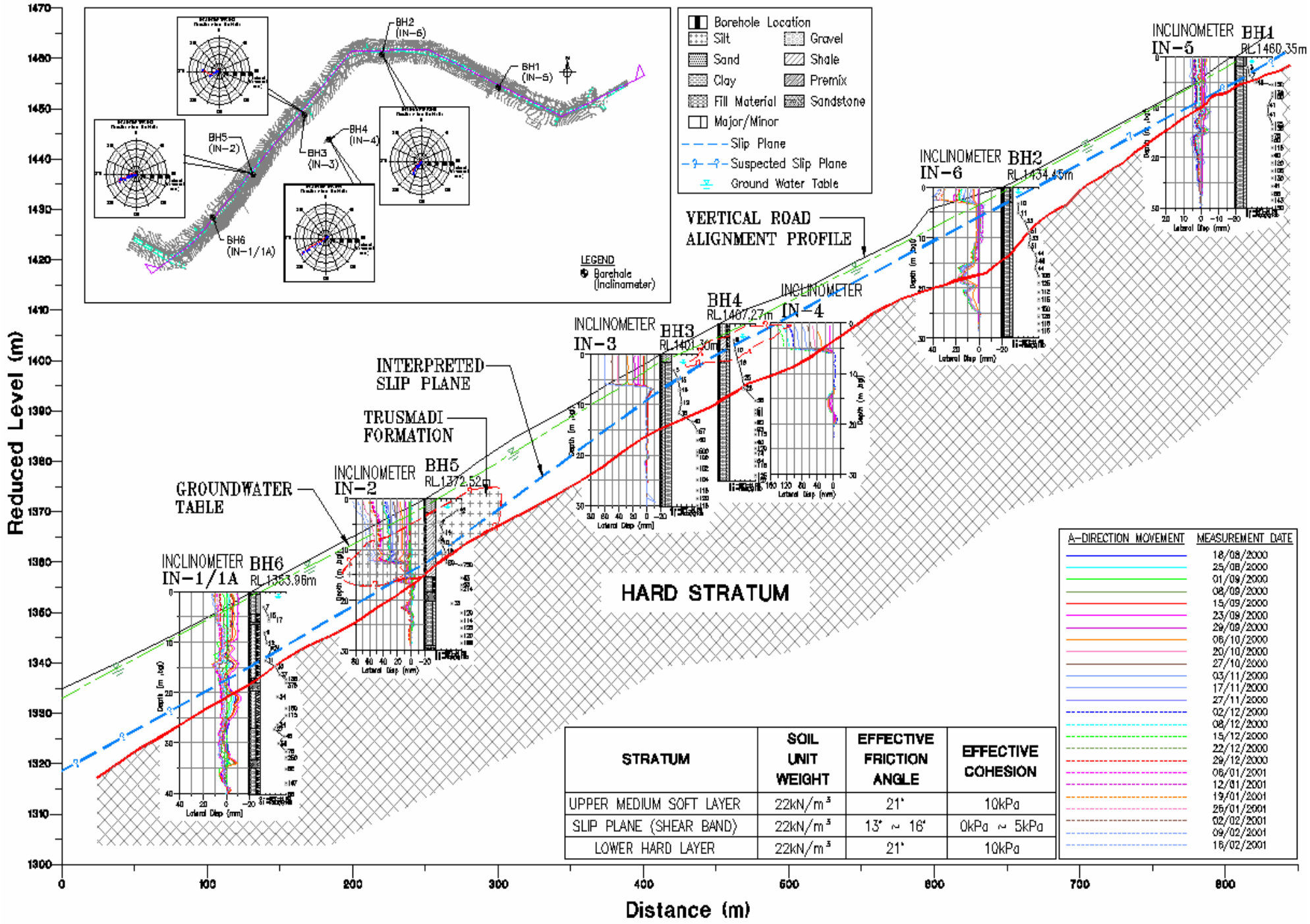
Engineering Assessment

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

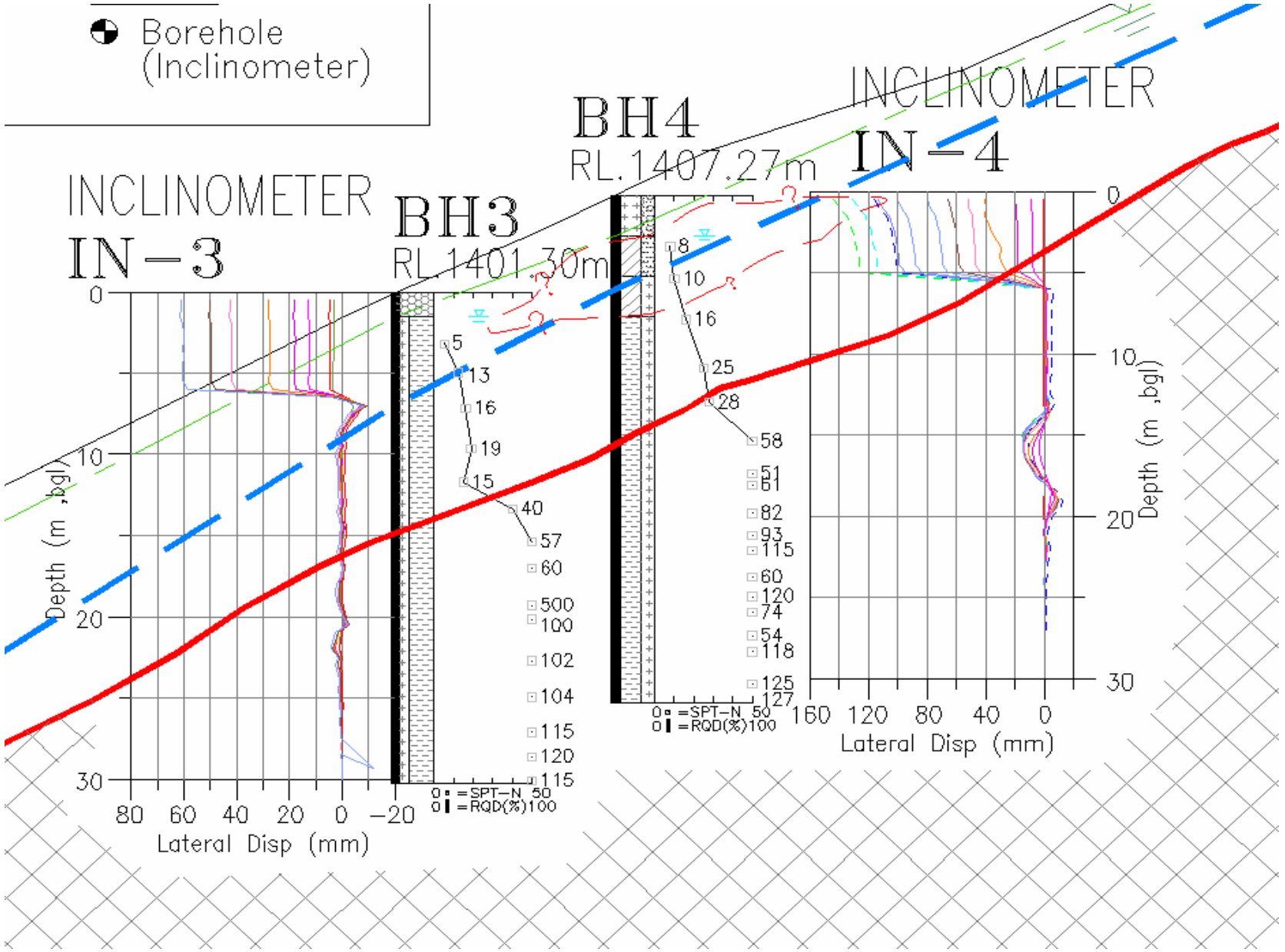
  ϕ'=13º~16º, c' = 0~5kPa

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.



STRATUM	SOIL UNIT WEIGHT	EFFECTIVE FRICTION ANGLE	EFFECTIVE COHESION
UPPER MEDIUM SOFT LAYER	22kN/m³	21°	10kPa
SLIP PLANE (SHEAR BAND)	22kN/m³	13° ~ 16°	0kPa ~ 5kPa
LOWER HARD LAYER	22kN/m³	21°	10kPa


Borehole
(Inclinometer)
INCLINOMETER
IN-3
BH3
RL.1401.30m
BH4
RL.1407.27m
INCLINOMETER
IN-4
Depth (m ,bgl)
Lateral Disp (mm)
0 =SPT-N 50
0 =RQD(%)100
5
13
16
19
15
40
57
60
500
100
102
104
115
120
115
8
10
16
25
28
58
51
61
82
93
115
60
120
74
54
118
125
127

Recommendations

- Carry out continuous sampling at shear plane to collect samples for testing.
- Carry out ring shear test or multiple reversal direct shear box test to determine residual strength.

Cut Slope Failure in Johor

Site Background

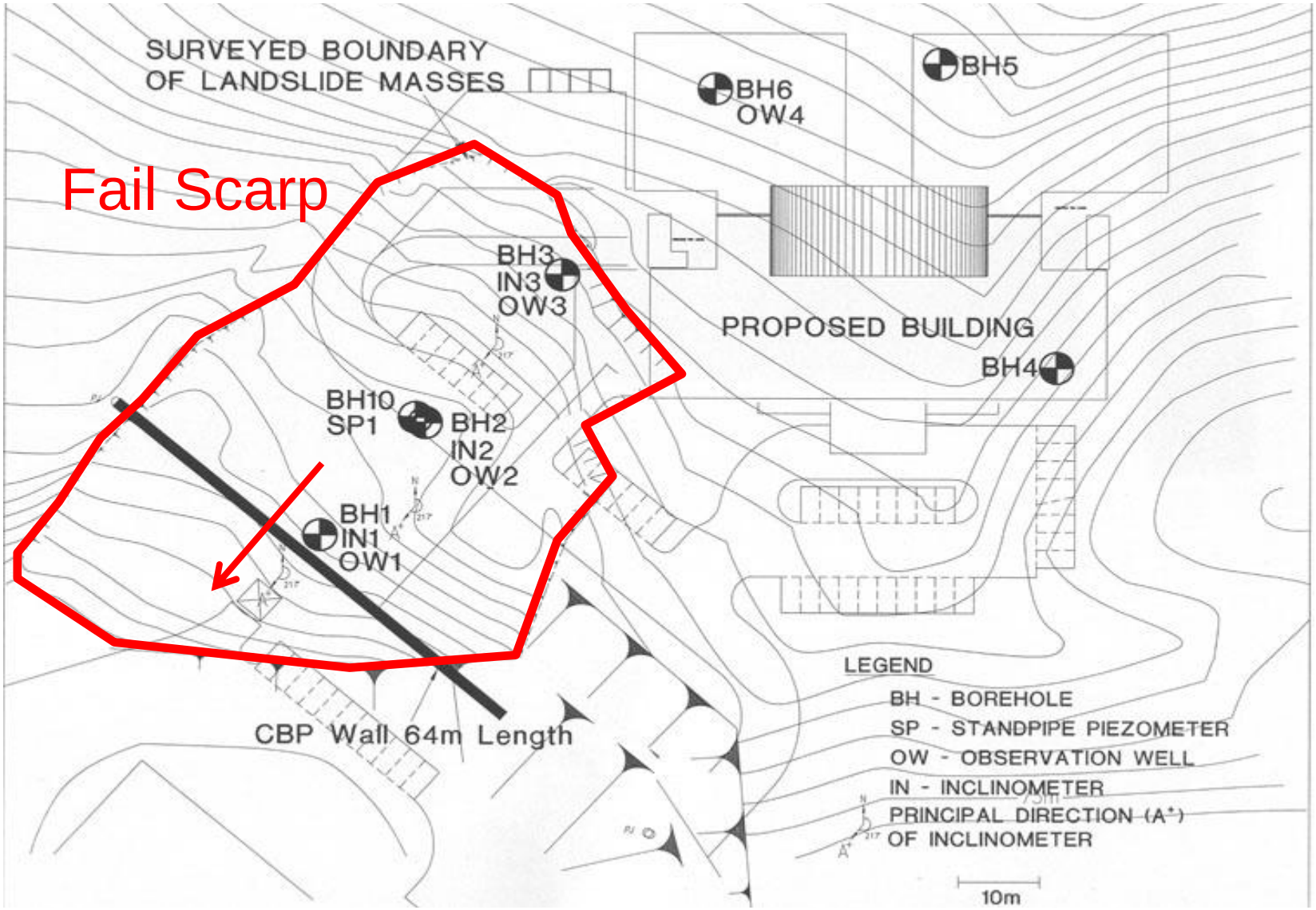
- RL54m to RL106m.
- Terrain : Slope.
- Geology: Mainly basic intrusive gabbro and intermediate intrusive.
- Two berms cut slope 1V:1.5H.
- Slope collapsed after heavy downpour.

Site Observations

SI and Instrumentations

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

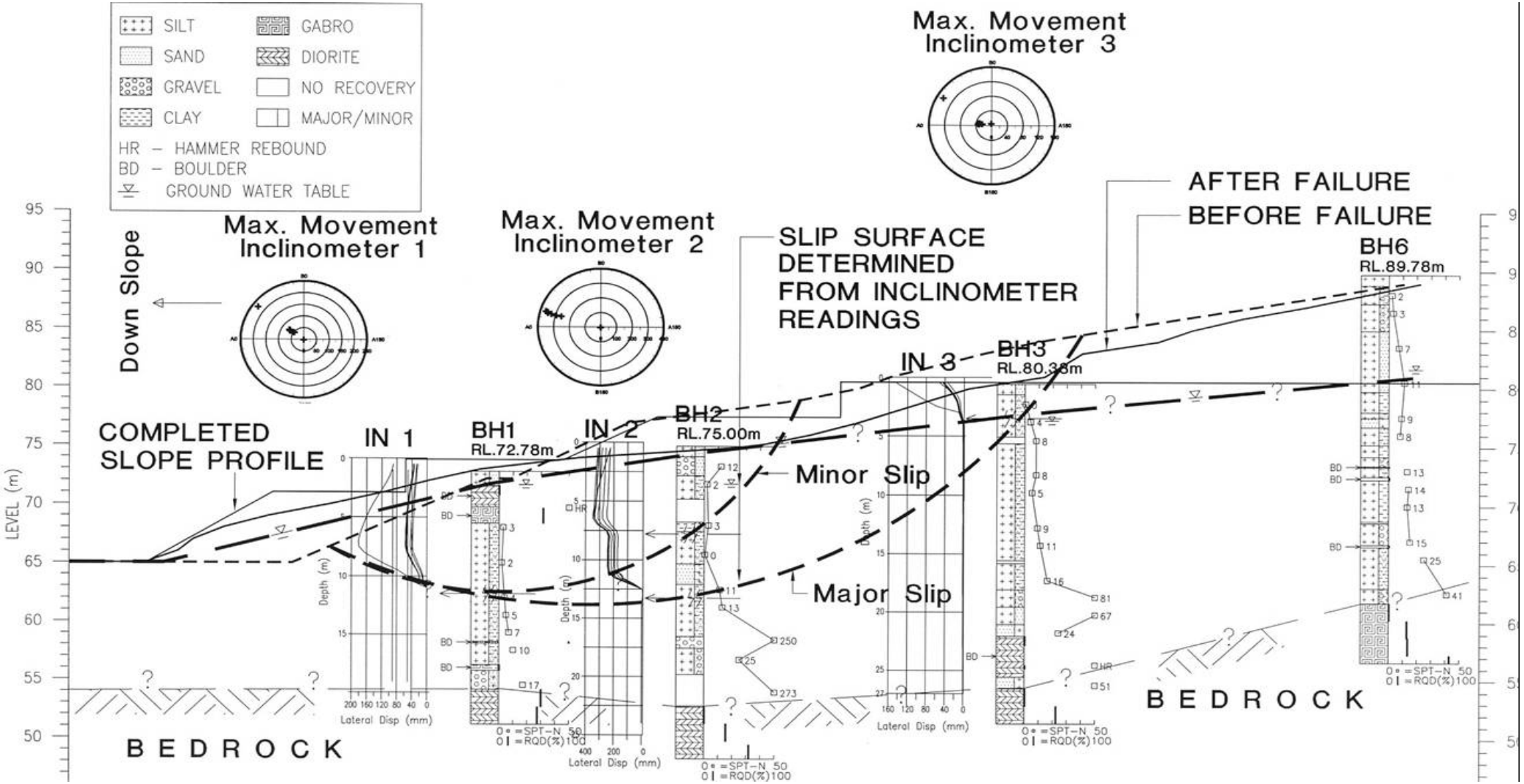
SI Layout Plan



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'=3.0kPa, ϕ'=29^o
- Direct Shear Box test : (fairly scattered)
  a. Peak strength – c'=15.7kPa, ϕ'=24^o
  b. Critical state strength – c'=5.9kPa, ϕ'=20^o

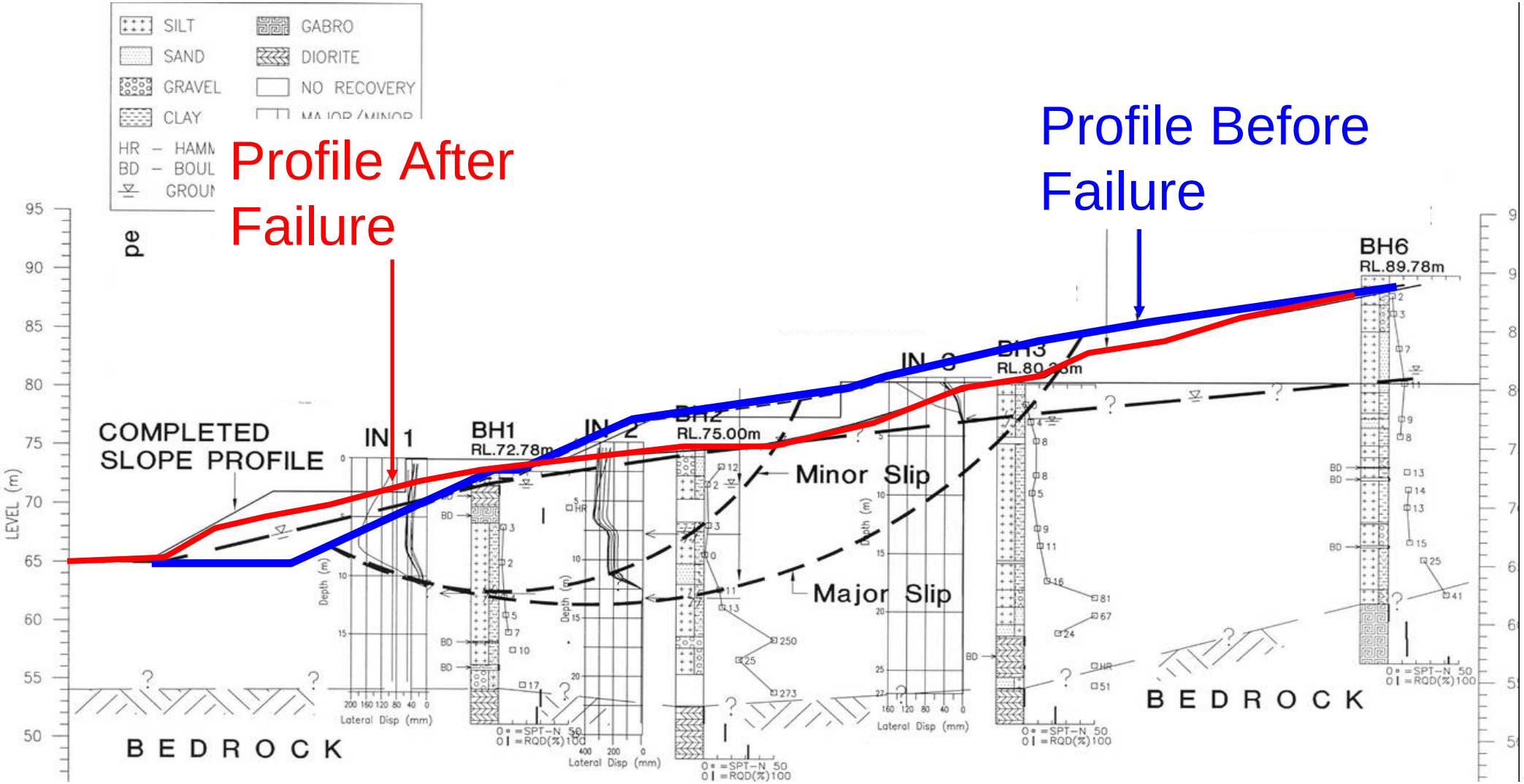
Back-Analysis

- 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 and 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. Critical state strength : c'=0 – 0.5 kPa, ϕ'=24^{o} – 25.9^{o}

  b. Residual strength : c'=0 – 0.5 kPa, ϕ'= 14.4^{o} – 15^{o}

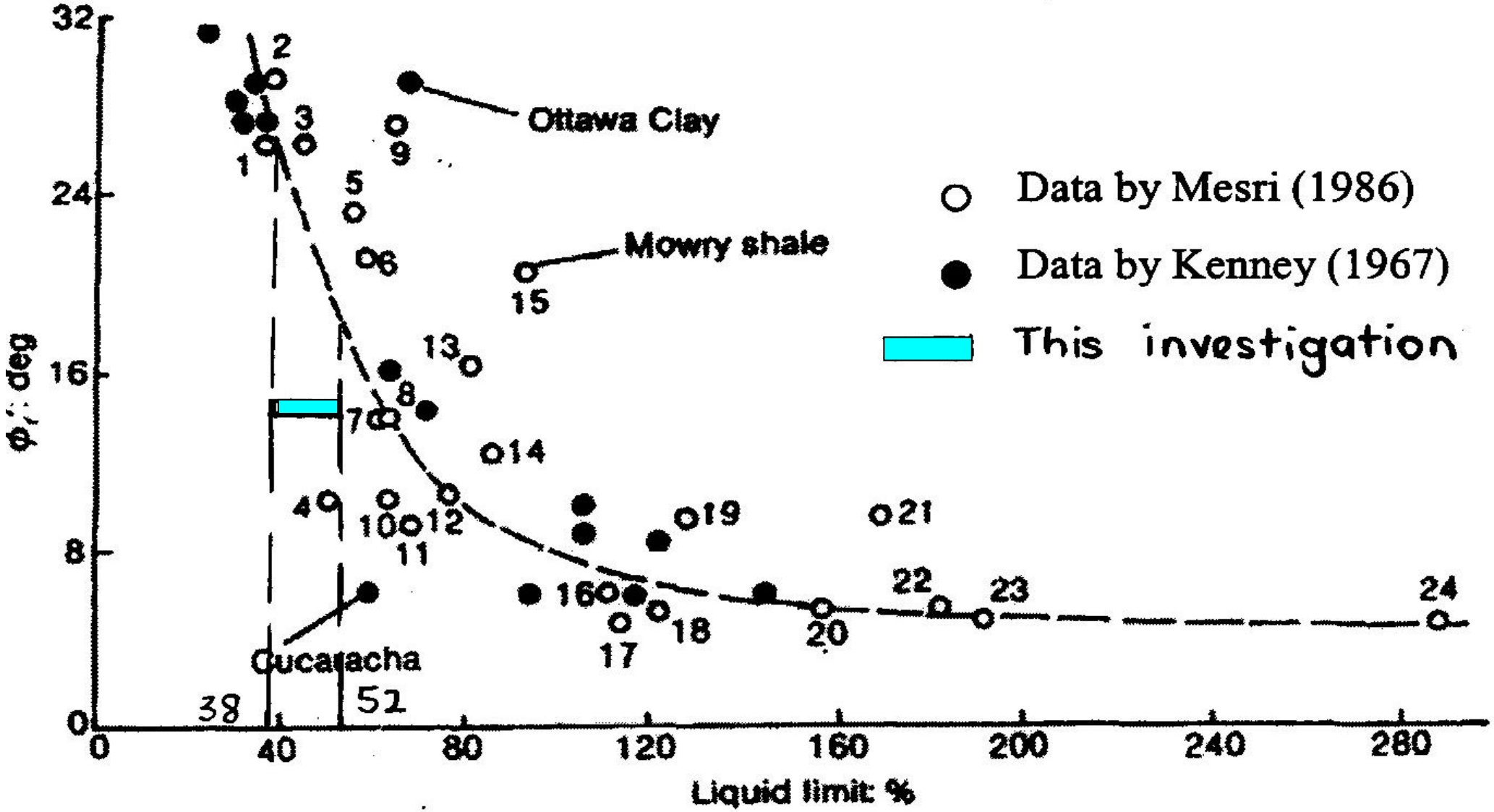
Residual Strength

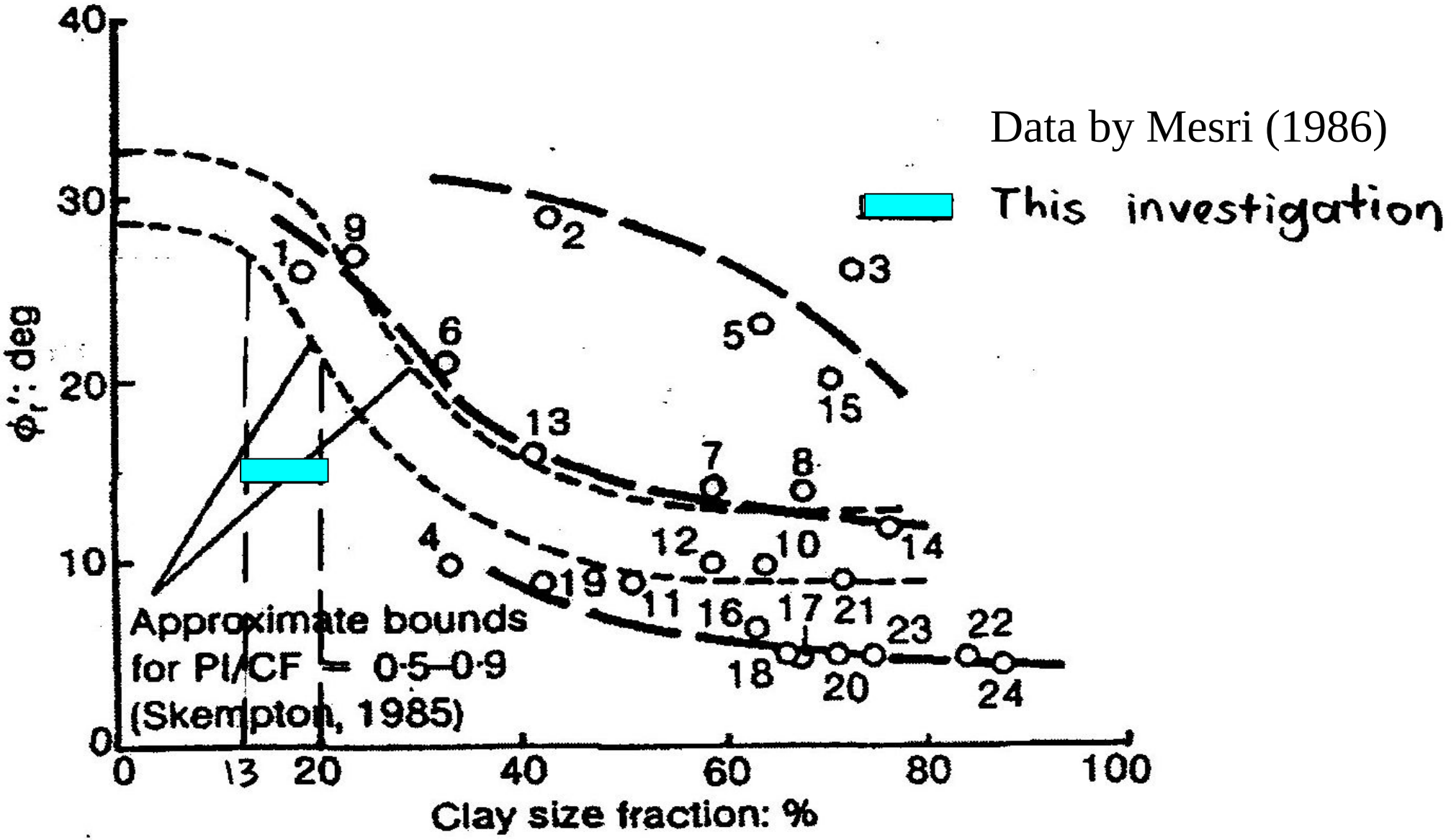
- Comparisons with literature:

  a. Residual friction angle – Liquid Limit.

  b. Residual friction angle – Clay size fraction.

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


32
24
16
8
0
φ', deg
0
40
80
120
160
200
240
280
Liquid limit %
Ottawa Clay
Mowry shale
Cucaracha
38
52
Data by Mesri (1986)
Data by Kenney (1967)
This investigation


Data by Mesri (1986)
This investigation
ϕ_r': deg
Clay size fraction: %
Approximate bounds
for PI/CF = 0·5–0·9
(Skempton, 1985)
0
10
20
30
40
0
13
20
40
60
80
100

Findings and Recommendations

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

Cut Slope Failure at Gua Musang, Kelantan

Site Observations

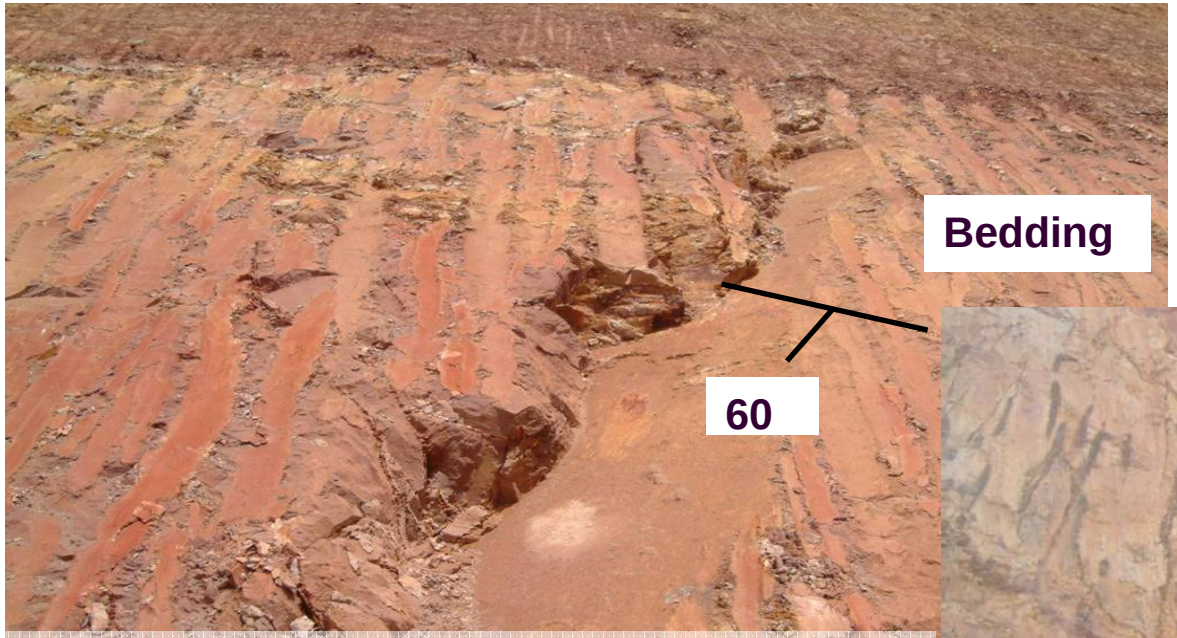
Site Background

- 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 which 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



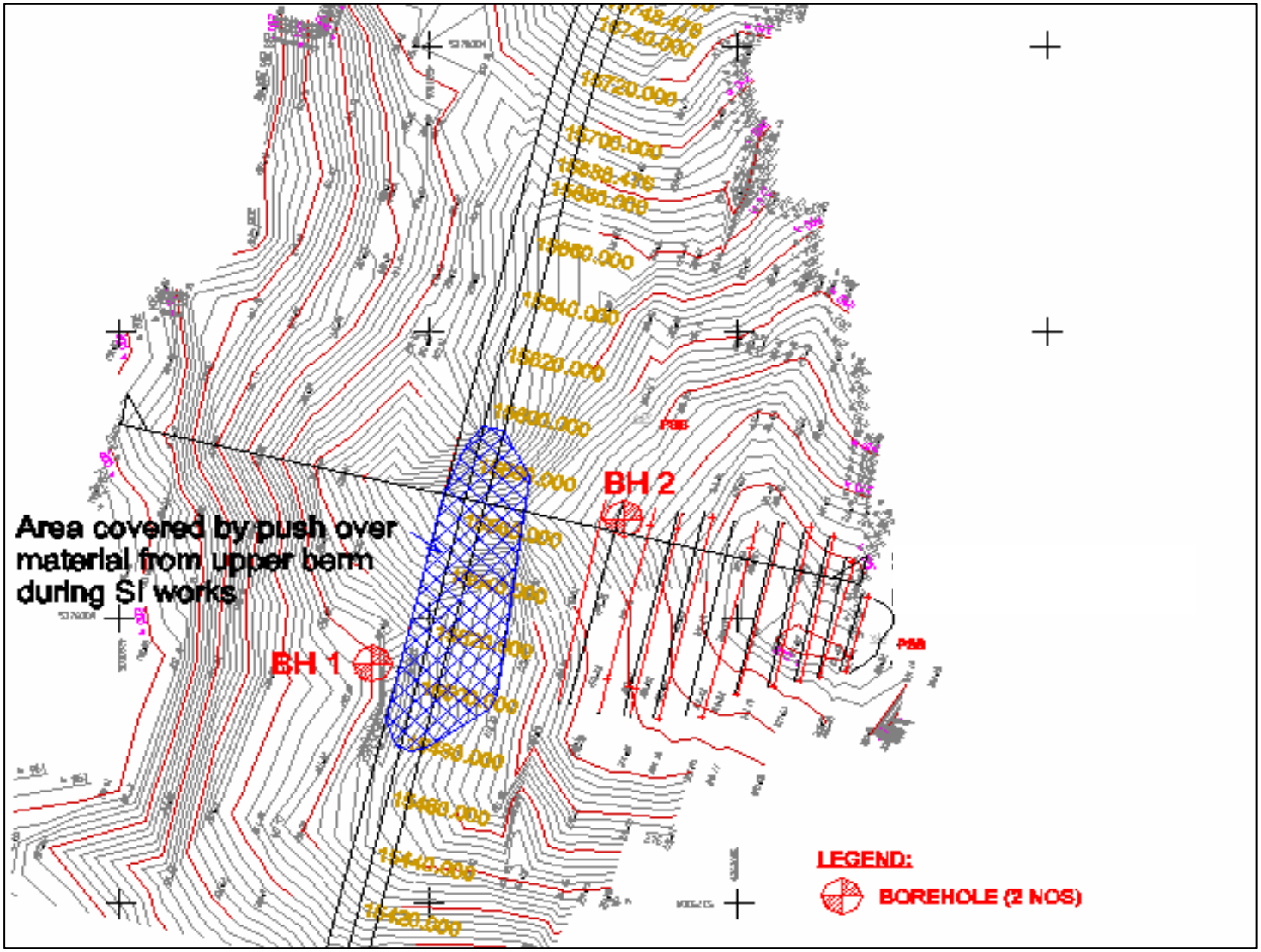
Bedding of Cut Slope Day-lighting Towards Main Road

Joints with Infilling Materials

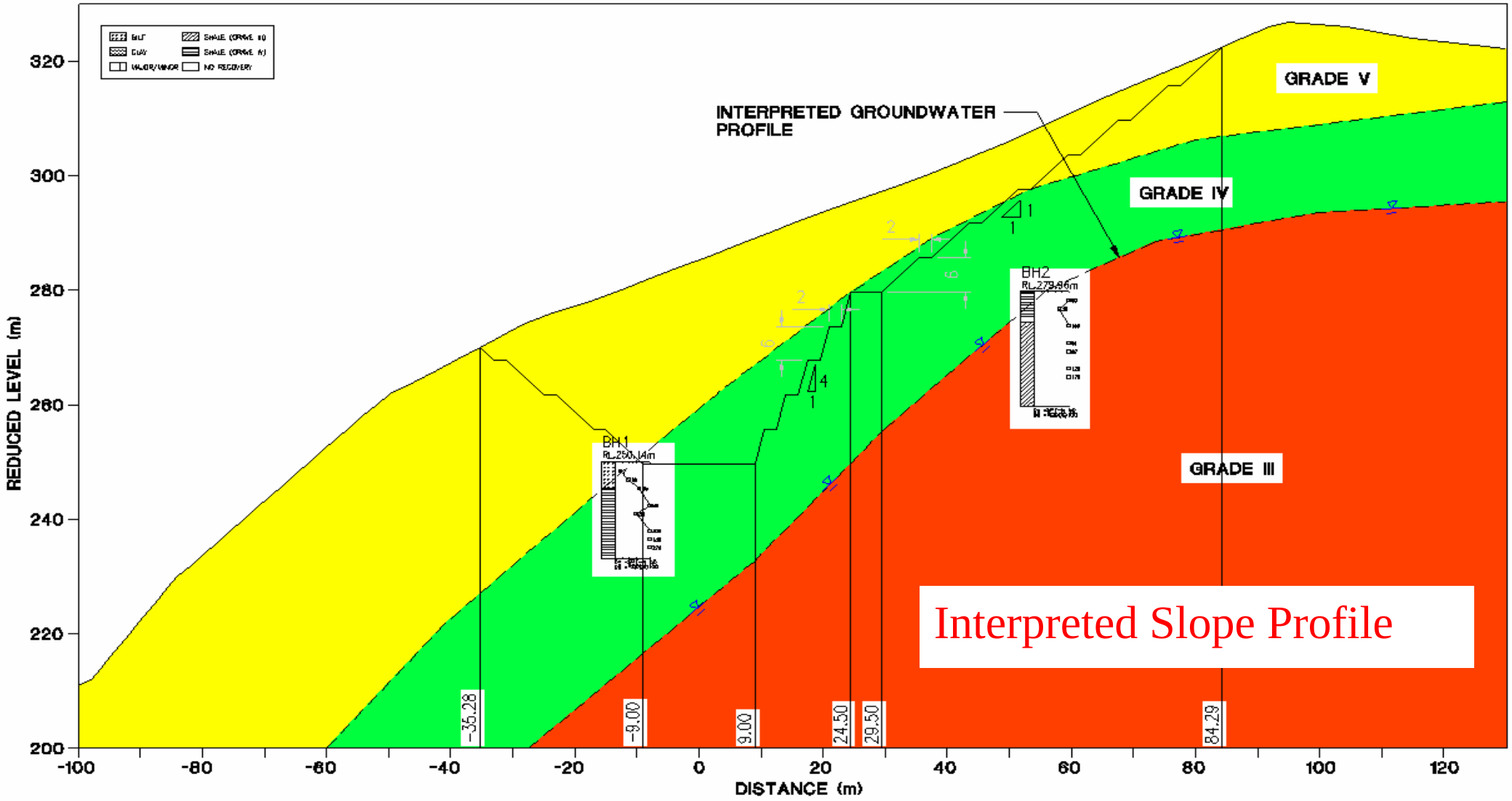
SI & Laboratory Works

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

SI Layout Plan

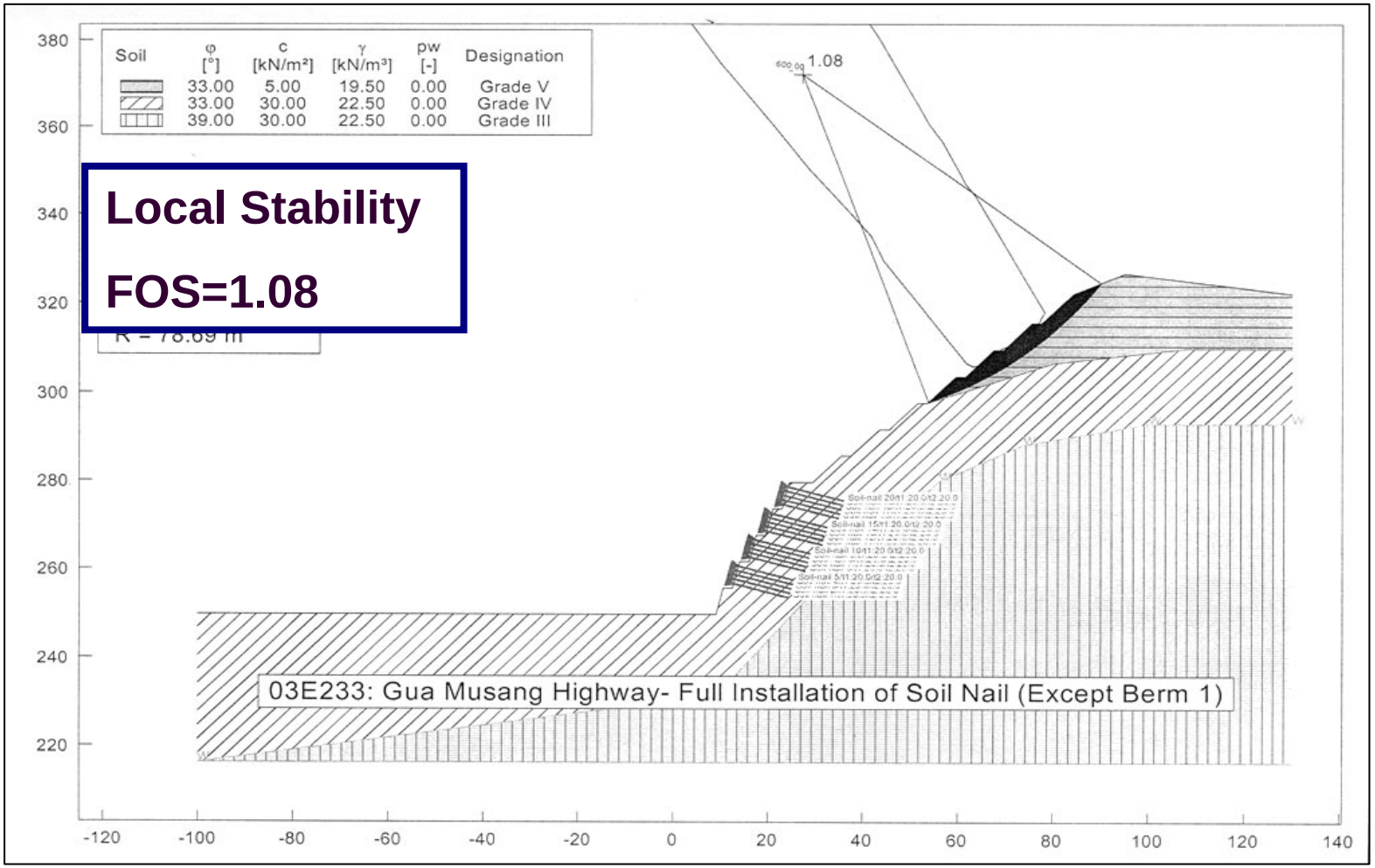


Slope Profile



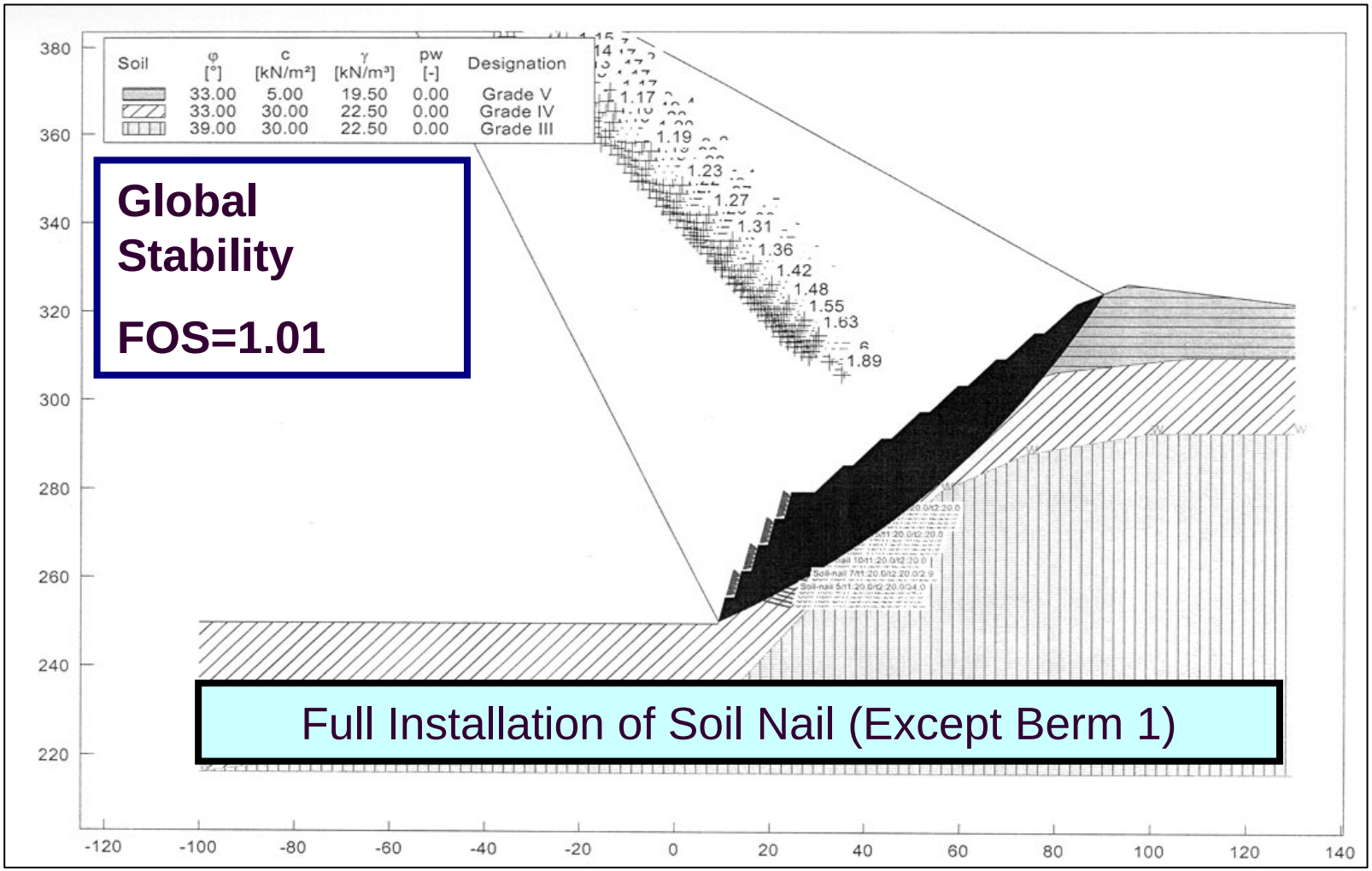
Engineering Assessment

Slope Stability Analyses



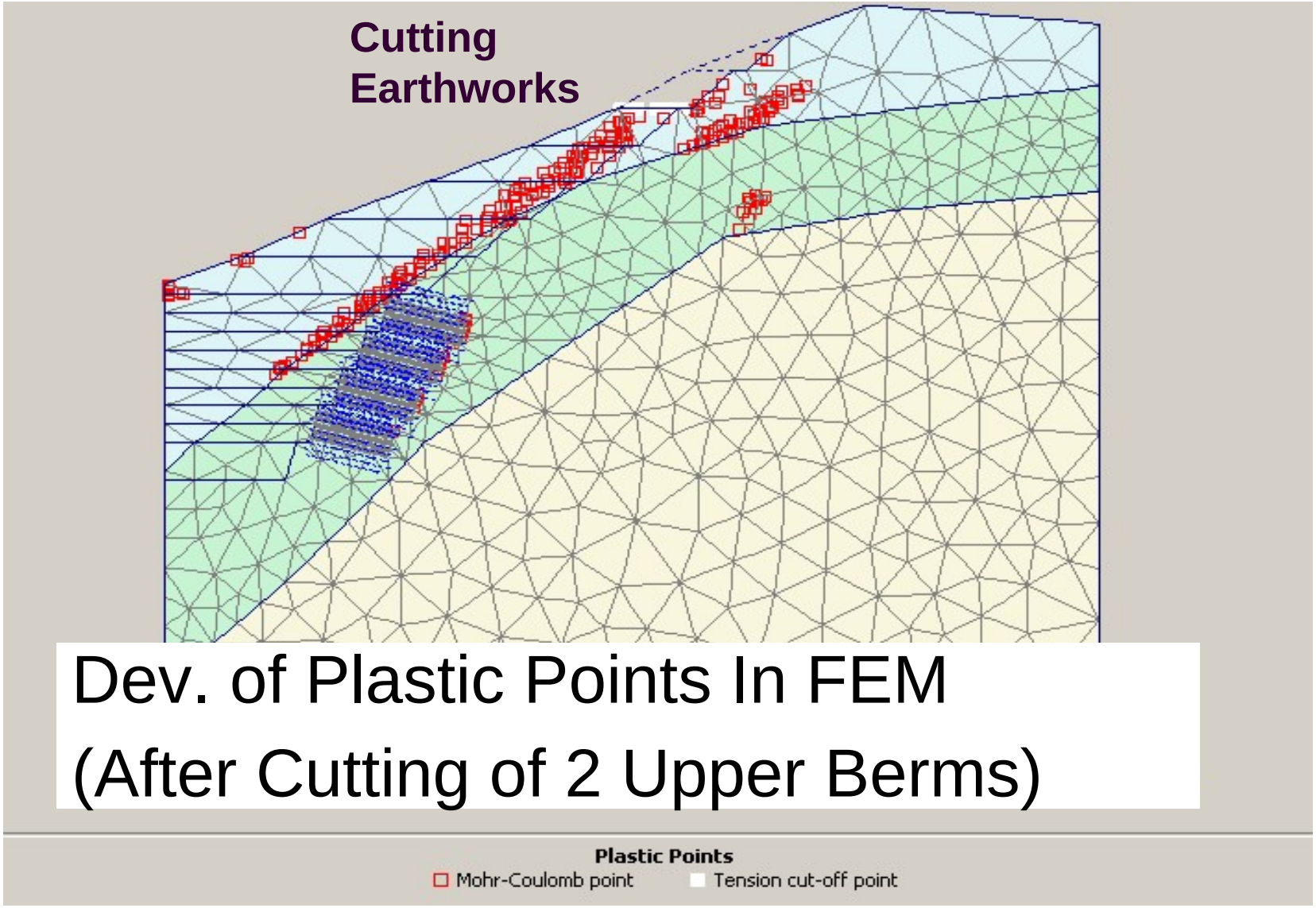
Limit Equilibrium Method

Slope Stability Analyses



Limit Equilibrium Method

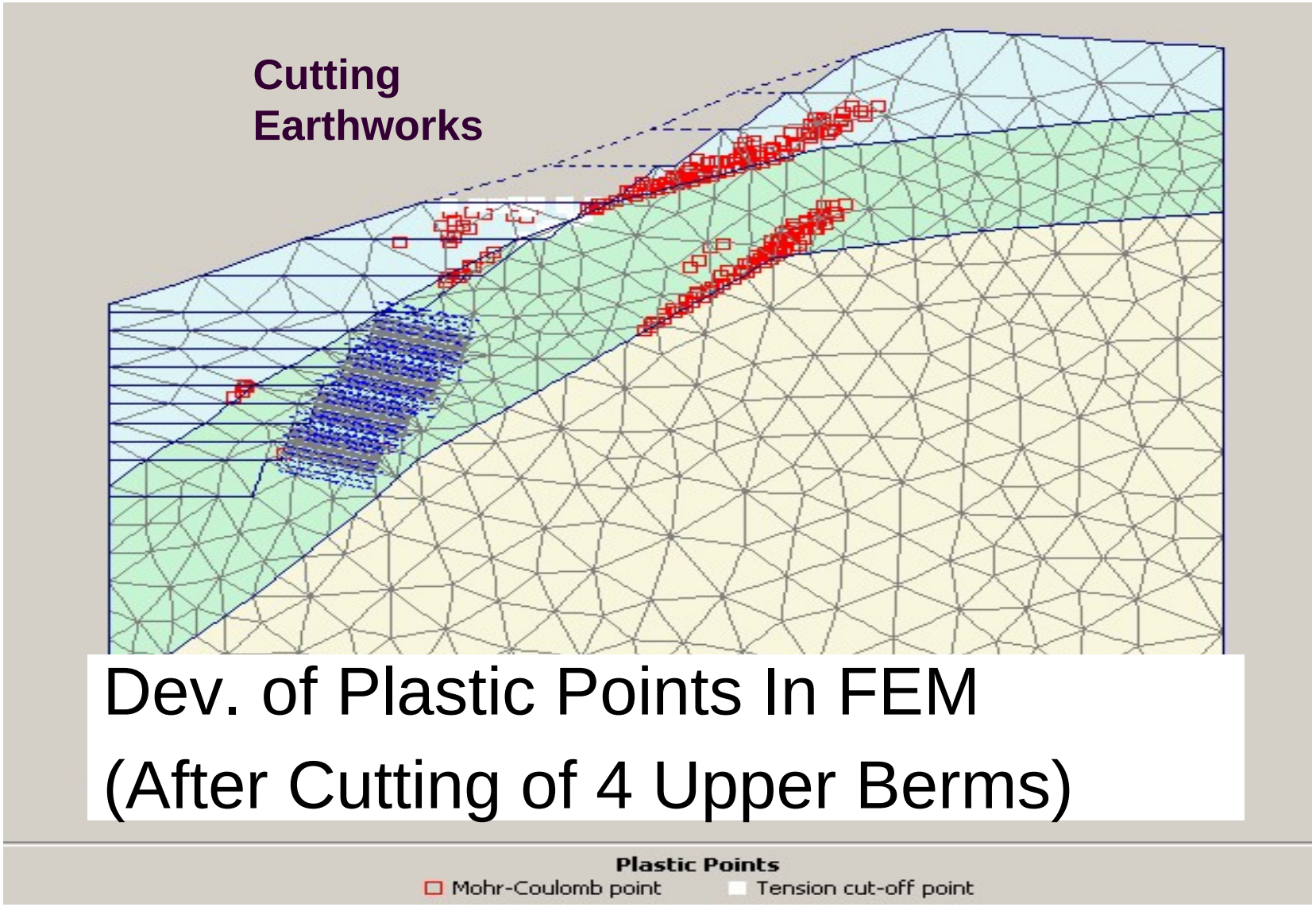
Finite Element Analyses



Dev. of Plastic Points In FEM

(After Cutting of 2 Upper Berms)

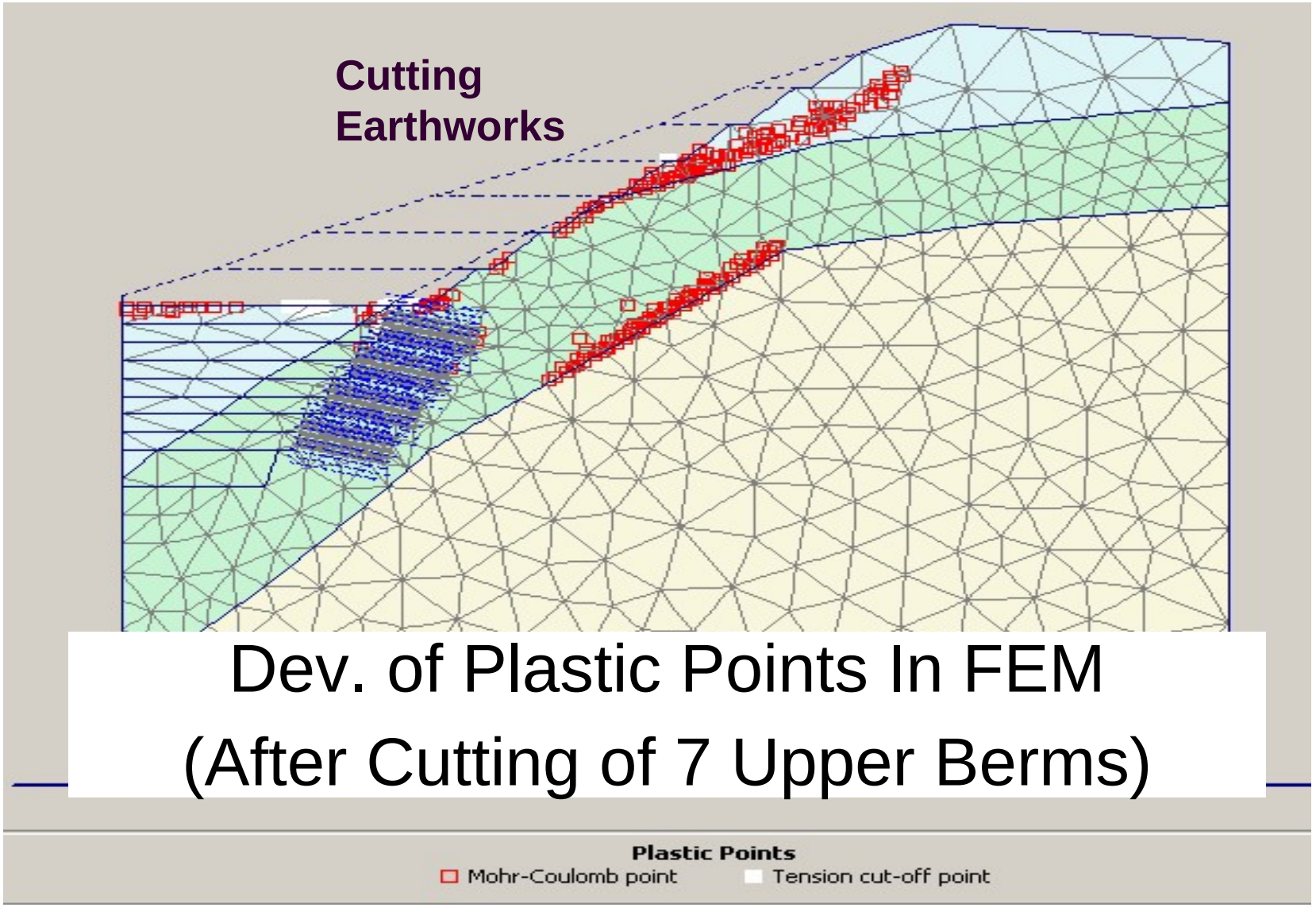
Finite Element Analyses



Dev. of Plastic Points In FEM

(After Cutting of 4 Upper Berms)

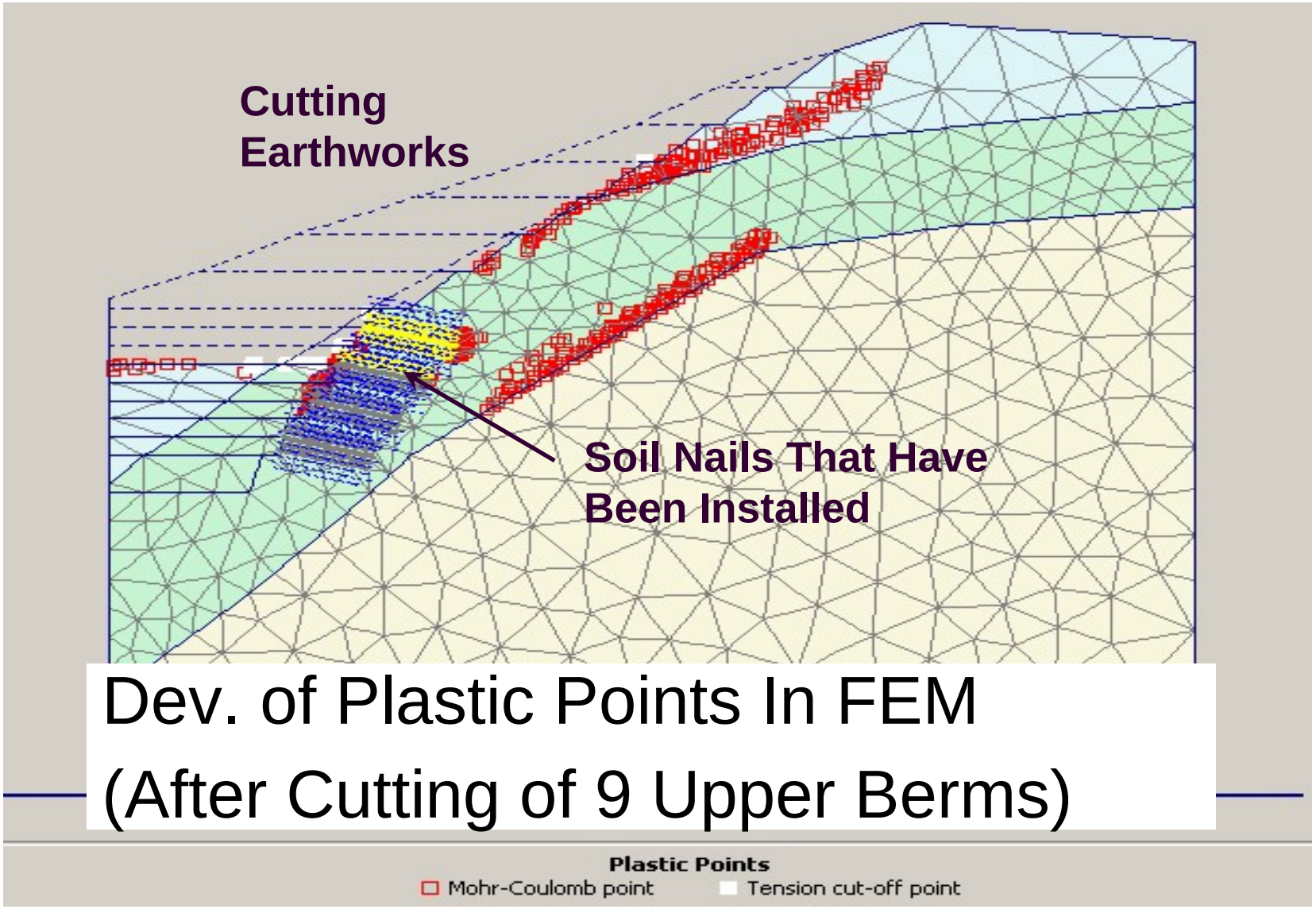
Finite Element Analyses



Dev. of Plastic Points In FEM

(After Cutting of 7 Upper Berms)

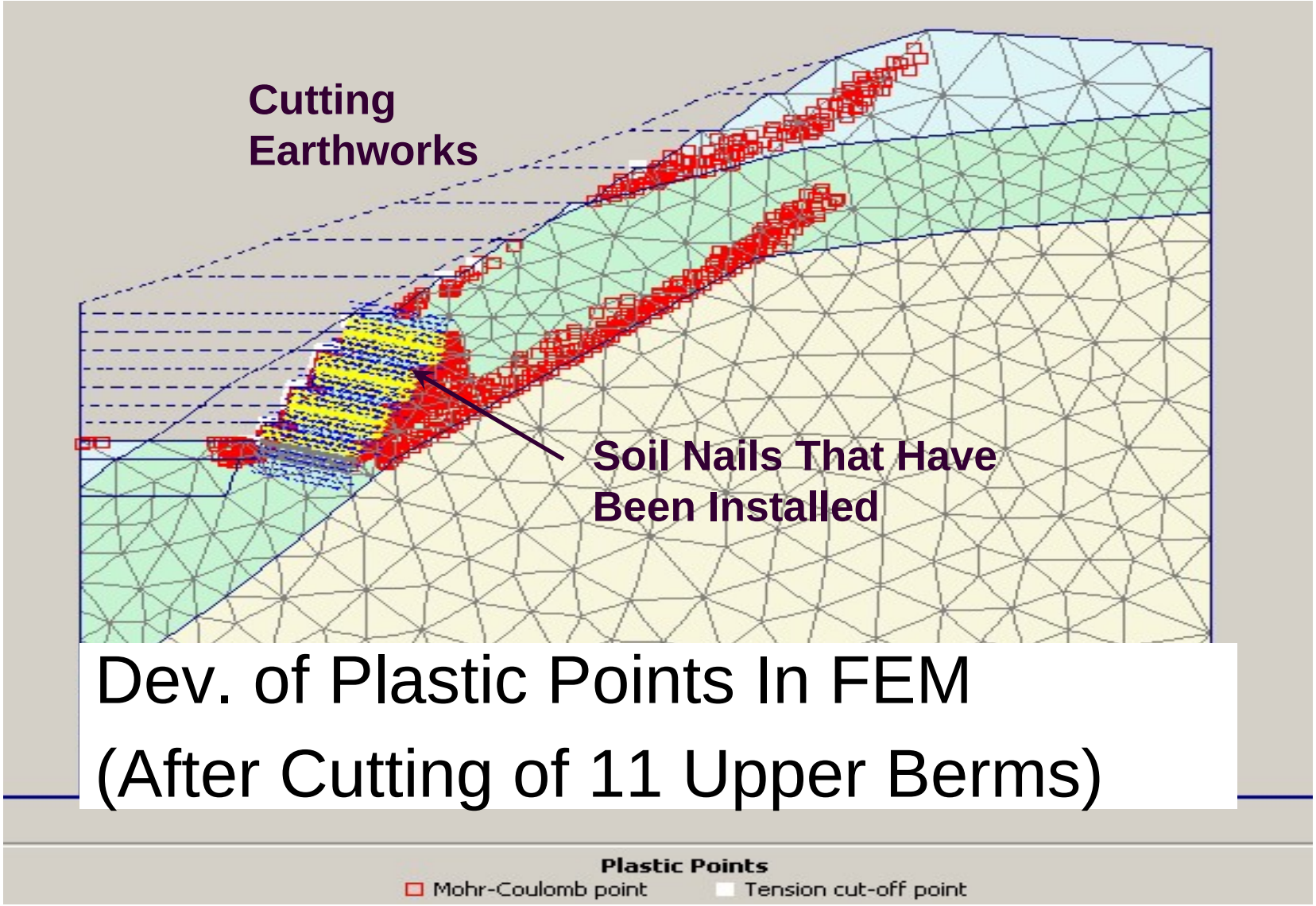
Finite Element Analyses



Dev. of Plastic Points In FEM

(After Cutting of 9 Upper Berms)

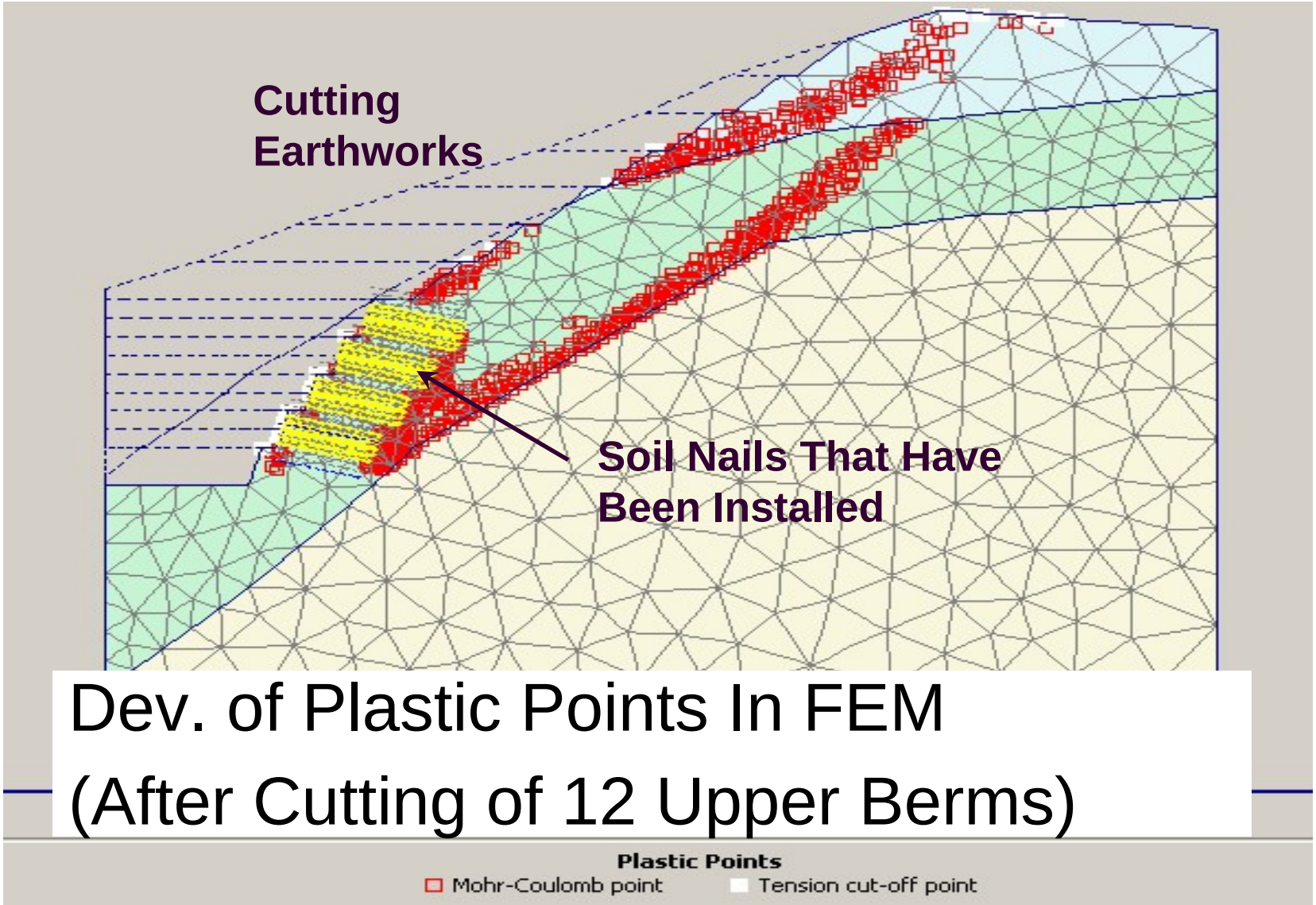
Finite Element Analyses



Dev. of Plastic Points In FEM

(After Cutting of 11 Upper Berms)

Finite Element Analyses



Dev. of Plastic Points In FEM

(After Cutting of 12 Upper Berms)

Findings

Possible Causes of Failure

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

Cut Slope Failure at Kuala Lumpur

Site Observations

Closed Drain at
Toe of Slope

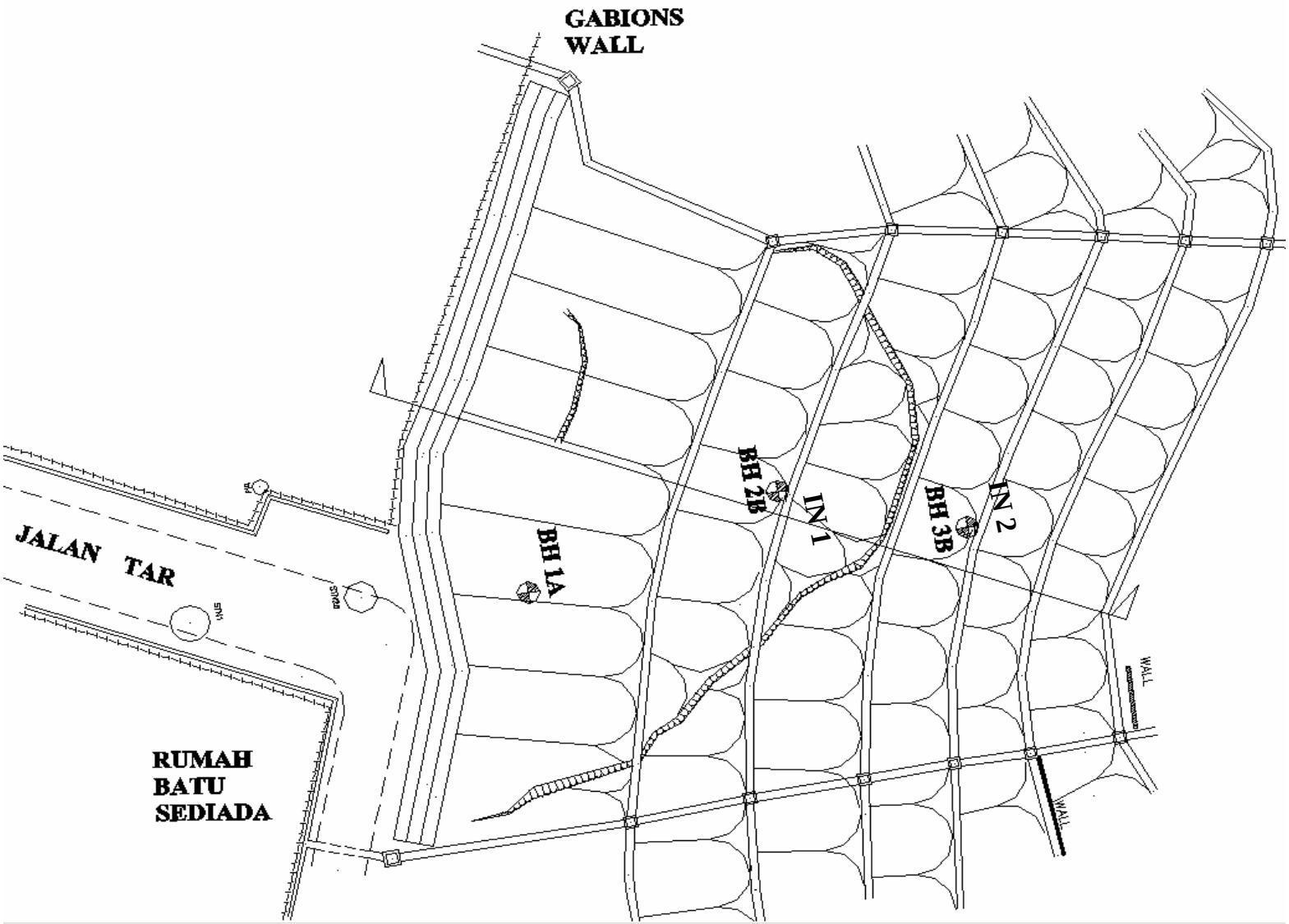
Site Background

- 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.

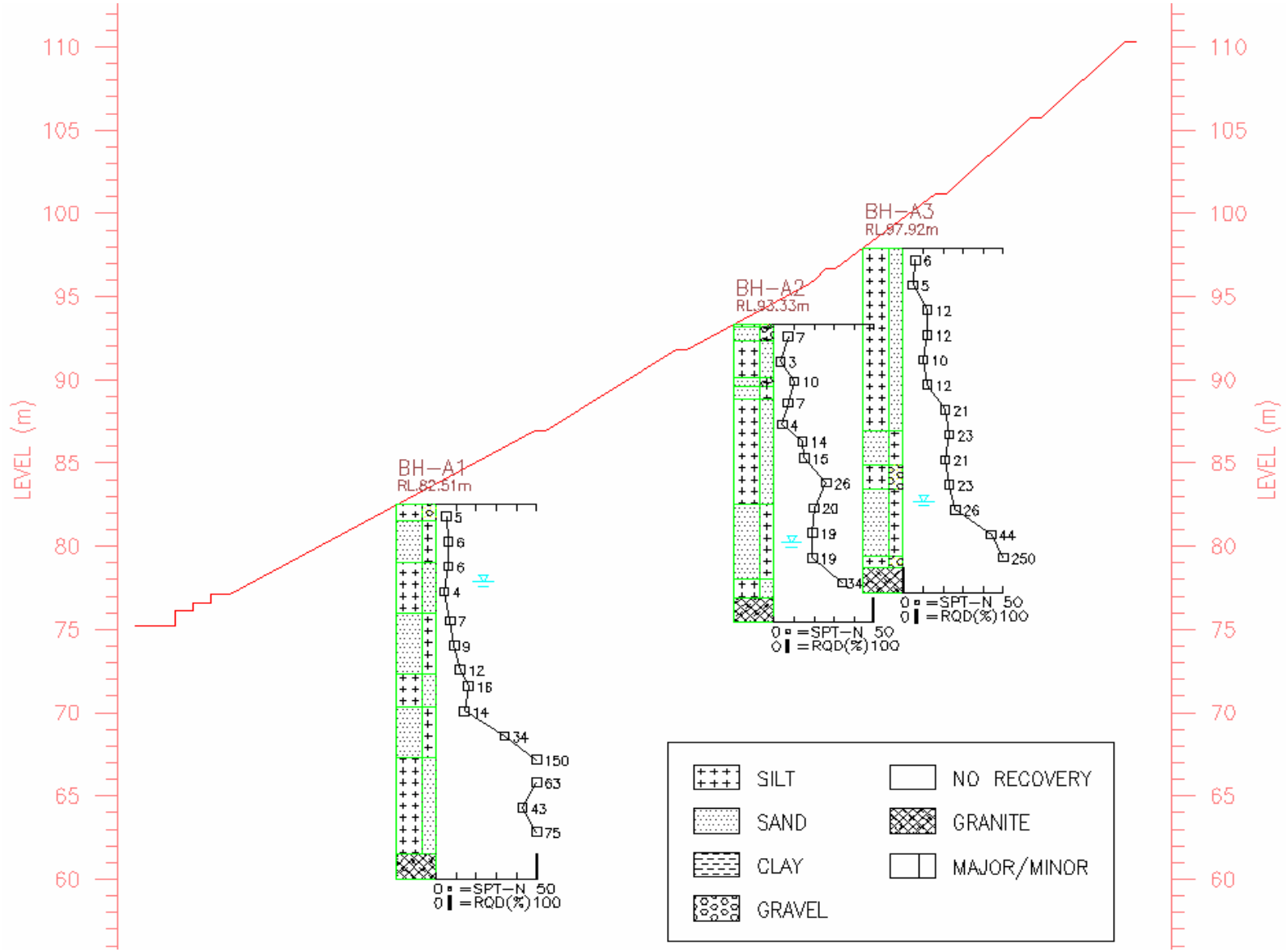
SI & Instrumentation

- 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:

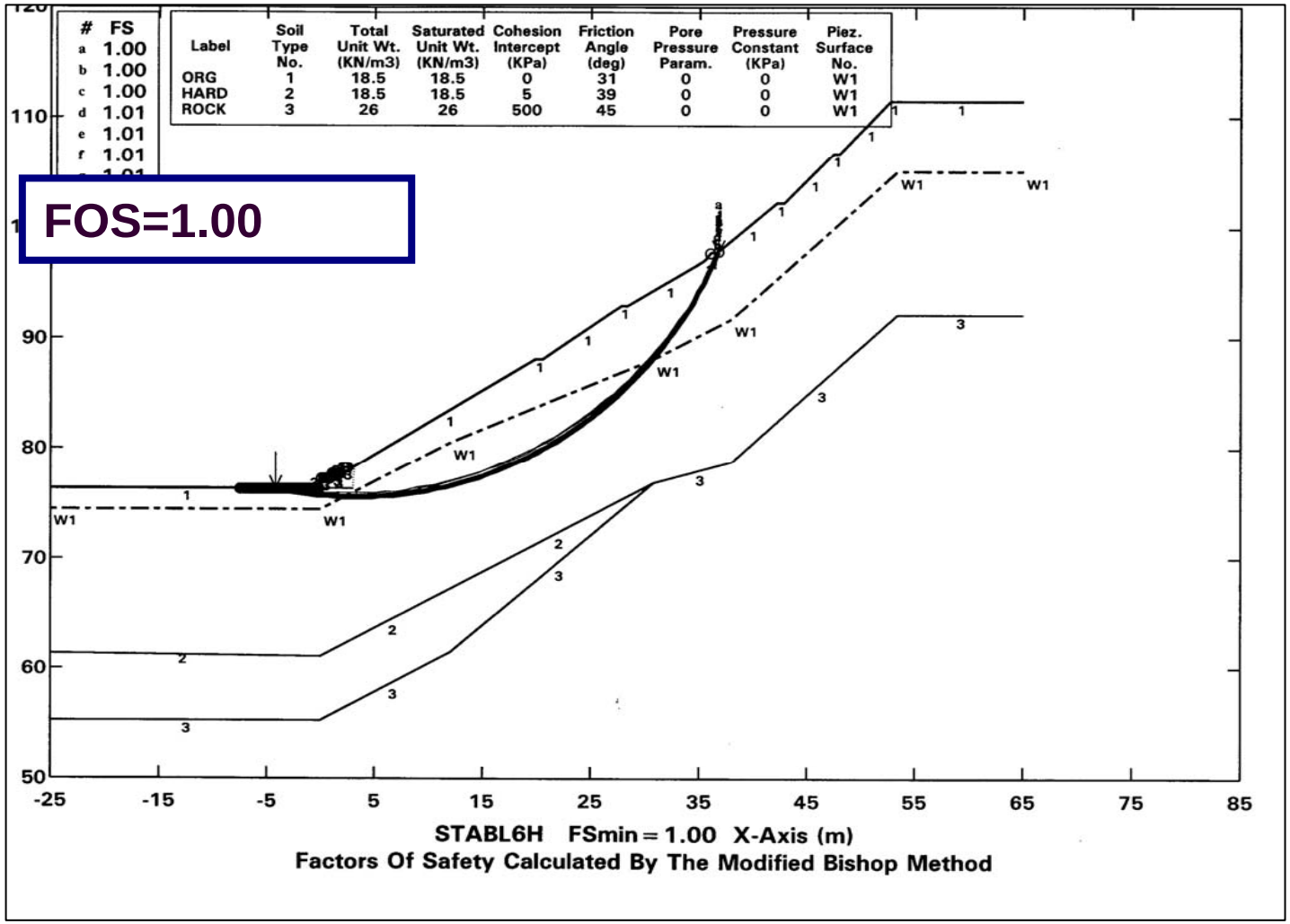
$c' = 2\text{kPa}, \phi' = 31^{o}$

Instrumentation Results

- Max lateral movement (IN. 1)

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

Slope Stability Analyses

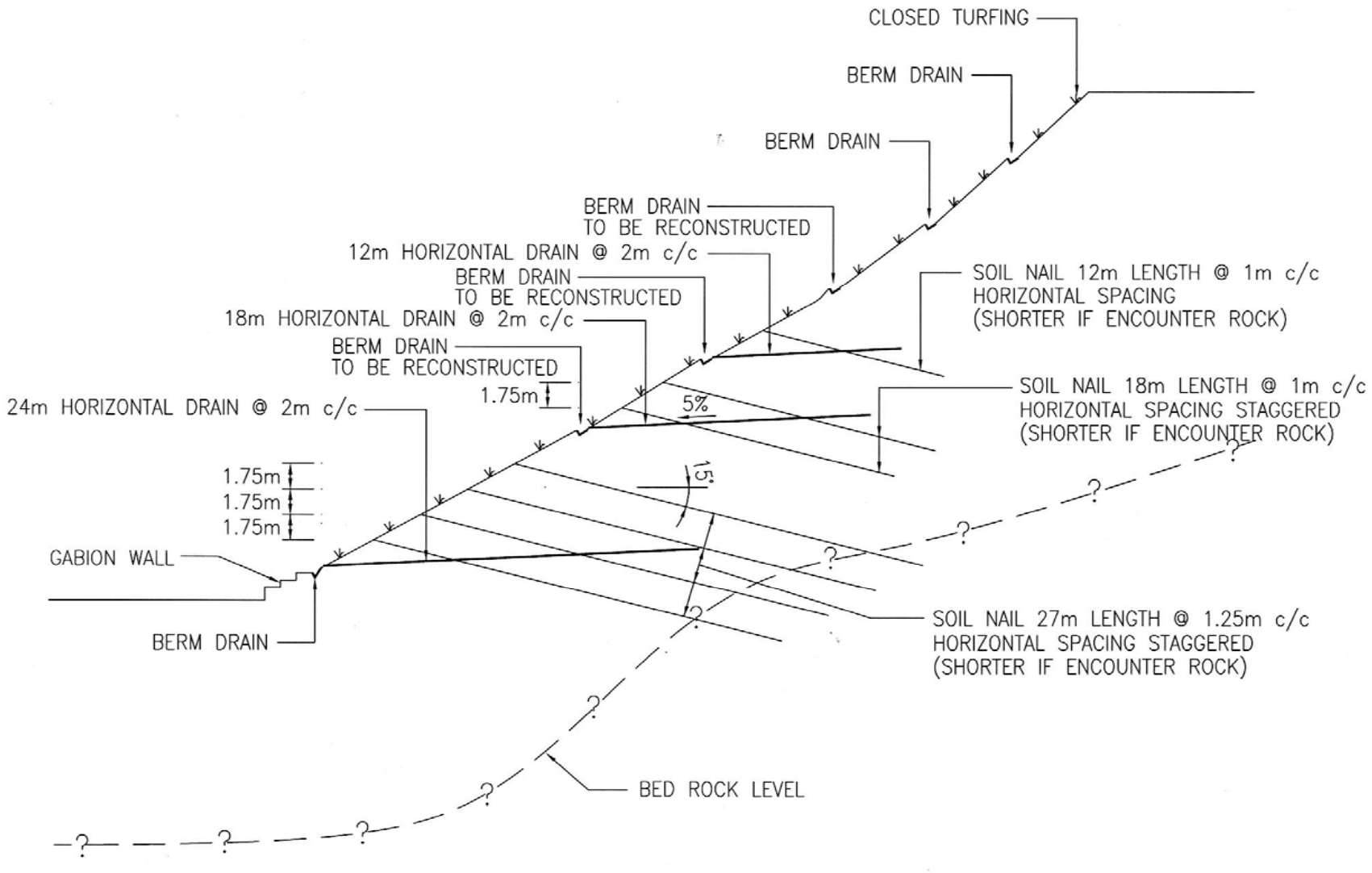


Limit Equilibrium Method

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.

Fill Slope Failure at Salak Tinggi

Site Background

- Fill slope over a natural valley to form 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.

Before Failure

After Failure

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

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.
- 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.

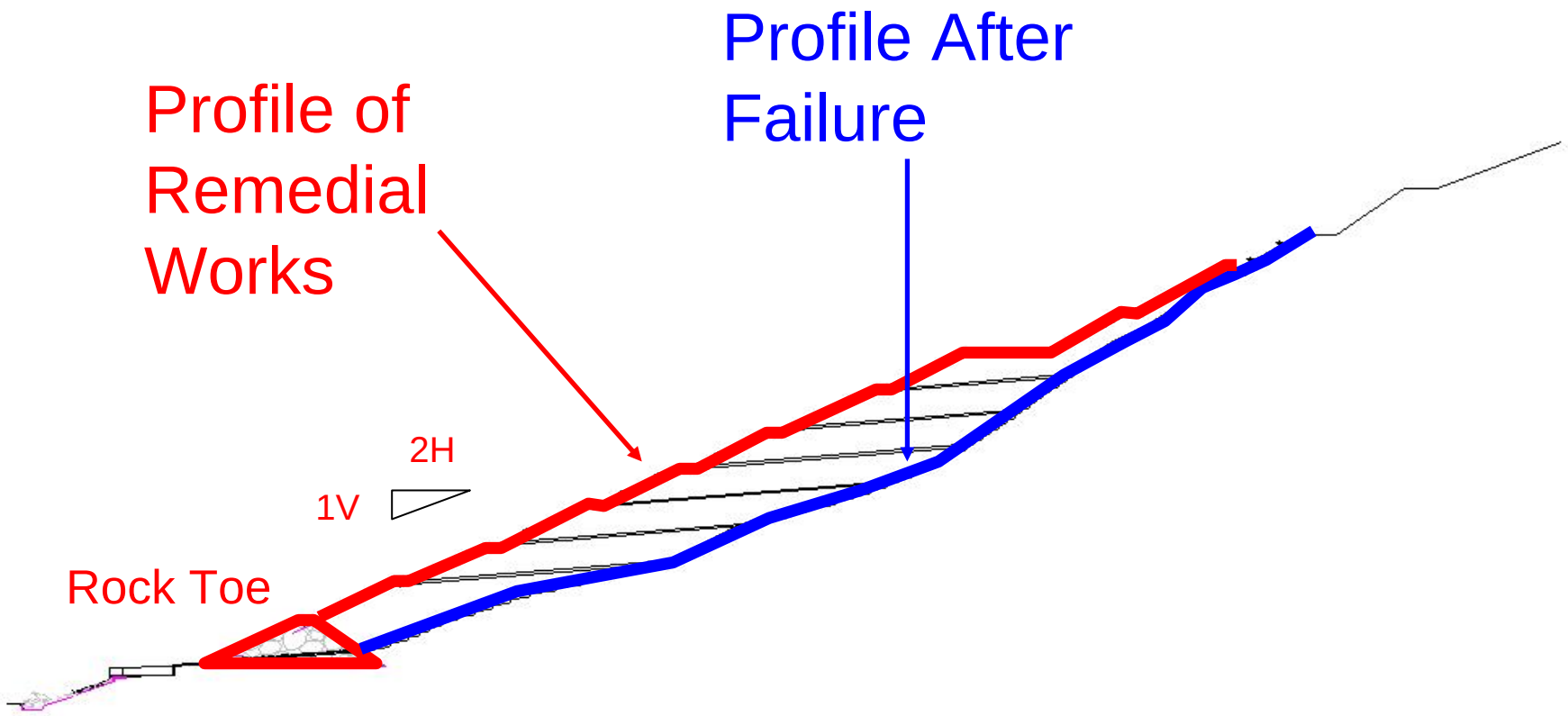
Remedial Works

- 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.

Cross Section of Remedial Works




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

After Completion of Construction Works

The End