Geotechnical Forensic Engineering – Case Histories

Ir. Dr. Gue See Sew

G&P Geotechnics Sdn Bhd

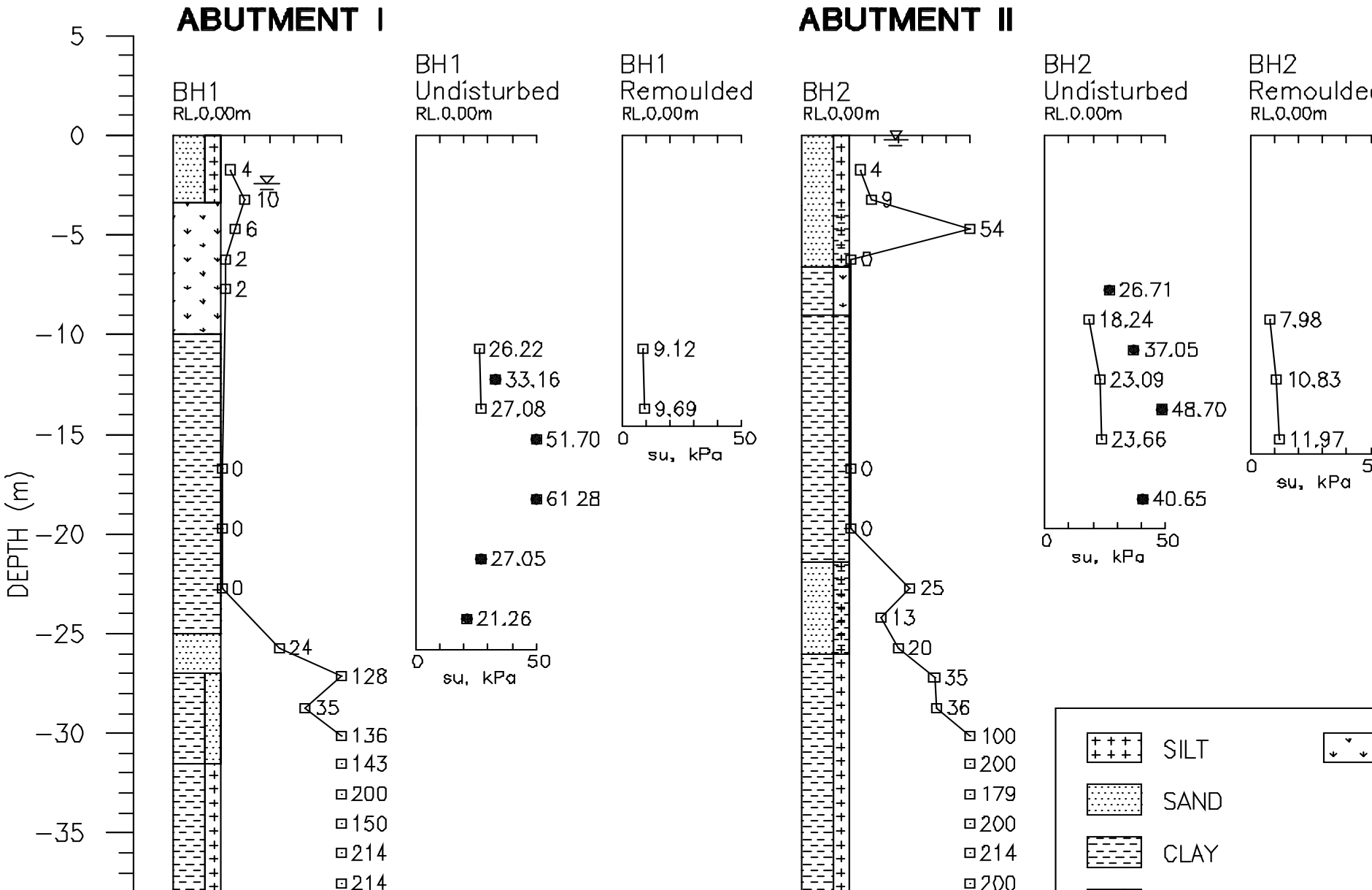
Contents

- Failure of Bridge Foundation and Approach Embankment
- Excavation Failure
- Retaining Wall Failure
- Category of Geotechnical Failures
- Conclusion

Bridge Foundation and Approach Embankment Failure

Overview

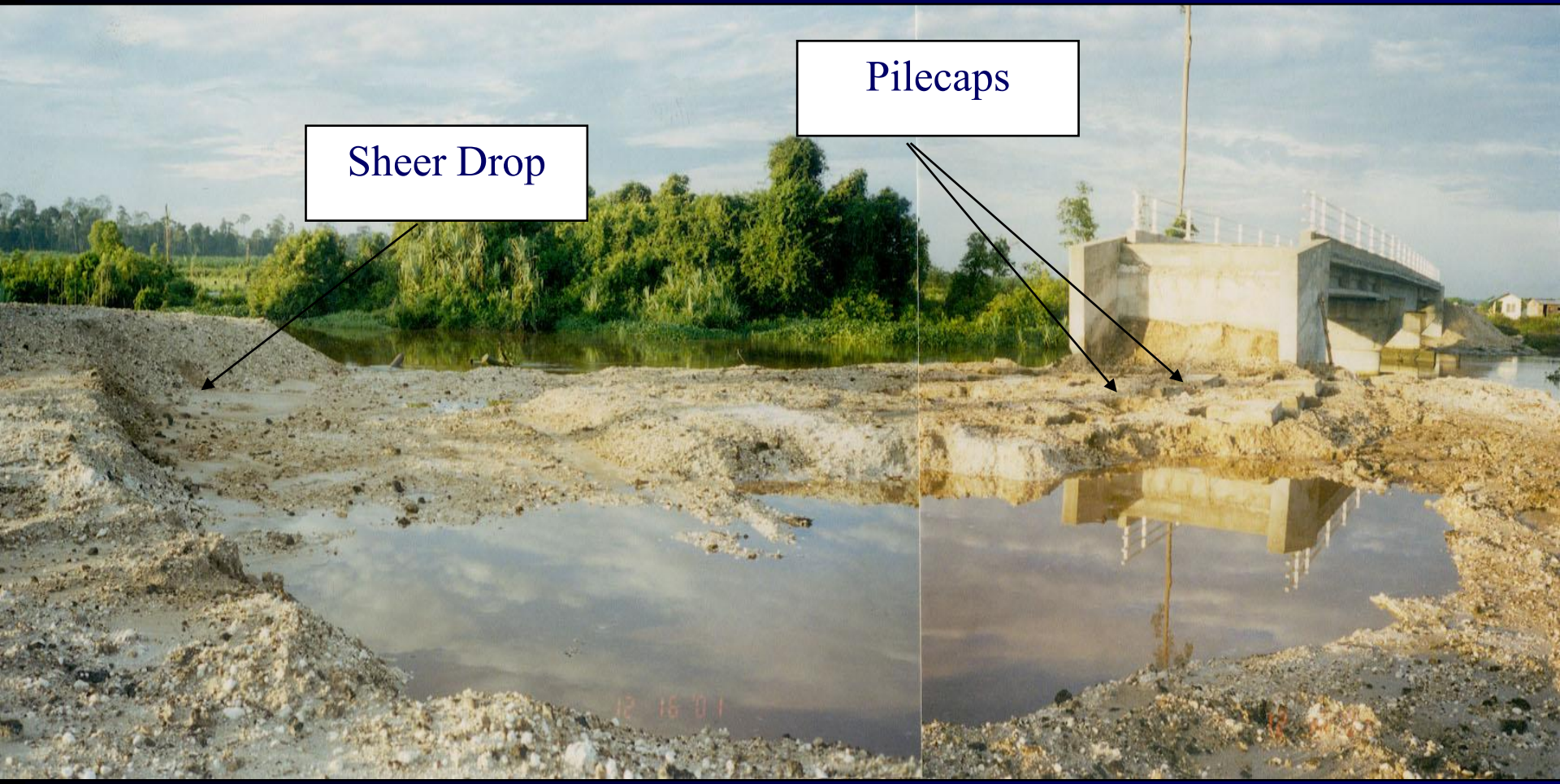
Subsoil Condition



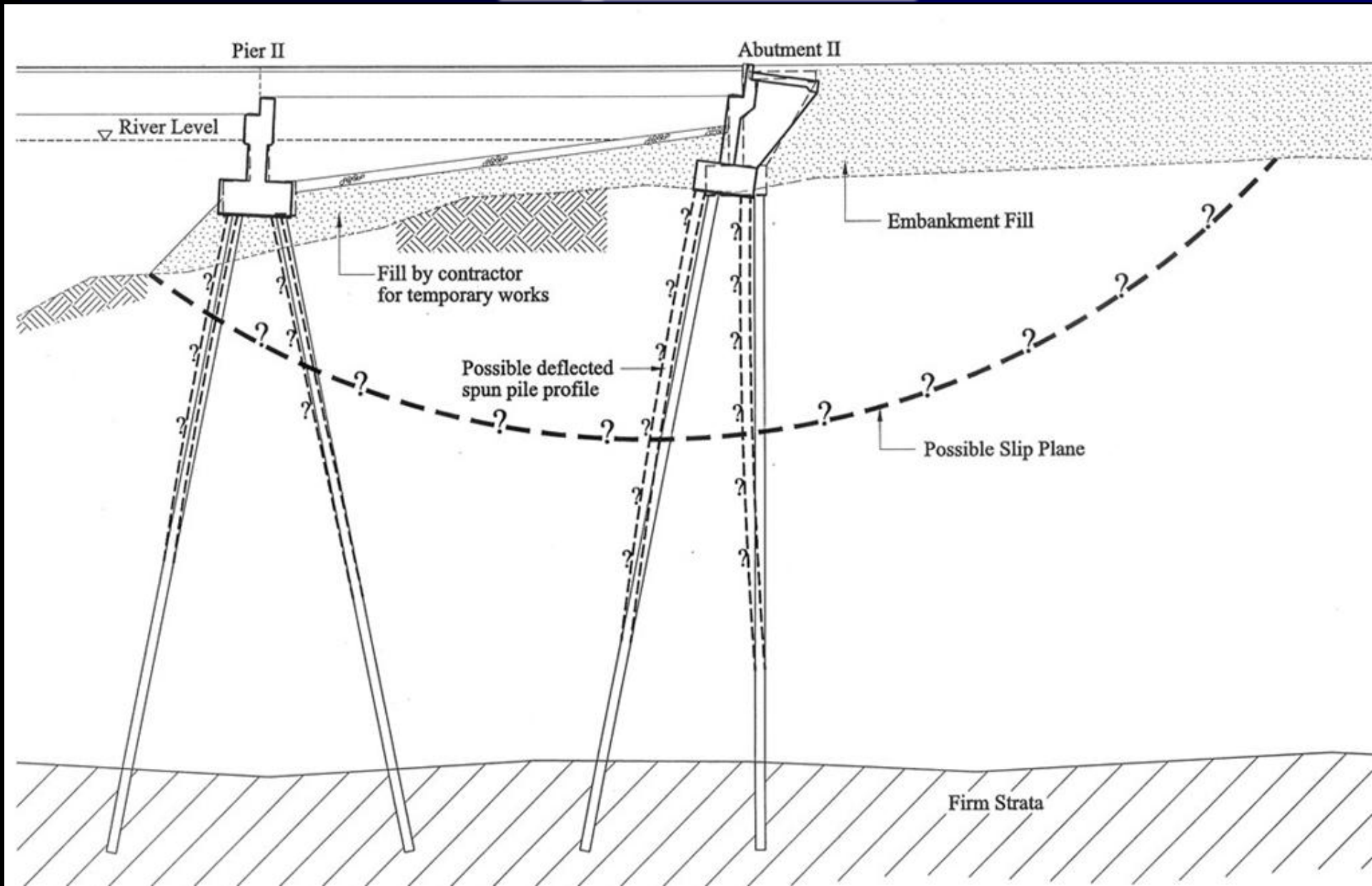
Slip Failure of Embankment

- At Approach Embankment
  25m from Abutment II
- Fill = 3m.
- Abutment II :
  - Tilted 550mm on top.
  - Angular distortion of 1/6
- 300mm gap between bridge decks.

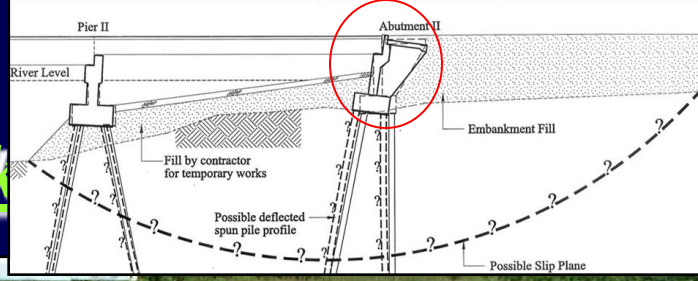
Sheer Drop

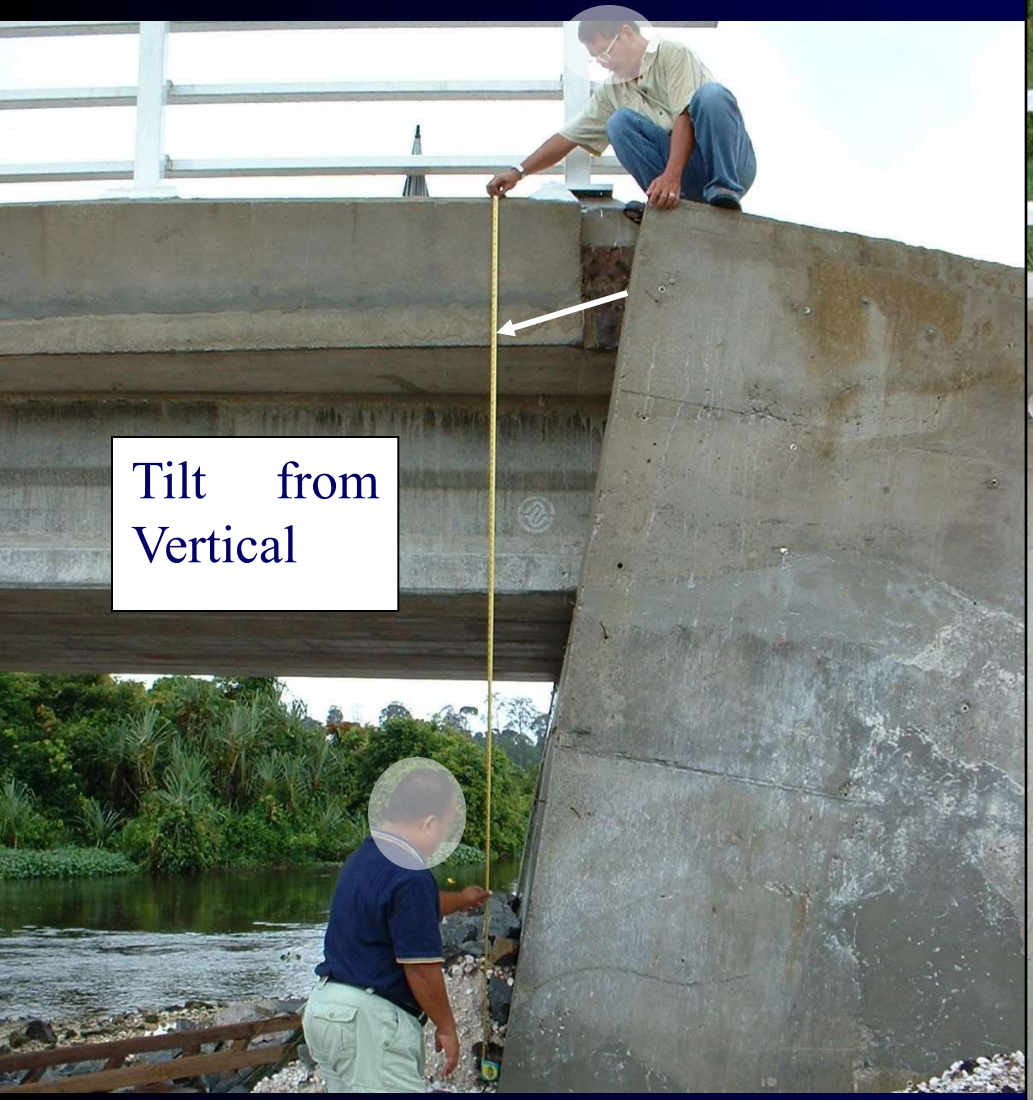


Slip Failure

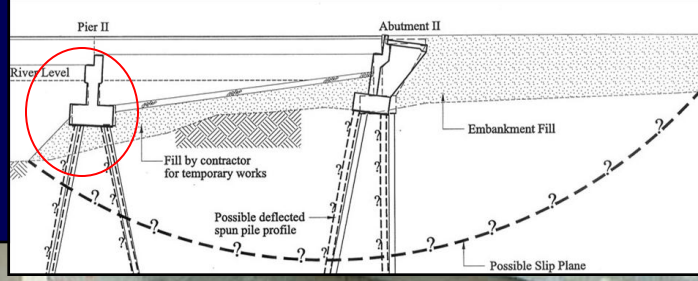


Tilted Abutment & Gap between Bridge Deck





Pier II



Tilted Pilecap

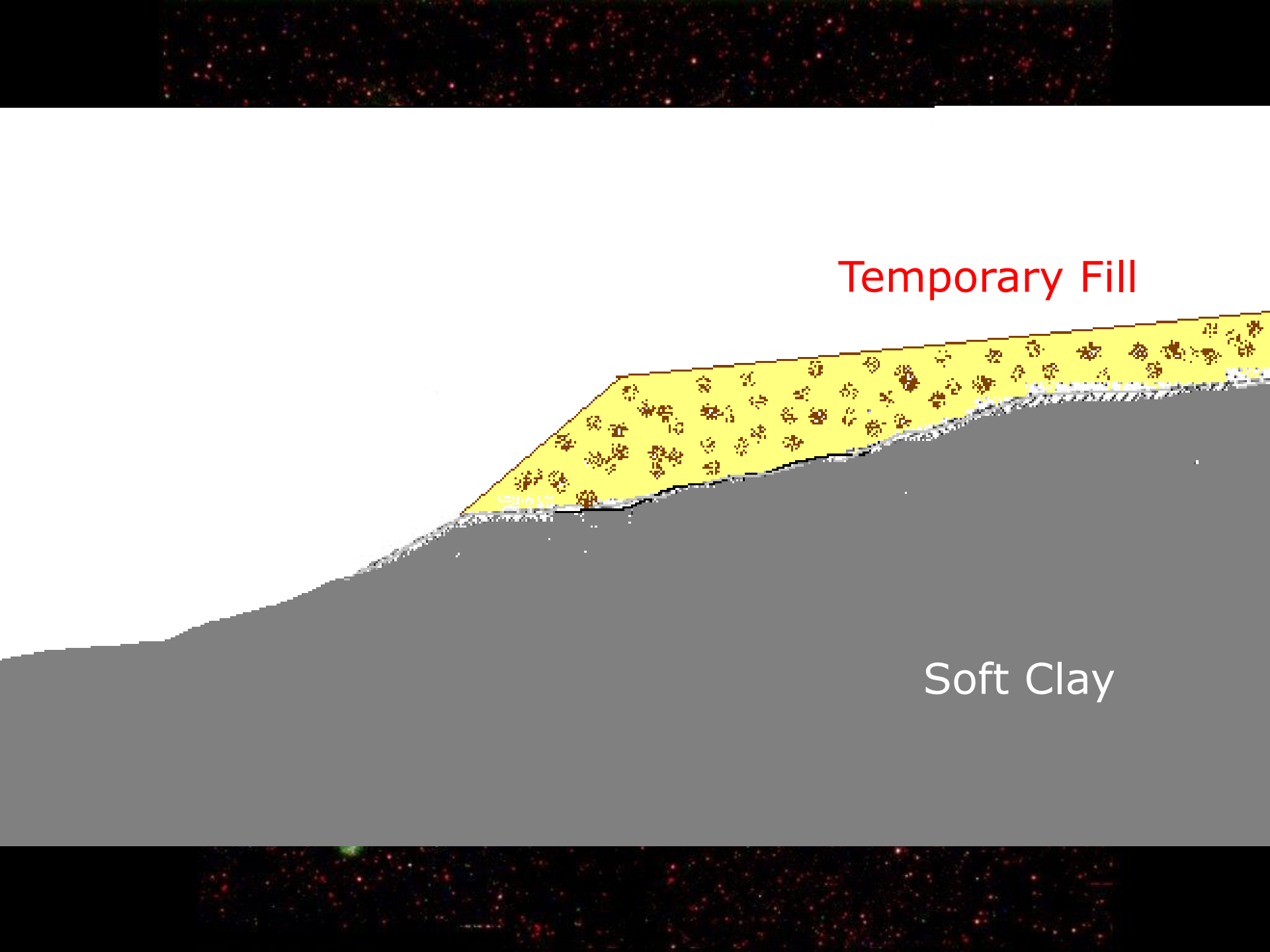
Geotechnical Investigation

- **Bearing capacity failure @ 3m**
- **Proposed fill height by designer = 5.5m = NOT SAFE**

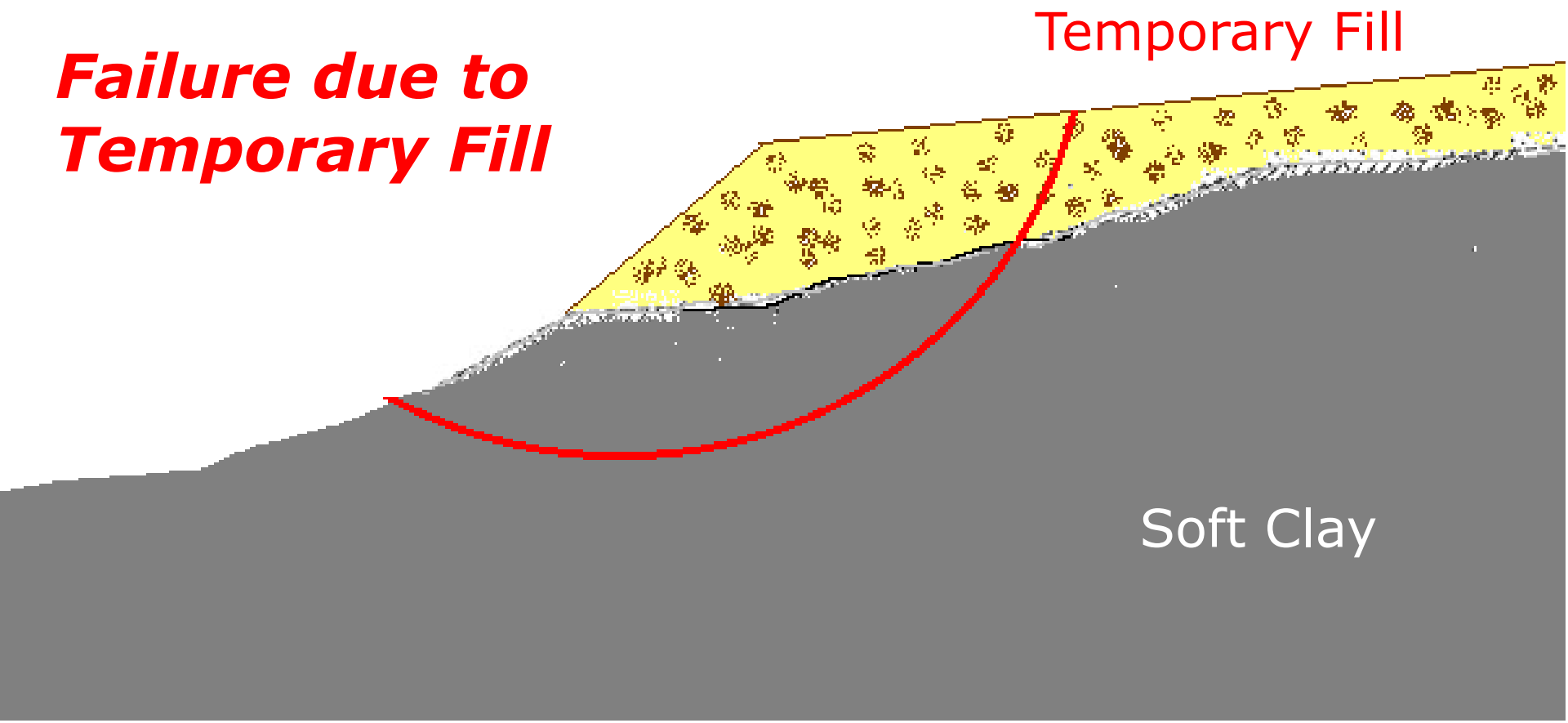
Lessons Learned

- **Failures ← (temporary works)**
  - **Inadequate geotechnical design**
  - **Subsoil Condition (Lack of understanding)**
  - **Lack of construction control & supervision.**


Soft Clay


Temporary Fill
Soft Clay

Failure due to Temporary Fill



Preventive Measures

- Proper design and review.
- Stability check of embankment & abutment
  (both circular & wedge failures)
- Most critical :-
  During construction.
  (must check temporary works)
- Proper full-time supervision
  (with relevant experience & understand design assumptions)

Simple Check

$$q_{allow} = (N_c \cdot s_u / FOS)$$

q_{allow} = allowable bearing pressure
= $(\gamma_{fill} \cdot H + 10)$ (in kPa)

N_c = 5

$$H_{failure} = (5 \times Su) / \gamma_{fill}$$

e.g. :
When Su = 10 kPa ; γ_{fill} = 18 kN/m^3

$H_{failure}$ = (5 x 10)/ 18 = 2.8 m


Excavation Failure

Sub-contractor buried alive

MALACCA: A sub-contractor who was digging a 2m-deep hole to lay power cables was buried alive yesterday when the soft earth around it collapsed.

Mohd Ali, 30, and a colleague were working at the site in Jalan Desa 1, Ayer Molek, when the excavation wall collapsed as the soil had softened and become muddy.

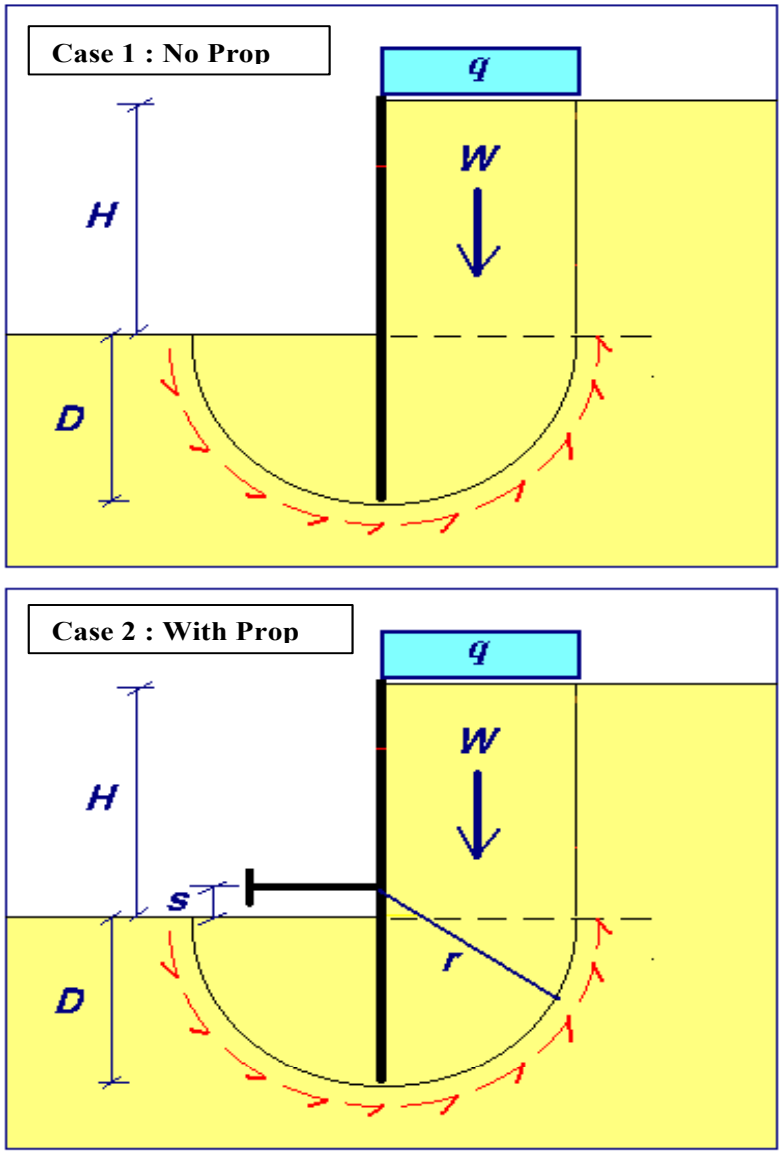
His colleague Mohd Suhardi Dollah, 27, said Mohd had gone inside the hole to do some inspection and clearing works when it collapsed.

"I tried to dig another hole beside the original so that the earth would flow away, but it was futile.

"I was also panicky and did not know what to do until the police arrived to help me dig out the body," he added.

Failure of Temporary Sheet Pile

Simplified Base Heave Check



Where
q = Surcharge Load
~ 10kPa (minimum)

Q = q x D (no prop)
= q x r (with prop)

W = Total Weigh of Soil
= γHD (no Prop)
= γHr (with Prop)

r = D + s

L = Total Arc Length of Soil Resistance
= πD (no prop)
= πr – 2s (simplified, with prop)

Case 1 : No Prop

$$FOS = \frac{s_u \times L \times D}{(W + Q) \times D/2}$$

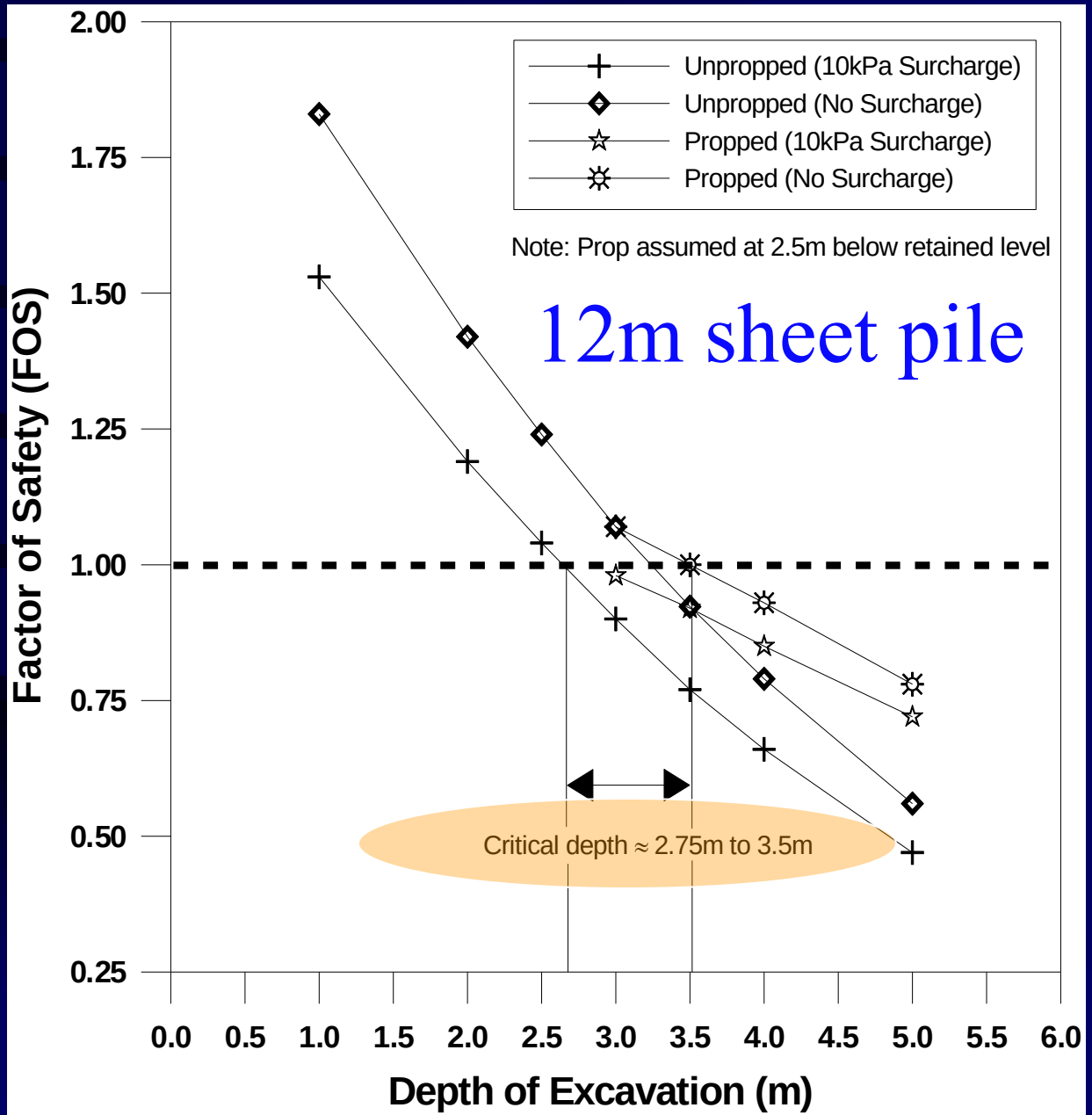
Case 2 : With Prop

$$FOS = \frac{s_u \times L \times r}{(W + Q) \times r/2}$$

Note :
The required FOS is 1.2 where the vertical shear resistance along the retained ground shallower than the excavations is ignored. (Kohsaka & Ishizuka, 1995).

Figure 14 – Base Heave Check based on Equilibrium of Moments

Stability of Sheet Pile Penetration Depth



Lessons Learned

- **Failures**
  - Inadequate geotechnical design
  - Over-excavation caused failure. (lack of site control)
  - Need to check for :-
    - Overall stability
    - Basal Failure
    - Hydraulic Failure

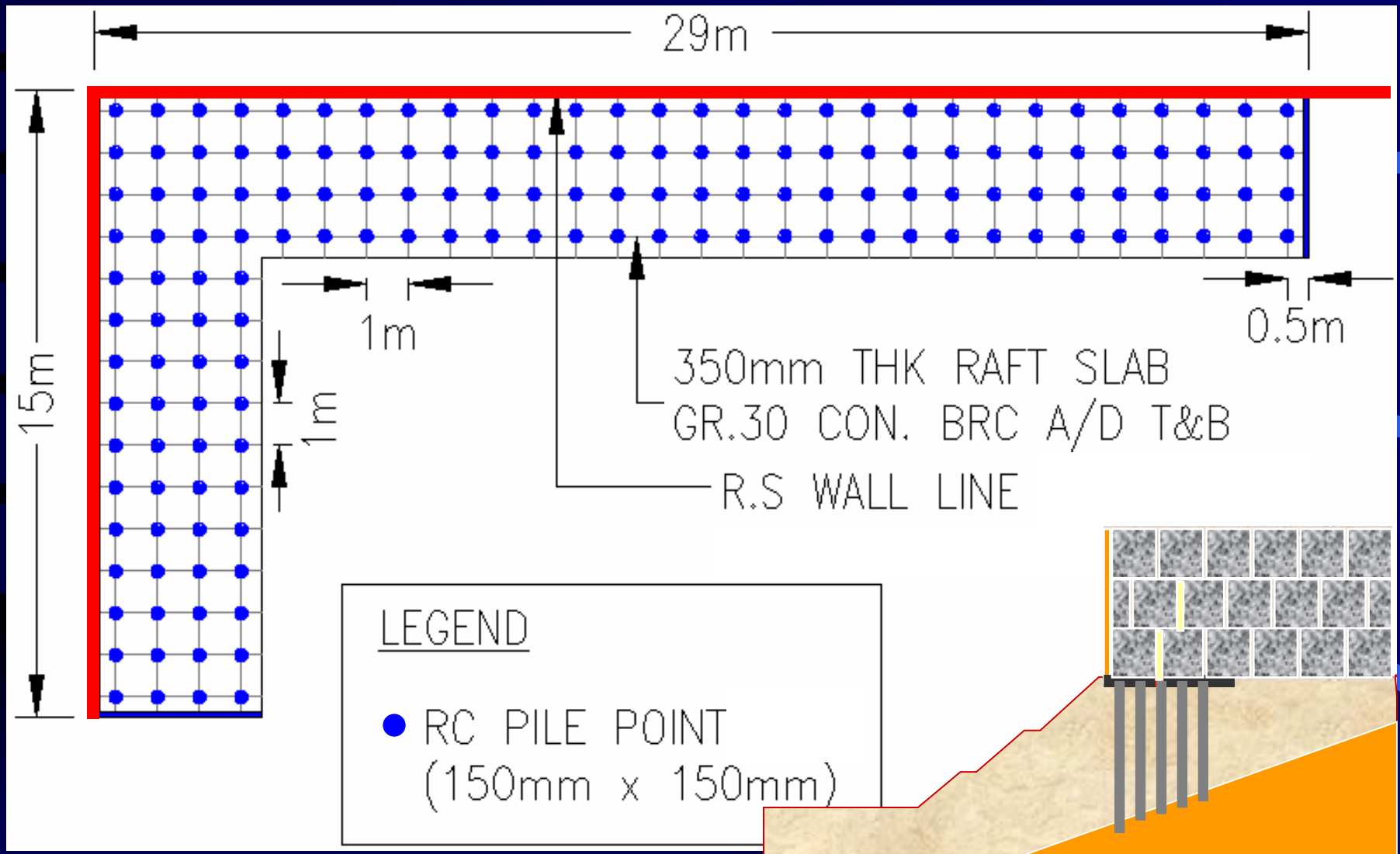
Retaining Wall Failure

INTRODUCTION

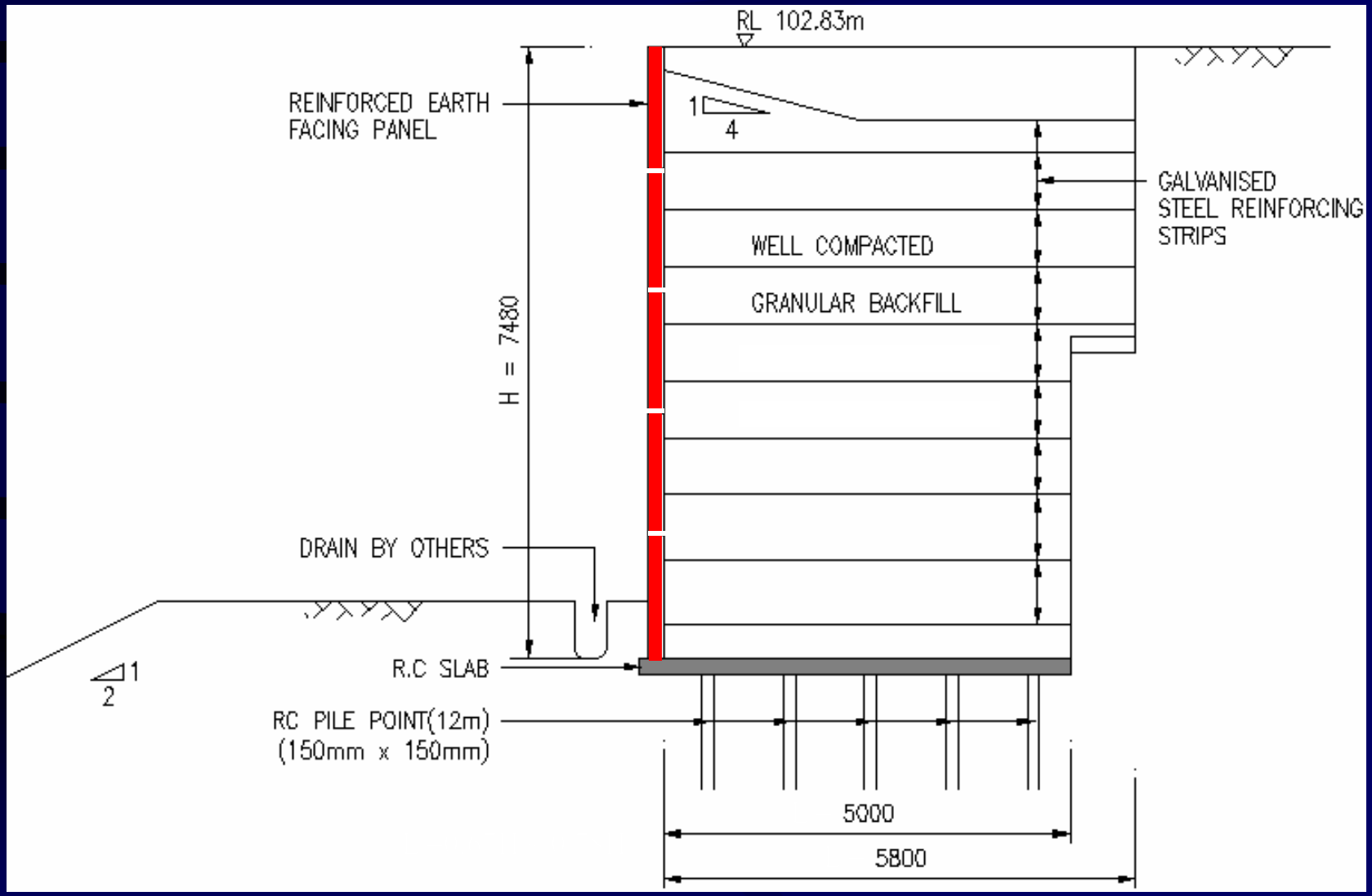
- Petrol station platform on a 7.5m high RS wall
- RS wall
  - located at the top of fill slope
  - supported by RC Slab with RC piles
- Opening of gaps within the wall

→ start of Investigation

ORIGINAL RS WALL AND FOUNDATION

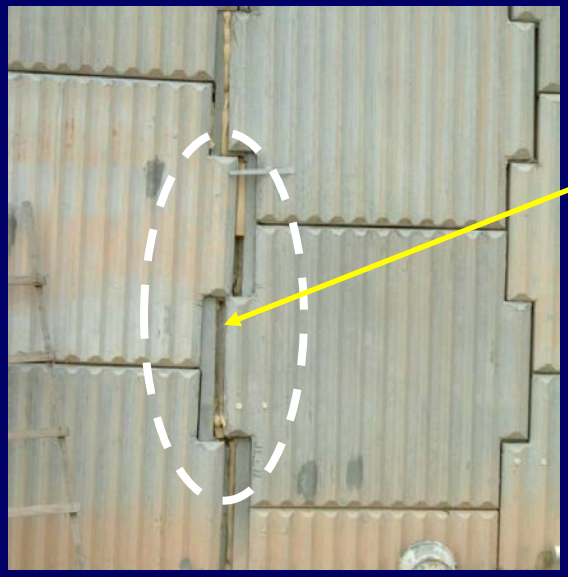


ORIGINAL RS WALL AND FOUNDATION DESIGN – cont'd



Typical Section of RS Wall

SITE CONDITIONS & OBSERVATIONS

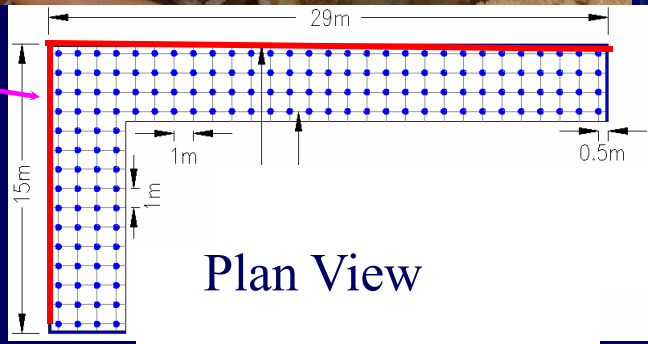


Gap Opening (December 2002)

Gap Opening (July 2003)

Wall Bulging (July 2003)

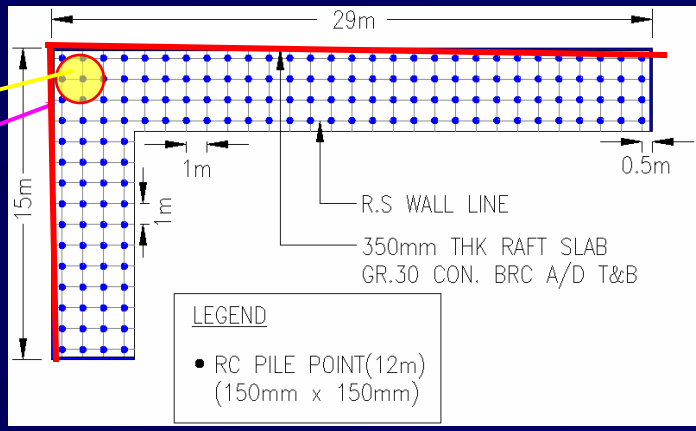
Gap Opening & Bulging



Plan View

SITE CONDITIONS & OBSERVATIONS

Gap Opening

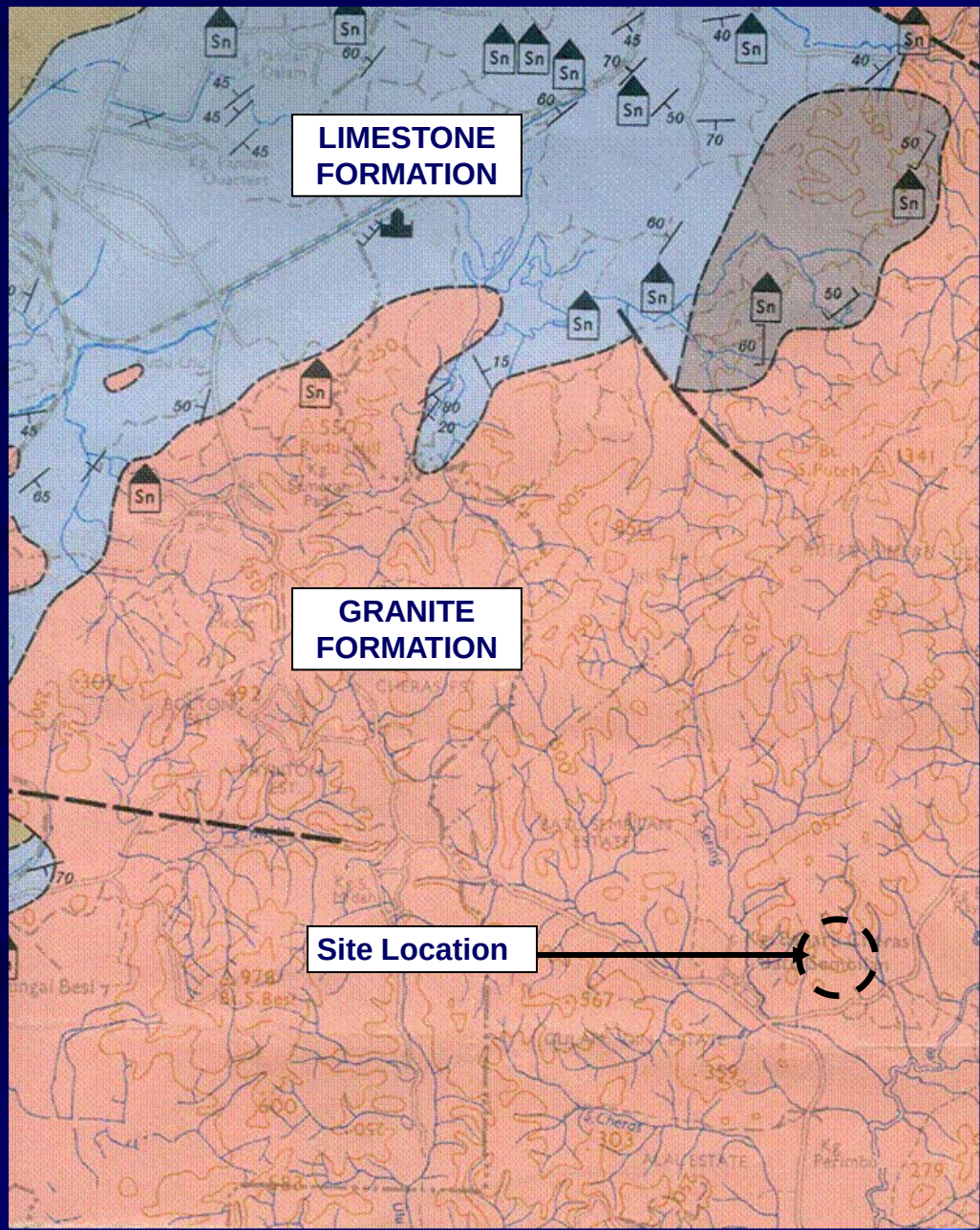


Loss of Fill Materials

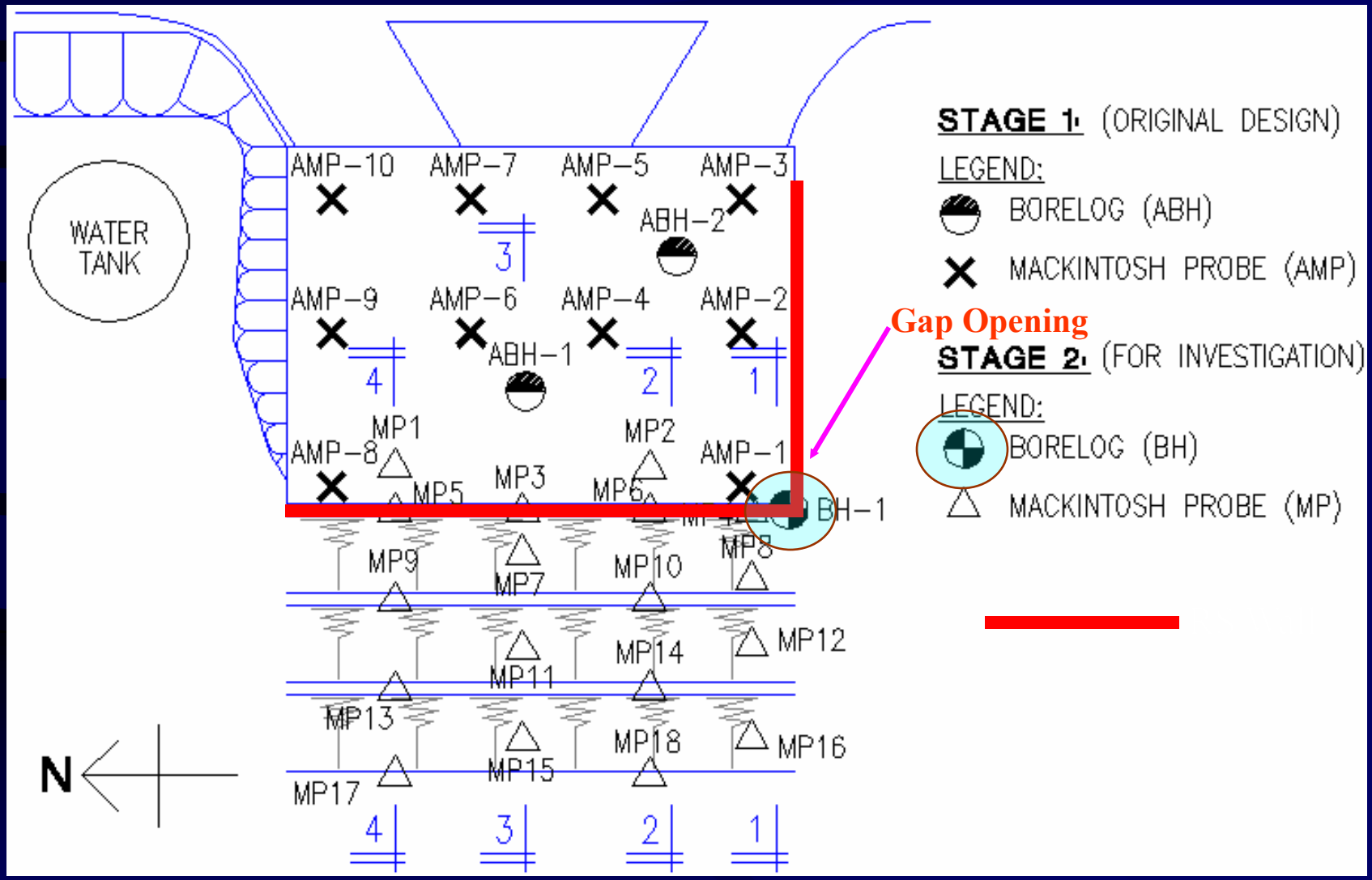
Ground Settlement at Top of RS Wall

GEOLOGICAL CONDITIONS

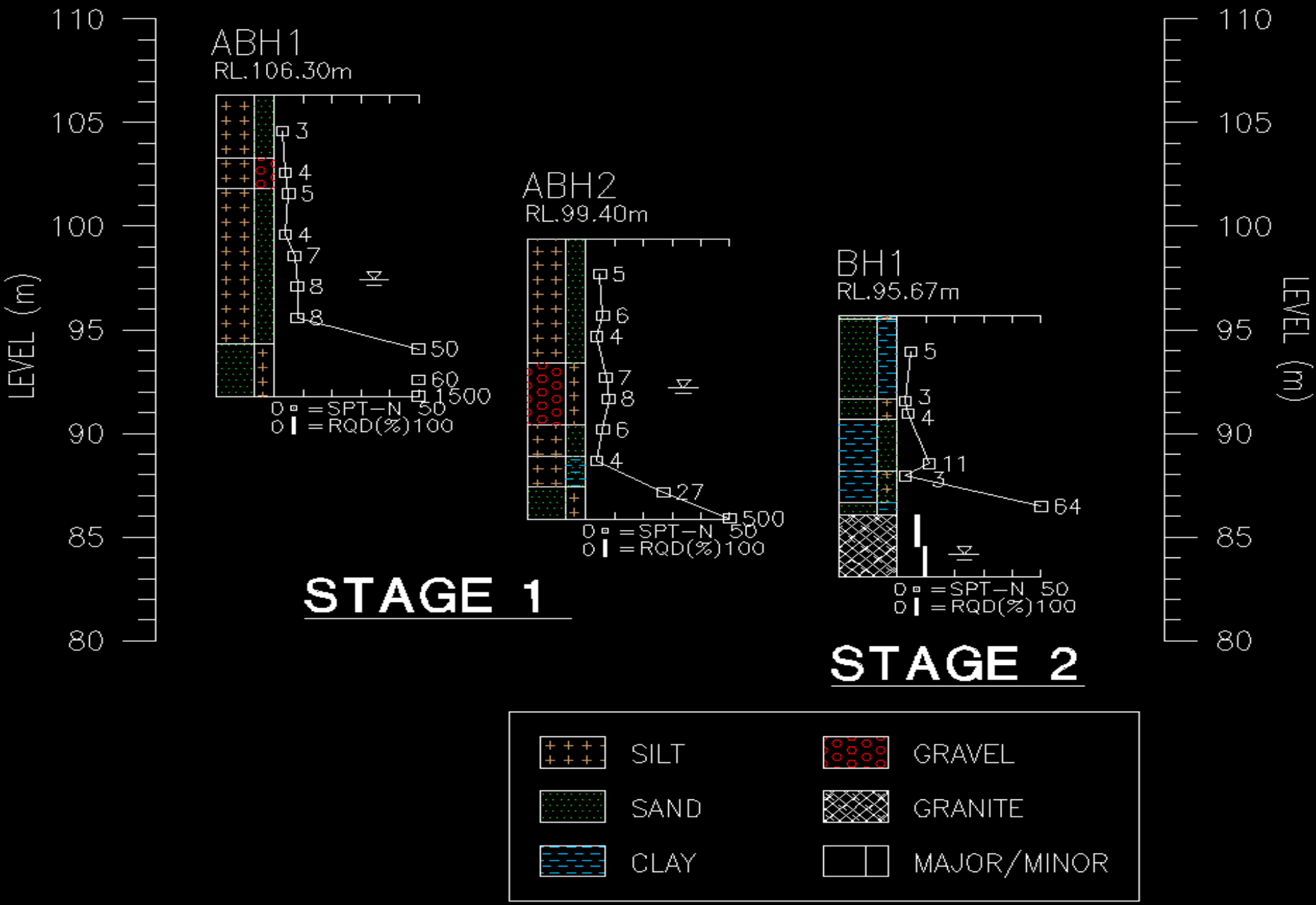
- K.L Granite formation



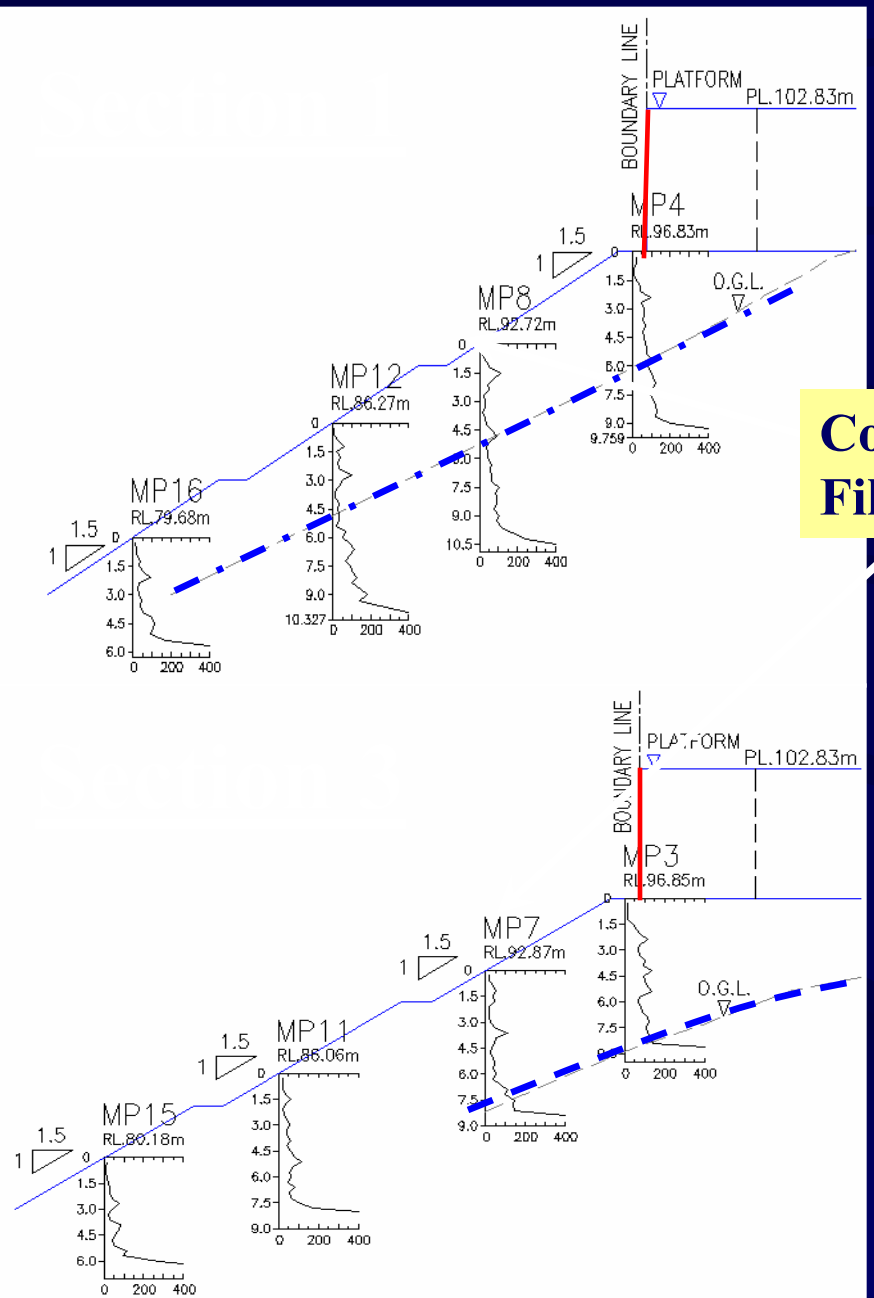
SUBSURFACE INVESTIGATION



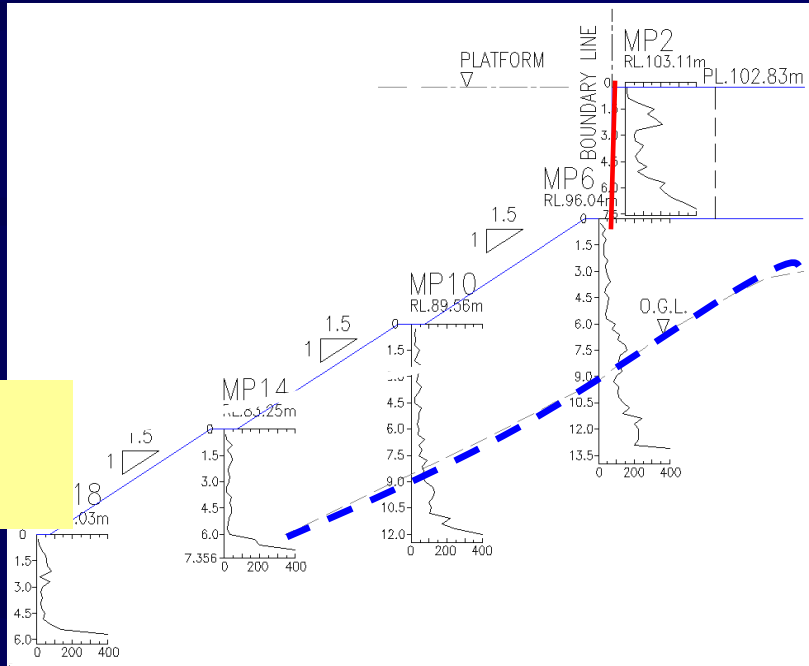
SUBSURFACE INVESTIGATION

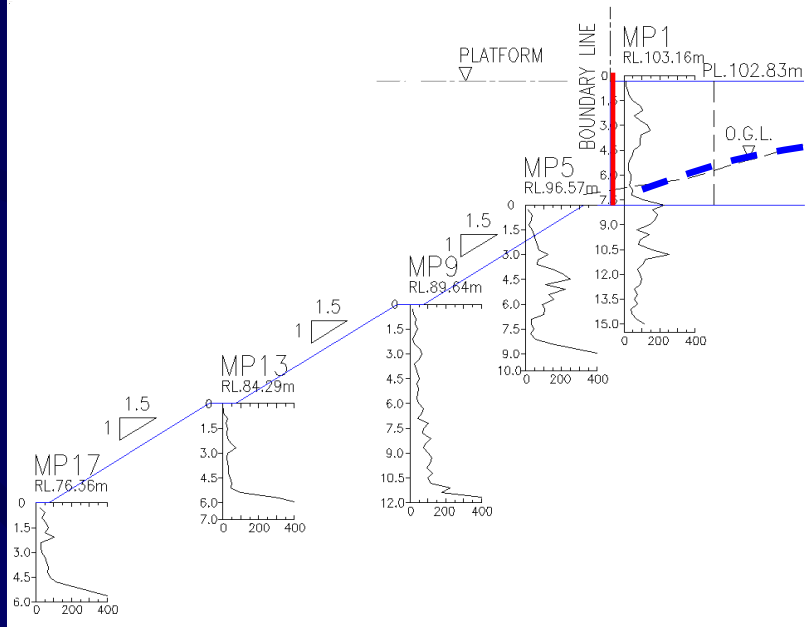


Mackintosh Probes Profiles



Compacted Fill Slope





Geotechnical Investigation into RS Wall Failure

	Analysis	Details
1	Global Stability of Wall and Slope	◆ Slip Failure (Slope Stability) ◆ Overturning & Bearing Capacity of Wall ◆ Sliding Failure of Wall
2	Internal Stability of Reinforced Soil (RS) Wall	◆ Rupture of Wall Reinforcements ◆ Adherence Failure of Wall Reinforcements
3	Structural & Geotechnical Capacity of Piled Foundation	◆ Pile Axial Capacity ◆ Pile Lateral Resistance ◆ RC Base Slab Structural Capacity
4	Degree of Compaction of Fill Slope Materials	◆ Adequacy of Compaction Effort

GLOBAL STABILITY OF WALL AND SLOPE

	Analysis	Remarks / Findings
1	**Overturning and Bearing Capacity**	Adequate (Safe)
	Slip Failure Analyses	**Suspected Significant Pile Displacement and Inadequate Lateral Resistance (later confirmed by FEM analyses)**
	Sliding Failure	Adequate (Safe)

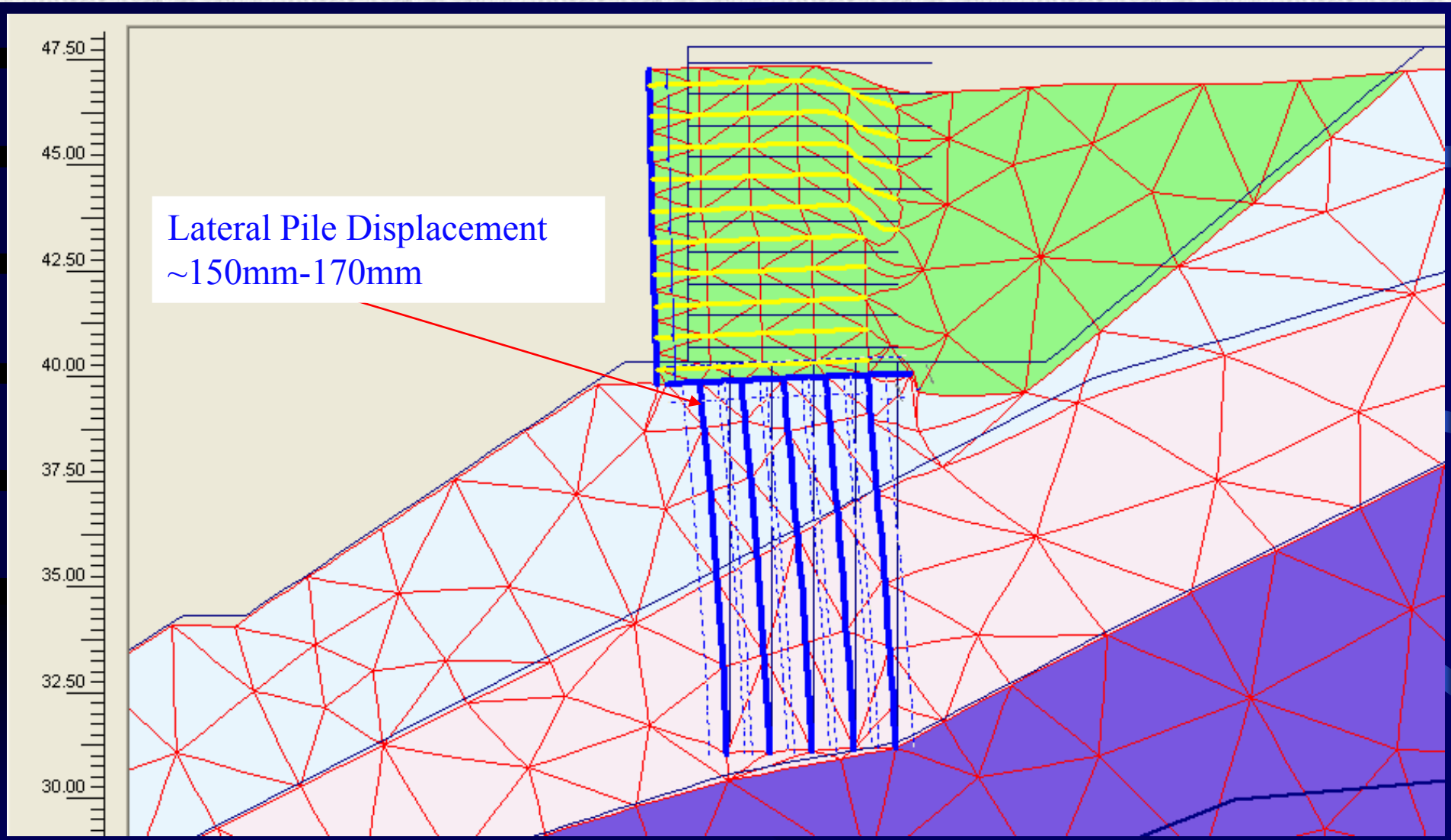
GLOBAL STABILITY OF WALL AND SLOPE

Case 1: RS wall with the presence of 150mm x 150mm reinforced concrete (RC) piles as per the original design by C&S consultant (assuming the piles were not displaced)

Case 2: RS wall without the piles to simulate the FOS if the ***small piles had been displaced***

RESULTS

Case	Section	Long Term Factor of Safety	
		Modified Bishop Method (Circular Failure)	**Spencer's Method (Non-Circular Failure)**
Case 1	With Piles	1.58 (>1.4)	1.69 (>1.4)
	With Piles (worst case Water Level)	1.26 (>1.1)	1.37 (≥1.1)
Case 2	Without Piles	1.25 (<1.4) **Not acceptable**	1.36 (<1.4) **Not acceptable**
	Without Piles (worst case of Water Level)	1.20 (> 1.1)	1.25 (>1.1)
Case 3	Local Stability of 1V:1.5H Fill Slope	1.37 (<1.4) Marginal	1.44(>1.4)
	Local Stability of 1V:1.5H Fill Slope (worst case of Water Level)	1.37 (>1.1)	1.44 (>1.1)



FEM Analysis – Displaced RC Piles

STRUCTURAL & GEOTECHNICAL CAPACITY CHECK

Analysis Type	Aspect	Remarks / Findings
Structural & Geotechnical Capacity of Piled Foundation	Pile Axial Capacity Check	Adequate
	Pile Lateral Resistance Check	**Inadequate (Fail)**
	RC Base Slab Check	**Inadequate (Fail)**

CAUSES OF FAILURE

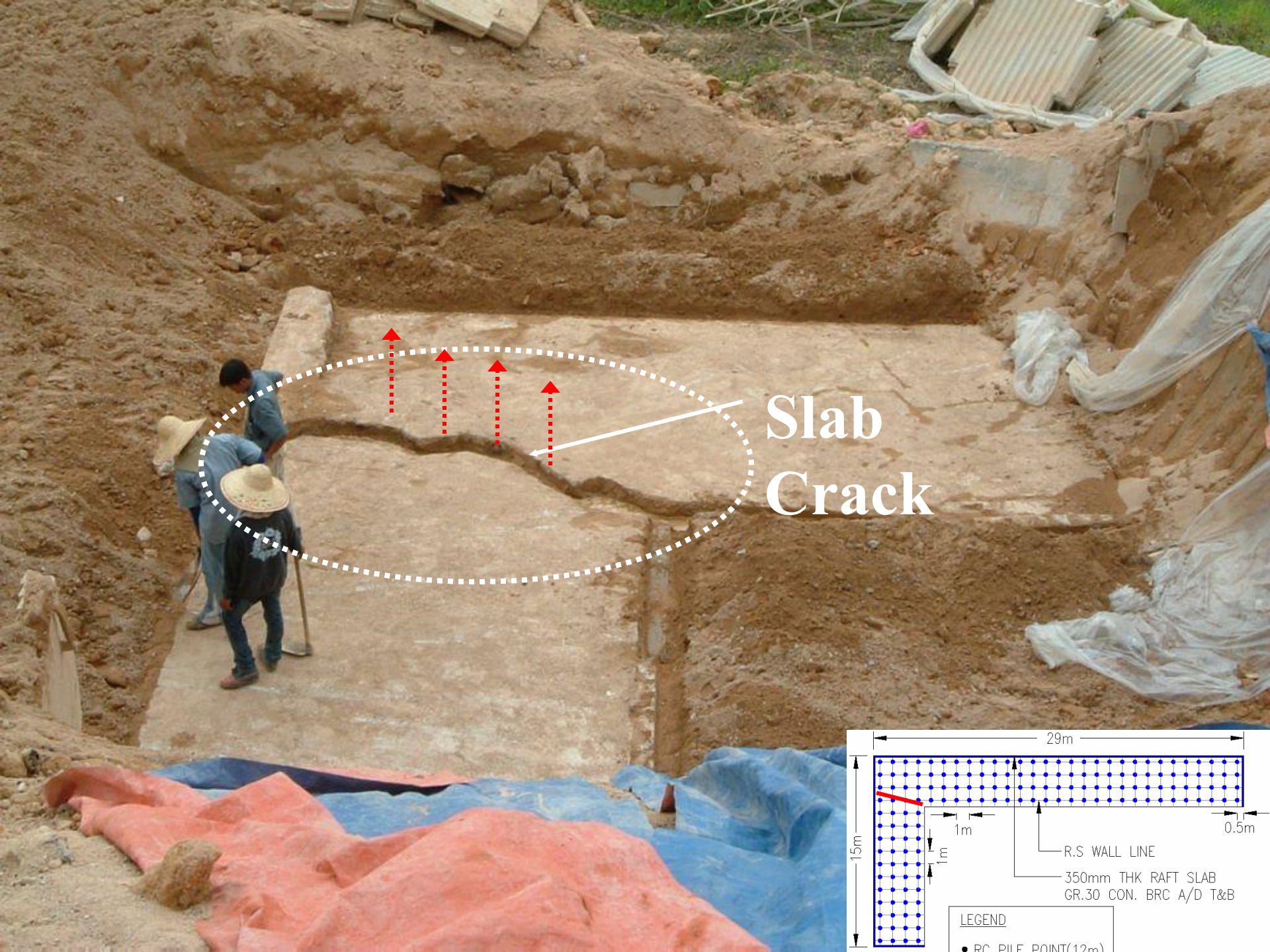
MAIN CAUSES

→Lateral Movement

→Foundation Instability

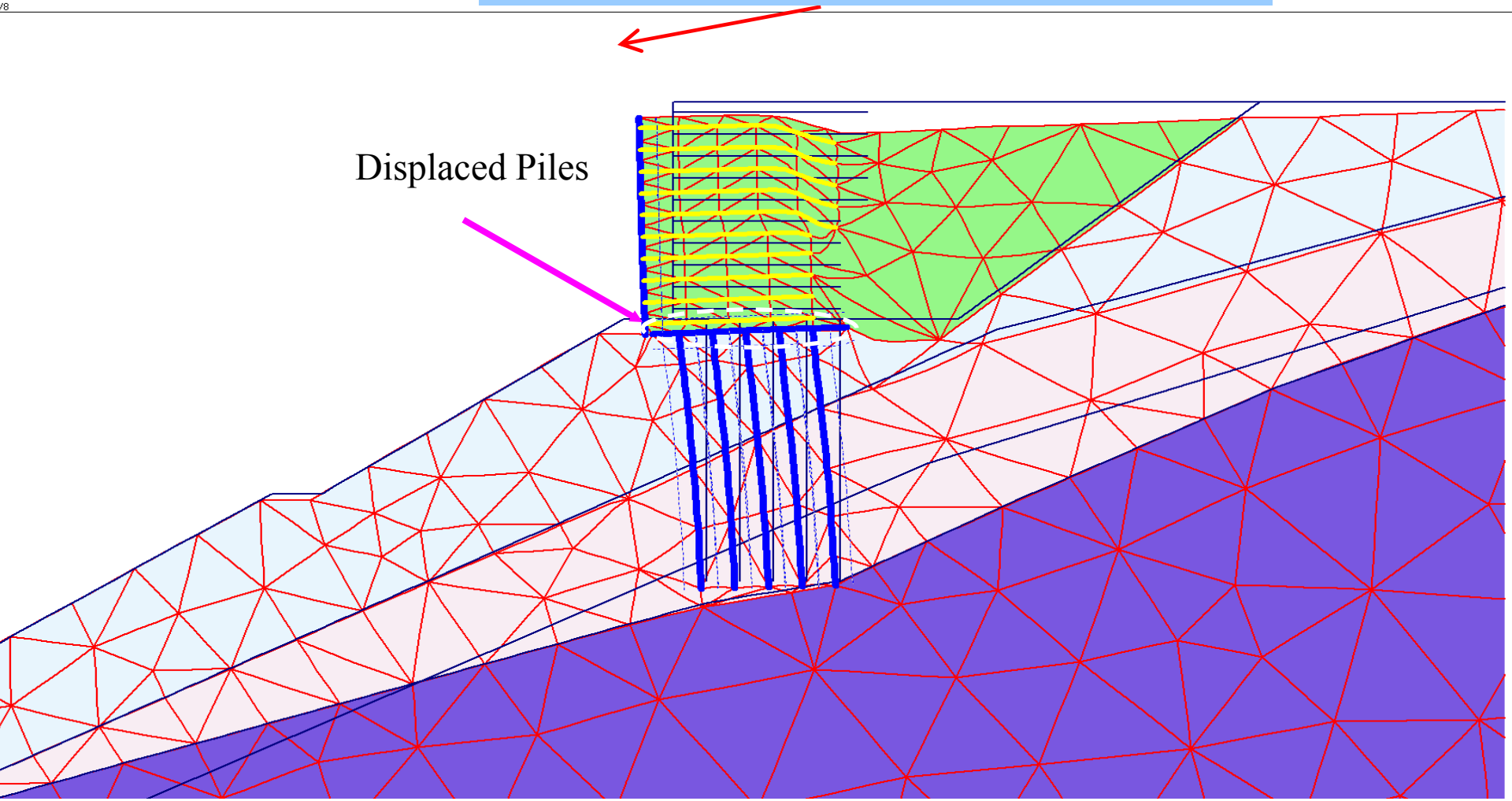
- Inadequate pile lateral resistance
- Inadequate shear and moment resistances of RC piles and slab

= Slab Cracked + Displaced Forward


Slab
Crack
29m
15m
1m
1m
0.5m
R.S WALL LINE
350mm THK RAFT SLAB
GR.30 CON. BRC A/D T&B
LEGEND
RC PILE POINT(12m)

FEM ANALYSES - RESULTS

Direction of Wall Movements




Cracks
Slope Creep
Forw
sheared
Materials
washed out
Lesson Learned :
-Try NOT TO USE RC PILE to
support RETAINING WALL


Category
of
Geotechnical Failures

Failures due to Design and Construction

Category	Design only	Construction only	Both Design and Construction
Number of Cases	25	8	22
Percentage (%)	45%	15%	40%

Gue, S. S. & Tan, Y. C. (2004), "Prevention of failures related to Geotechnical Works on Soft Ground", Special Lecture, Malaysian Geotechnical Conference, Sheraton Subang, Petaling Jaya, Malaysia, 16 - 18 March, 2004

Mode of Failures

Mode of Failures	Complete or Partial Failure	Damage due to Differential Settlement
Number of Cases	18	37
Percentage (%)	33%	67%


Conclusion

Conclusion

- Failures quite similar & Avoidable.
- ≥50% due to Inadequacy in Design.
- Important to have
  - Adequate Geotechnical Knowledge
  - Proper full-time supervision with a team having suitable experience.
- Extra Care on TEMPORARY WORKS.


Thank You