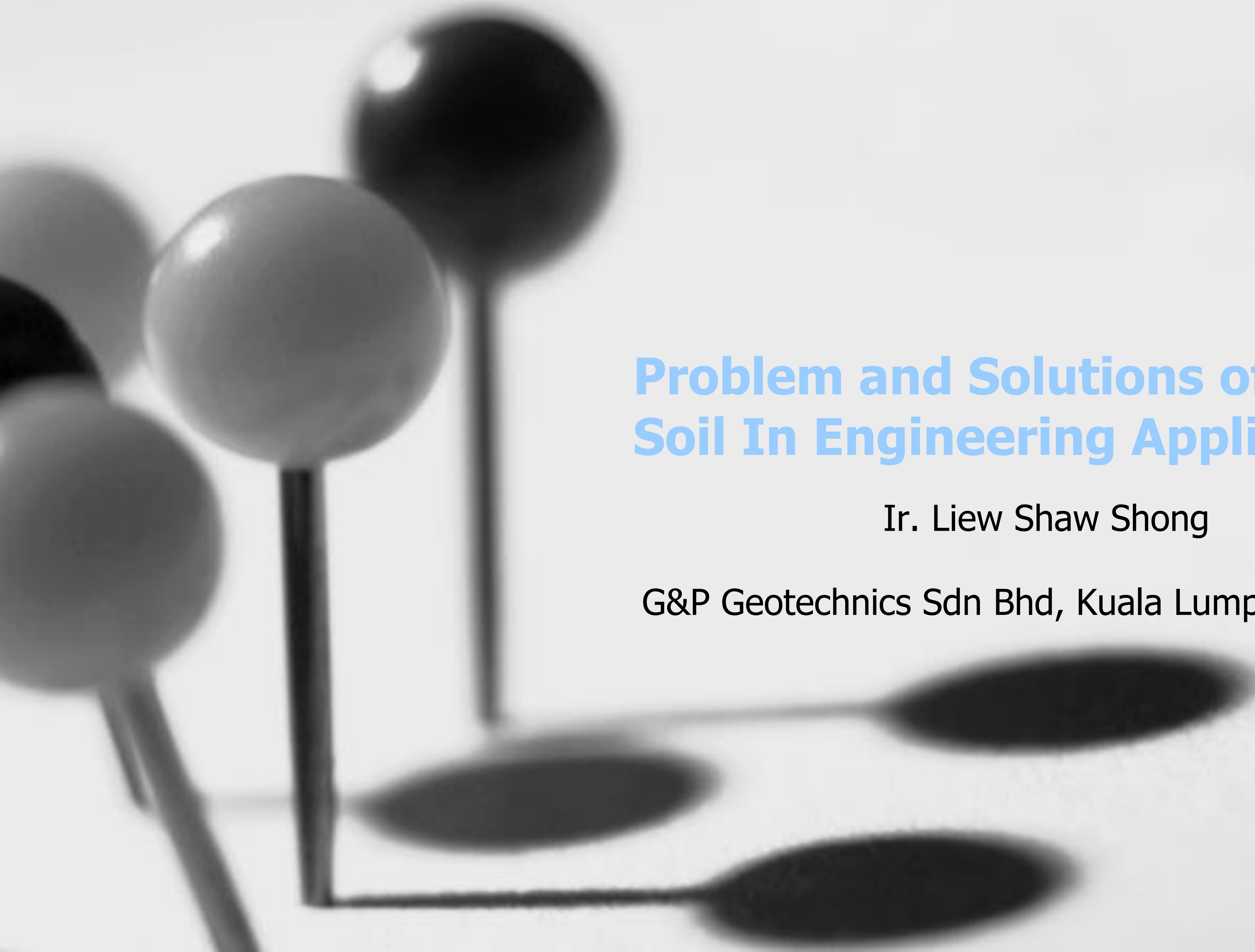

Problem and Solutions of Weak Soil In Engineering Application

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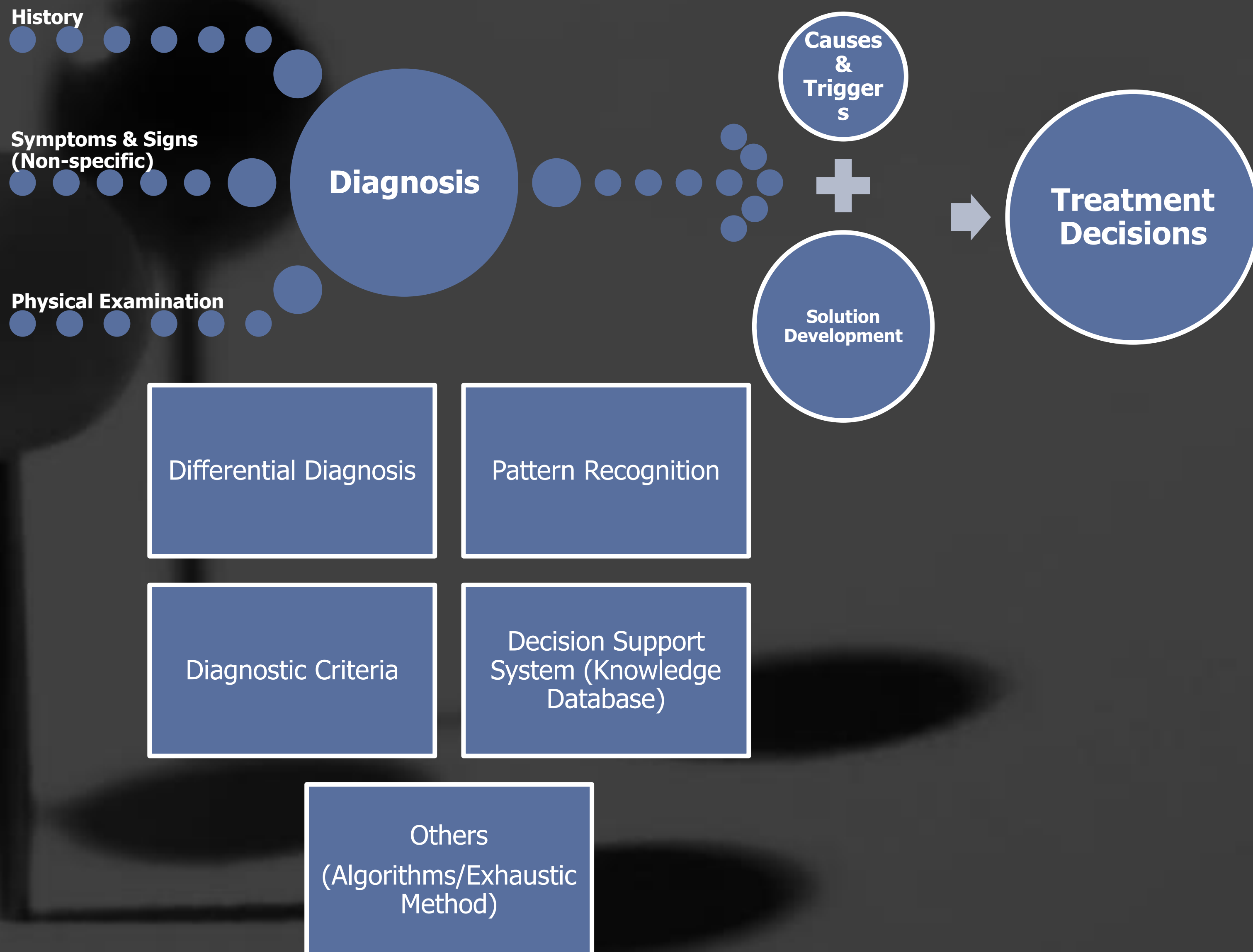
Content

- Common Problems in Linear Infrastructure Project
- Site Investigation
  - Planning, Execution & Interpretation
- Forensic Investigation
  - Stability of Piled Supported Retaining Wall
  - Embankment Distress (Strain Incompatibility)
  - Abutment Distress due to Piled Embankment Failure
  - Unreliable Facing Capacity of Soil Nailed Slope
- Design of Stone Columns for Wall Support in Soft Ground

Common Problems of Linear Infrastructure Projects

- Alignment – Cut & Fill Problems over Terrains & Formations
  - Cut : Slope Stability, Excavation in Rocks & Hard Materials
  - Fill : Walls, Embankment Bearing Stability & Settlement
- Bisecting Drainage Catchment & Flow Path : Internal/Scouring Erosion & Bridge Foundation

S.I. .vs. Medical Diagnosis



Site Investigation

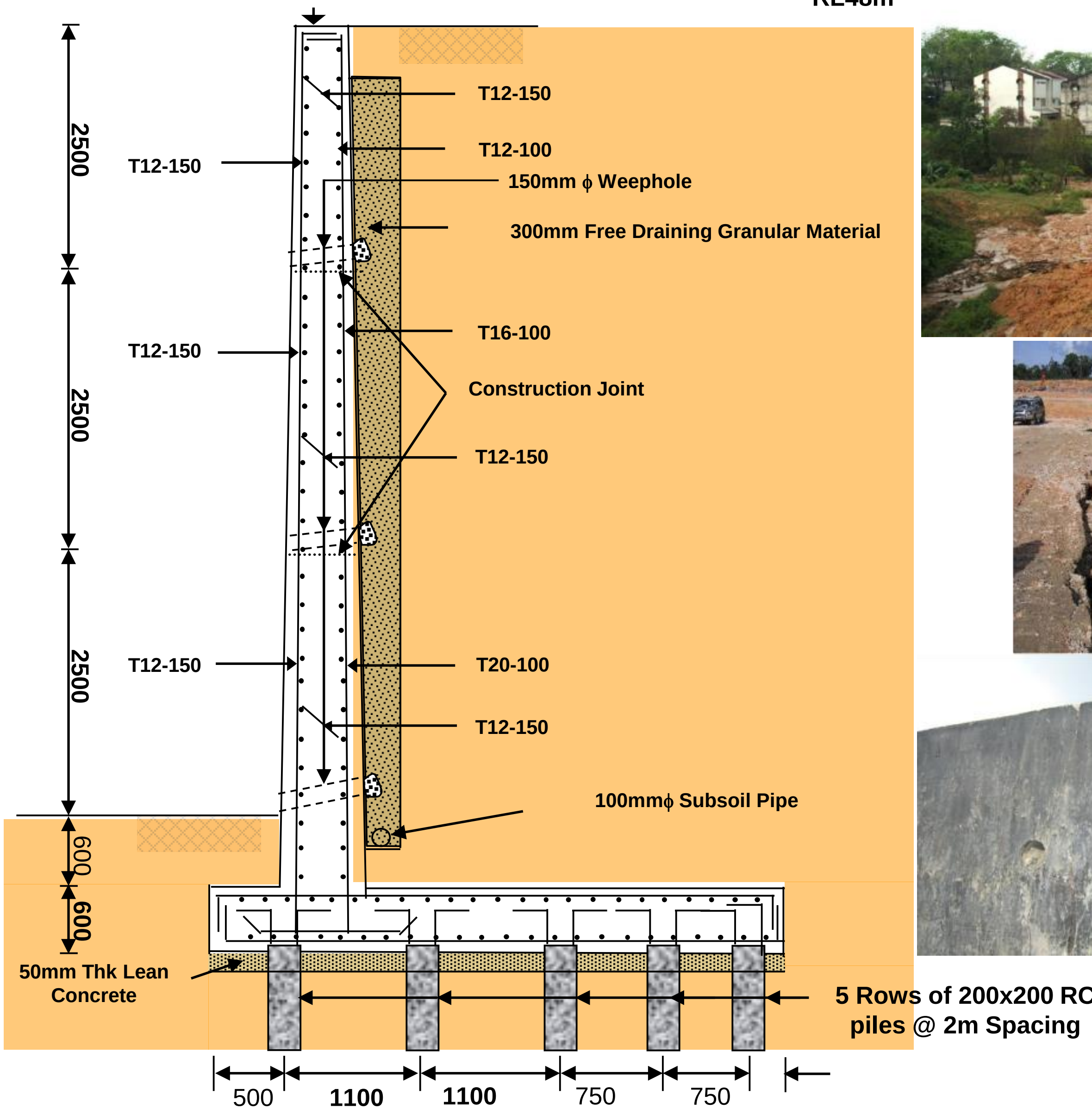
- Planning, Execution and Interpretation of Site Investigation (SI)
  - Lack of Geological & Geographical Knowledge (Genesis of ground formation, sequences of geo-processes, alteration with development activities, etc)
  - Inadequate Desktop Study
  - Over-emphasis on sampling & laboratory testing within project site & often ignoring macroscopic view of site
  - Time dependent variation of site condition
  - Validity of empirical calibration between pre and post site disturbance

Site Investigation

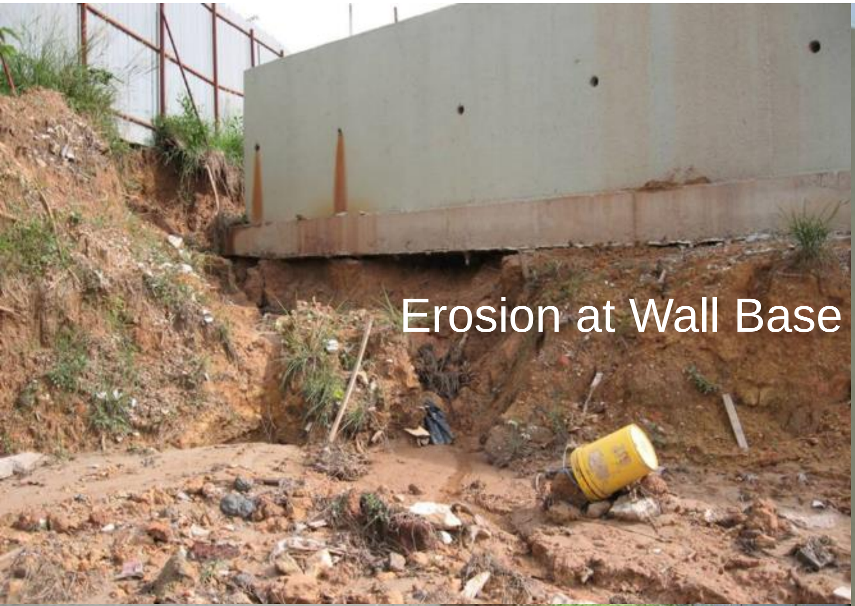
- Establish appropriate geological model from desktop study
  - Topographical & terrain maps
  - Geological & hydrogeological maps
  - Pre & post site disturbance survey
  - Historical land use information
  - Adjacent site information
- Minimise investigative resources to validate geological model and characterise the site with engineering properties
- Review the strategy of sampling and testing during drilling by experienced site supervising engineer
- Use of Geophysical exploration tools with good communication on investigating objectives & expectation

Case 1 : Lessons Learnt on Stability of a Piled Retaining Wall in Weak Soils

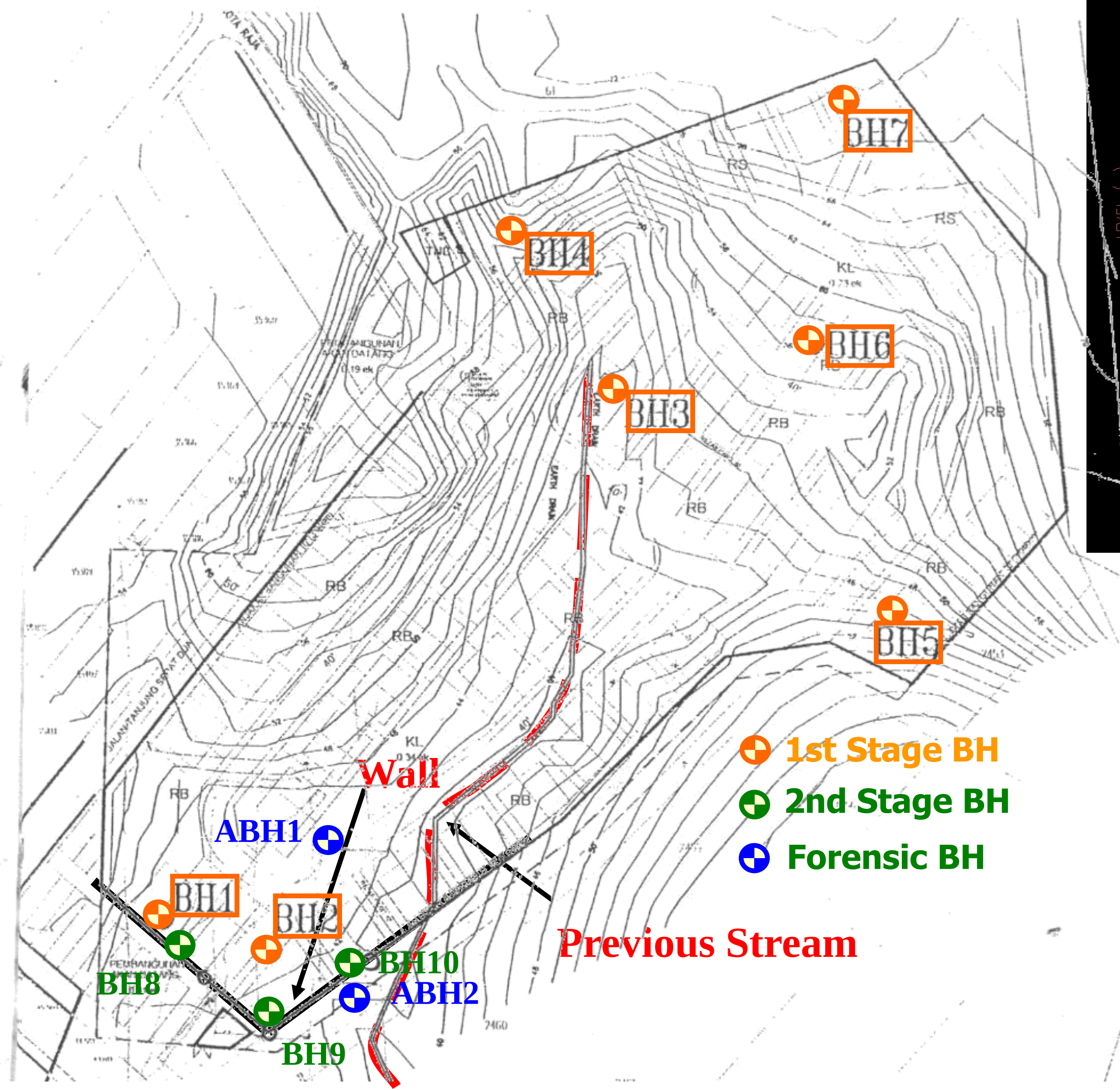
Cross Section of Wall

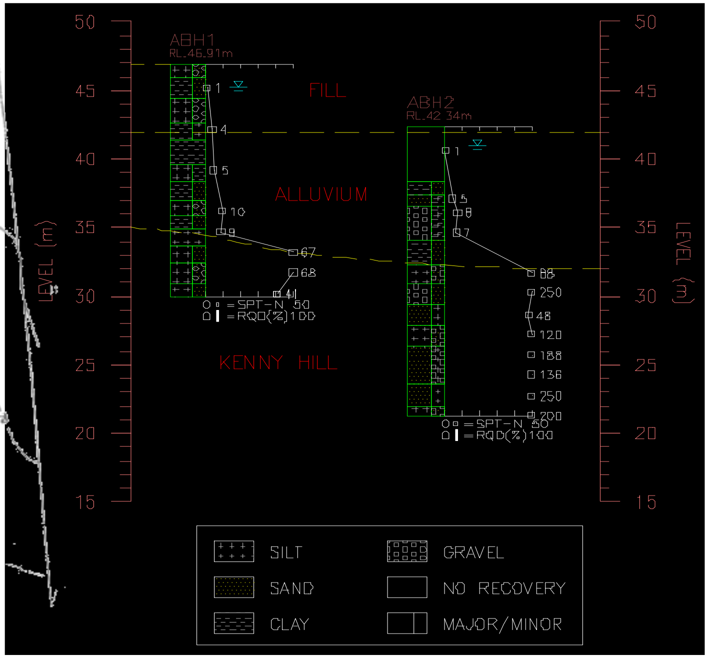


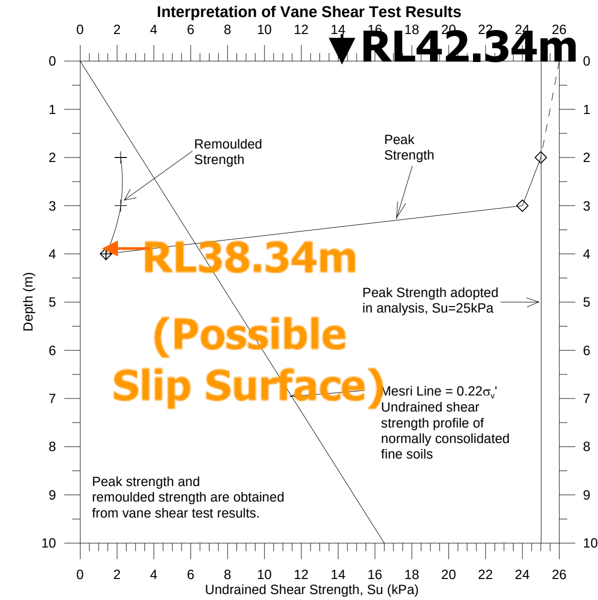
Water Level & Erosion



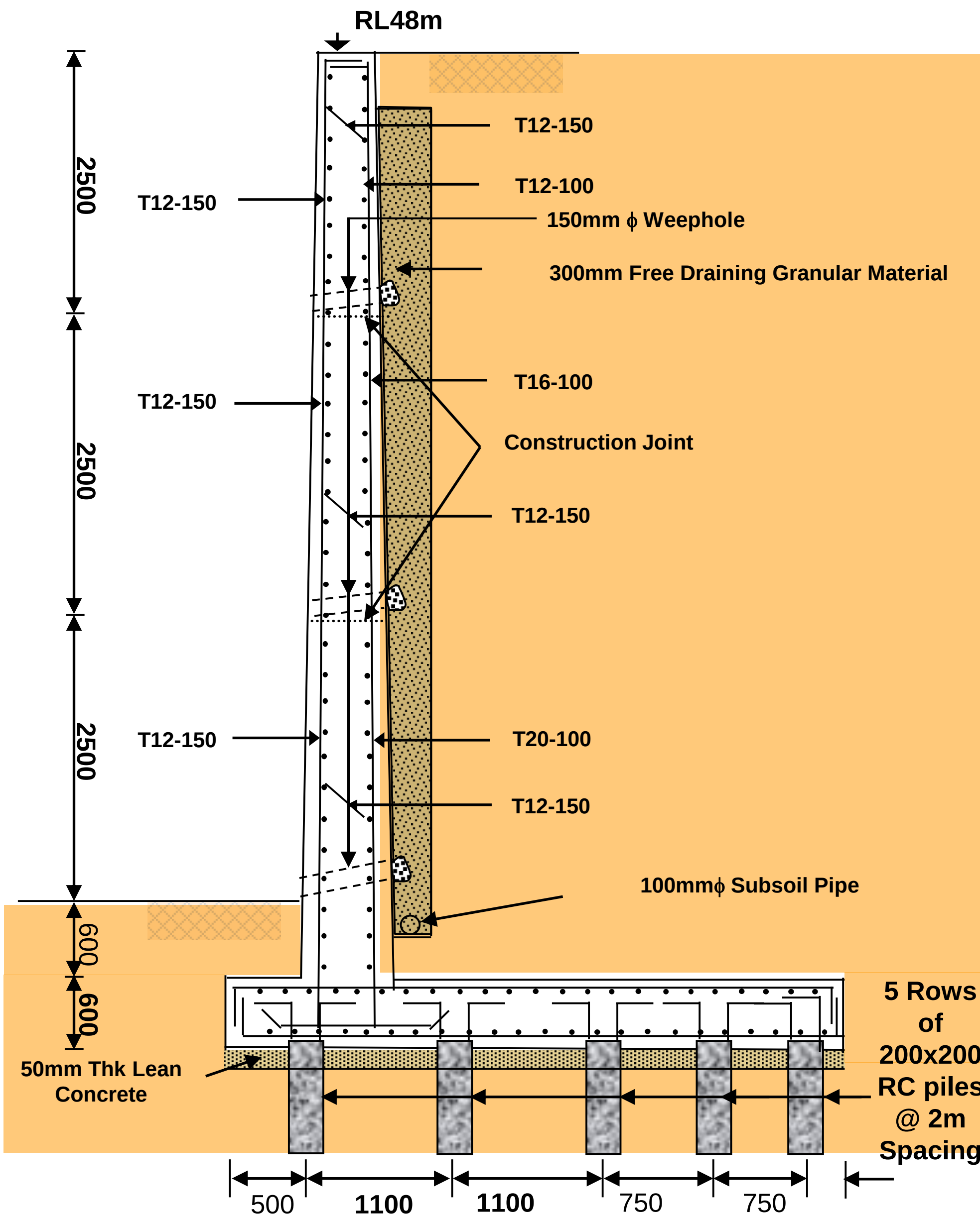
Forensic Boreholes







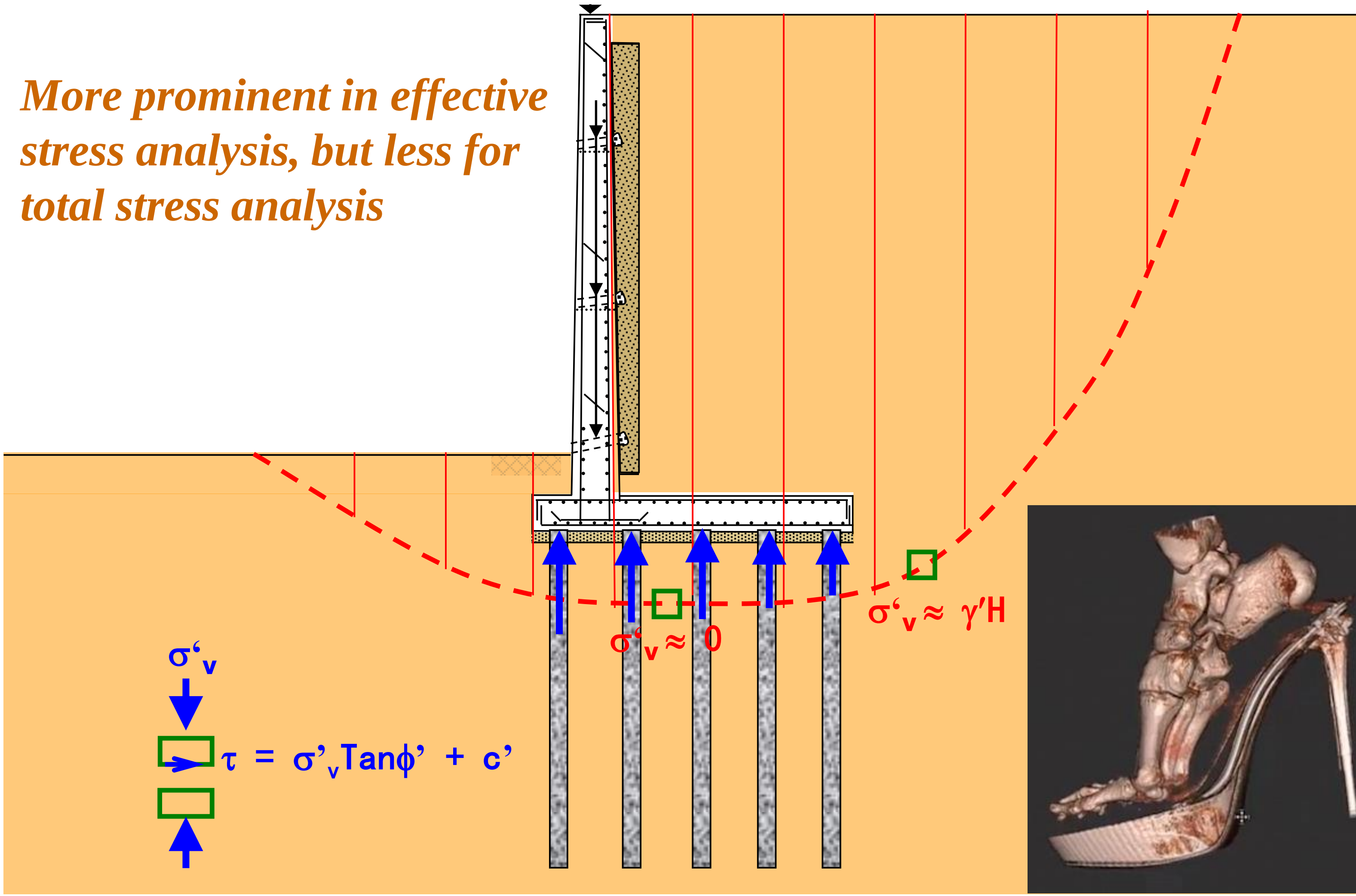
Stability Assessments



FOS of External Wall Stability			
GWT	**Over-turning**	**Sliding**	**Global Stability**
RL45m	✓ 2.9>2.0	✗ 0.97<1.0 (Failure)	✗ 1.13/1.17
RL42.5m	✓ 3.7>2.0	✗ 1.34<1.5	✓/✗ 1.16/1.24
RL40.4m	✓ 3.8>2.0	✗ 1.5	✓/✗ 1.19/1.25

Bearing Capacity is never a concern as pile foundation is designed to take the vertical loading of wall

More prominent in effective stress analysis, but less for total stress analysis

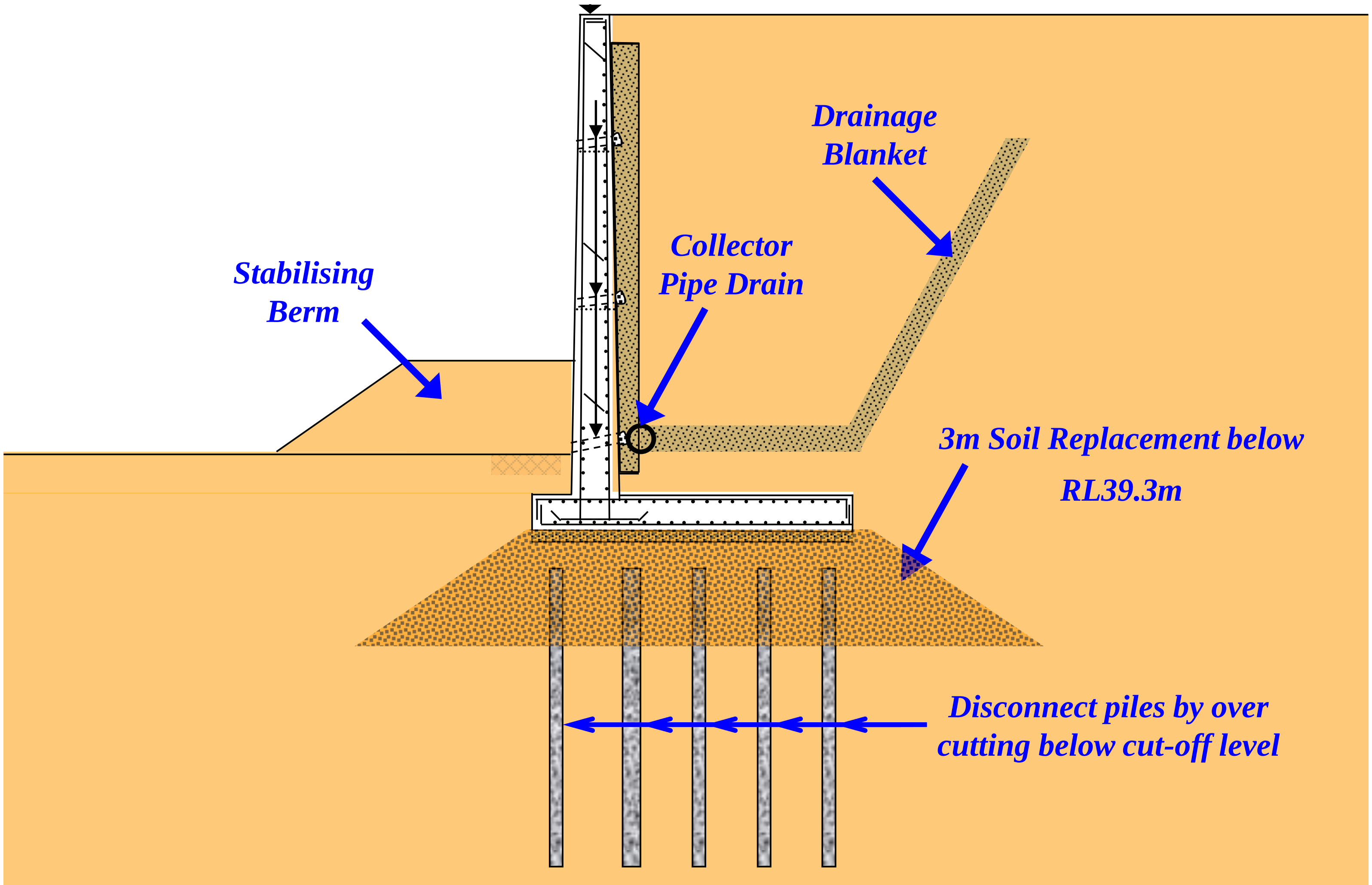


Pile Integrity Testing

Probable Causes of Wall Distress

- Potential perched water regime in natural valley terrain after raining
- Rise of groundwater increases the lateral force on wall
- Inadequate lateral pile resistance
  - Fixed Head : 32kN/pile (Likely the case)
  - Free Head : 20kN/pile
- Ultimate lateral pile capacity reached when RL42.5m<GWT<RL45m
- Reduction of effective soil strength due to reduction of vertical stress as wall loading carried by piles

Remedial Solution

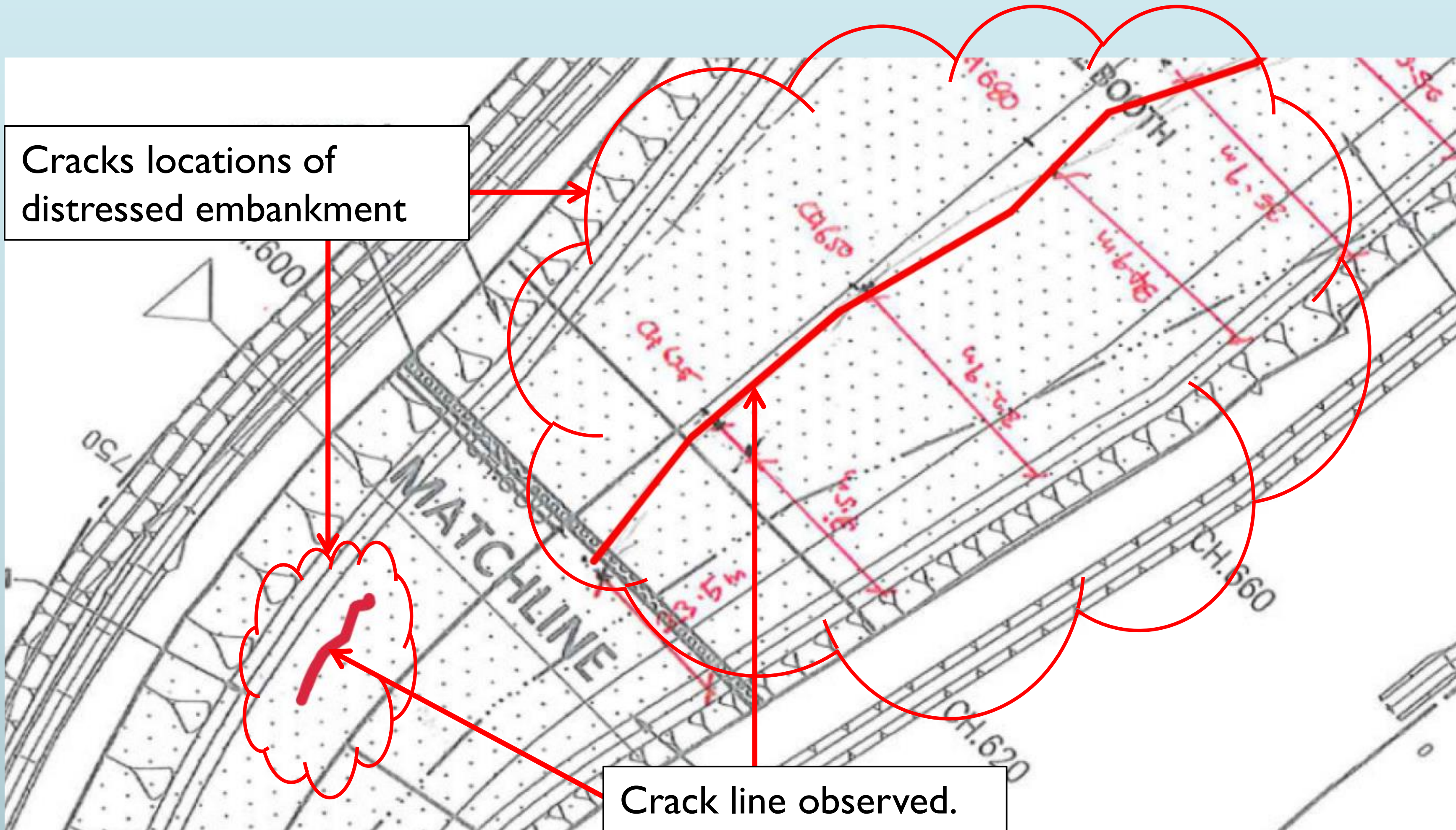


Case 2 : Extendible Basal Reinforcement for Embankment Construction Over Soft Soils

- Problem Statements
  - Embankment Fill over Soft Deposits
  - PVD Treatment with Staged Fill Construction
  - Basal Reinforcement for Temporary Embankment Stability
  - BS8006
  - Strain Incompatibility

- Distresses
  - Longitudinal flexural cracks on embankment surface

Embankment Distresses



Embankment Distresses

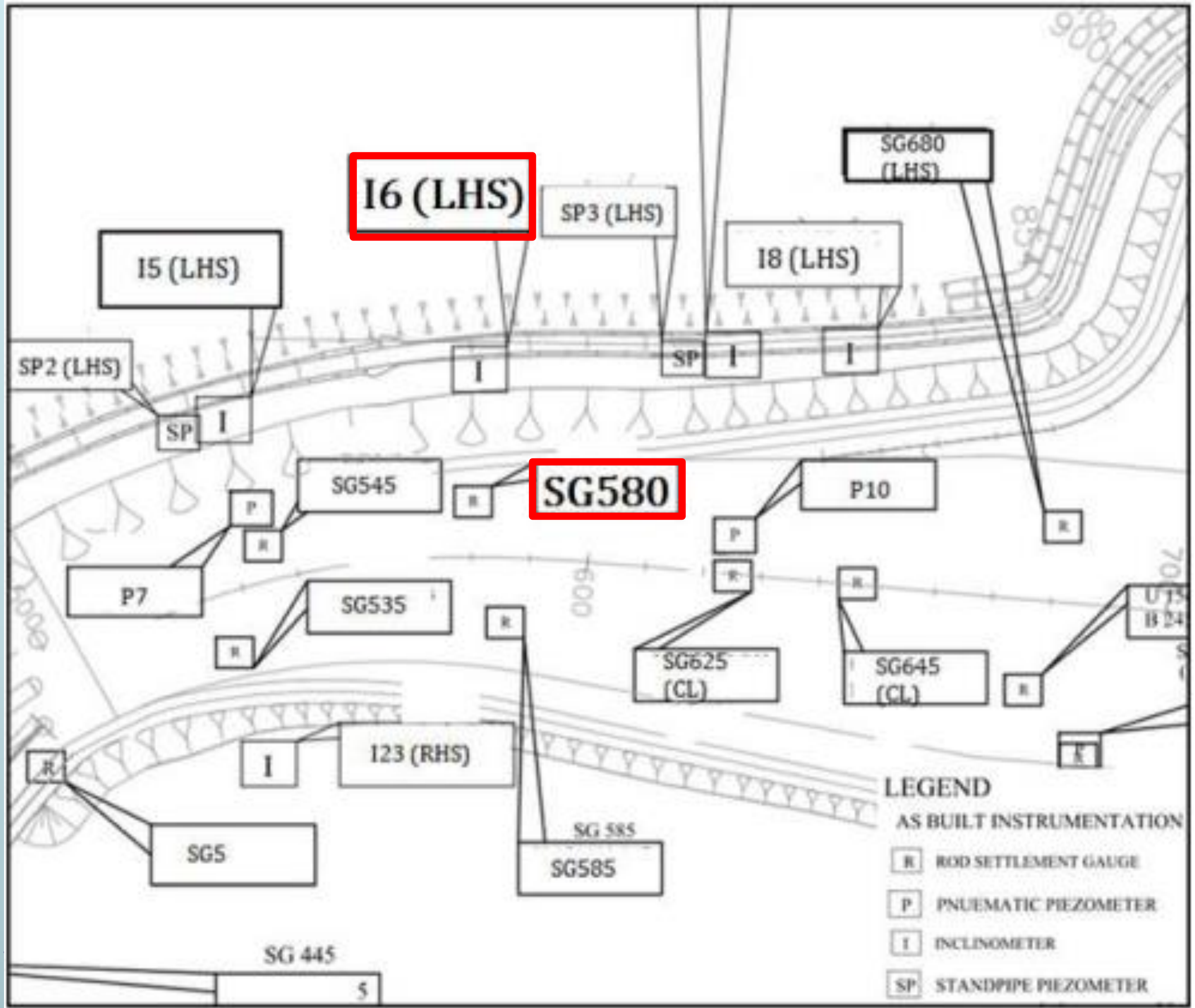
Embankment Distresses

Embankment Distresses

Excavation on cracks found after 1m surcharge removal

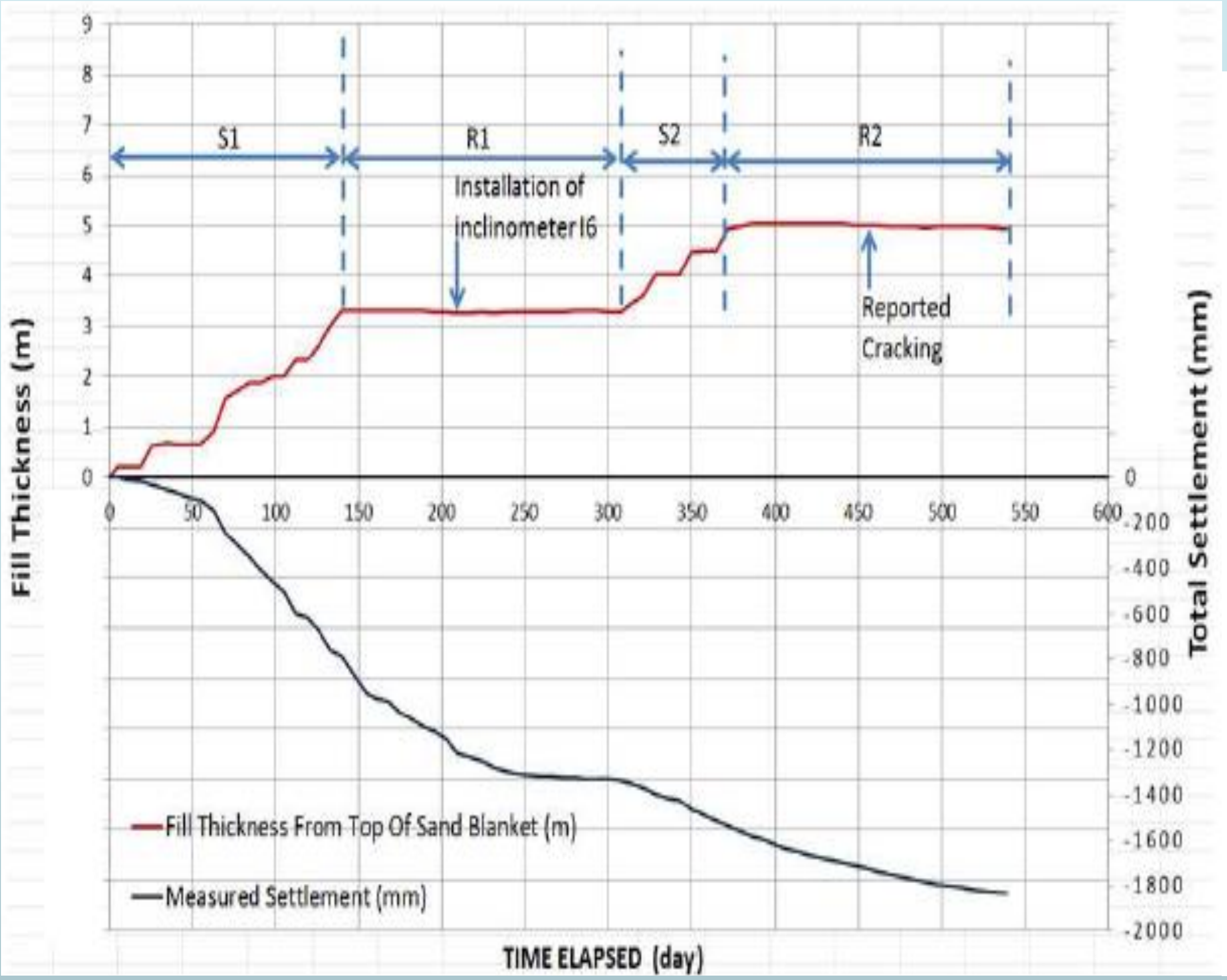
Instrumentation Layout

Instrumentation Layout Plan at Distresses area

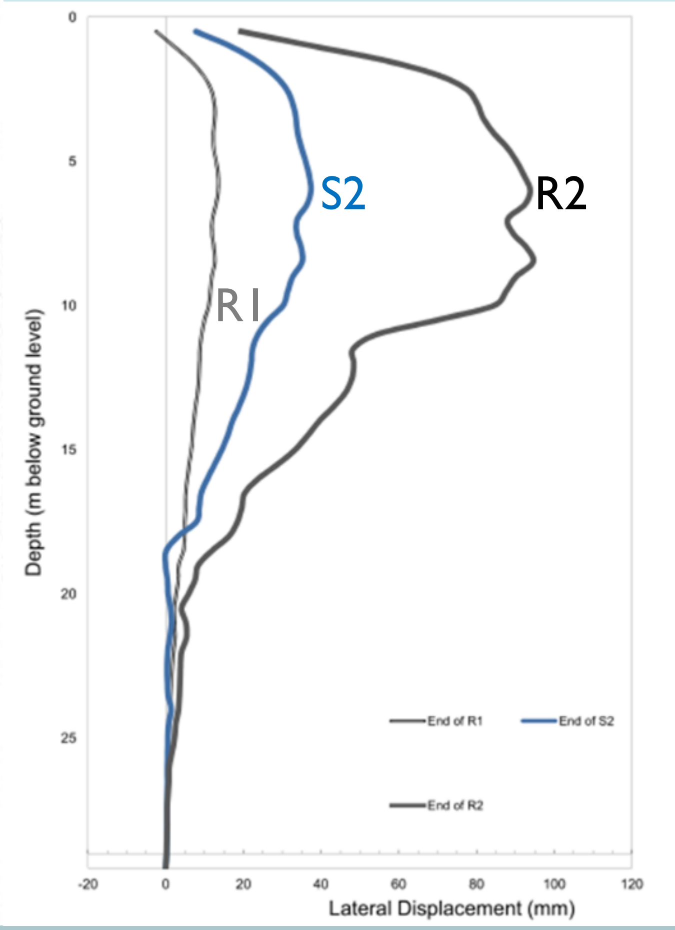


Instrumentation Results

Fill Thickness and Settlement of Embankment with time monitoring by **SG580**

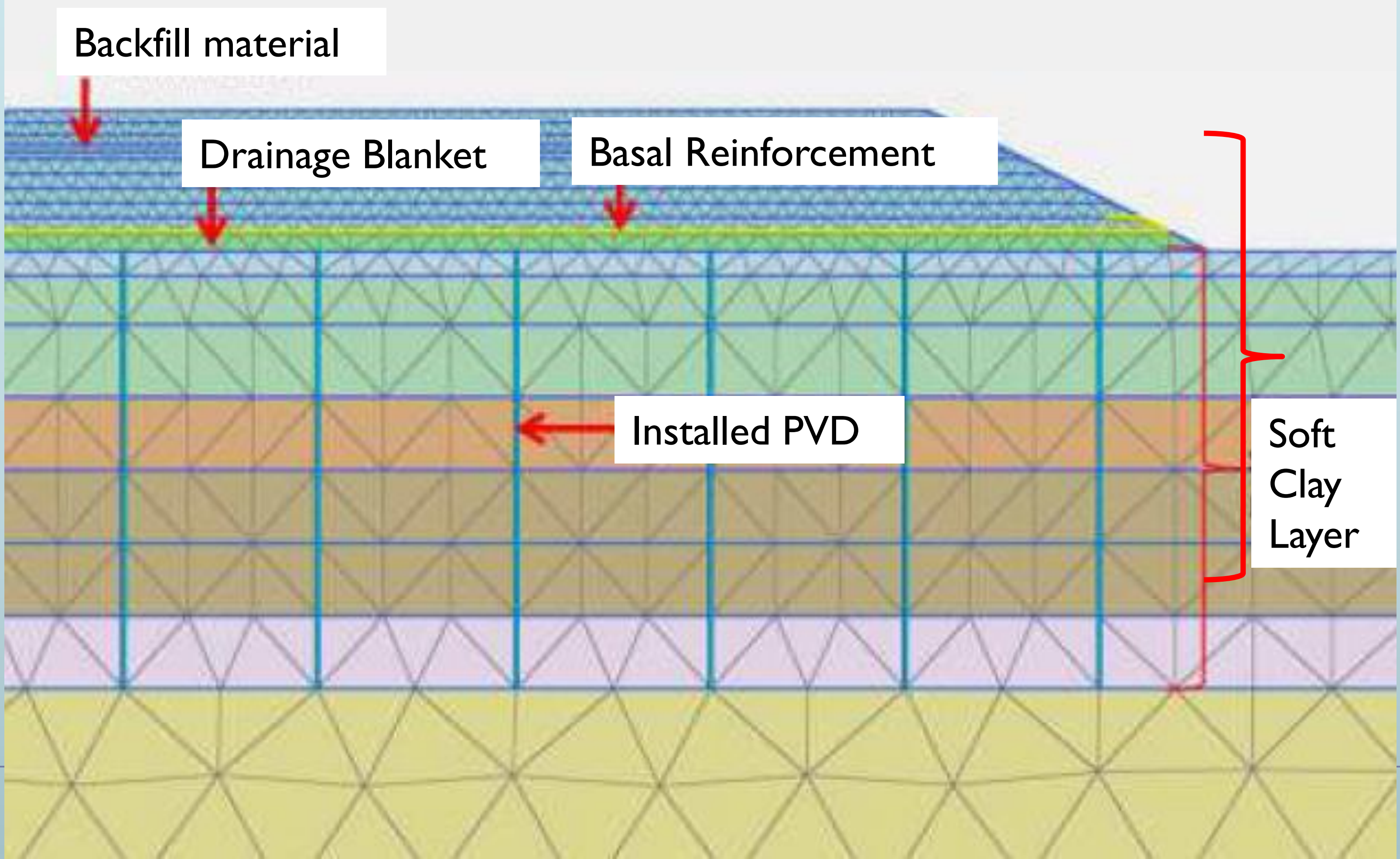


Inclinometer I6 Monitoring Results



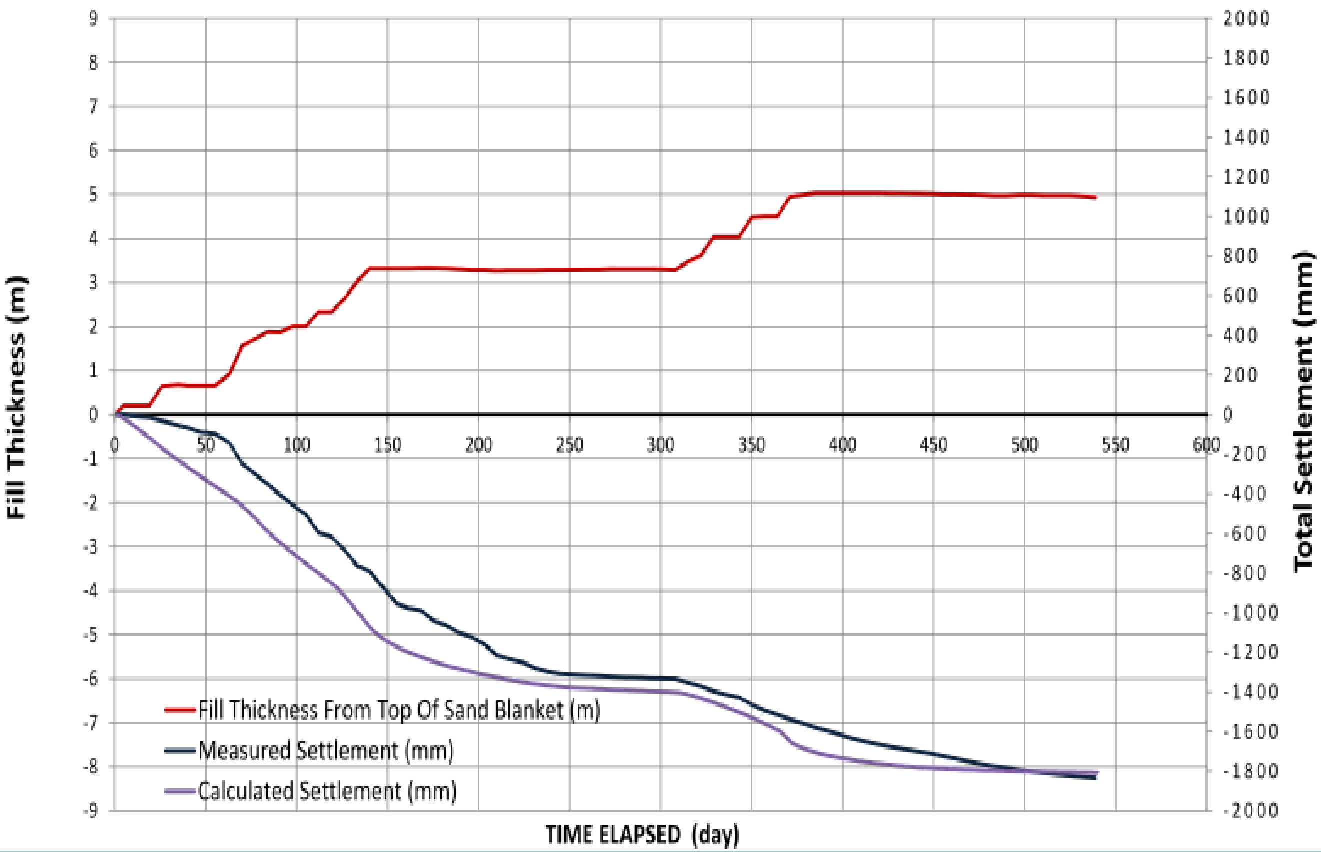
Finite Element Model (Back Analyses)

Case 1: Ultimate strength (600kN/m) mobilized at 10%
Case 2: Ultimate strength (140kN/m) mobilized at 1%

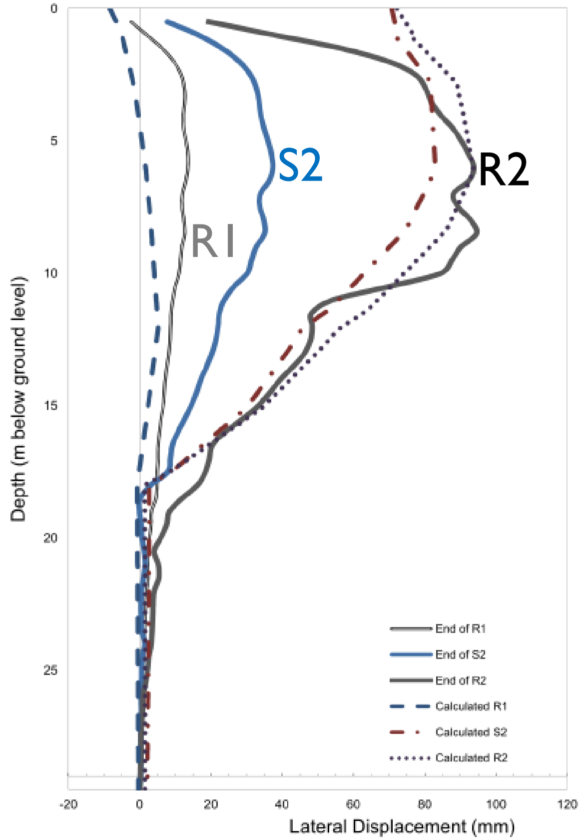


Finite Element Model

Comparison of Back Analysed Settlement Trend With Actual Measurement (Case 1)



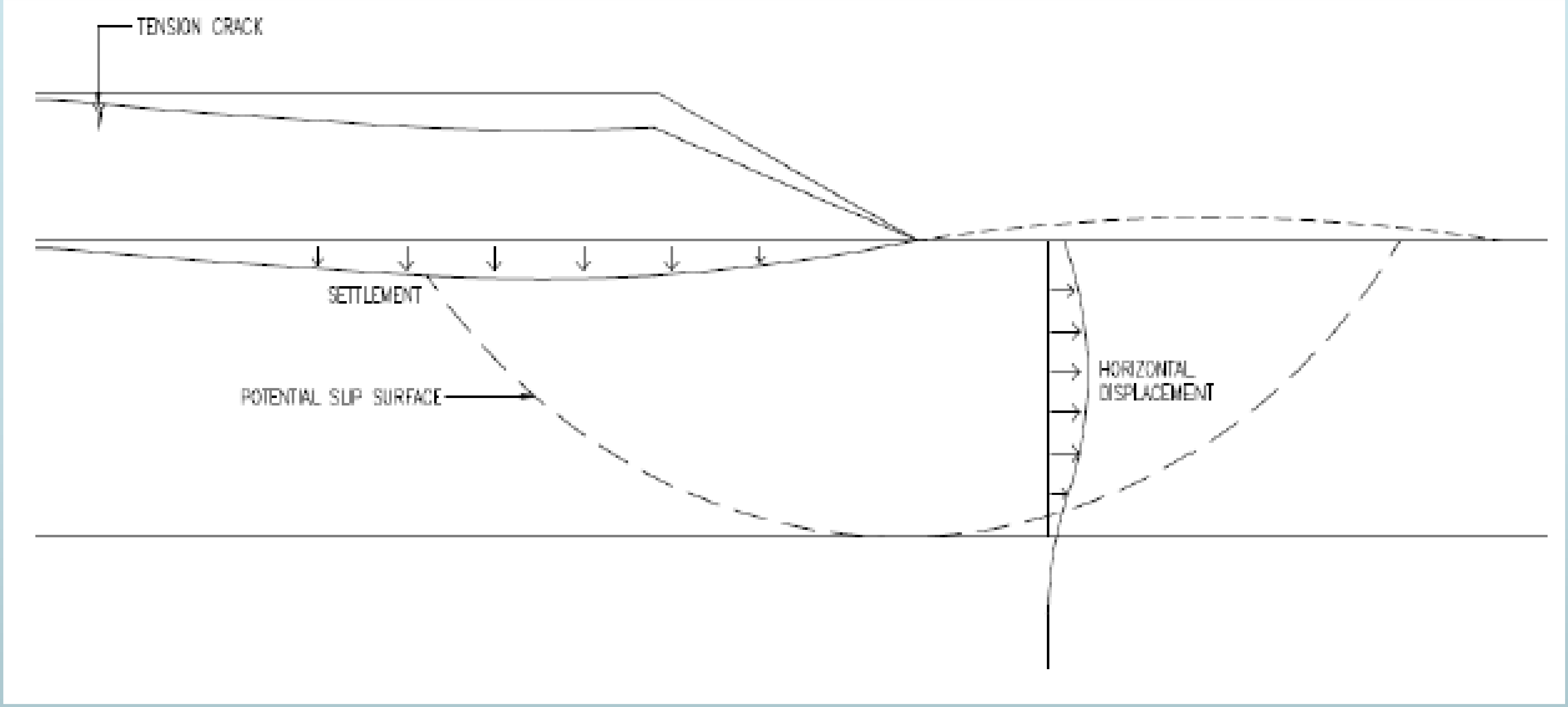
Comparison of Lateral Displacement Profile (Case 1)



Summary of Back Analyses

Stage	Tensile Stiffness	Mobilised Tensile Load / Tensile Strain	Maximum Lateral Deflection at Edge of Embankment (mm)
S1	Case 1 Case 2	40.6kN/m / 0.68% 65.9kN/m / 0.47%	267 (173)
R1	Case 1 Case 2	41.8kN/m / 0.70% 67.4kN/m / 0.48%	295 (180)
S2	Case 1 Case 2	64.6kN/m / 1.08% 106.8kN/m / 0.76%	400 (253)
R2	Case 1 Case 2	67.4kN/m / 1.12% 110.3kN/m / 0.79%	425 (265)

Probable Mechanism



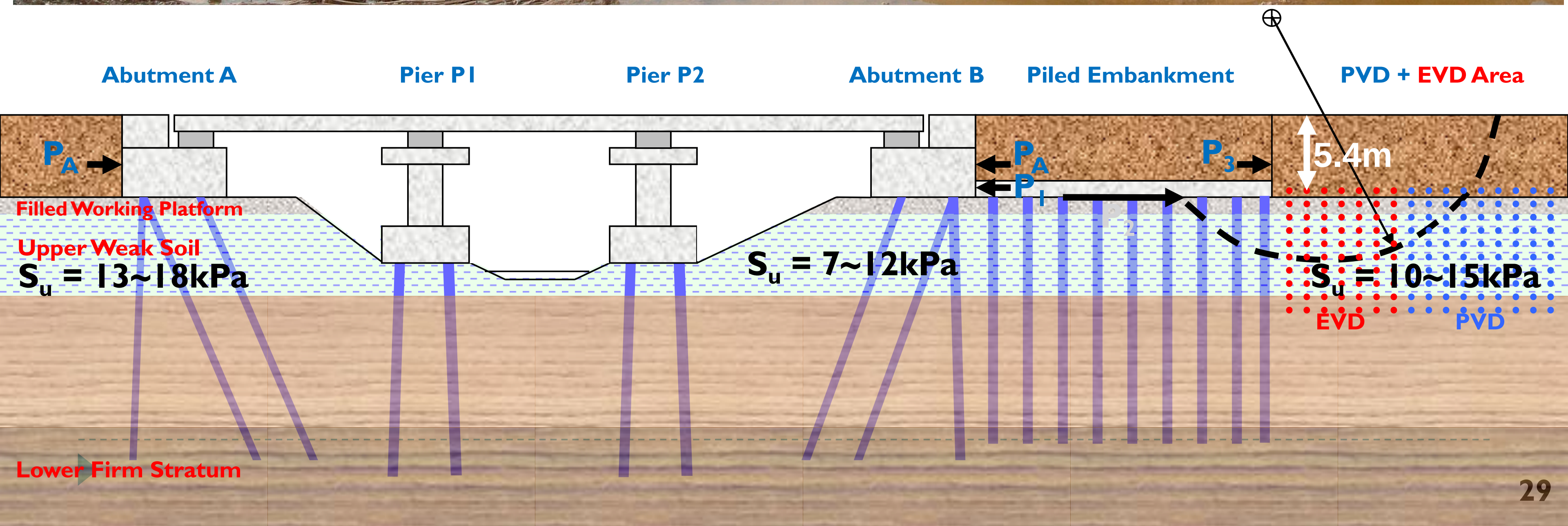
Conclusions

- Back-analysis result ➔ indicated mobilised tensile strength and strain << conventional assumed values for LEA stability analysis
- Strain incompatibility (Strain level) : Weak Alluvial Soil (Plastic Straining) >> Basal Reinforcement (Extendible) >> Compacted Fill (Brittle) ➔ Longitudinal cracks
- Review on current design practice by arbitrarily adopting unrealistic high mobilised strength is needed
- Wishful high tensile strain assumed in LEA can lead to misrepresentation on safety margin of embankment.

Recommendations

- Counterweight berm was proposed to solve the strain incompatibility between basal reinforcement and the subsoil.
- Instrument on basal reinforcement to reveal the distribution profile and performance of installed basal reinforcement.

Case 3 : Piled Supported Embankment Failure

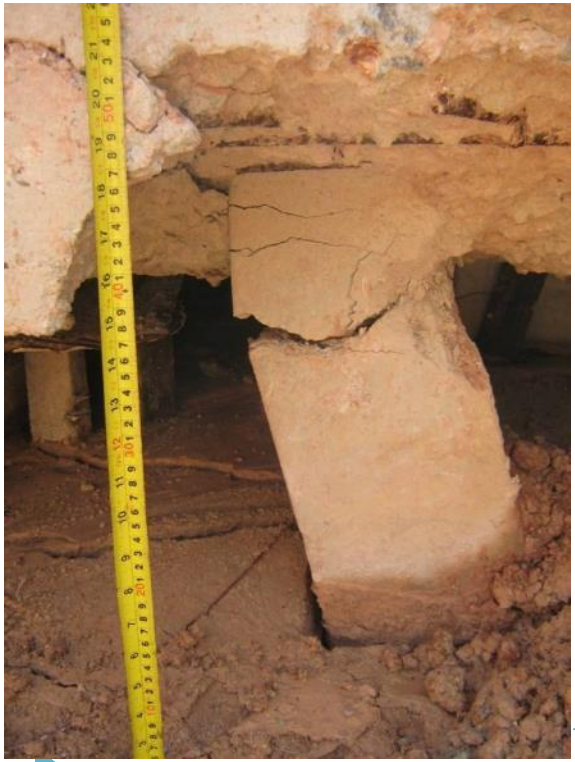


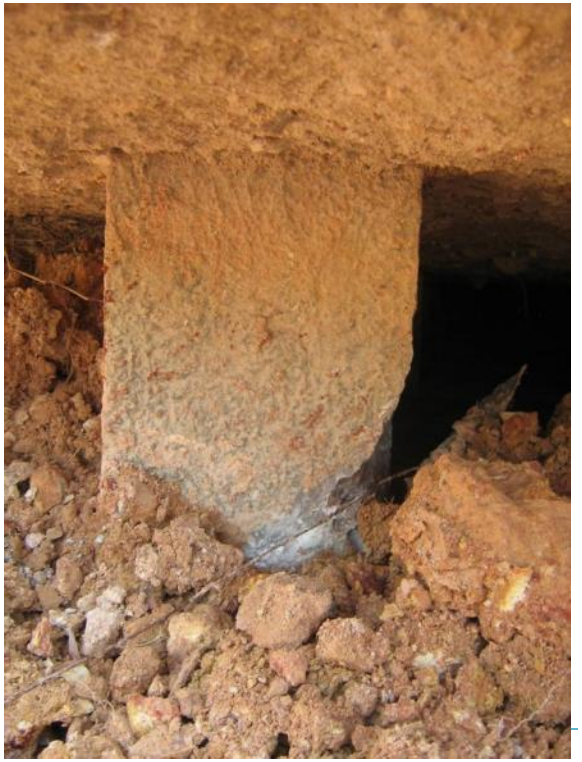
Site Inspection Findings

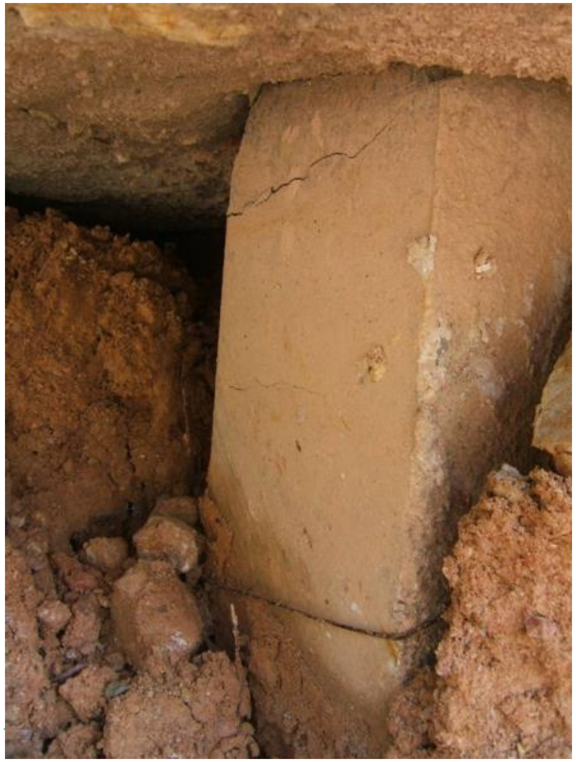
- Piled Embankment 30m from Abutment B shown structural distress

Site Inspections Findings

- Piles of Piled Embankment has shown flexural cracks







Site Inspections Findings

- Damaged piled embankment slab damaged & 100mm gap at slab joint

Site Inspections Findings

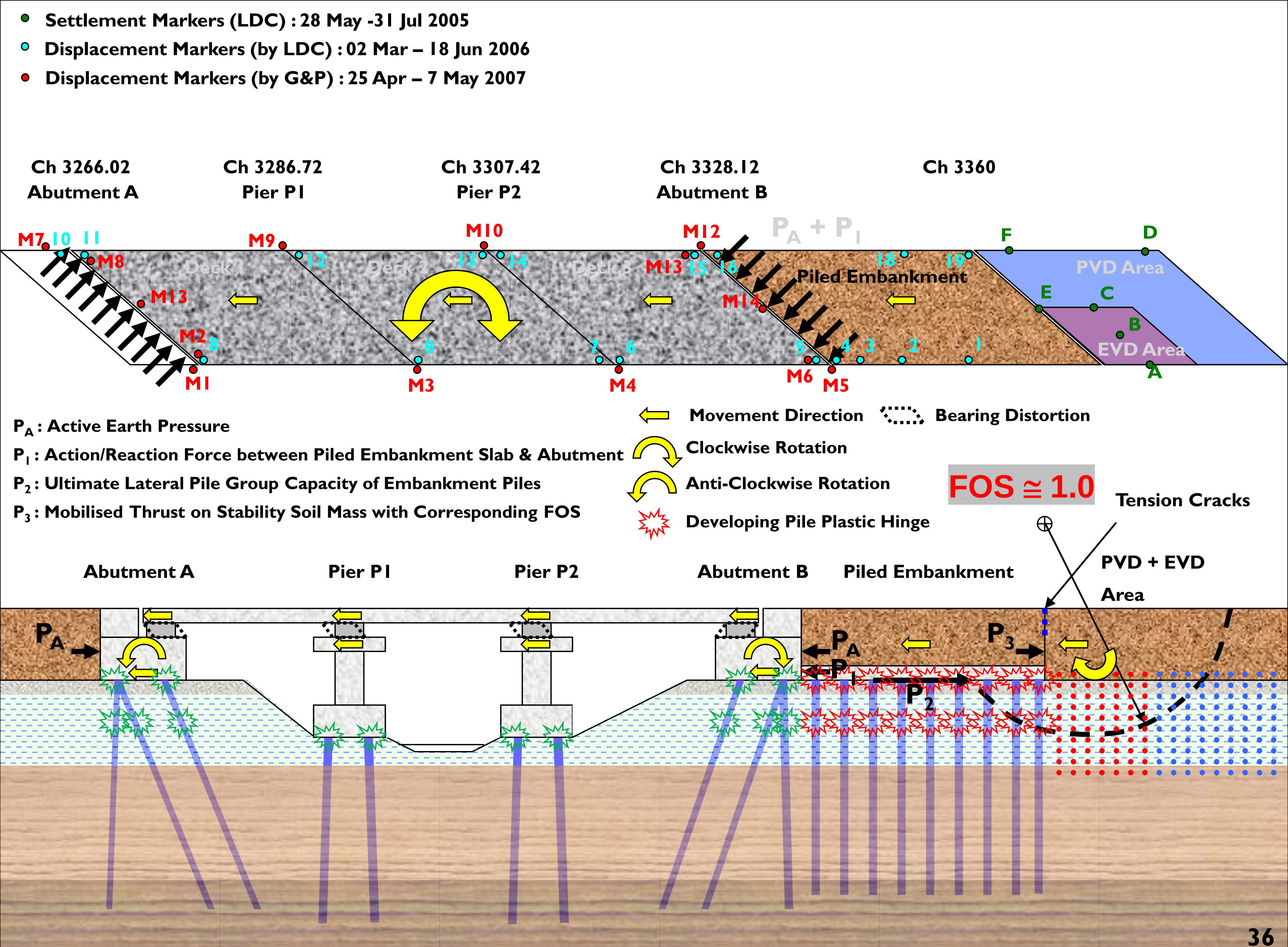
- Settlement of 0.4 to 1.0m under the Piled Embankment

Site Inspections Findings

- Bearing distortion at Pier P1

Site Inspections Findings

- Bearing distortion at Pier P2


Settlement Markers (LDC) : 28 May -31 Jul 2005
Displacement Markers (by LDC) : 02 Mar – 18 Jun 2006
Displacement Markers (by G&P) : 25 Apr – 7 May 2007
Ch 3266.02
Abutment A
Ch 3286.72
Pier P1
Ch 3307.42
Pier P2
Ch 3328.12
Abutment B
Ch 3360
PA + PI
Deck 1
Deck 2
Deck 3
Piled Embankment
PVD Area
EVD Area
M7 10 11 M8 M13 M2 8 M1 M9 12 M3 8 M10 13 14 7 6 M4 M12 M13 15 16 M14 5 4 3 2 1 M6 M5 18 19
F D E C B A
PA : Active Earth Pressure
PI : Action/Reaction Force between Piled Embankment Slab & Abutment
P2 : Ultimate Lateral Pile Group Capacity of Embankment Piles
P3 : Mobilised Thrust on Stability Soil Mass with Corresponding FOS
Movement Direction
Bearing Distortion
Clockwise Rotation
Anti-Clockwise Rotation
Developing Pile Plastic Hinge
FOS ≅ 1.0
Tension Cracks
PVD + EVD Area
Abutment A
Pier P1
Pier P2
Abutment B
Piled Embankment
PA
PA
PI
P2
P3

Conclusions

- Weak post-treatment soil strength unable to support embankment
- Creep movement of weak subsoil beneath embankment coupled with embankment instability due to low FOS
- Monitored bridge displacement confirmed pattern of lateral movement of entire bridge & piled embankment
- Further consolidation of weak overburden soil beneath working fill platform resulting in free standing pile conditions
- Structural damage on free standing embankment piles was expected as structural threshold has been reached

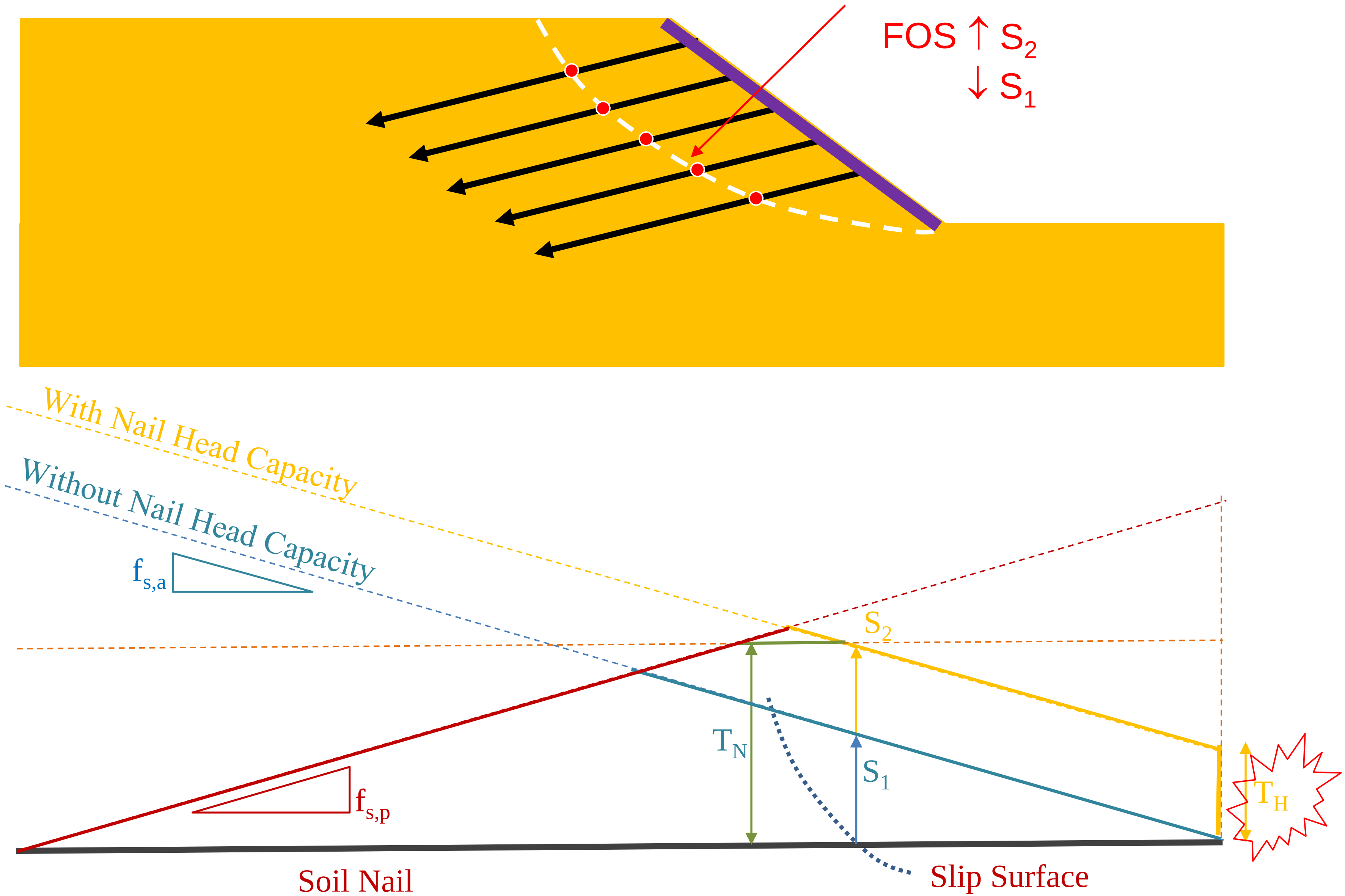
Case 4 : Unreliable Facing Capacity of Soil Nailed Slope

- With intention of minimized earthwork cutting forming any platform, soil nailed slope profile is normally steep
- Facing capacity has remarkable effect on Internal Stability of steep soil nailed slope
- Volumetric swelling & shrinkage of soils with moisture variation are realistic observation
- Moisture depletion after covering with shotcrete surface results in volumetric shrinkage of slope soil face leaving air gap with separation of contact with shotcrete
- Mobilisation of face capacity in uncontacted slope surface is unrealistic, thus giving incorrect safety margin of slope stability

Volumetric Shrinkage of Exposed Soil

Gap below Shotcrete Surface with Depleting Moisture

Nail Force Diagram & Stability



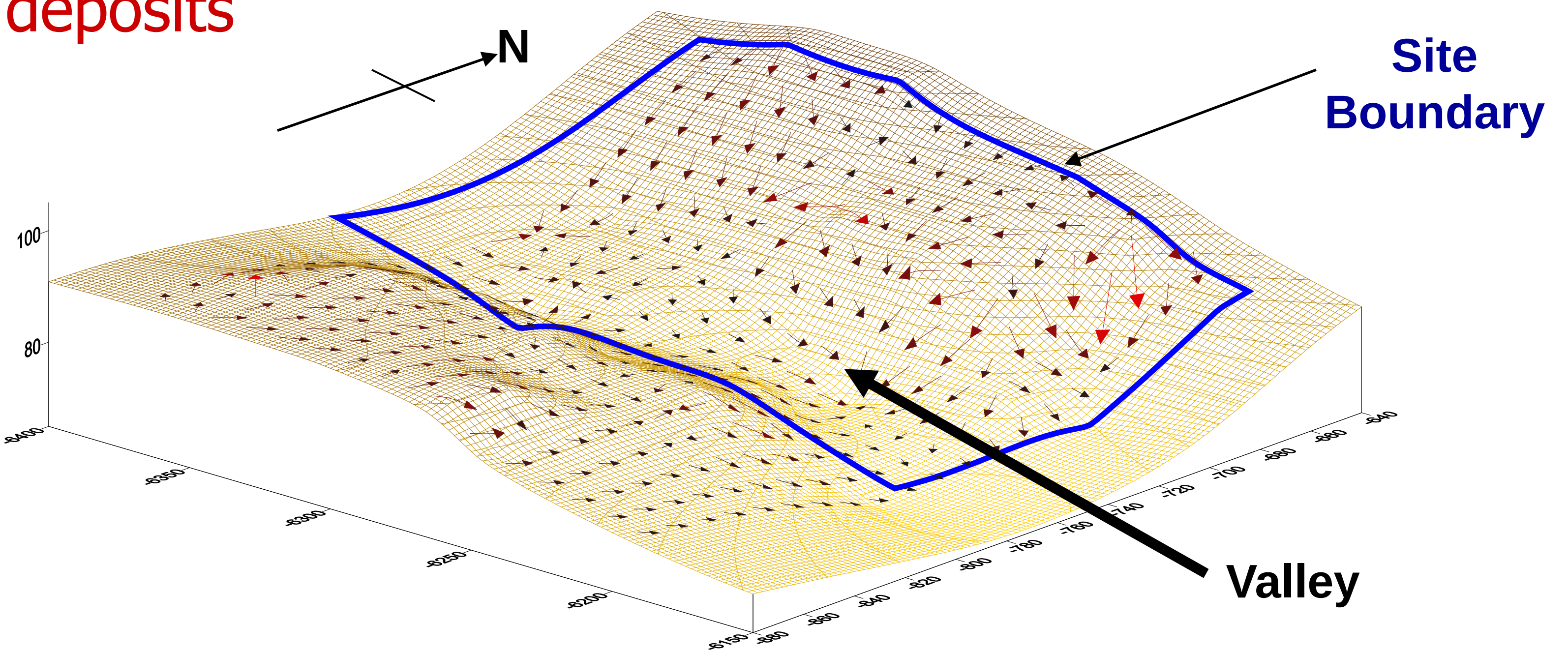
Case Study 5 : Performance of Stone Columns Supported RS Wall

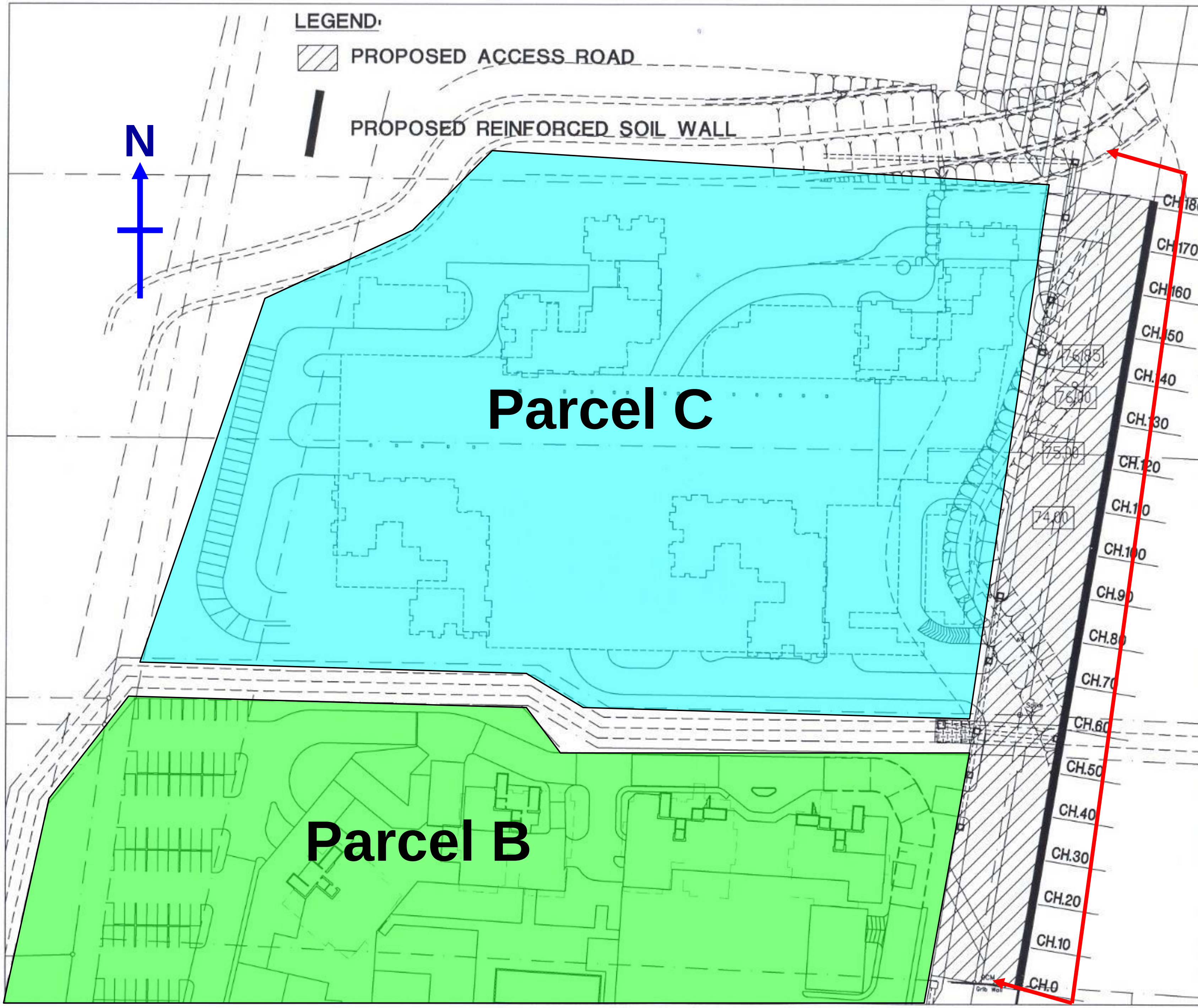
- Original Topography
- Subsurface Information
- Adopted Foundation System for RS Wall
- Design Consideration
- QA/QC During Construction
- Design Verification
- Conclusion

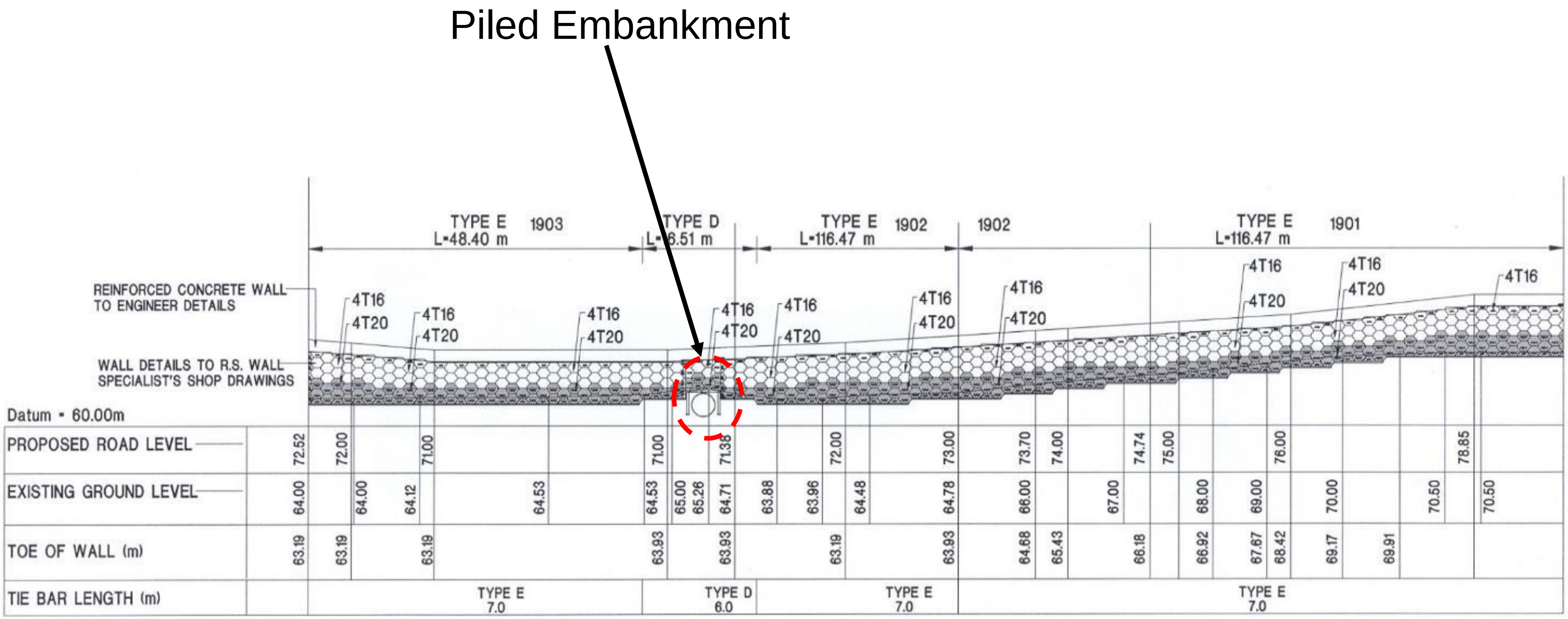
Original Topography of Site

- Original ground is hilly
- Surface runoff towards natural valley area
- Within proximity of previous water stream

➔ Weak deposits



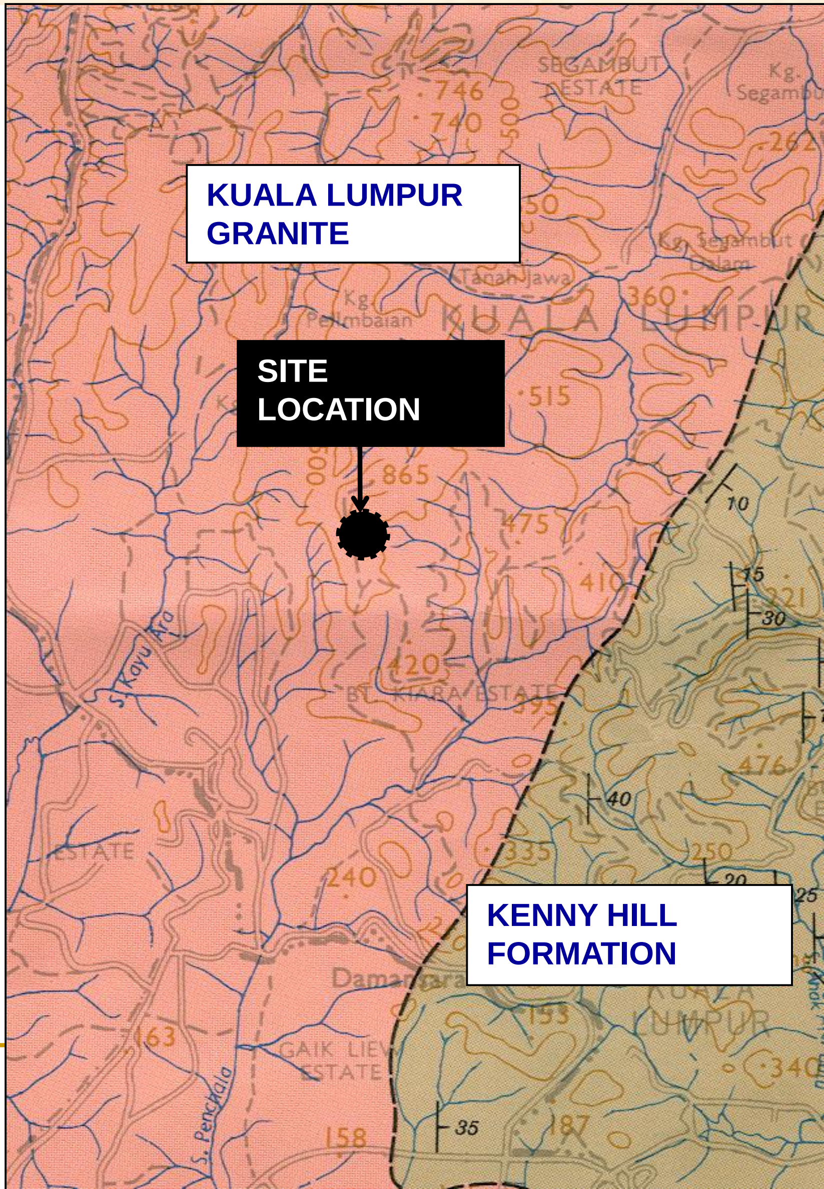

LEGEND:
PROPOSED ACCESS ROAD
PROPOSED REINFORCED SOIL WALL
N
Parcel C
Parcel B
CH.180
CH.170
CH.160
CH.150
CH.140
CH.130
CH.120
CH.110
CH.100
CH.90
CH.80
CH.70
CH.60
CH.50
CH.40
CH.30
CH.20
CH.10
CH.0



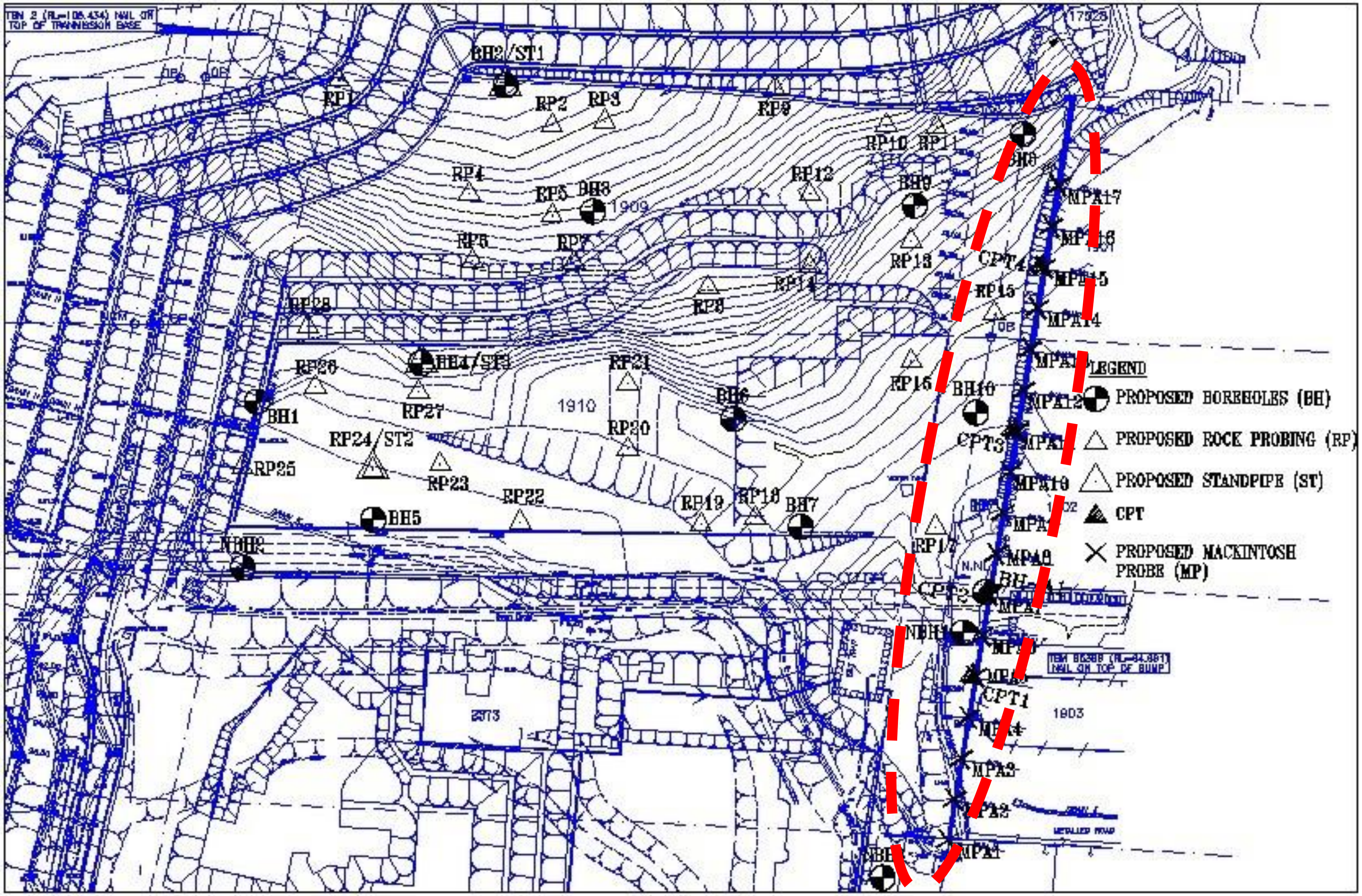
RS Wall Elevation Profile

SUBSURFACE INFORMATION

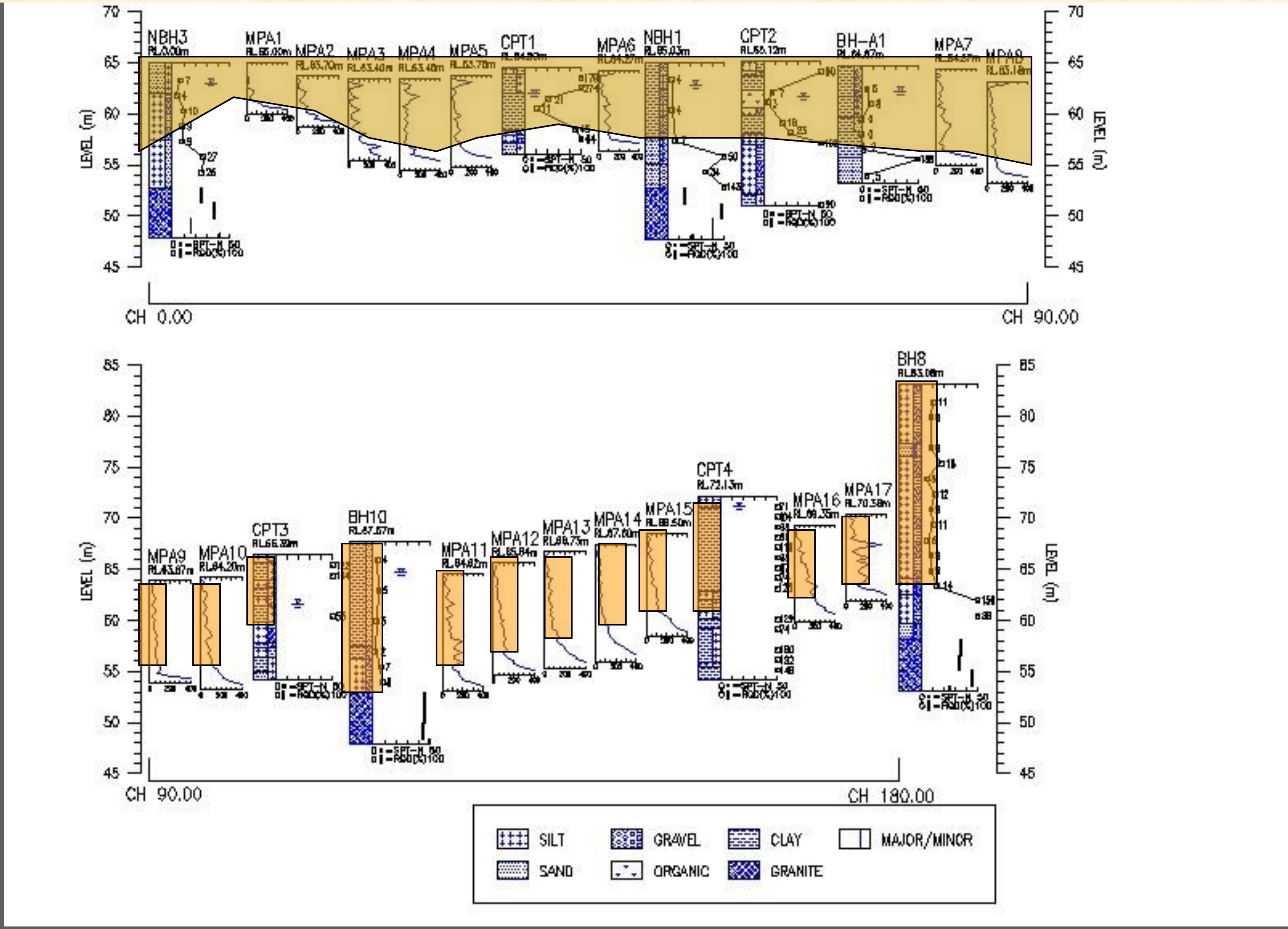
- Residual Soil
- Granitic Formation
- Intermediate Boulders



S.I. Layout Along RS Wall

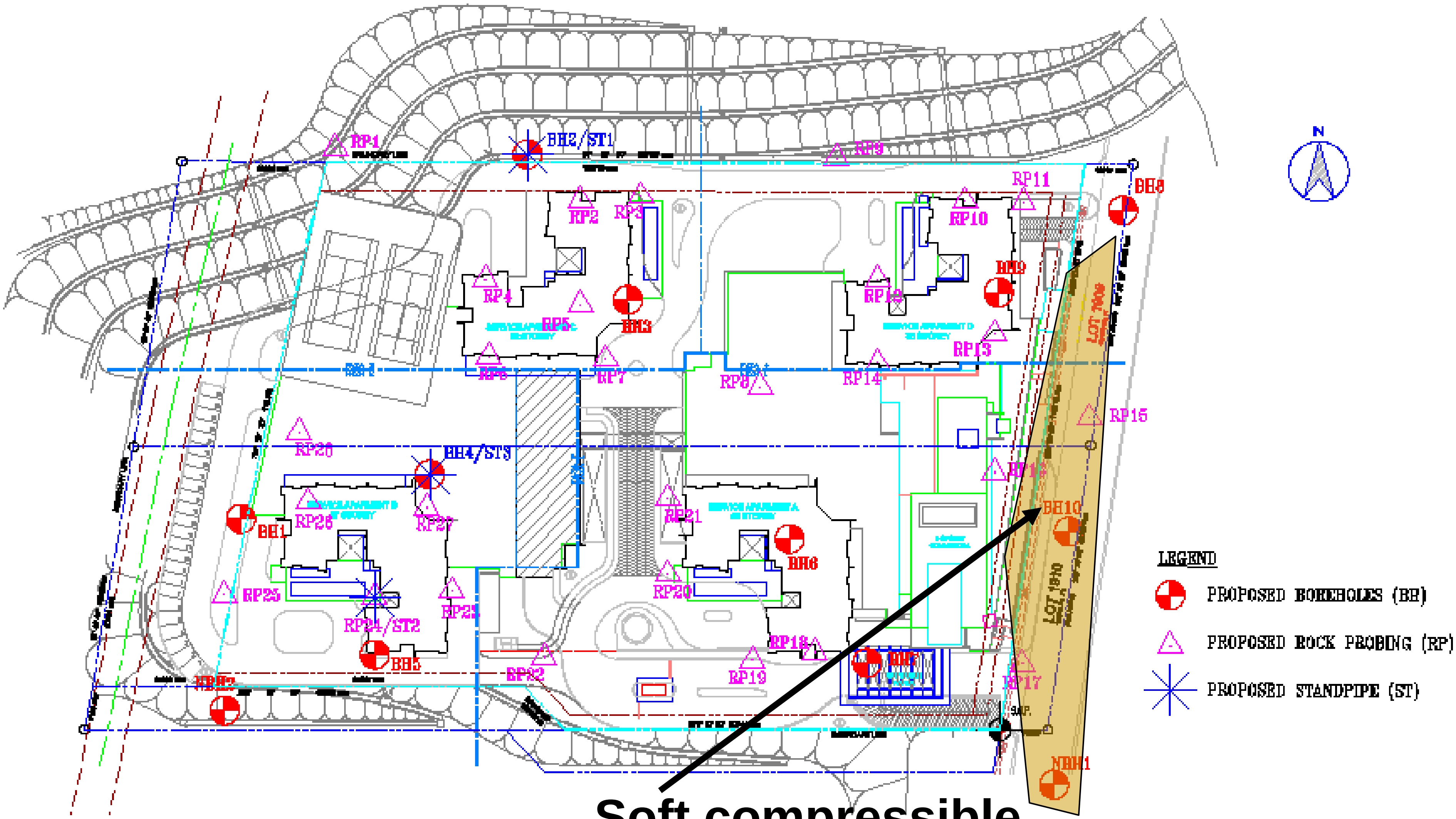


Subsurface Profile Along RS Wall



Soft Compressible Layer

Implications



Soft compressible subsoil

ADOPTED FOUNDATION DESIGN SYSTEM FOR RS WALL

- 10m high reinforced soil wall on up to 12m thick soft compressible subsoil

➔ Stone column

  - 1m diameter
  - 2m centre to centre spacing

ADOPTED FOUNDATION DESIGN SYSTEM FOR RS WALL

- Reasons
  - Reinforcement of weak subsoil
  - Drainage for dissipation of excess pore pressure generation
  - Improving strength and deformation properties of soil

DESIGN CONSIDERATIONS

- Bulging of individual stone column
- General shear of stone column
- Stress distribution between stone columns and subsoil

DESIGN CONSIDERATIONS

- Bearing capacity of subsoil and stone column
- Global stability of RS wall
- Overall ground settlement after improvement

QA / QC DURING CONSTRUCTION

- Material control

- Appropriate termination criteria of stone column installation

- Verification test (plate load test)

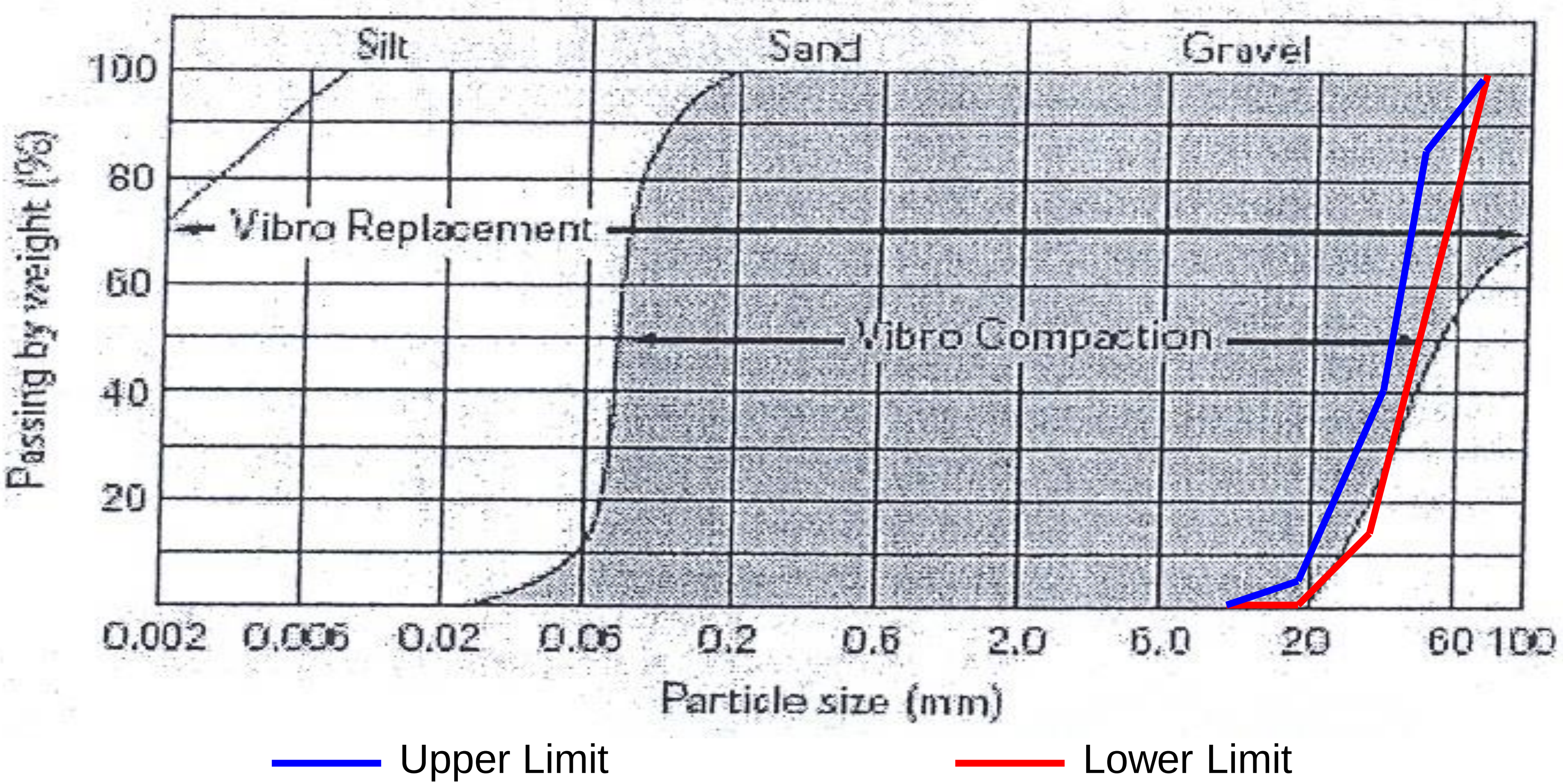
Material Control

- Clean, hard, durable
- Chemically inert natural materials

Test	Standard	Criteria	Frequency
Crushing Value	BS 882:1992	<30%	1 test per 30,000 tonnes of aggregate
Los Angeles Abrasion	ASTM C131	Max loss of 40% at 500 revolutions	
Flakiness Index	BS 882:1992	<30%	
Sulphate Soundness	ASTM C88	<12%	

Material Control

(Allowable grading of stone aggregates)



Range of Soils suitable for Vibro Compaction Methods

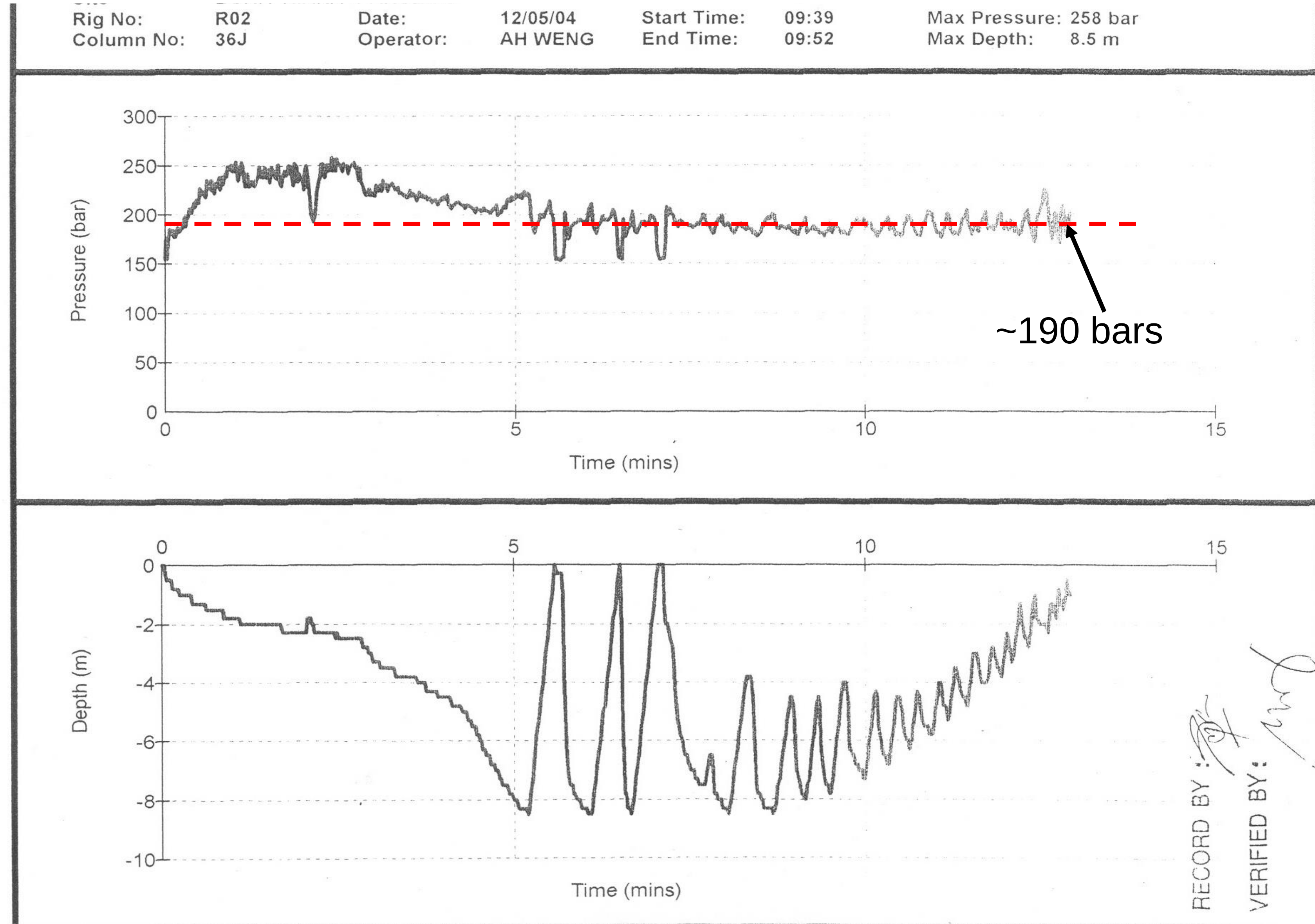
(Baumann and Bauer, 1974)

Termination Criteria

- Hydraulic pressure in the vibratory probe = 190 bars

TO BE VERIFIED BY PLATE LOAD TEST DURING FIRST COLUMN INSTALLATION

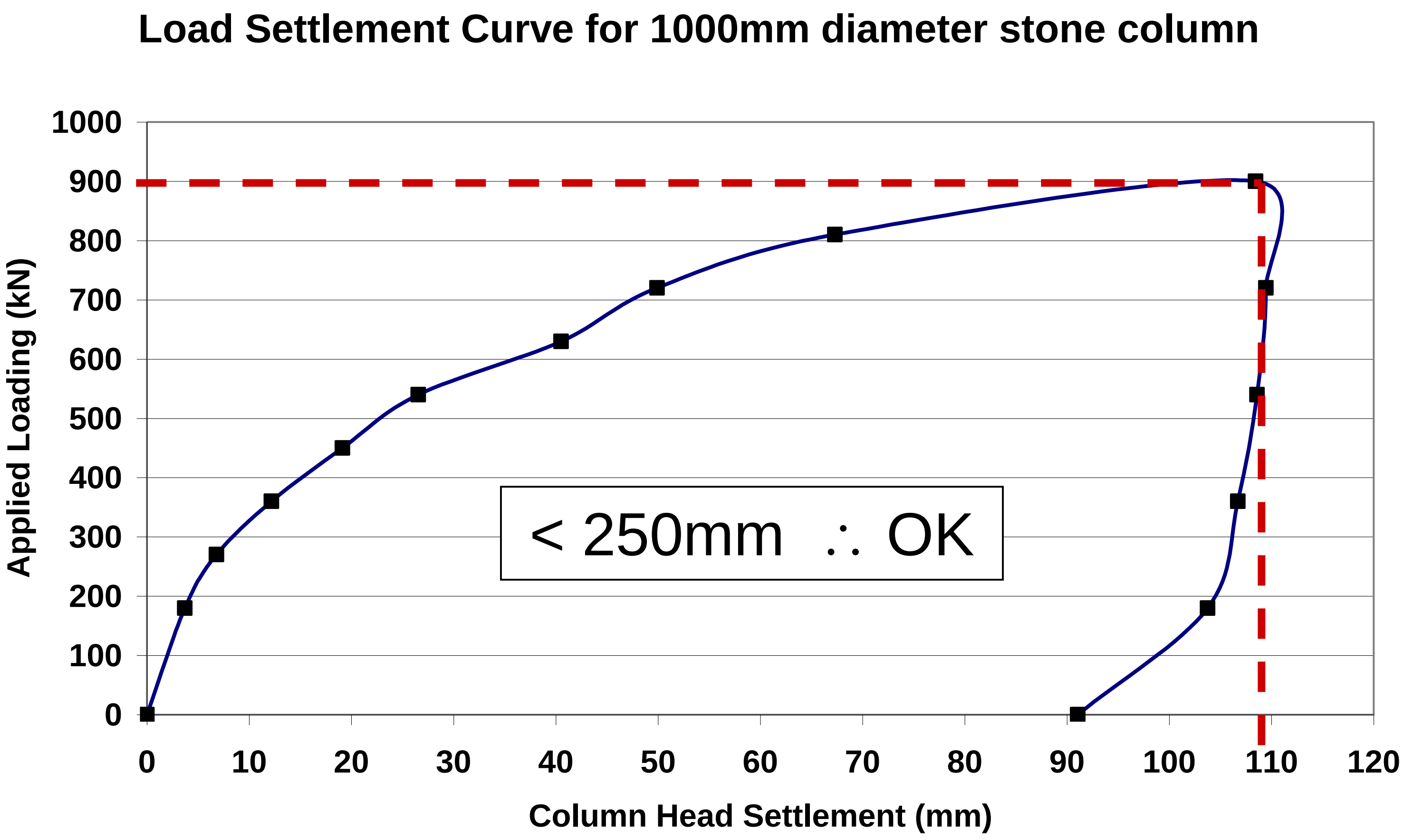
Termination Criteria



Verification Test (Plate Load Test)

Verification Test (Plate Load Test)

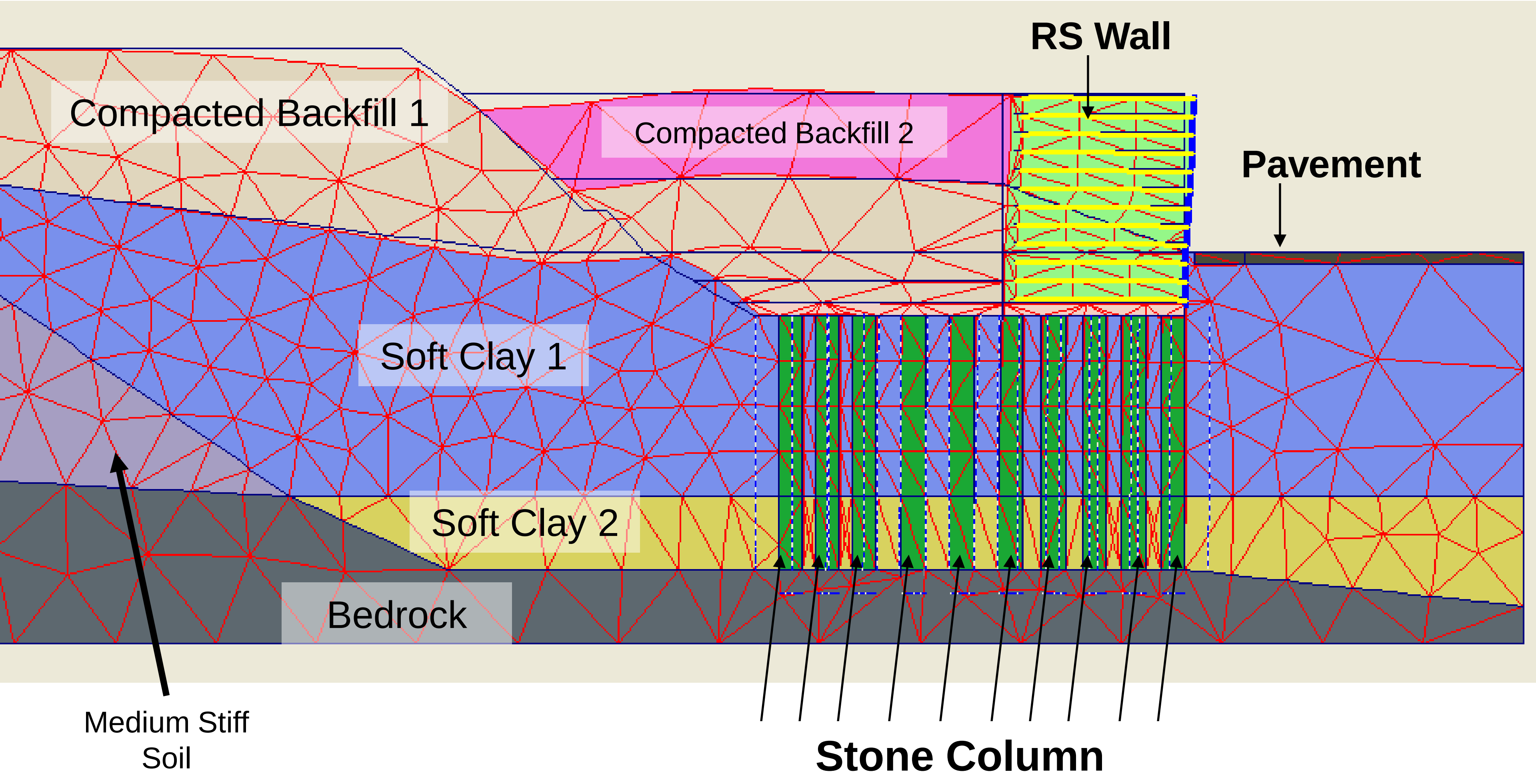
Verification Test



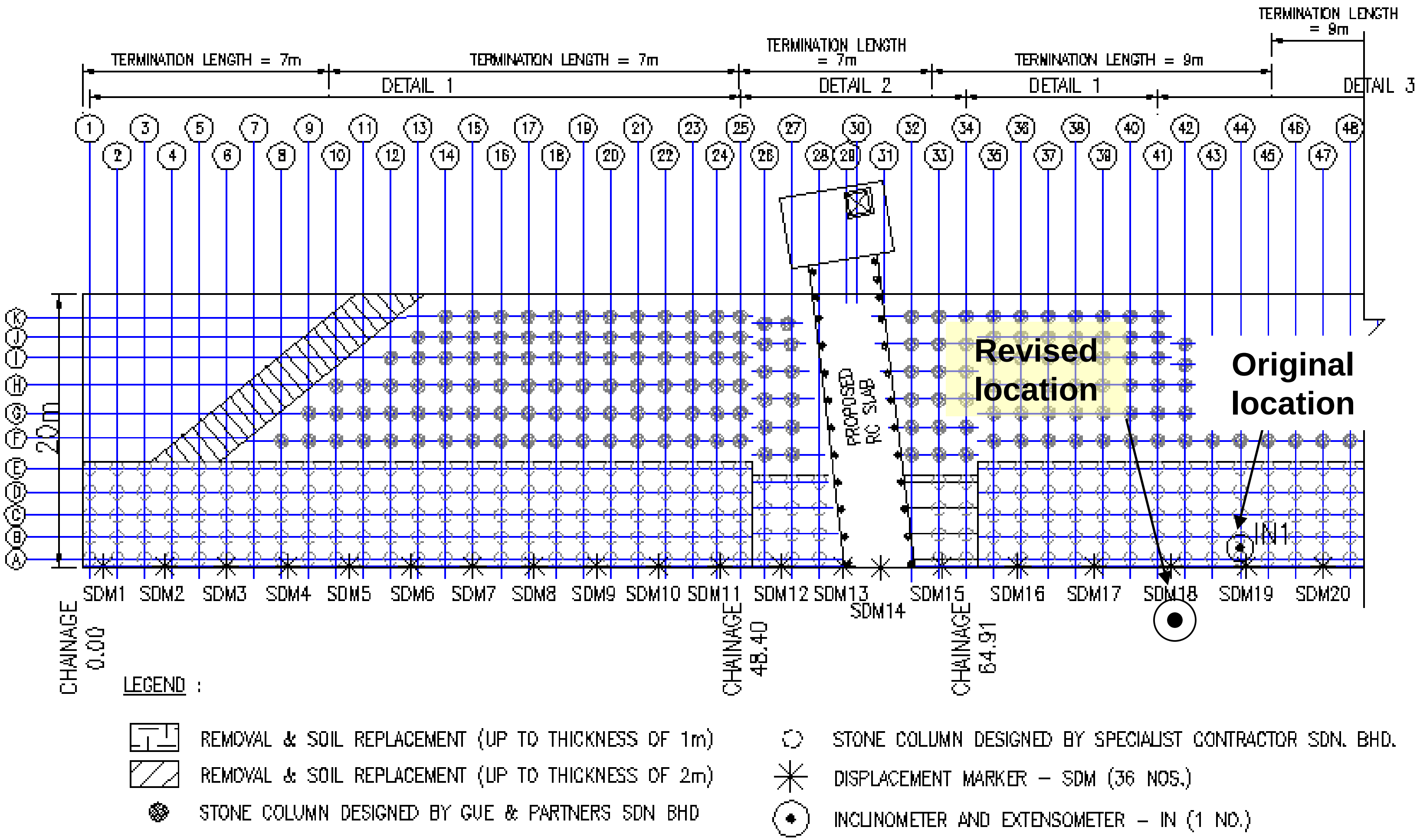
DESIGN VERIFICATION

- Finite element method (FEM) analyses using PLAXIS
- Monitoring instrumentation scheme

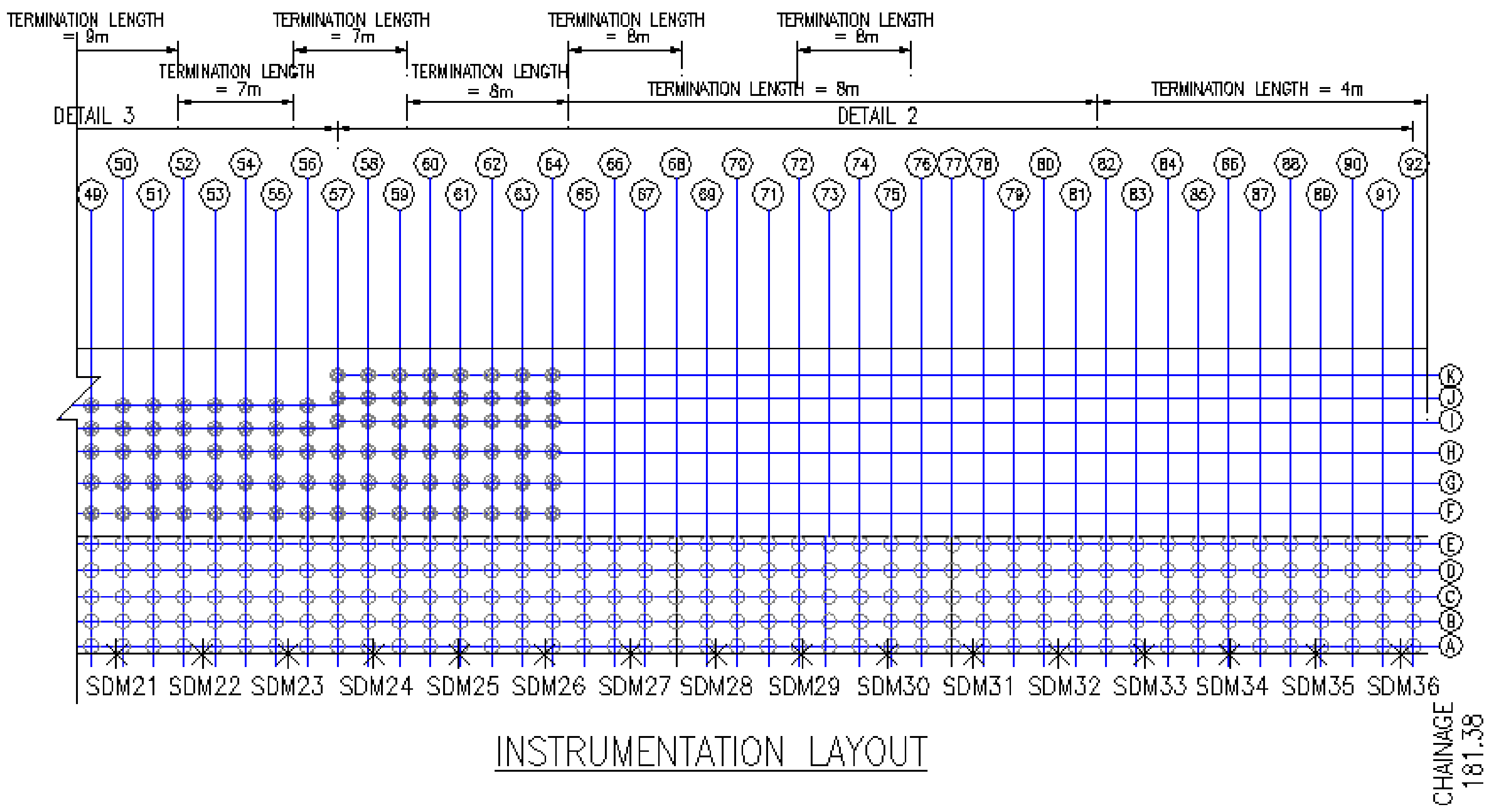
PLAXIS Model & Analyses



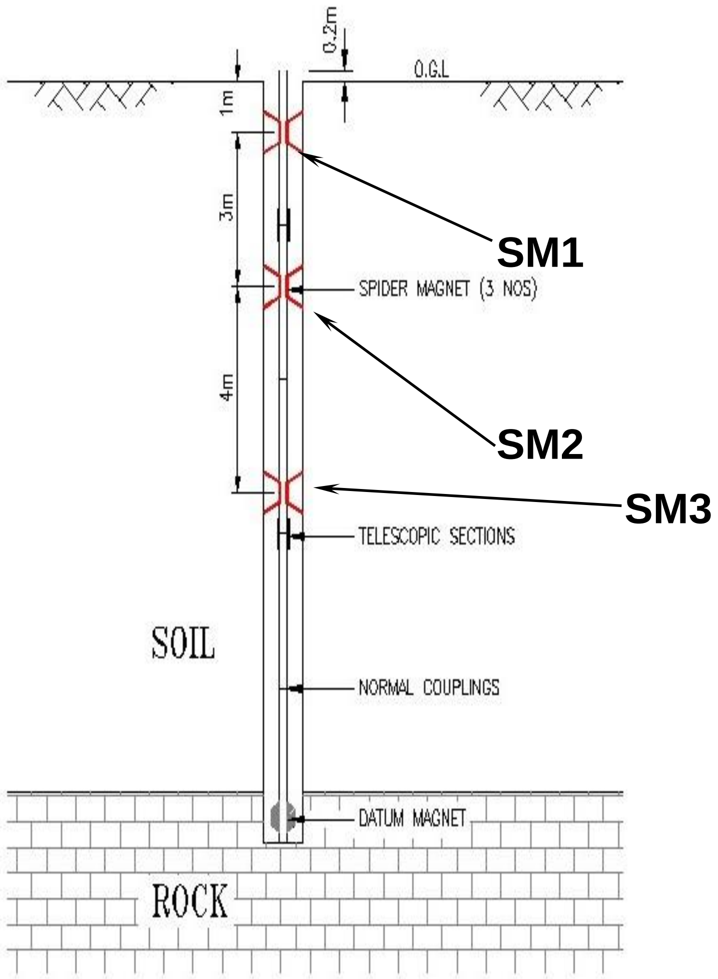
Instrumentation Monitoring Scheme



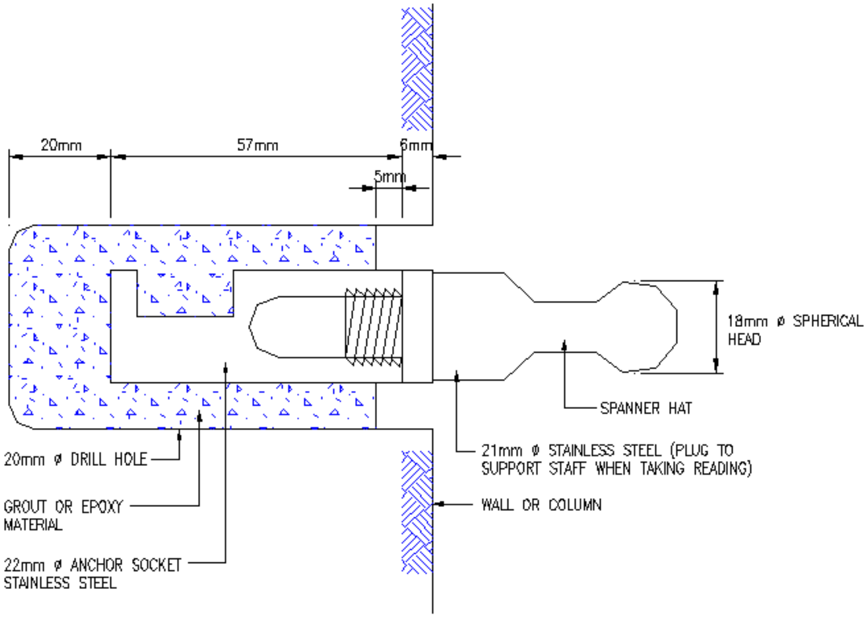
Instrumentation Monitoring Scheme



Instrumentation Monitoring Scheme

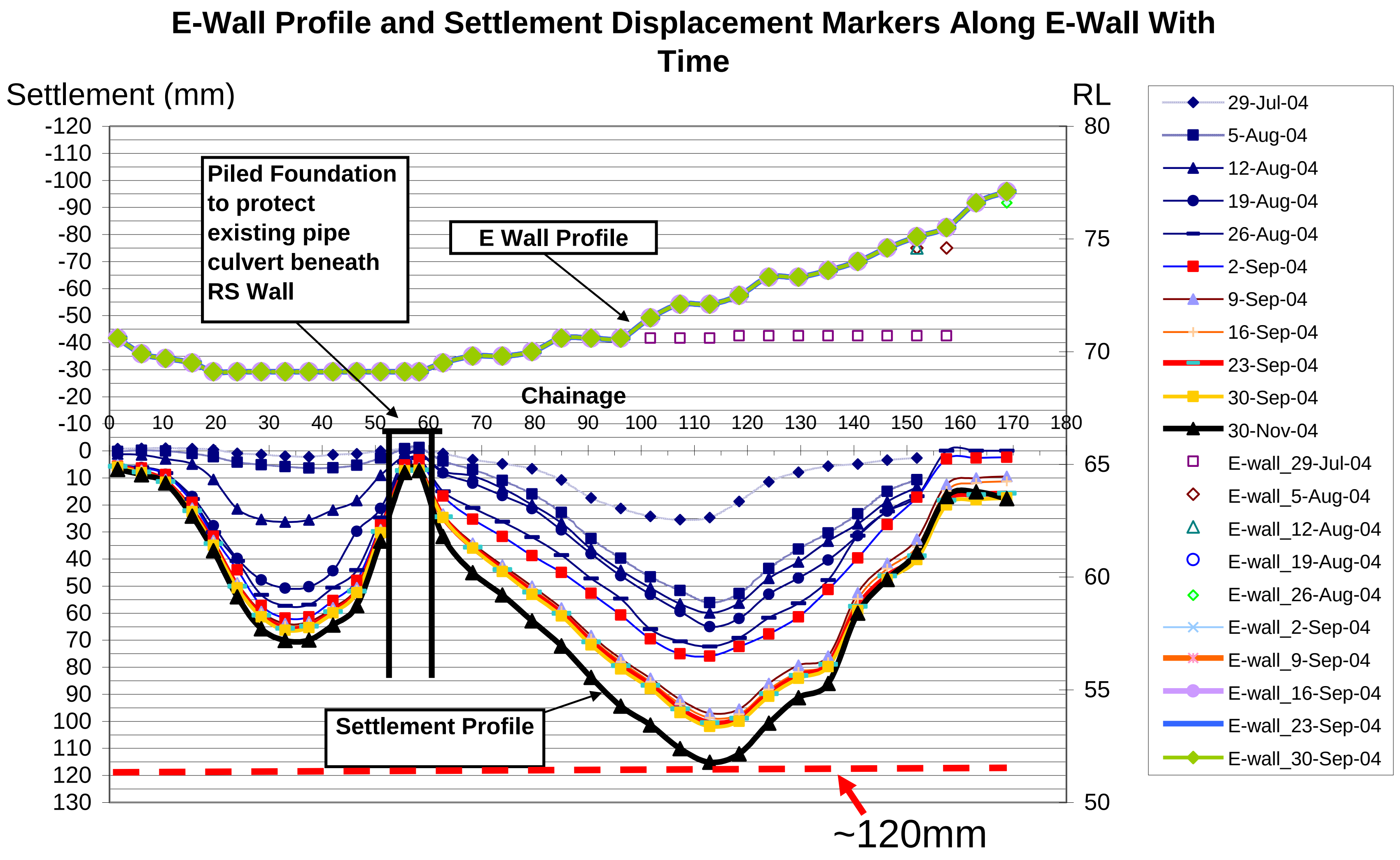


Inclinometer with Magnetic Extensometers

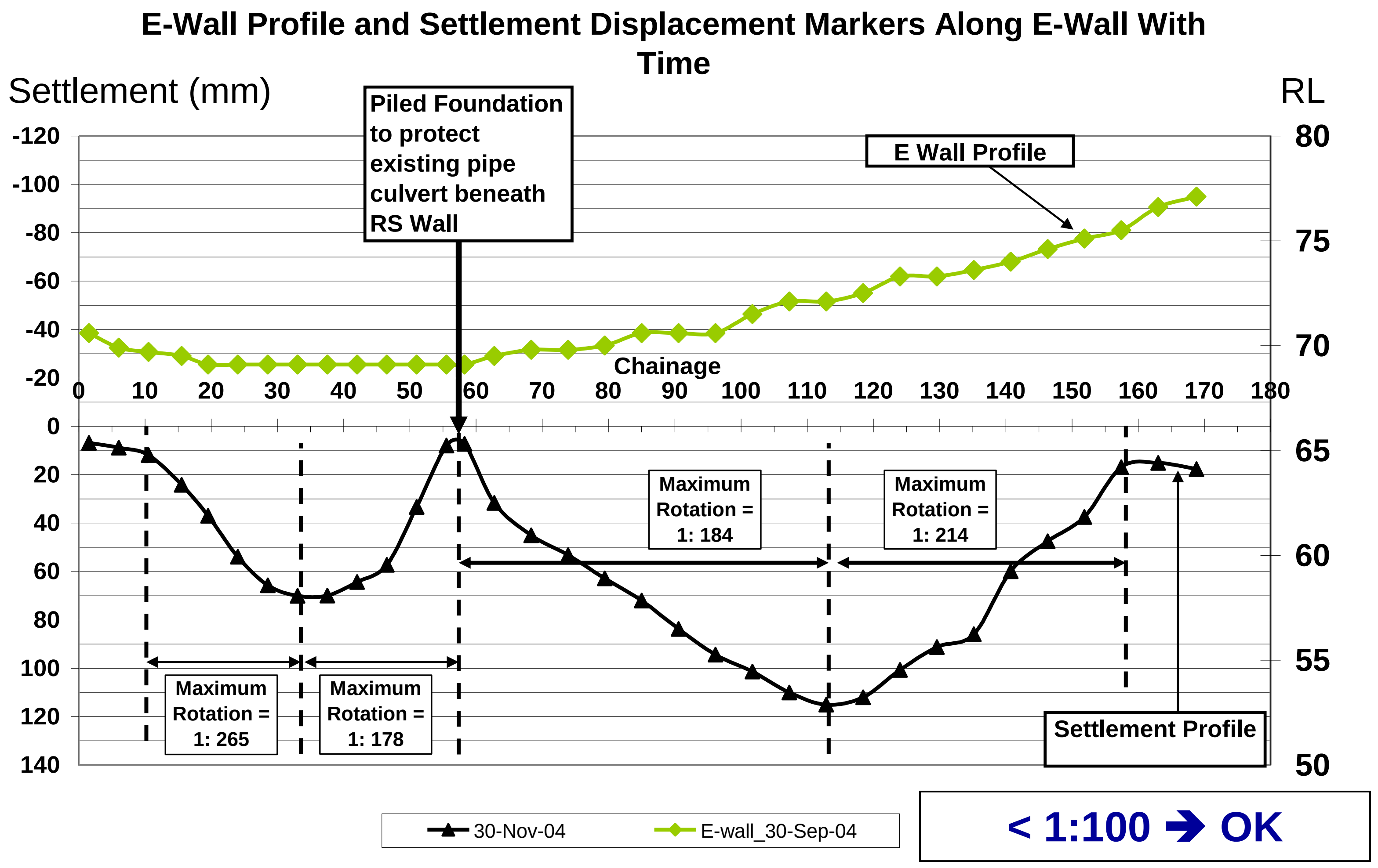


Details of Displacement Markers

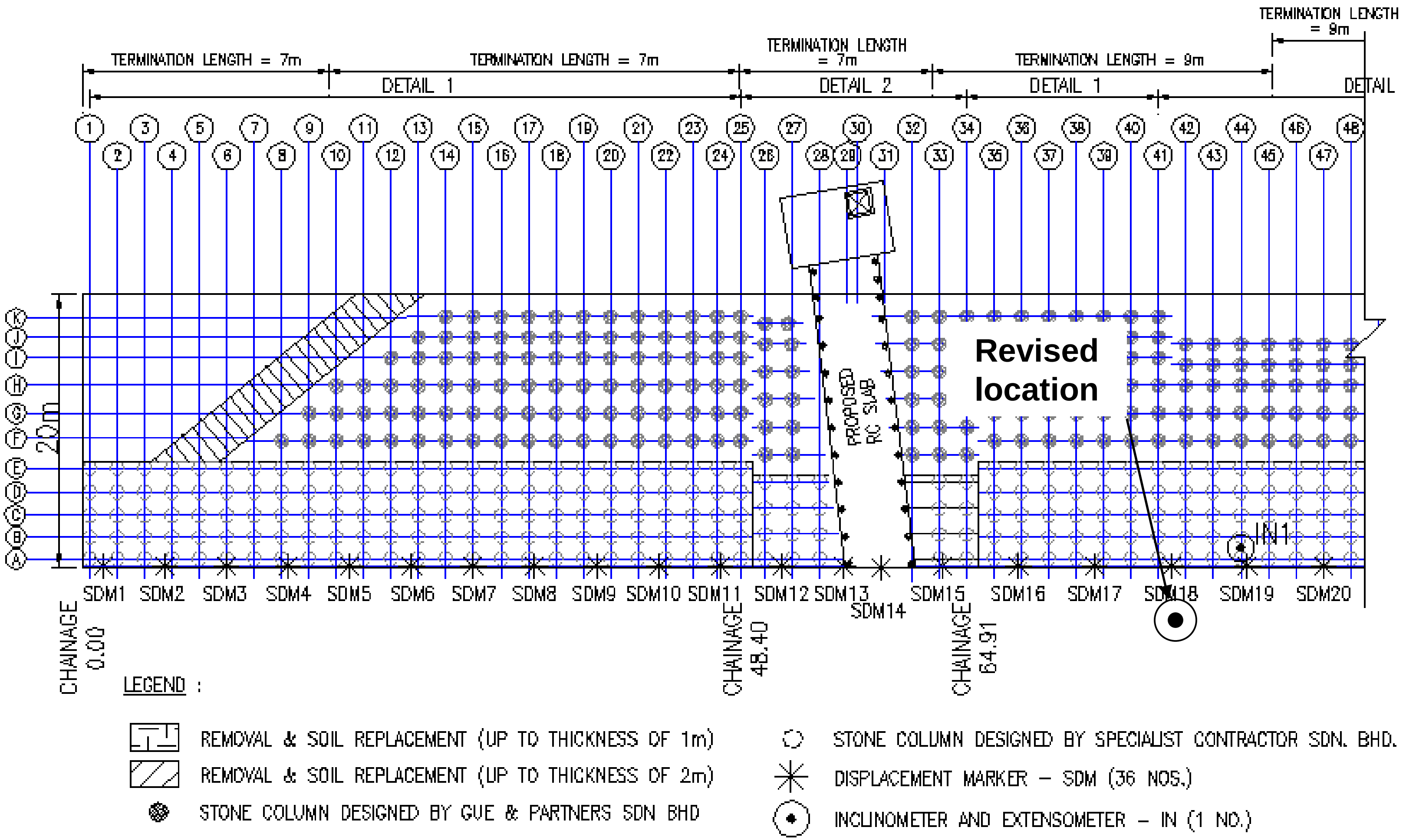
Instrumentation Results



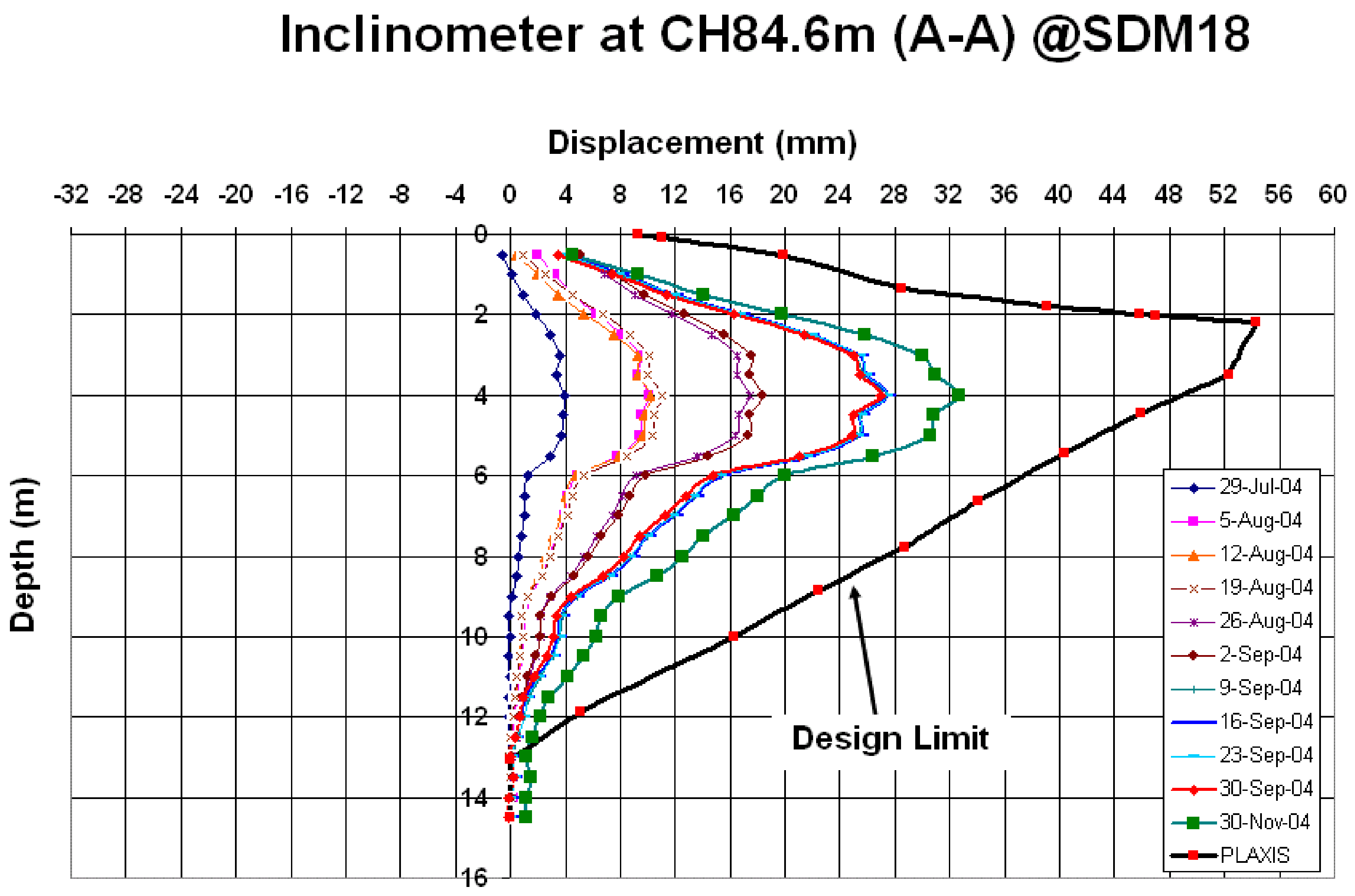
Instrumentation Results



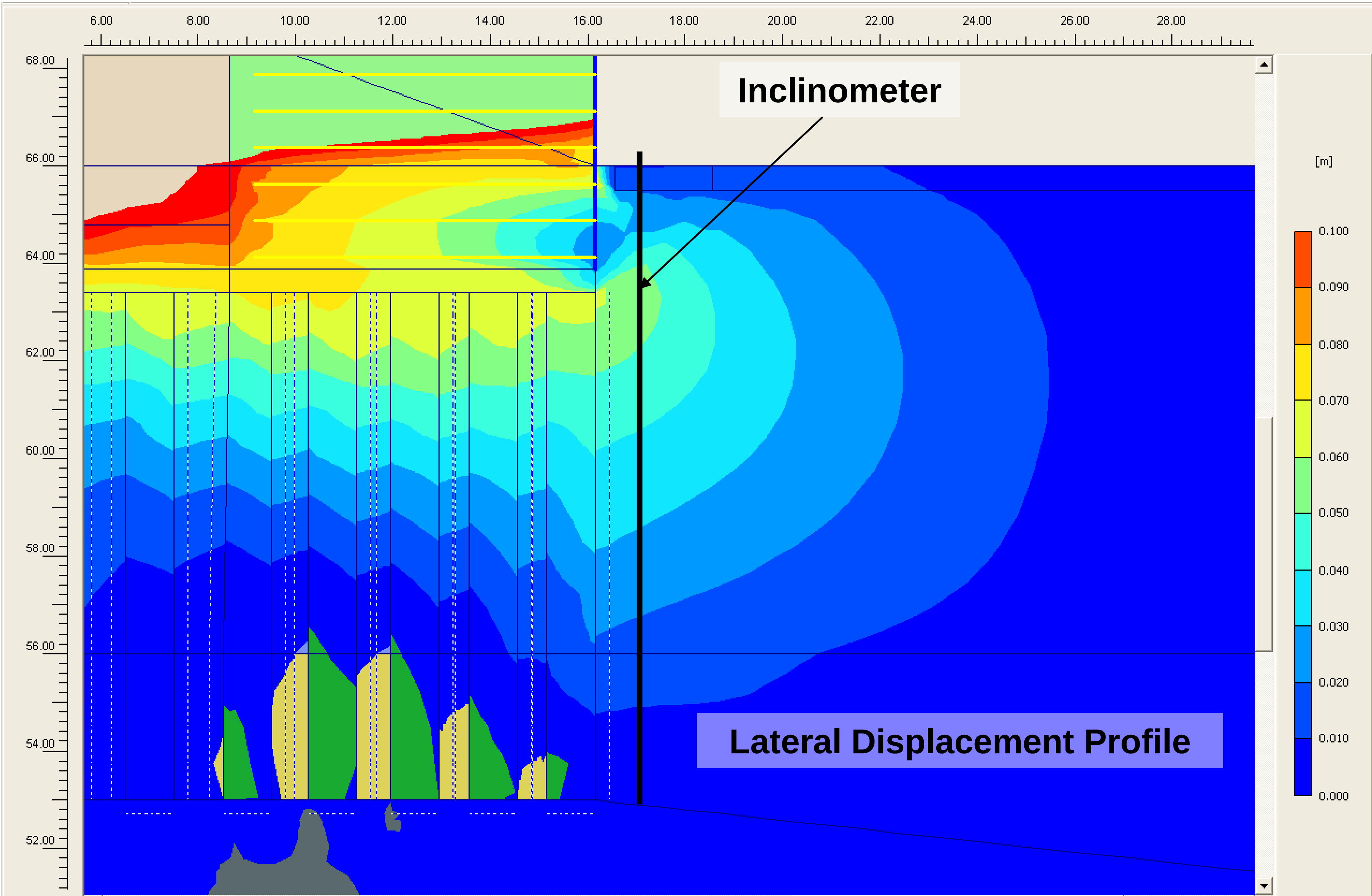
Instrumentation Monitoring Scheme



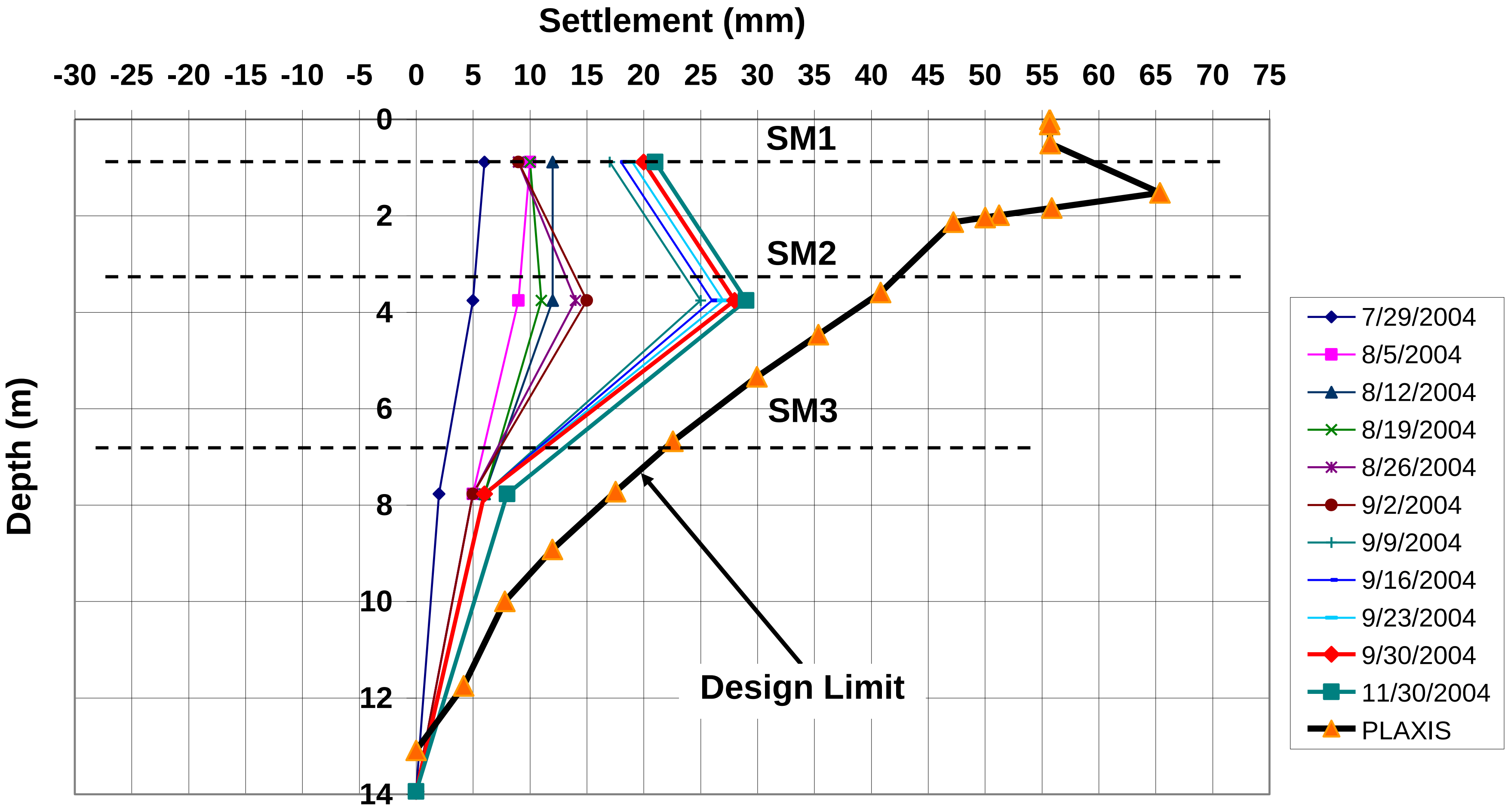
Instrumentation Results



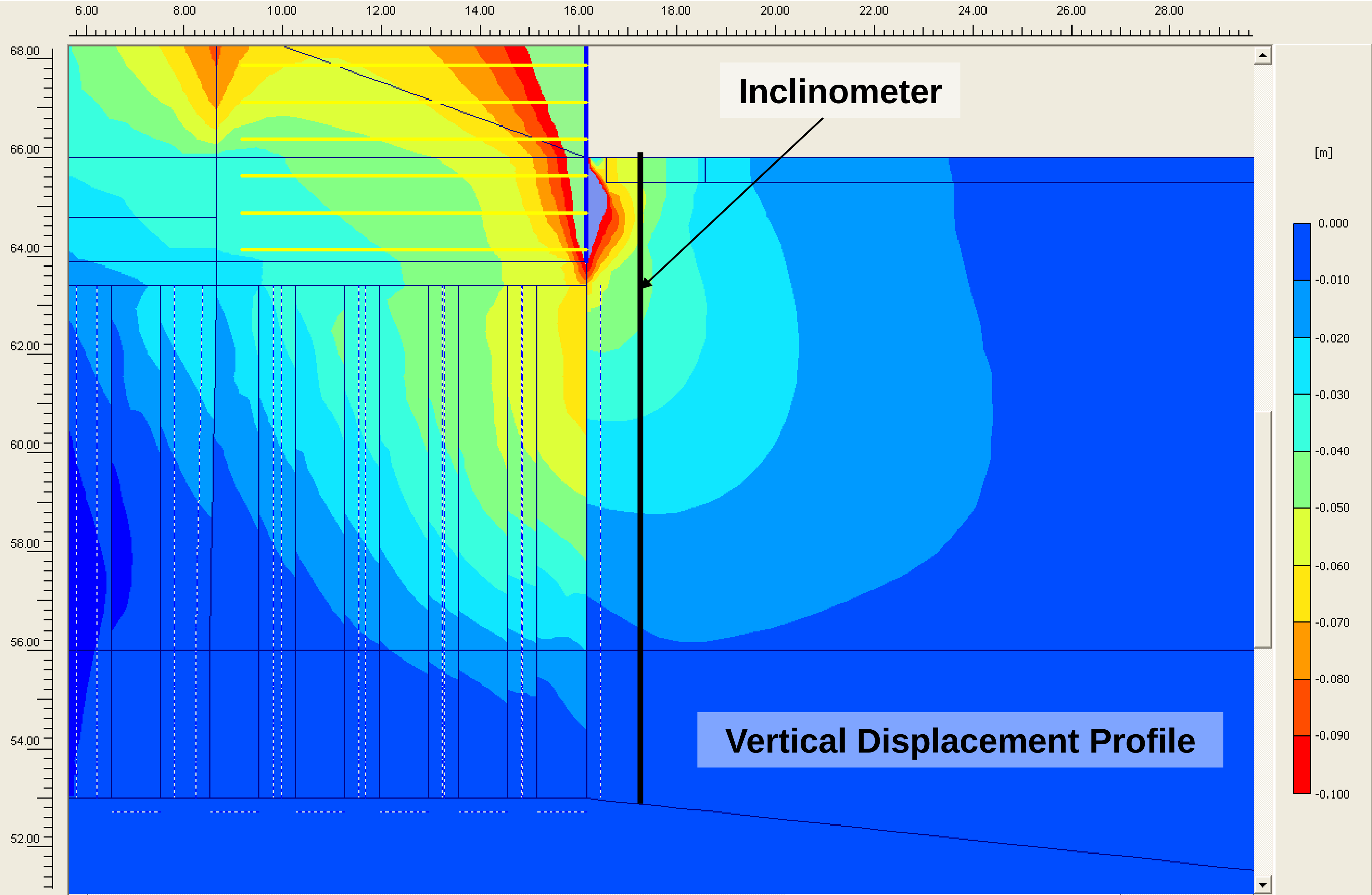
Instrumentation Results



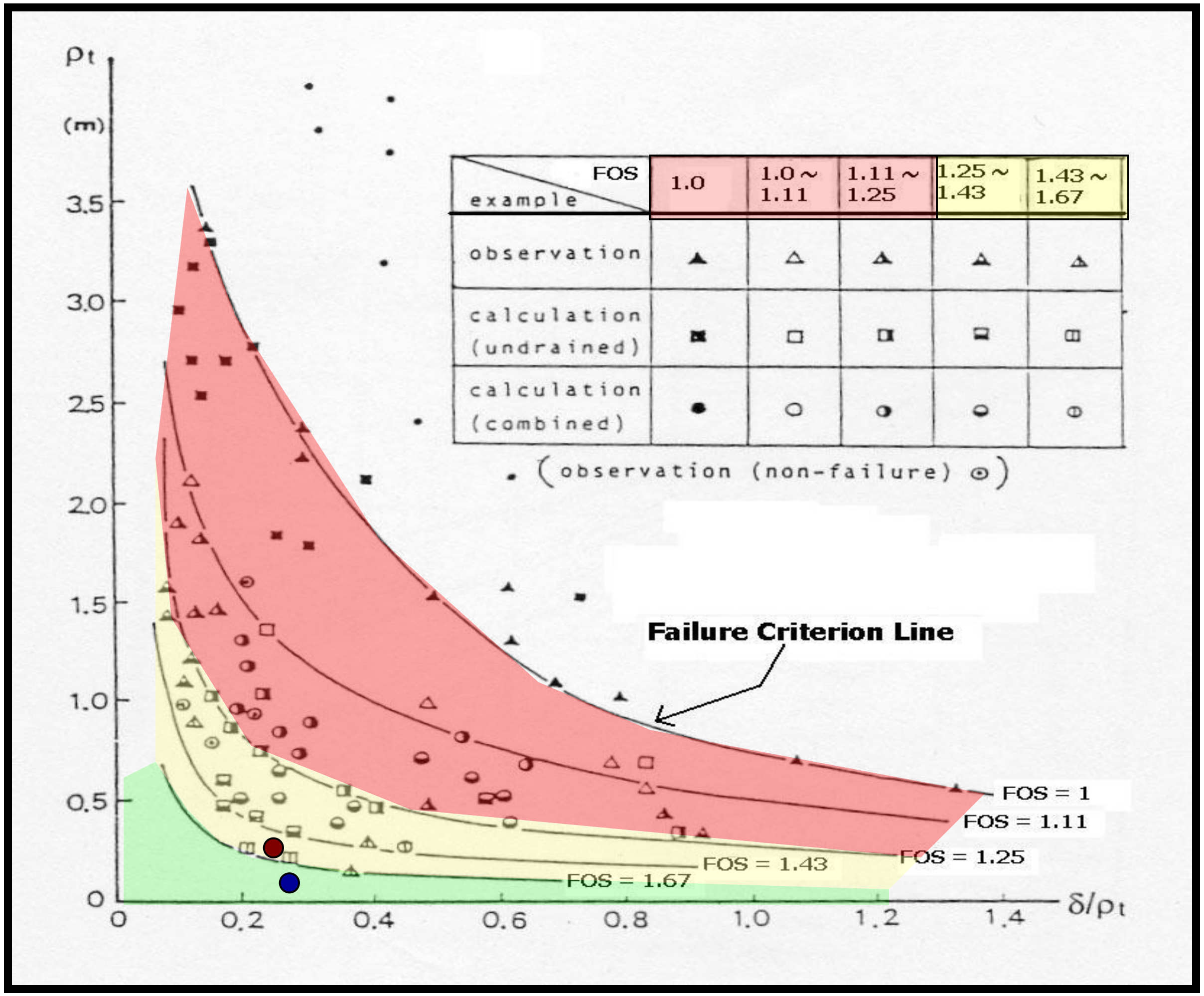
Instrumentation Results



Instrumentation Results



Instrumentation Results



Legend

- Current
- Predicted

(δ/ρt) Diagram with Factor of Safety (After Matsuo et al, 1977)

CONCLUSIONS

- Successful installation of stone columns within economical means

- To consider

  ➔ Design Aspects

  ➔ Quality Assurance and Quality Control during construction

CONCLUSIONS

- Use Observational Method and Finite Element Analysis

- Matsuo plot can also be applied to verify the FOS of RS wall

Conclusions

- Site investigation practices .vs. medical diagnosis
- Five case studies
  - Erroneous external wall stability of pile supported wall
  - Incompatible straining of basal reinforcement with brittle compacted fill and plastic supporting soft clay
  - Unstable piled embankment due to free standing pile support from consolidation of piling platform fill
  - Unreliable face capacity of soil nailed slope due to volumetric soil shrinkage by depleting moisture content
  - Stone Columns in Soft Clay for Wall Support

Thank You for Your Attention