Challenges in Design an Construction of Deep Excavation With Case Studies - KVMRT in KL Limestone

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- SOIL PARAMETERS
- NUMERICAL ANALYSES
- CASE HISTORIES
  - 3 Underground Stations for KVMRT
  - Circular Shaft for Launching of TBM
  - Hydraulic Failure @ Penang
- CONCLUSIONS

INTRODUCTION

- Deep basement construction
  - Urban areas for parking space
  - Infrastructures, e.g. KVMRT
- **Risk** associated with deep baseme
  construction high!

Excavated depth

24.5m - 28.5m (6-level basement)

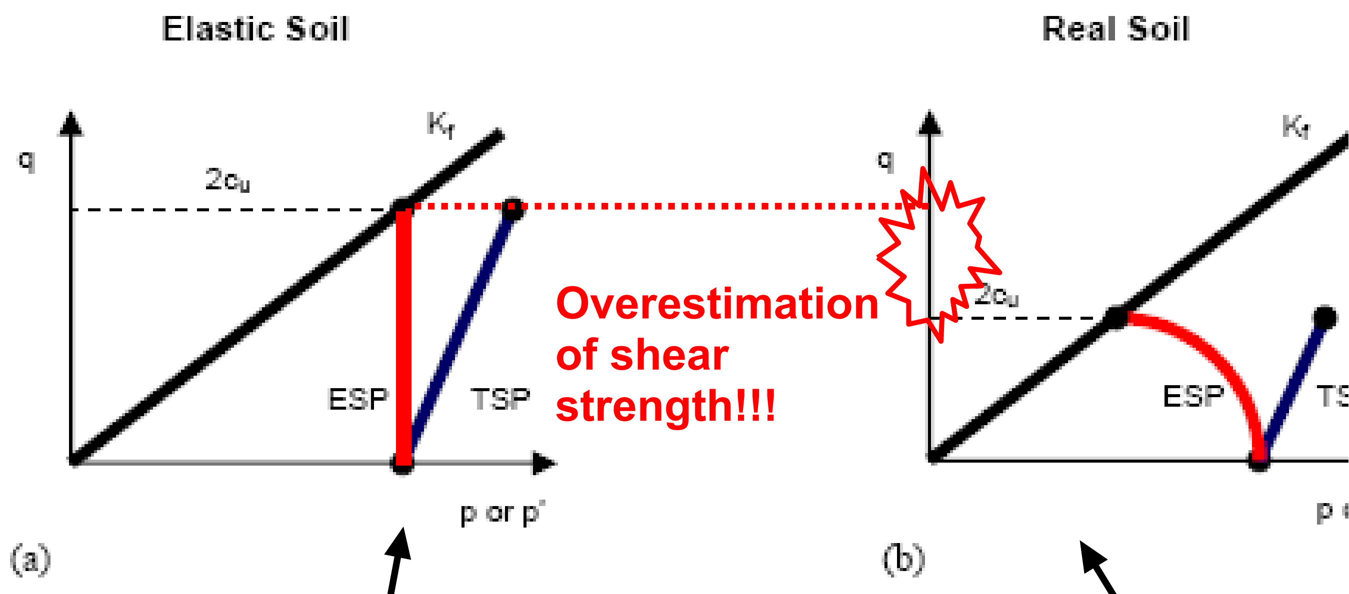
Retaining wall

1.2m thick diaph
walls

FAILURES of DEEP EXCAVATION

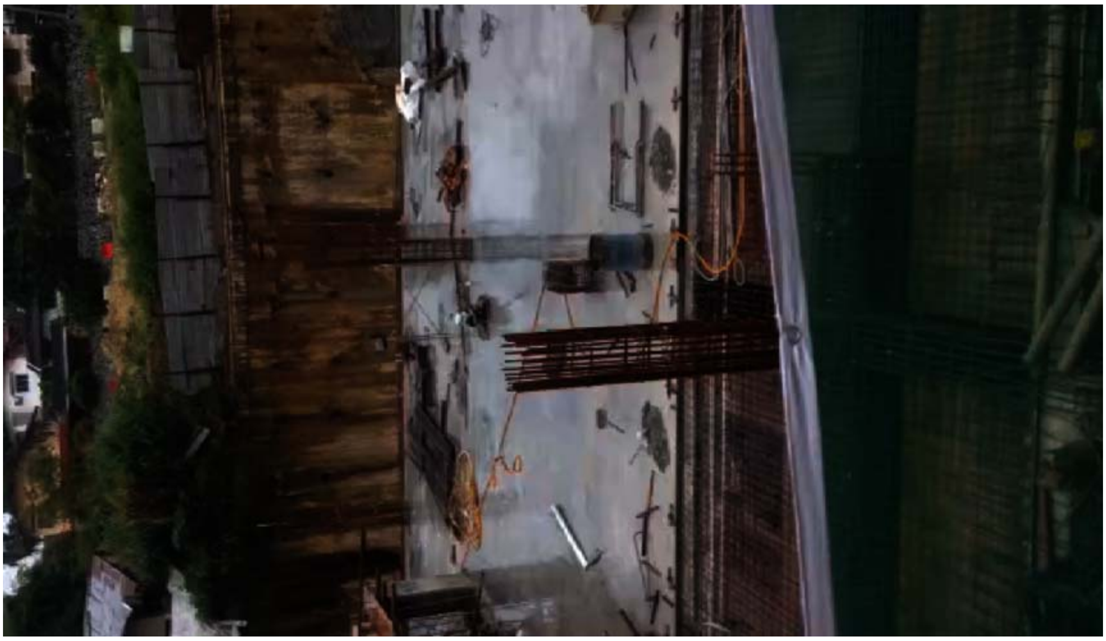

FAILURES of DEEP EXCAVATION

FAILURES of DEEP EXCAVATION



Stress path using Mohr-Coulomb model

Stress pat
of real so



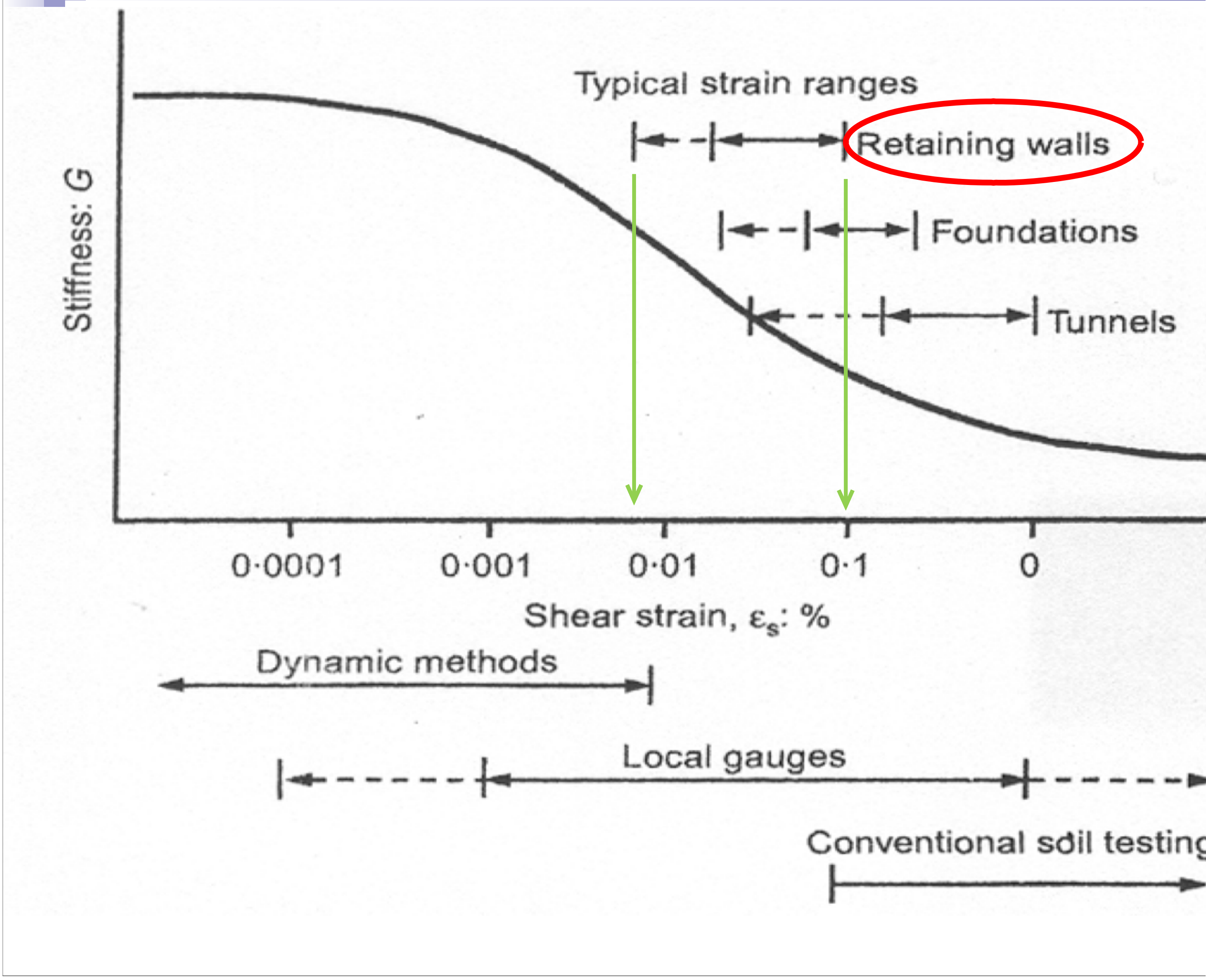
SOIL PARAMETERS

SOIL PARAMETERS

- Some important soil parameters related to retaining wall and suppor system design:
  - **Shear strength** parameters (s_u, ϕ' & c
  - Soil **permeability**
  - Soil **stiffness**

SOIL PARAMETERS

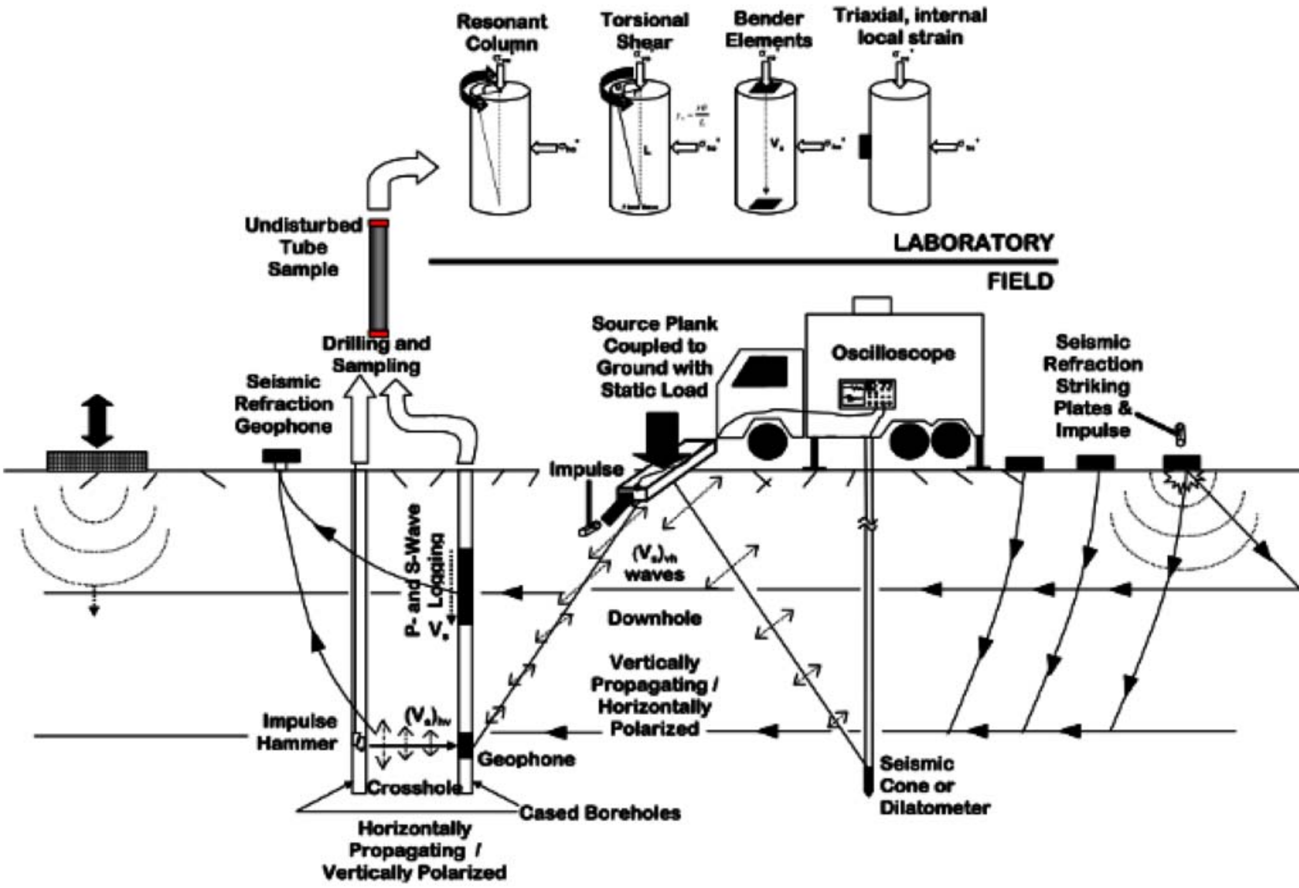
- Soil stiffness
  - Important parameters for retaining wall des
    BUT **difficult to obtain reliably**
  - In Malaysia, sometimes based on **empiric
    correlations**
  - **Laboratory tests unreliable** and values obtained significantly smaller than appropriate values for retaining wall desigr
  - Designer should be aware of **small-strain** nature of retaining wall design



Stiffness: G
Typical strain ranges
Retaining walls
Foundations
Tunnels
0·0001
0·001
0·01
0·1
0
Shear strain, εs: %
Dynamic methods
Local gauges
Conventional soil testing

SOIL PARAMETERS

- Soil stiffness
  - Seismic tests or seismic piezocone appear promising
  - **Basis of empirical correlations should b understood** – e.g. local soil conditions, constitutive model used, etc.
  - Example, correlations in Kenny Hill formati using hardening soil model of PLAXIS software



Field and laboratory methods to evaluate shear wave veloci

Soil Type	Maximum small-strain shear mo G_0 (kPa)
Soft clays	2,750 to 13,750
Firm clays	6,900 to 34,500
Silty sands	27,600 to 138,000
Dense sands and gravels	69,000 to 345,000

Typical values of maximum small-strain shear modulus

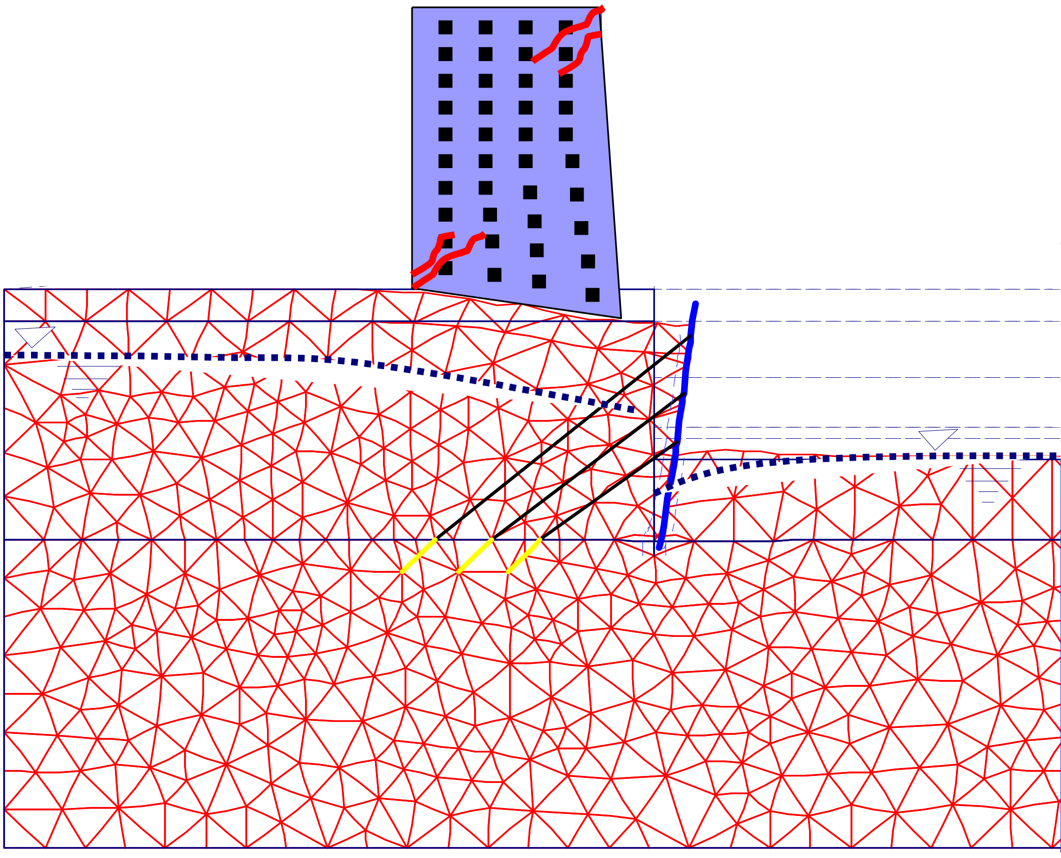
$$G_0 = 15{,}560\,(N_{60})^{0.68}$$

$$G_0 = 1{,}634(q_c)^{0.25}(\sigma'_{vo})^{0.375}$$

$$\gamma_{0.7} = \frac{0.385}{4G_0}\left(2c(1+\cos 2\emptyset) + \sigma'(1+Ko)\sin 2\emptyset\right)$$

NUMERICAL ANALYSES

GROUND MOVEMENT INDUCED E
DEEP EXCAVATION



FINITE ELEMENT ANALYSIS

- Some important considerations in FEM:
  - Locations of the **boundaries of the proble**
  - Details of **mesh**
  - Modelling of **stages of construction**
  - Modelling of **interfaces**
  - Use of suitable **constitutive soil model**
  - Use of appropriate soil parameters, especi
    empirical parameters

CONSTITUTIVE SOIL MODE

- Various constitutive soil models, e.g. Mo Coulomb, Cam Clay, Hardening Soil, So Soil, etc.
  - **Proper understanding and limitations** of each model important!
  - Incorrect use of soil models in Nicoll Highw

Berjaya Times Square

- **Hardening Soil Model** of PLAXIS able model the problem sufficiently accurate
- From FEM back-analysis, the correlatio between soil stiffness (E') and SPT 'N' a follows:
  - **E' = 2000*SPT'N'(kN/m^2)**
  - **E'$_{ur}$ = 3*E' = 6000*SPT'N'(kN/m^2)**

MONITORING TRIGGER LEVELS

GENERAL MONITORING TRIGGER LEVELS

FEATURE TO BE MONITORED	INSTRUMENT / PARAMETER TO BE MONITORED	ALERT	ACTION	ALAR
HERITAGE STRUCTURES/ BUILDINGS	BUILDING SETTLEMENT (mm)	5	8	10
	DISTORTION ANGLE	1:1000	1:750	1:50
STRUCTURES/ BUILDINGS ON DEEP FOUNDATION	BUILDING SETTLEMENT (mm)	7	12	15
	DISTORTION ANGLE	1:750	1:500	1:25
STRUCTURES/ BUILDING ON SHALLOW FOUNDATION	BUILDING SETTLEMENT (mm)	12	20	25
	DISTORTION ANGLE	1:750	1:500	1:25
EXISTING BUILDING/ STRUCTURES	AIR OVERPRESSURE	100dBL	120dBL	130d
GROUNDWATER DRAWDOWN (NOT PIEZOMETRIC HEAD)	STANDPIPE/ PIEZOMETER STANDPIPE	1000mm WITH REFERENCE TO BASELINE READING	1500mm WITH REFERENCE TO BASELINE READING	2000mm REFER TO BAS READ

NOTE: THE ABOVE VALUES ARE SUBJECT TO ADJUSTMENT AFTER COMPLETION OF BUILDING CONDITION SURVEY WOR

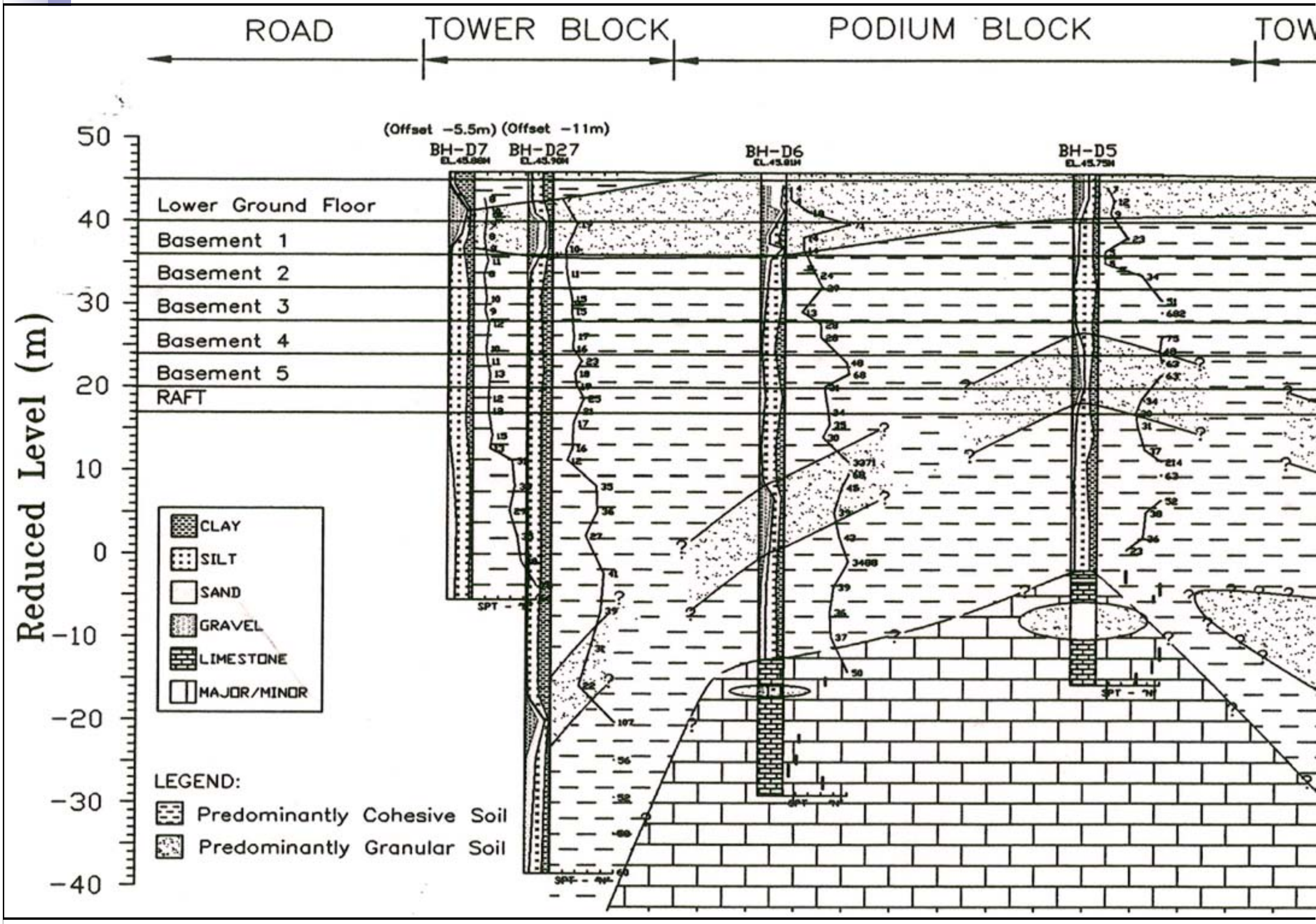
MONITORING TRIGGER LEVEL

- Example for inclinometer:
  - Alert: **0.8*Maximum** predicted lateral movement us
    moderately conservative parameters
  - Action: **0.9*Maximum** predicted lateral movement
    moderately conservative parameters
  - Alarm: **1.0*Maximum** predicted lateral movement u
    moderately conservative parameters

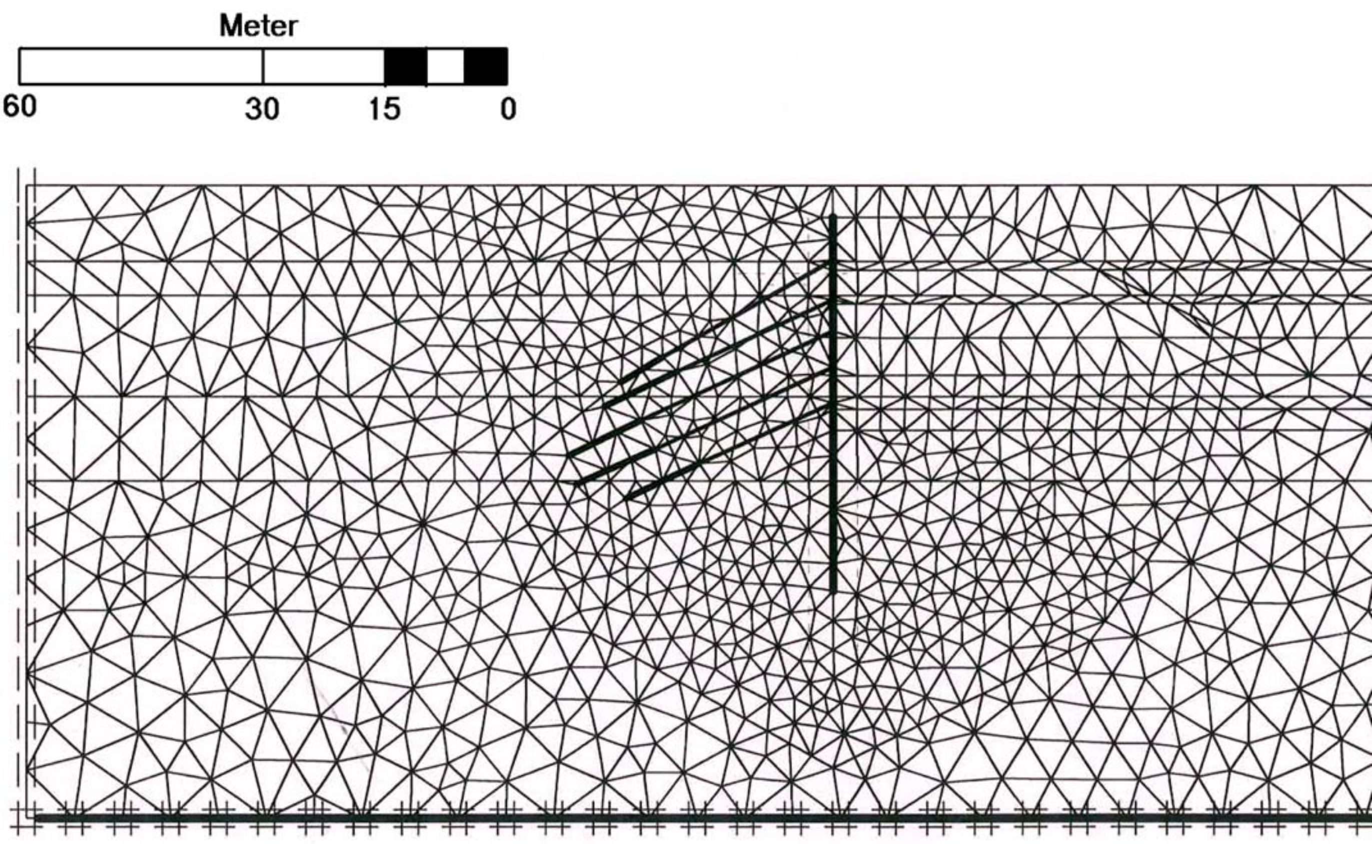
To be developed based on specific project/site requirements depending on factors such as risk to public safety, nature o the works, site control measures, etc.

Berjaya Times Square

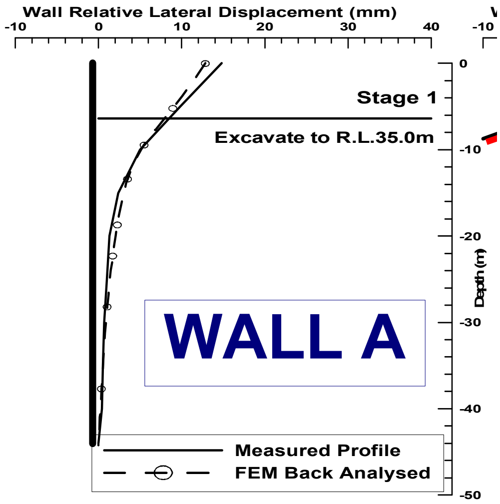
- Excavated depth
  24.5m - 28.5m (6-level basement)
- Retaining wall
  1.2m thick diaphragm walls
- Support system
  Prestressed Ground Anchors



TYPICAL SUBSOIL PROFILE



FINITE ELEMENT MODELLING



Wall Relative Lateral Displacement (mm)
-10
0
10
20
30
40
Stage 1
Excavate to R.L.35.0m
0
-10
-20
-30
-40
-50
Depth (m)
WALL A
Measured Profile
FEM Back Analysed

Berjaya Times Square

- **Hardening Soil Model** of PLAXIS able model the problem sufficiently accurate
- From FEM back-analysis, the correlatio between soil stiffness (E') and SPT 'N' a follows:
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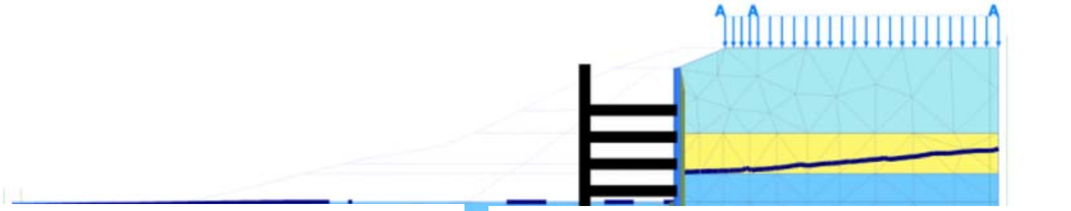


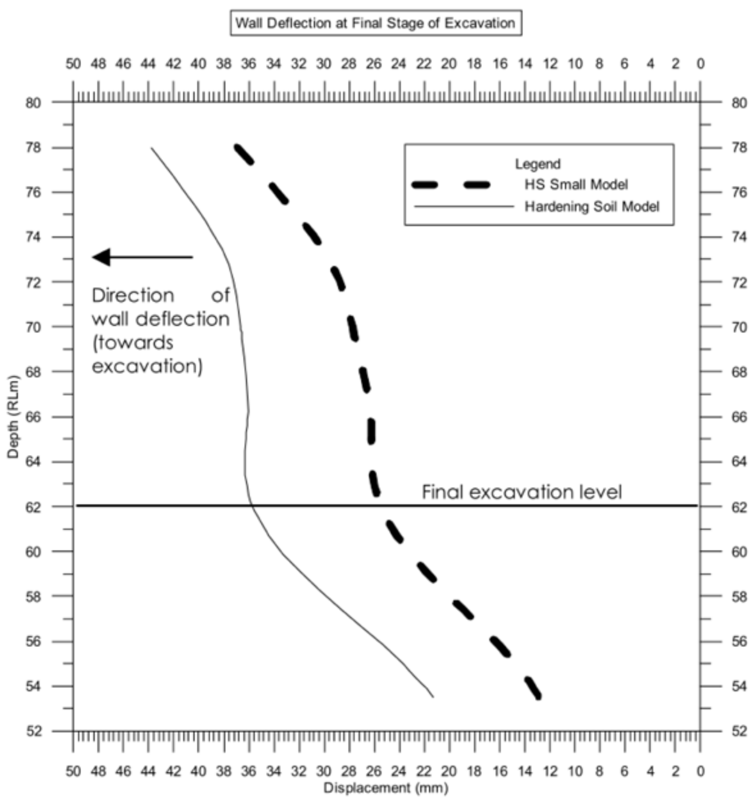


Figure 5 Comparison of wall deflection at final stage of excavation between Hardening Soil Model and HS-Small Model.

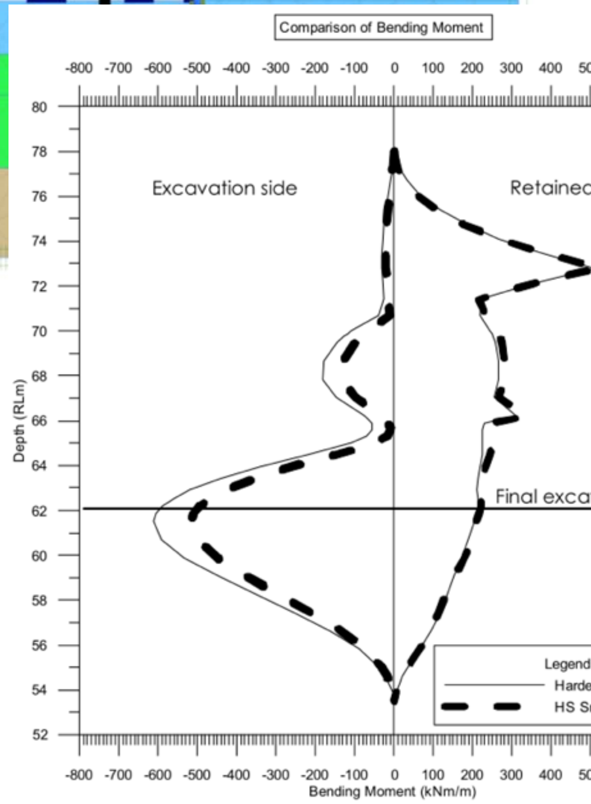


Figure 6 Comparison of bending moment at excavation between Hardening Soil Model Model.

CASE HISTORIES

Case History 1 :

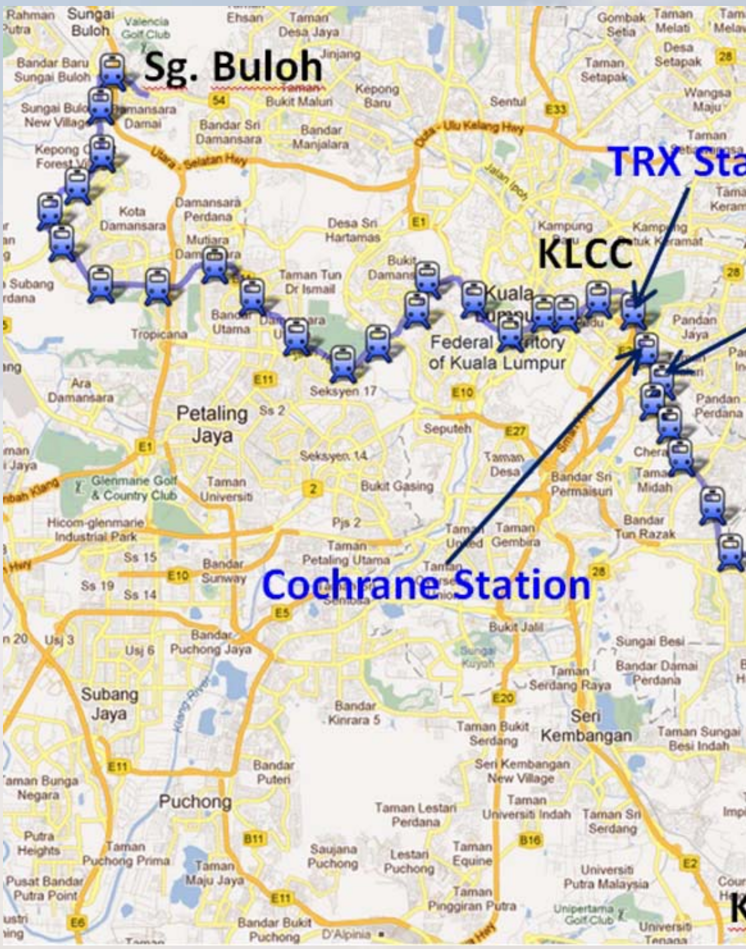
Deep Excavation for Three (3

Underground Stations for KV

– Sungai Buloh to Kajang Lin

(Line 1)

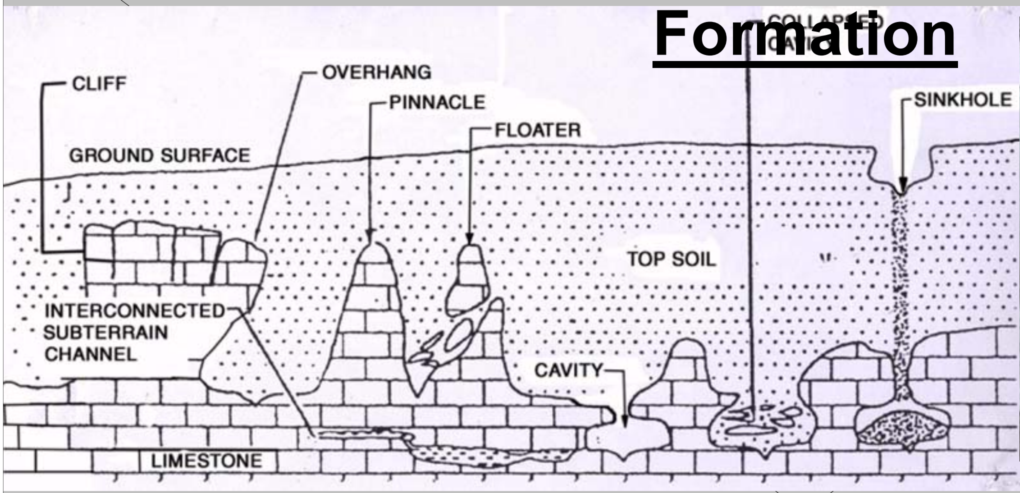
Locations of the MRT Underground Stations



Geology of Kuala Lumpur

All three underground stations in KL Limestone Formation (with Karstic Features)

Karstic Features of Kuala Lumpur Limesto
Formation



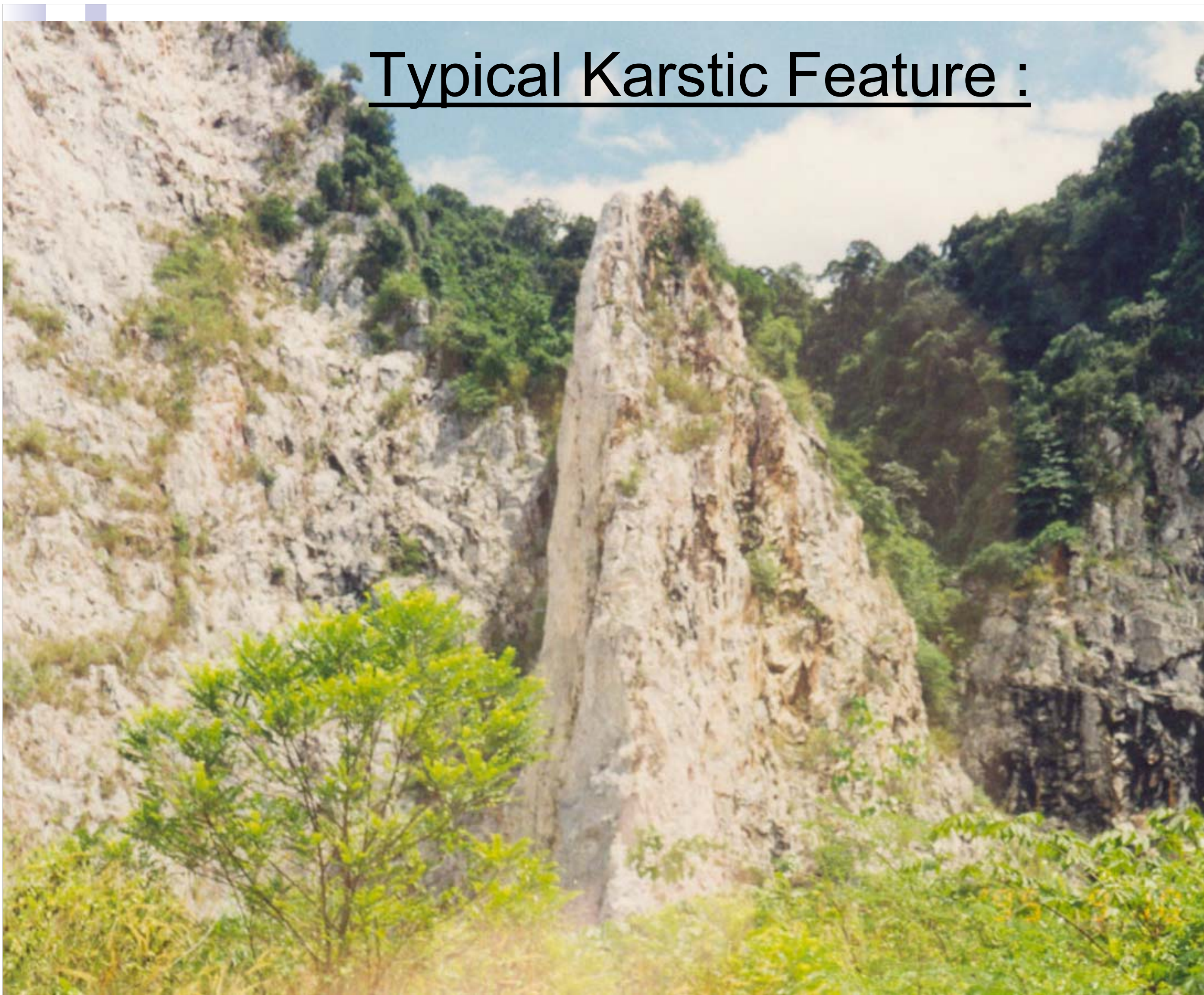

Valley in the bedro


Cavity in the Bedrock

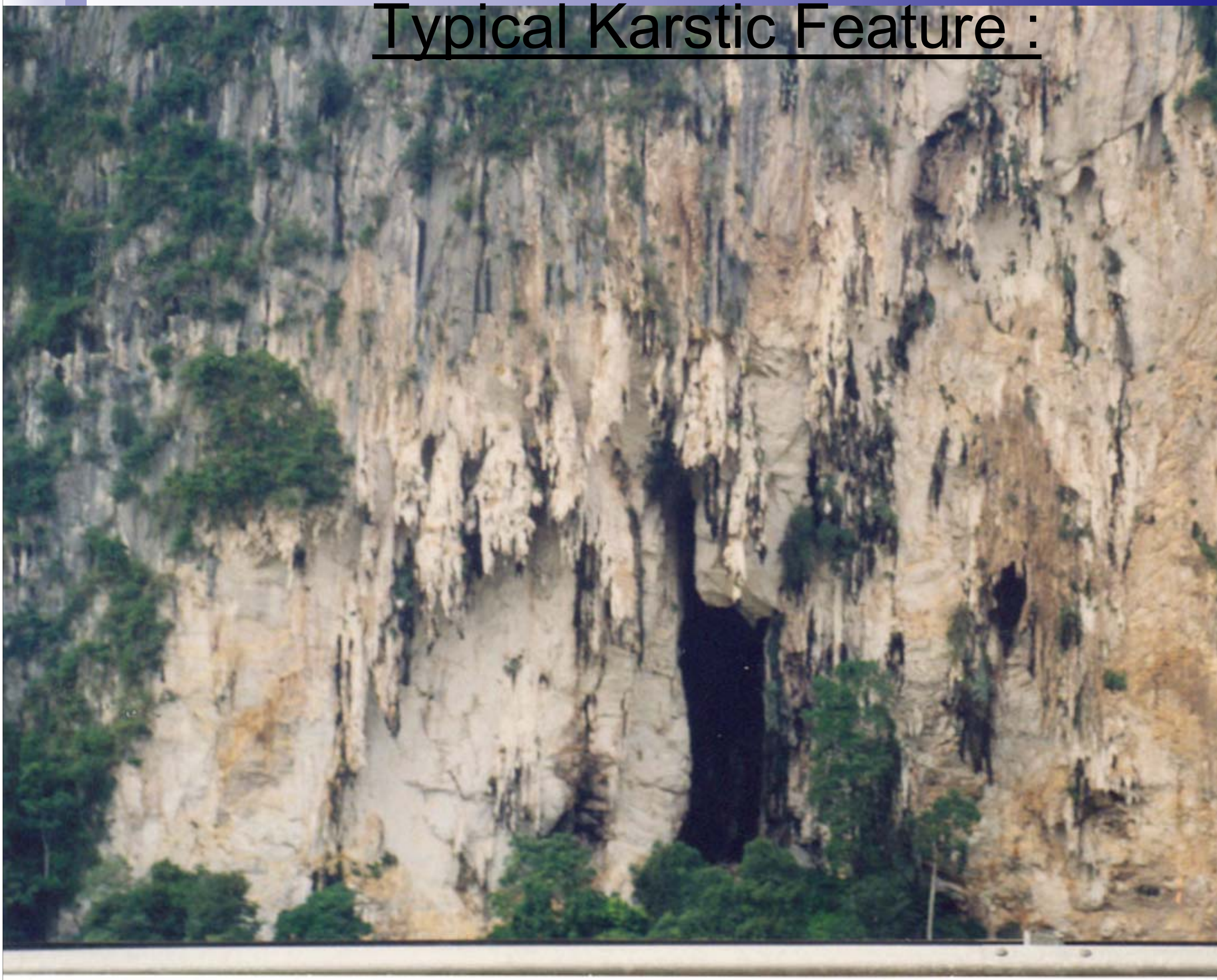

Highly fractured bedrock


Lime
Pinn

Typical Karstic Feature :



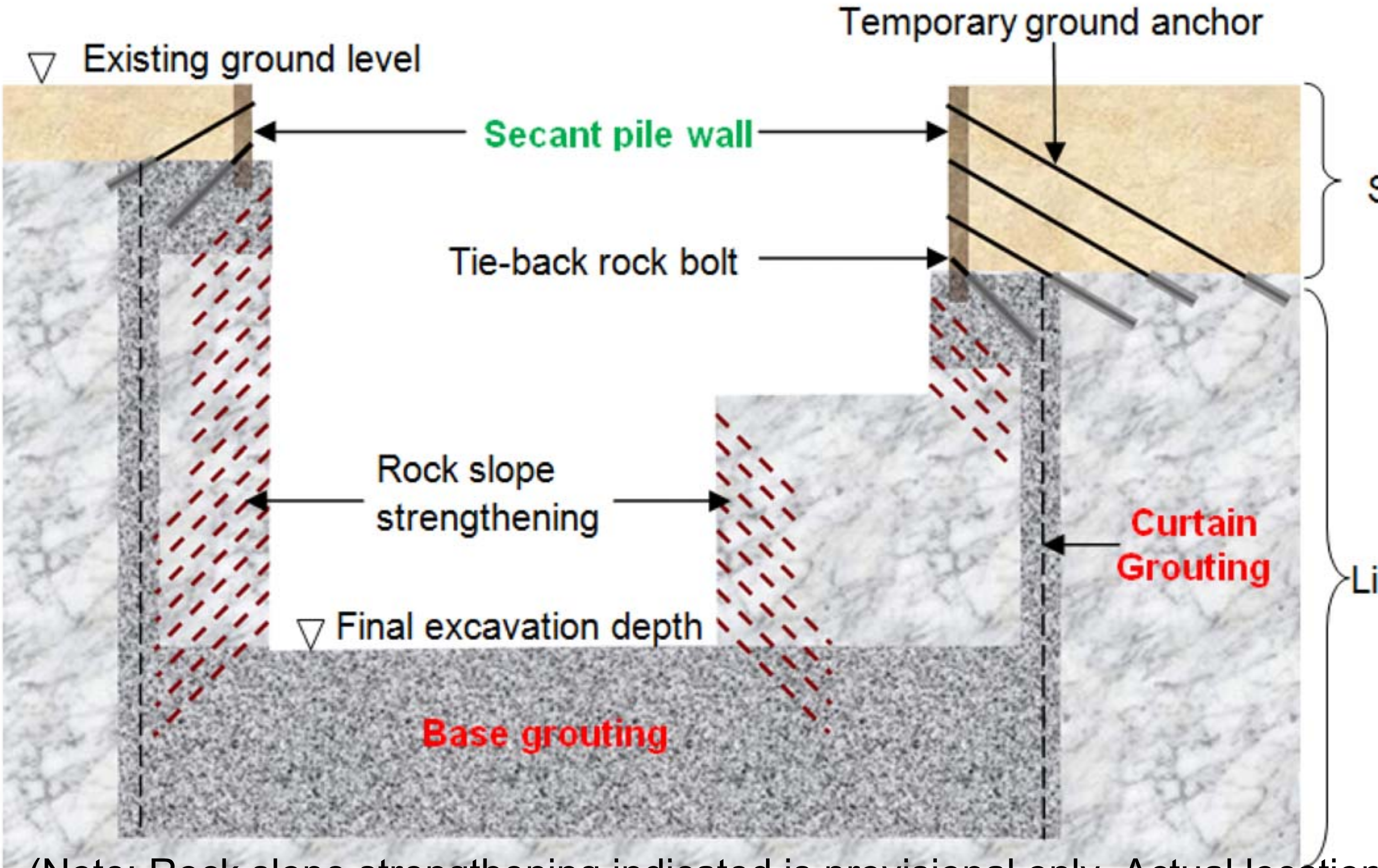
Typical Karstic Feature :



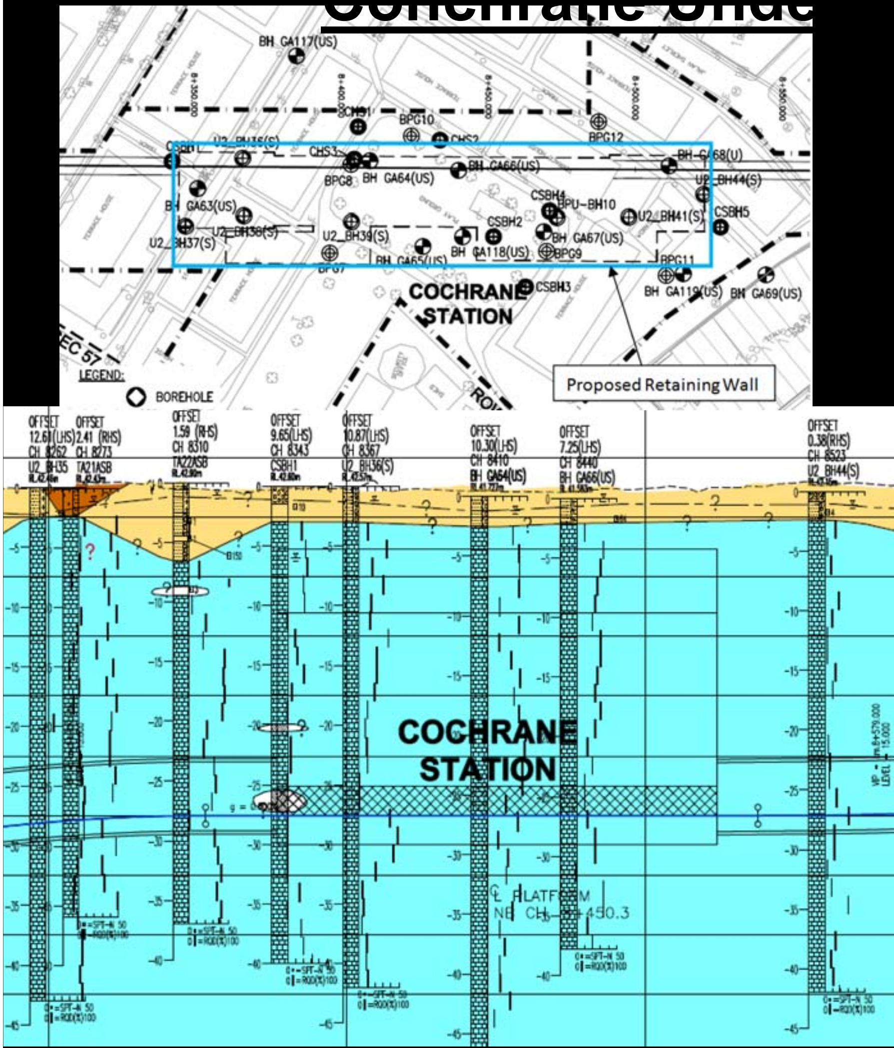
Typical Karstic Feature :

CAVERN/CAVITY EXPOSED AFTER EXCAVATIO

Typical Excavation Section for Undergrou

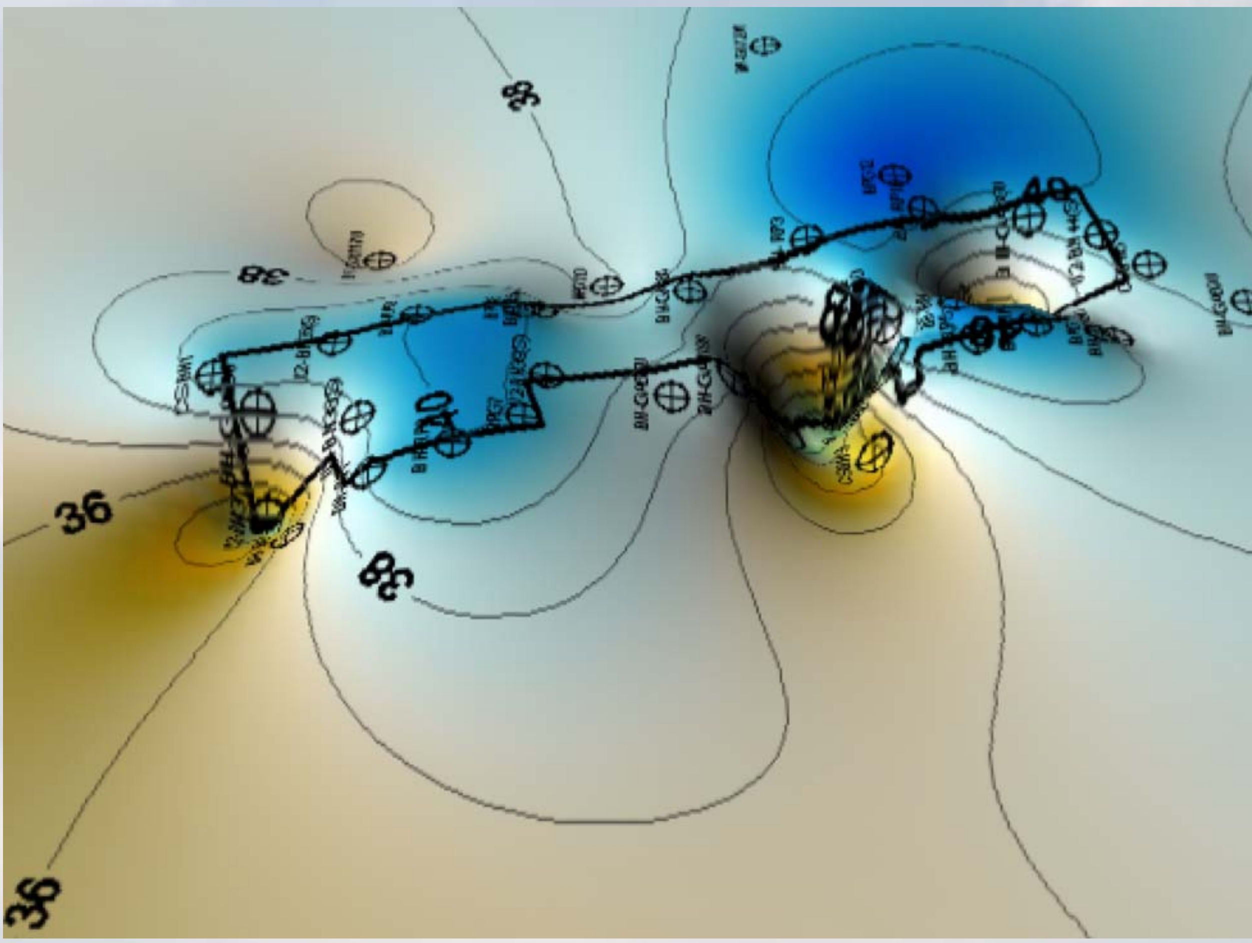


(Note: Rock slope strengthening indicated is provisional only. Actual location
extent of rock slope strengthening are determined after geological mapping
and kinematic analysis).

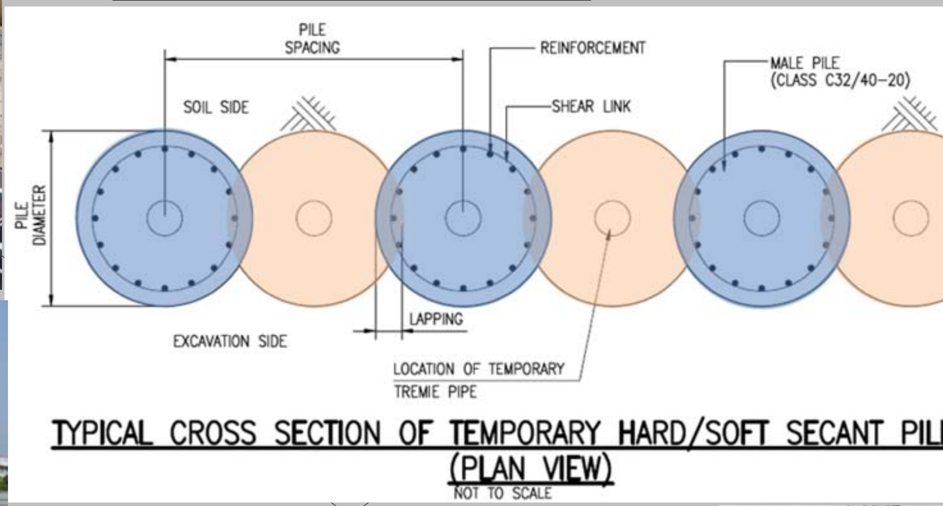


	Subsoil	E
Material type	Silty Sand	L
Average depth	5m	5
Unit weight	18 kN/m^3	2
SPT N	2 - 4	
RQD	-	0
Average UCS	-	
Effective shear strength	c’= 1 kPa ϕ’= 29º	c’
Elastic Modulus, E' (kPa)	4000 - 12000	
Hydraulic conductivity, k	1.0E-5 m/s	

Conchrane Station Bedrock Contour



Secant Pile Wall



Secant Pi

Typical Secant Pile Wall Elevation View

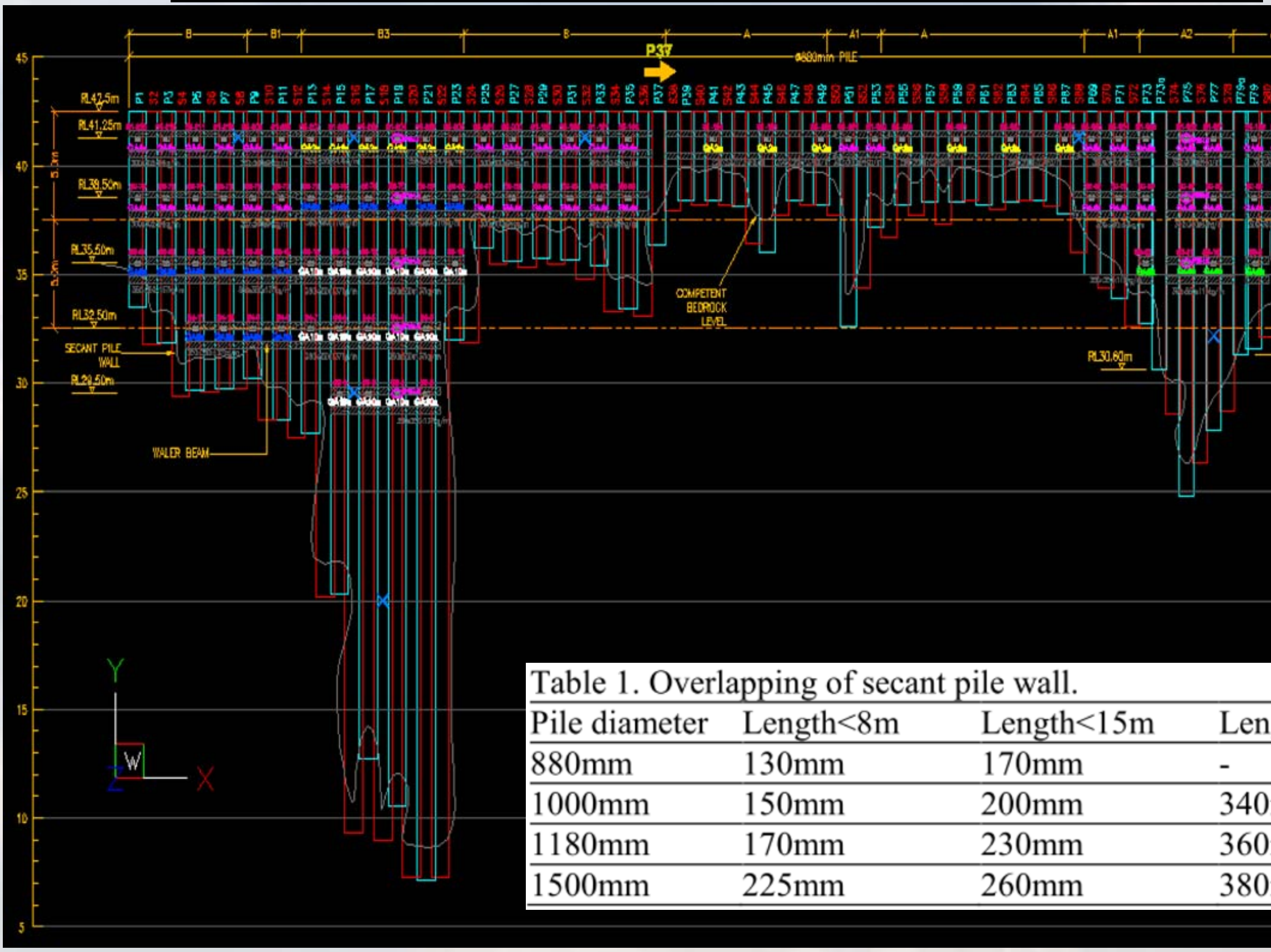
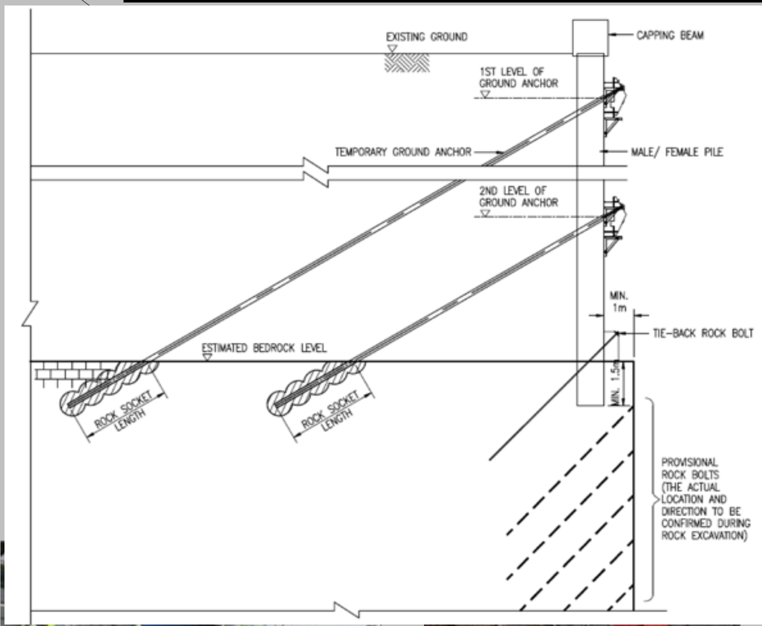


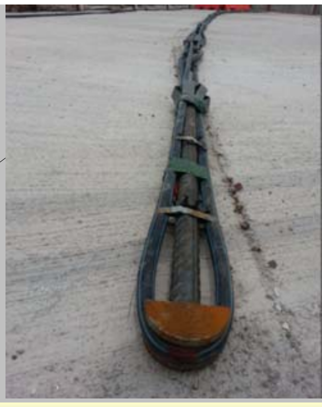
Table 1. Overlapping of secant pile wall.

Pile diameter	Length<8m	Length<15m	Len
880mm	130mm	170mm	-
1000mm	150mm	200mm	340
1180mm	170mm	230mm	360
1500mm	225mm	260mm	380

Temporary Ground Anchor Support Syste



Description	Properties
Working loads (kN)	212; 424; 63
No. of strand	2; 4; 6; 8
Strand diameter	15.24mm
Breaking load	260.7 kN
Factor of safety	1.6
Strand U-turn radius	47.5mm
Reduction factor	0.65
Drill hole diameter	175mm
Allowable bond stress	400 kPa (lim
Free length	Varies (until bedrock)
	3; 3; 4.5; 6



Curtain & Base Grouting to seal the Limesto Karstic Features

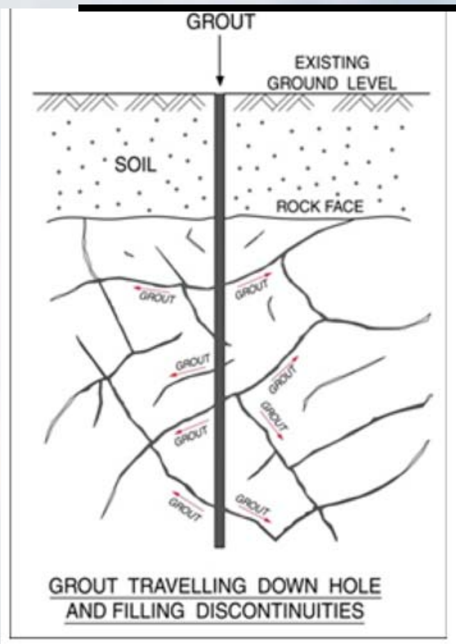
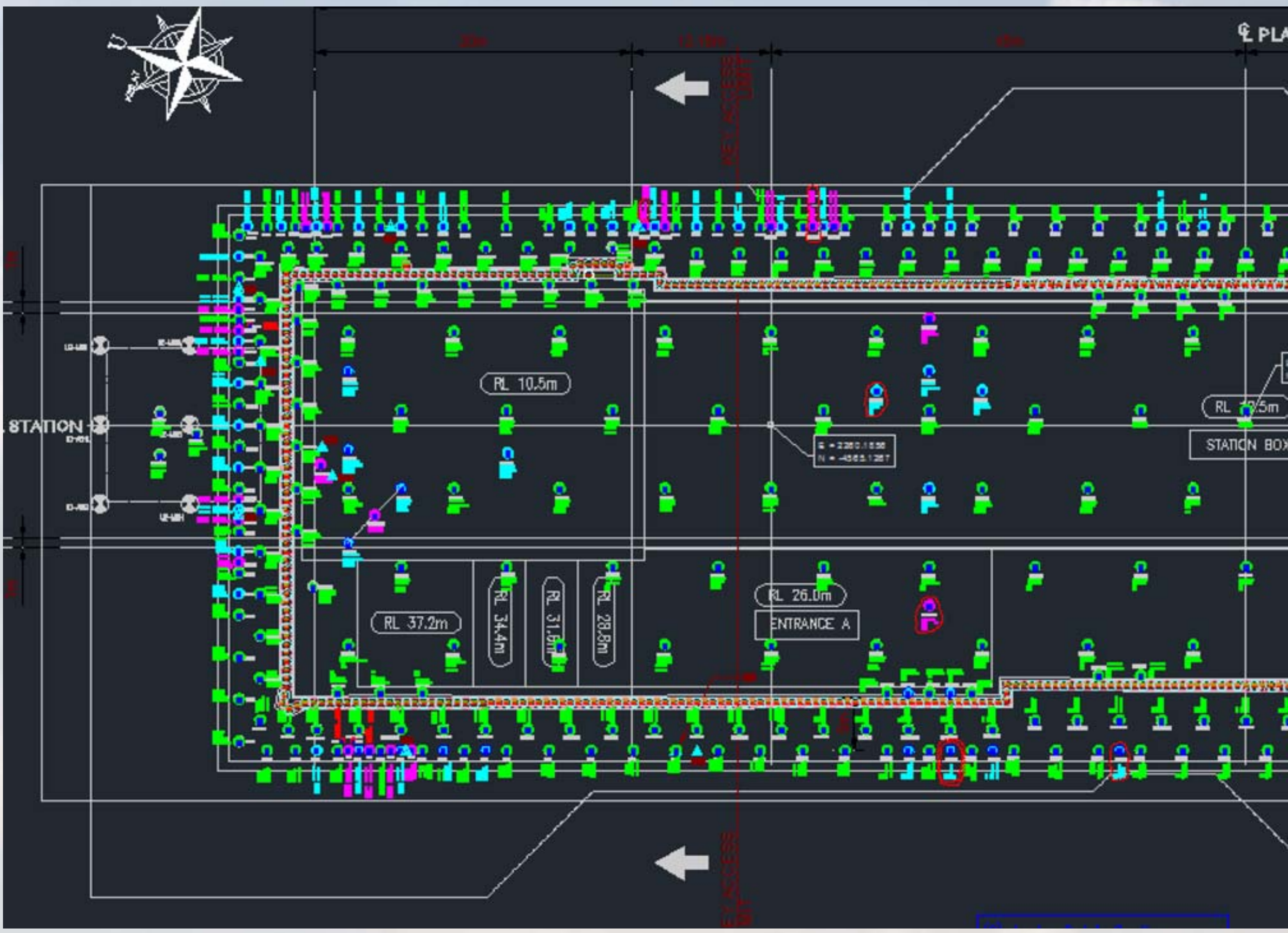


Table 3. Holding pressure for fissure grouting.

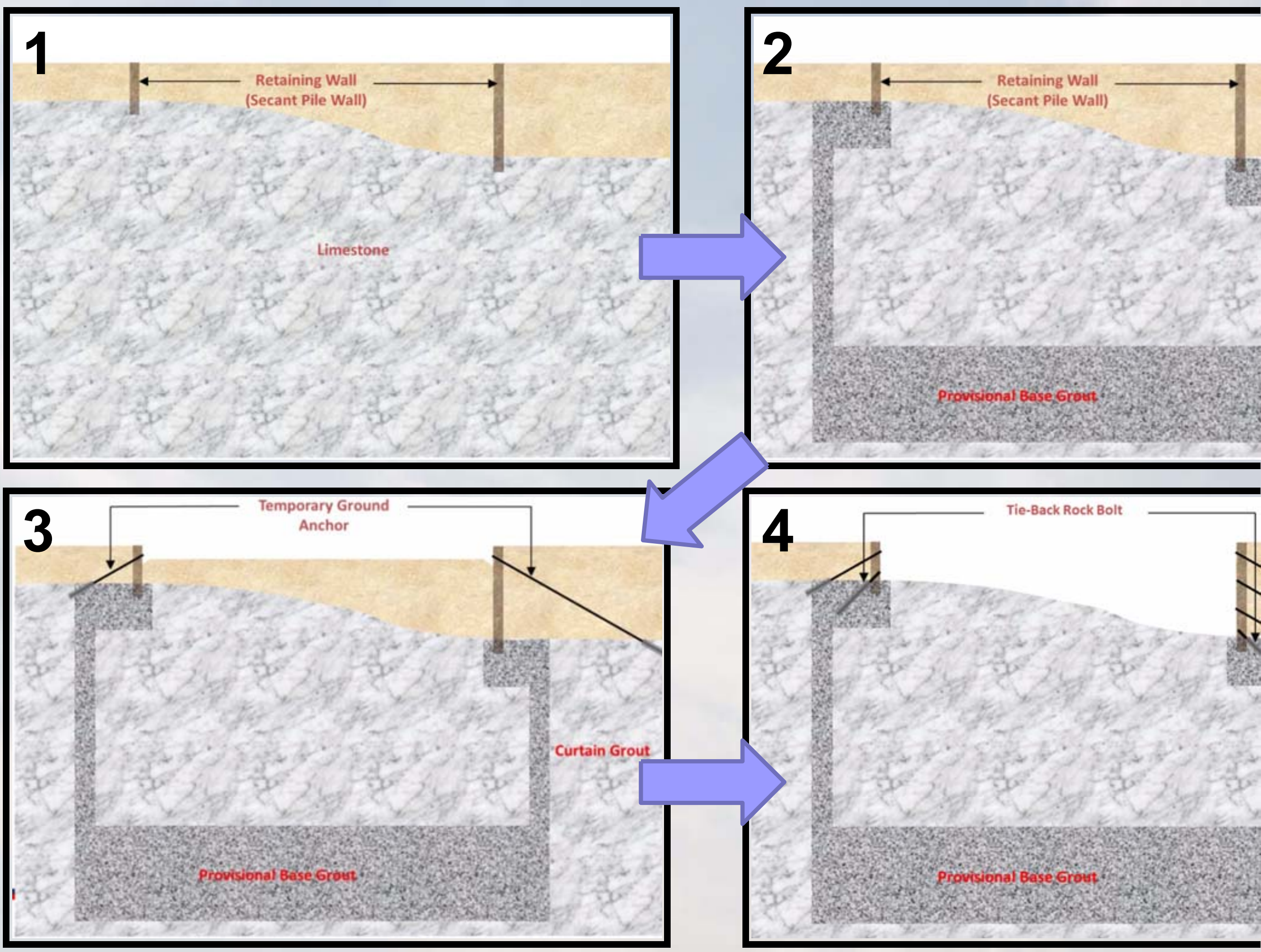
Depth (m)	Holding pressure (Bar)
0 to 10	2 to 4
10 to 20	6 to 8
20 to 30	10 to 12
30 to 40	14 to 16
40 to 50	18 to 20
>50	>22

Note: Termination criteria shall be satisfied with flow rate less than 2 liters per minute or grout volume reaches $10m^3$ for every grouting zone in 5m depth.

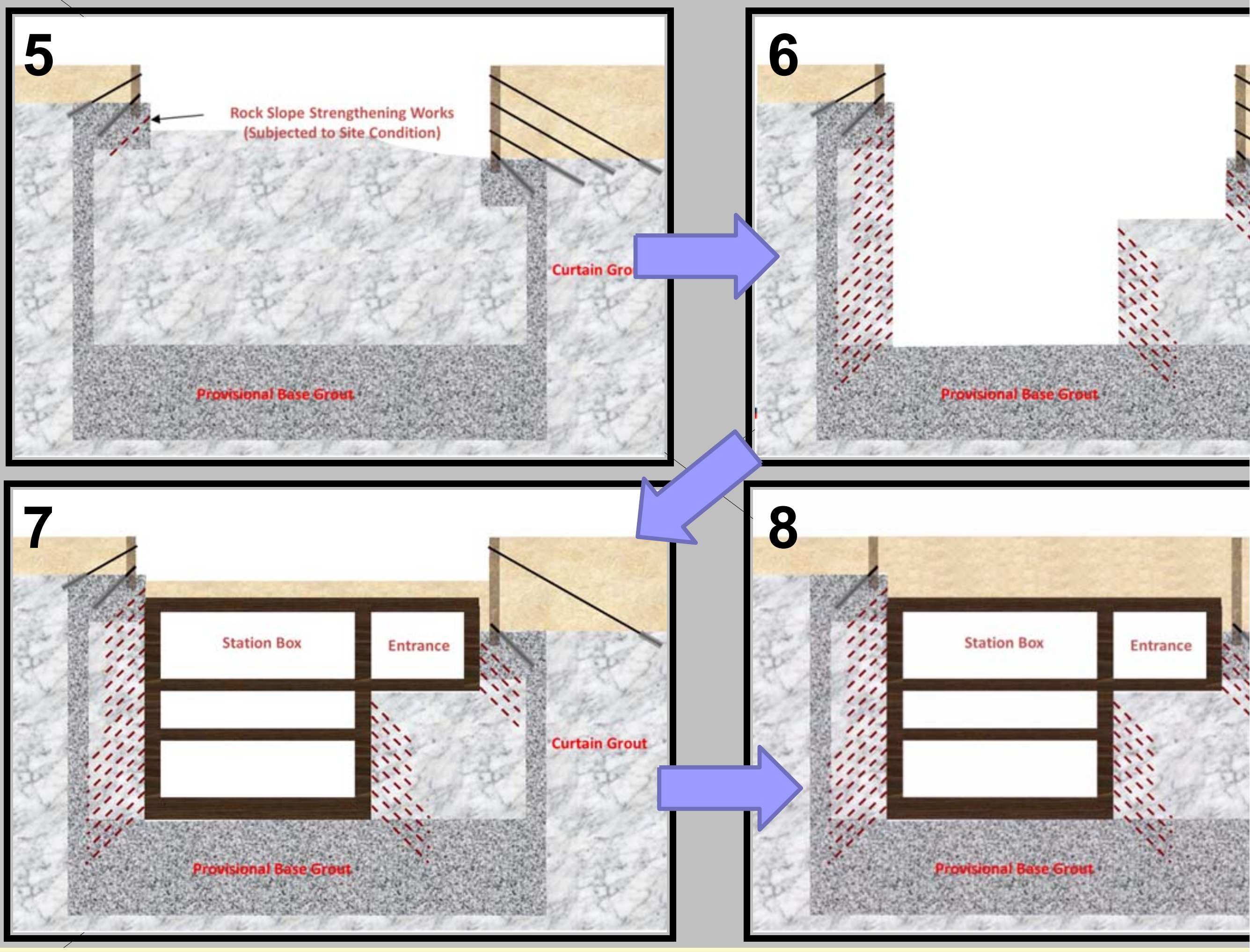
Typical Curtain & Base Grouting Holes Lay



Construction Sequence



Constrution Sequence (con't)



Exposed Vertical Rock Face of the Excavat

Maluri Portal (excavation in progress)

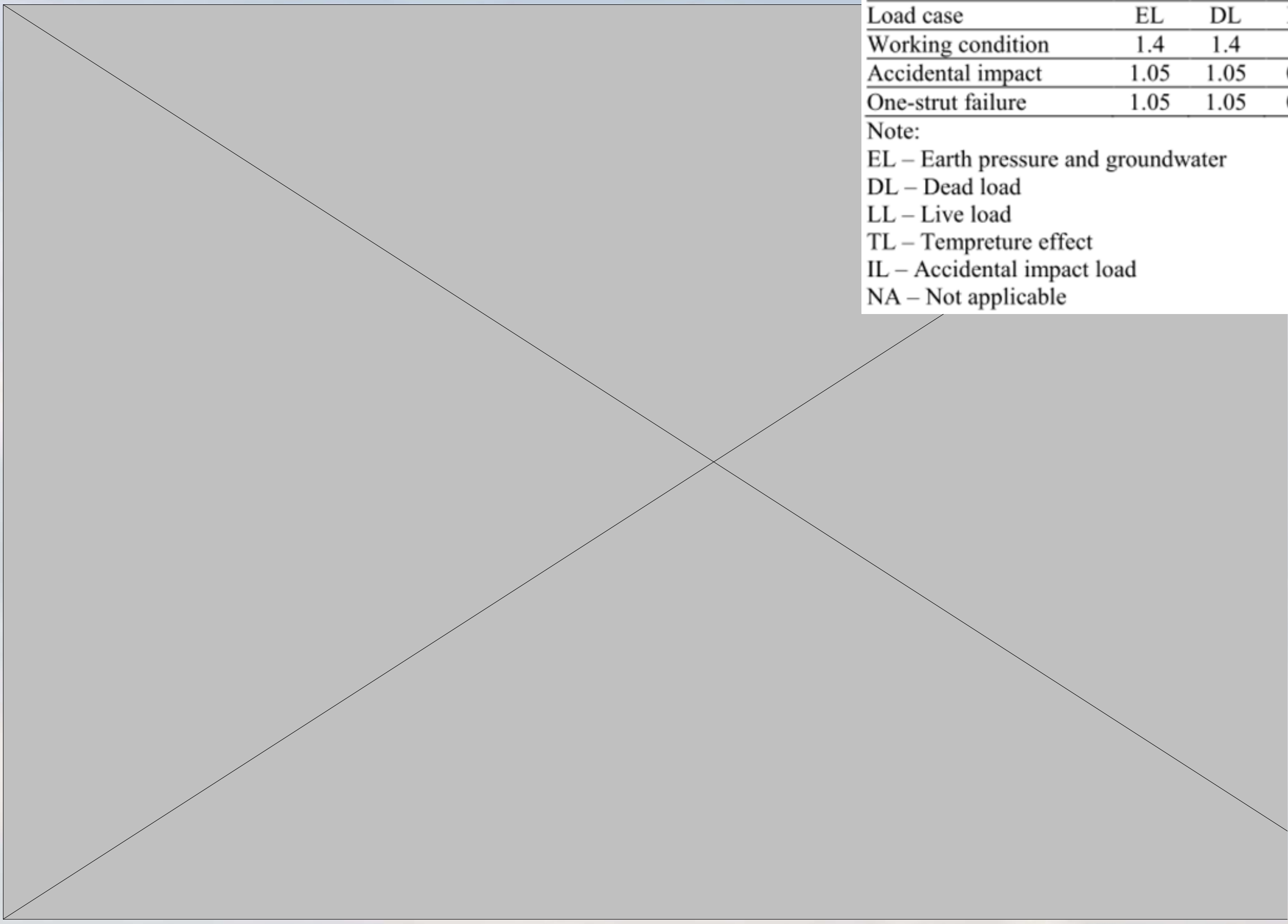


Table 2. Partial load factors.

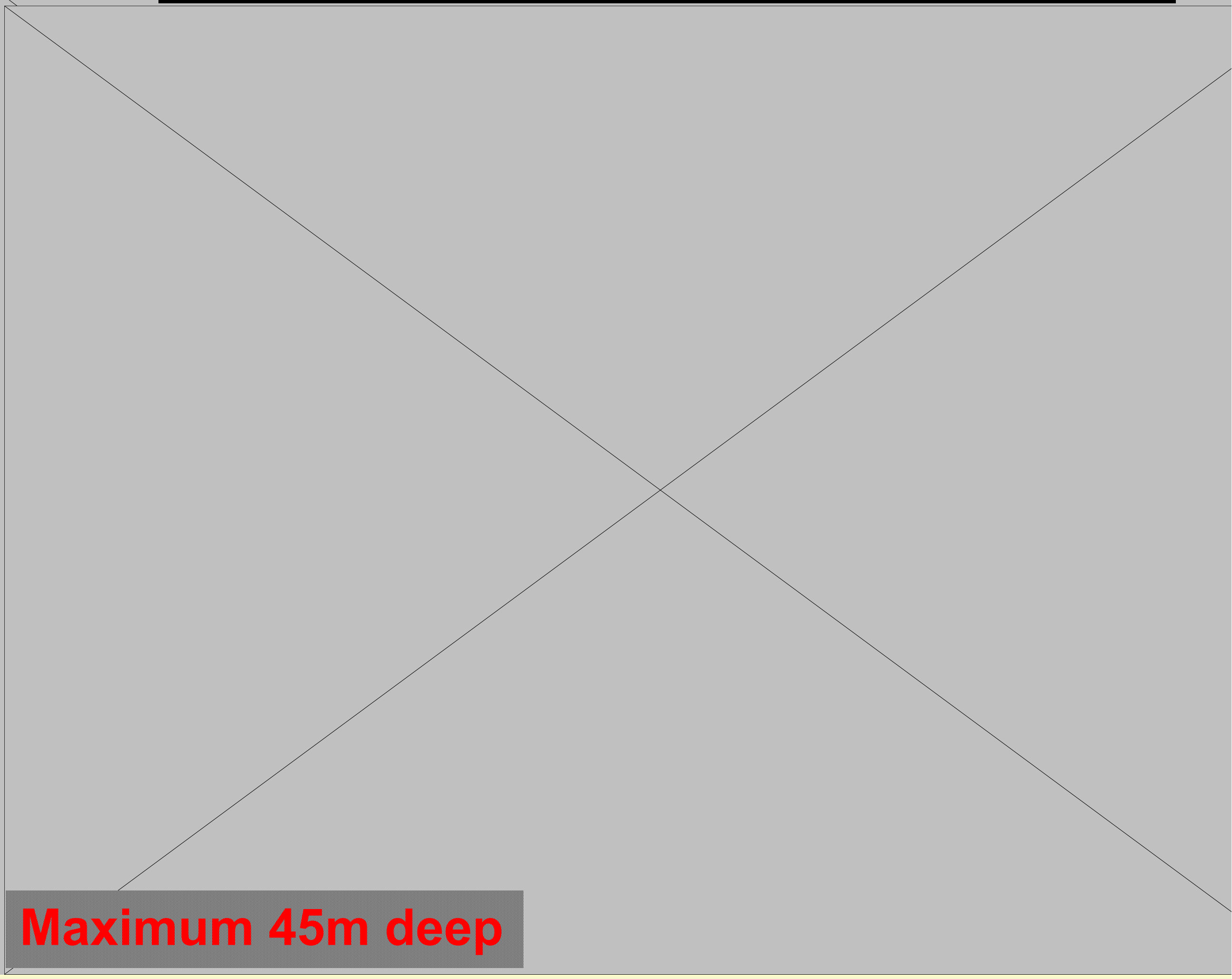
Load case	EL	DL
Working condition	1.4	1.4
Accidental impact	1.05	1.05
One-strut failure	1.05	1.05

Note:
EL – Earth pressure and groundwater
DL – Dead load
LL – Live load
TL – Tempreture effect
IL – Accidental impact load
NA – Not applicable

Steel Decking for the Traffic diversion abov
Maluri

Maximum 25m deep

TRX Station (Excavation in Progres)



Conchrane Station (Excavation Stage)

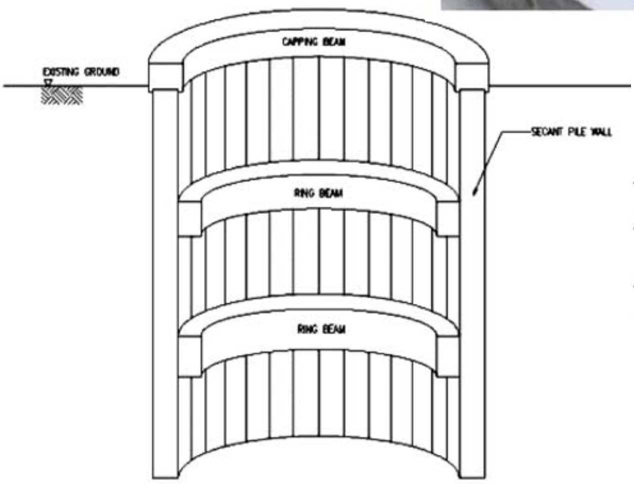

Maximum 35m deep

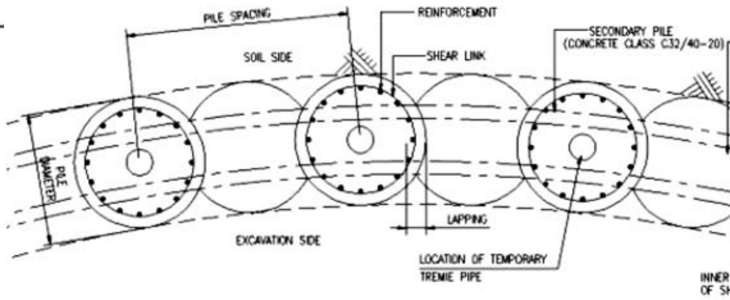
Case History 2 :

Circular Shaft for Launching of TBM

Circular TBM Launching Shaft

Circular Shaft during Excavation





Sectional view of circular shaft with ring beams.

Design Based on Hoop Force

$$\frac{Critical\ hoop\ force\ in\ wall}{Effective\ thickness\ of\ wall} < Allowable\ compressive\ stress\ of\ concrete$$

where

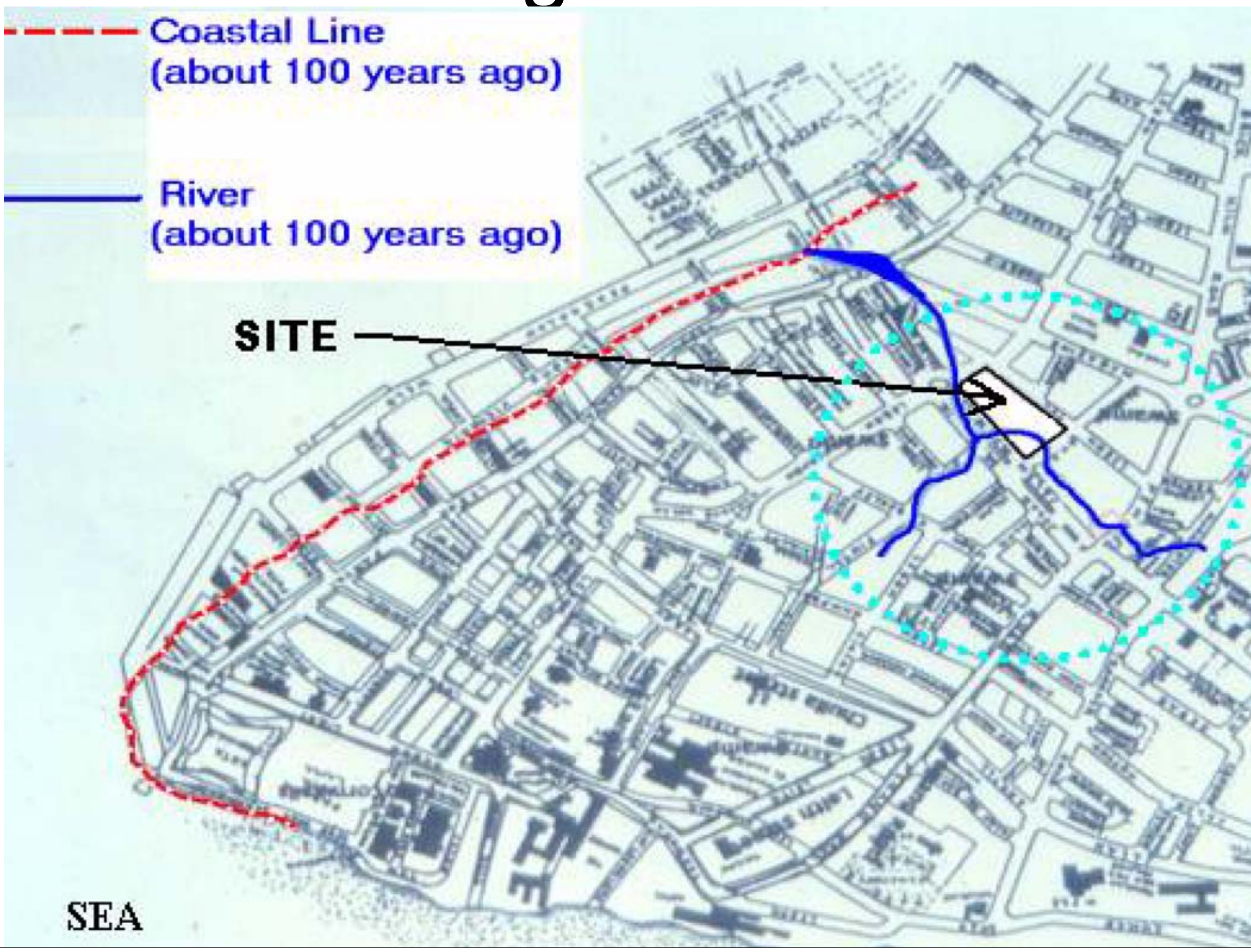
Critical hoop force (kN per meter)
= (Maximum lateral pressure) x (0.5 of circular shaft outer diameter)

Effective thickness (m)
= (structurally connected area of retaining wall) – (pile deviation and verticality at critical depth during installation)

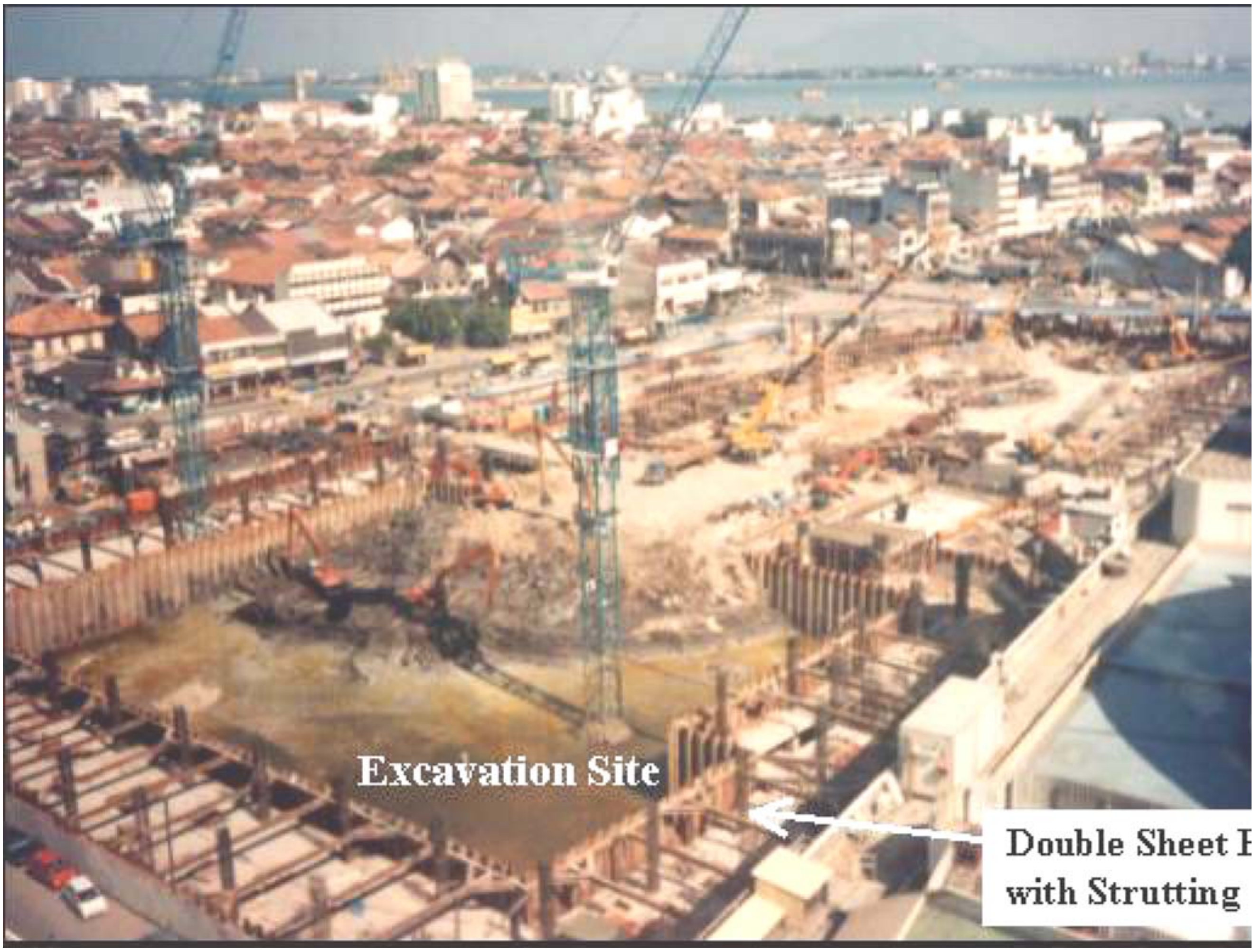
Allowable compressive stress of concrete (kPa)
= 0.25 of concrete design strength

Case History 3 :
Hydraulic Failure @ Penan

100 Years Ago

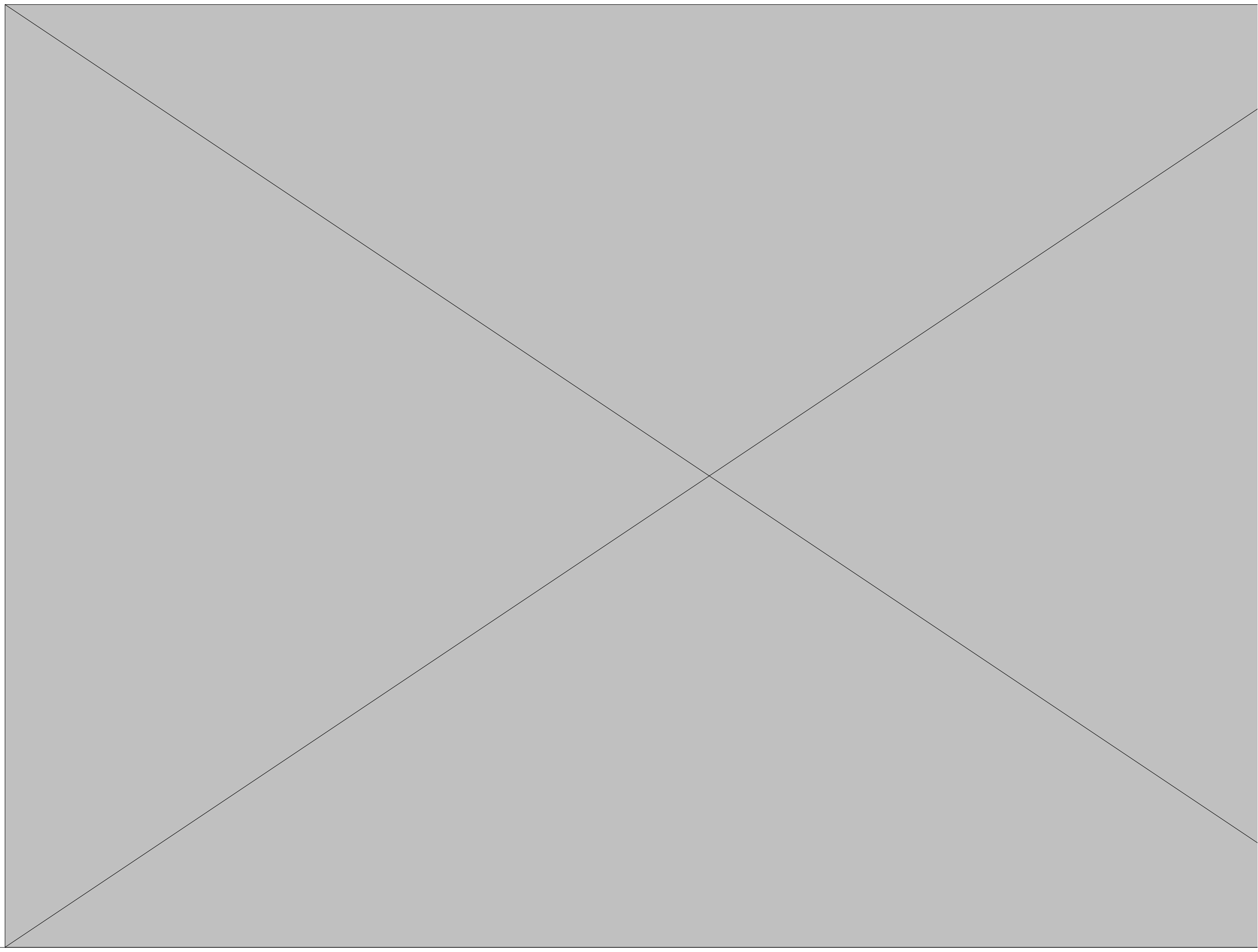


The Site

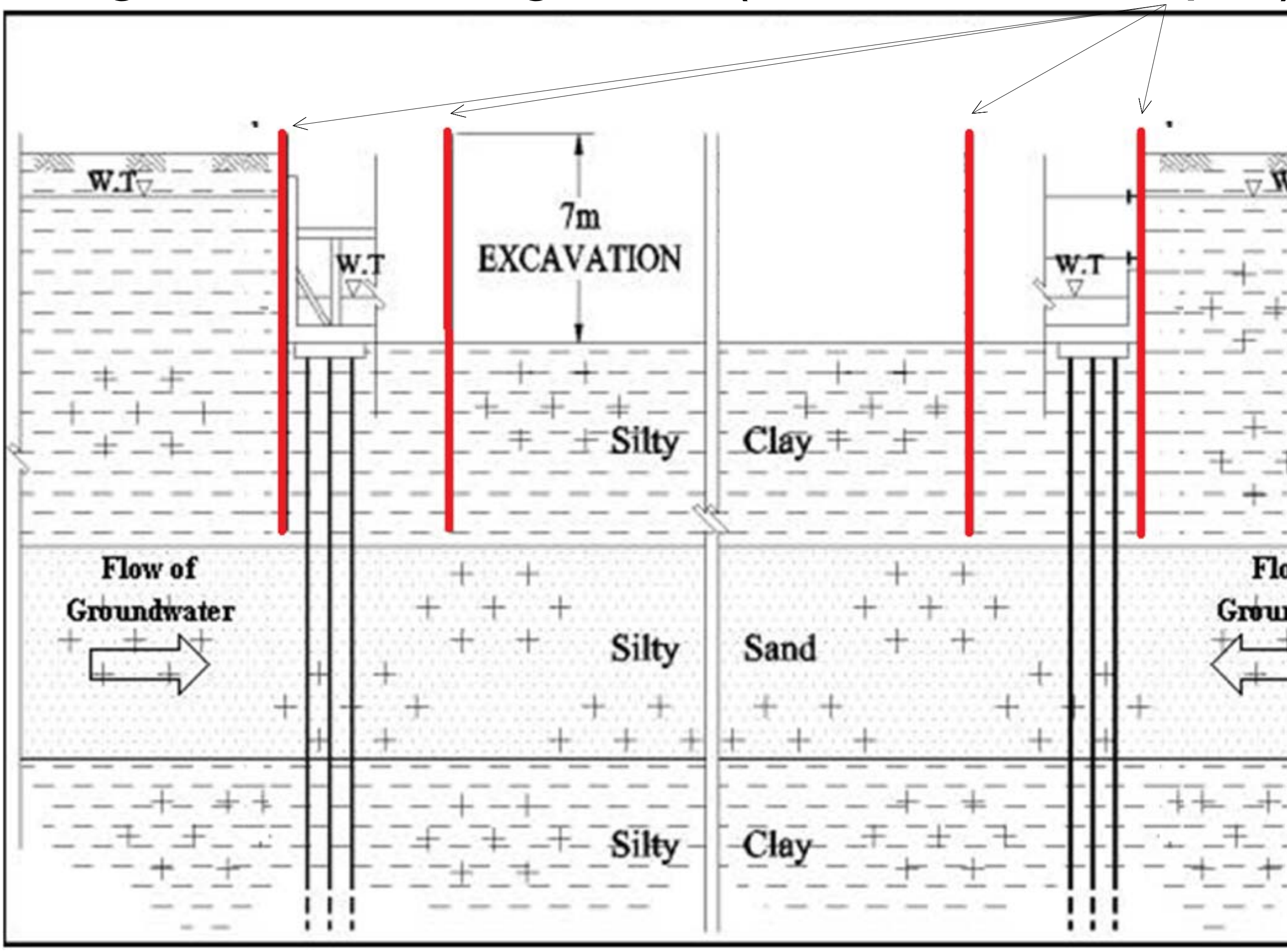


Subsoil Profile

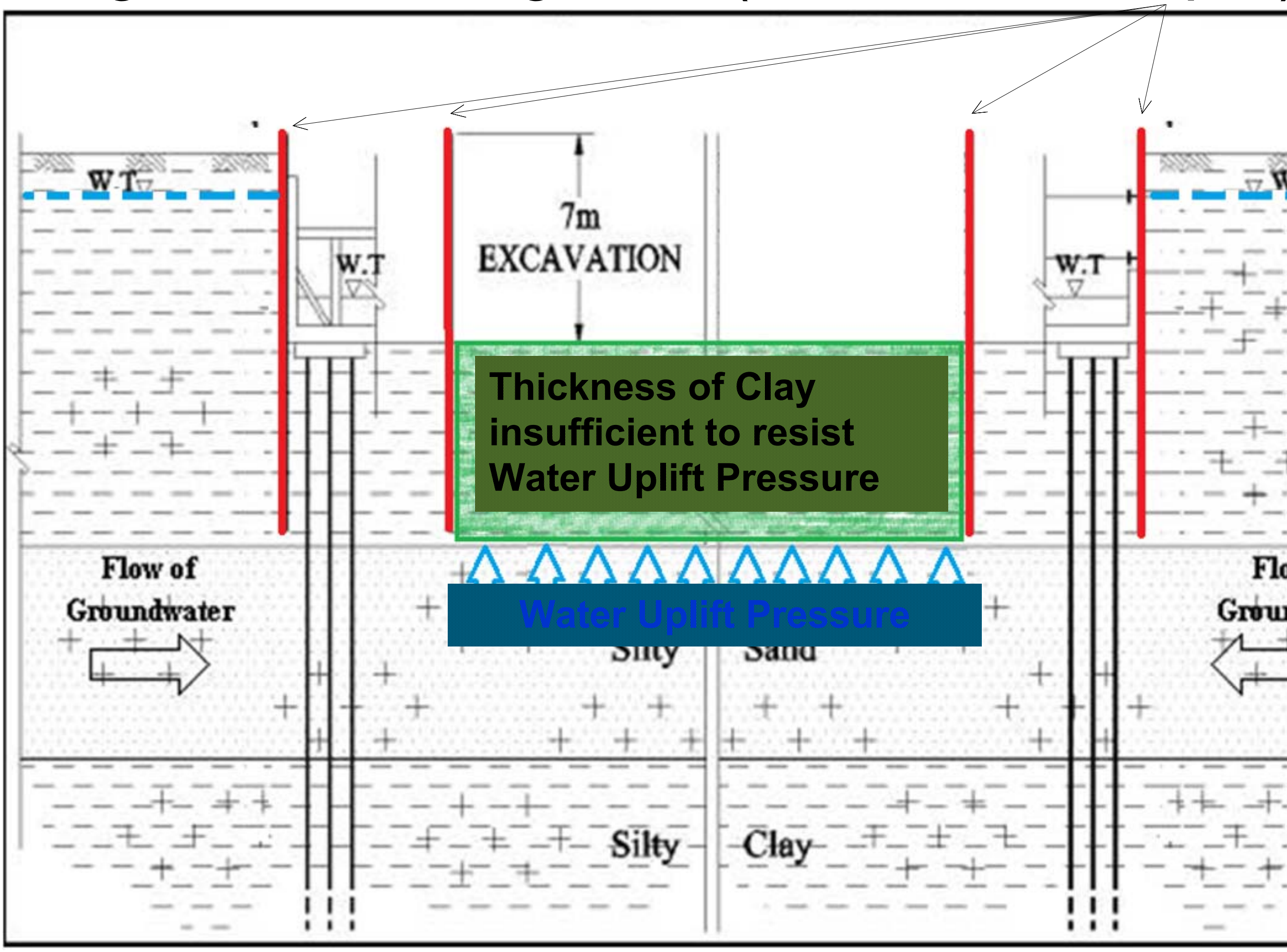
Original Design



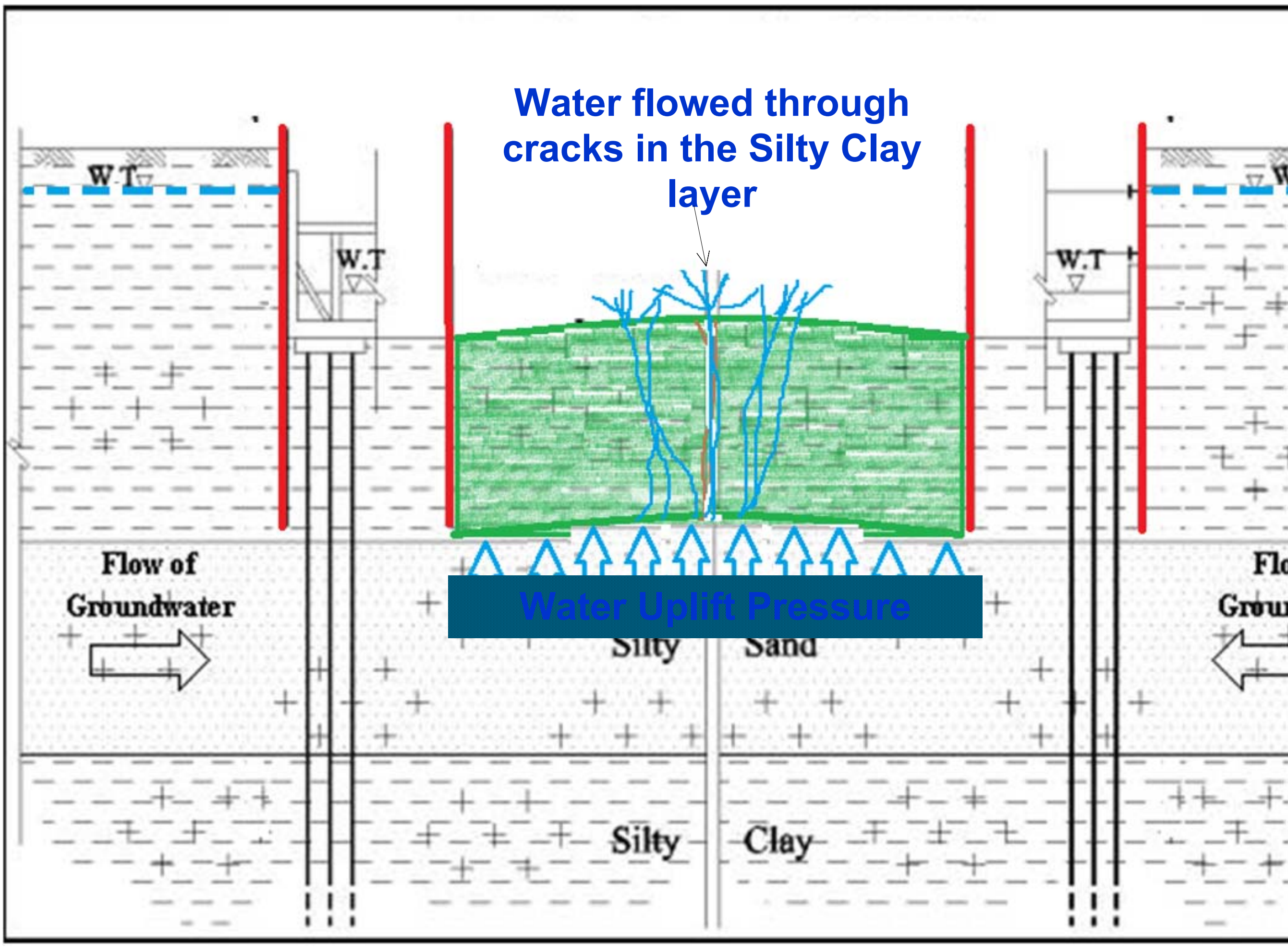
Original Retaining Wall (Insufficient Depth)



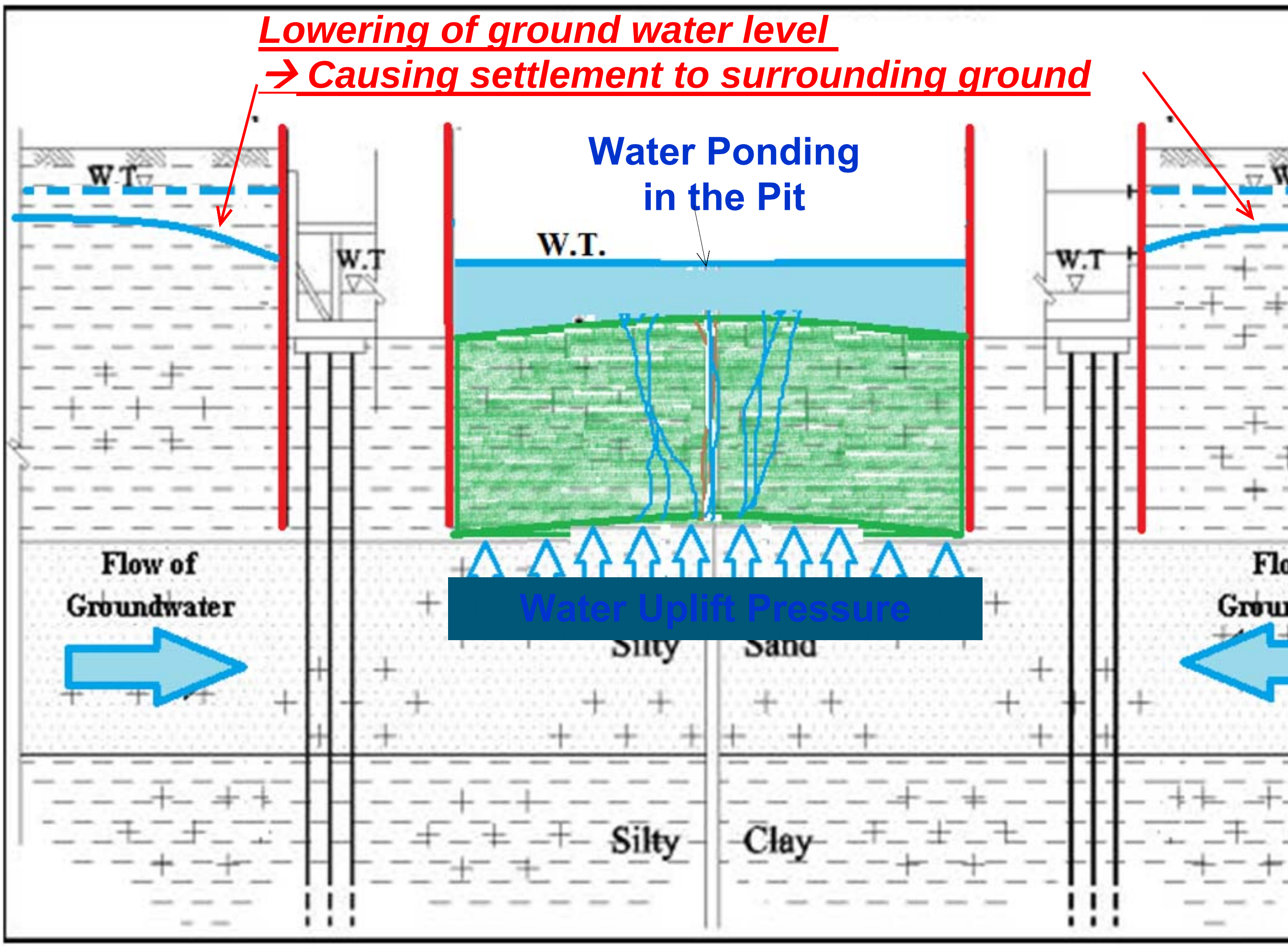
Original Retaining Wall (Insufficient Depth)



Original Retaining Wall (Insufficient Depth)

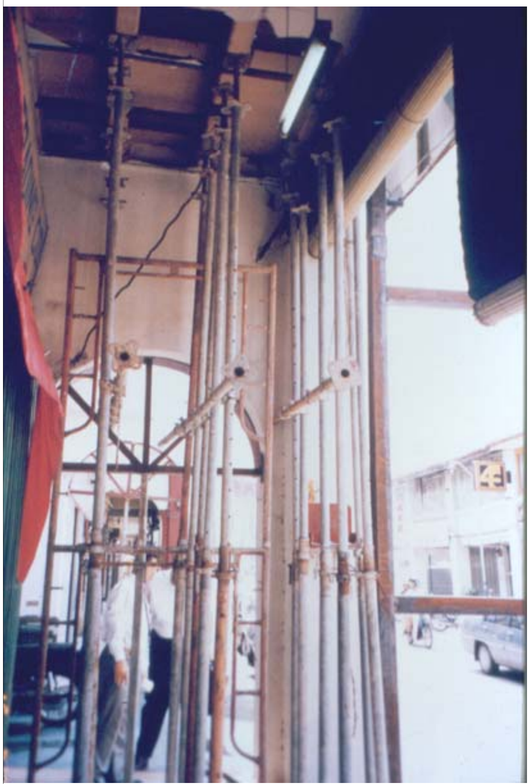


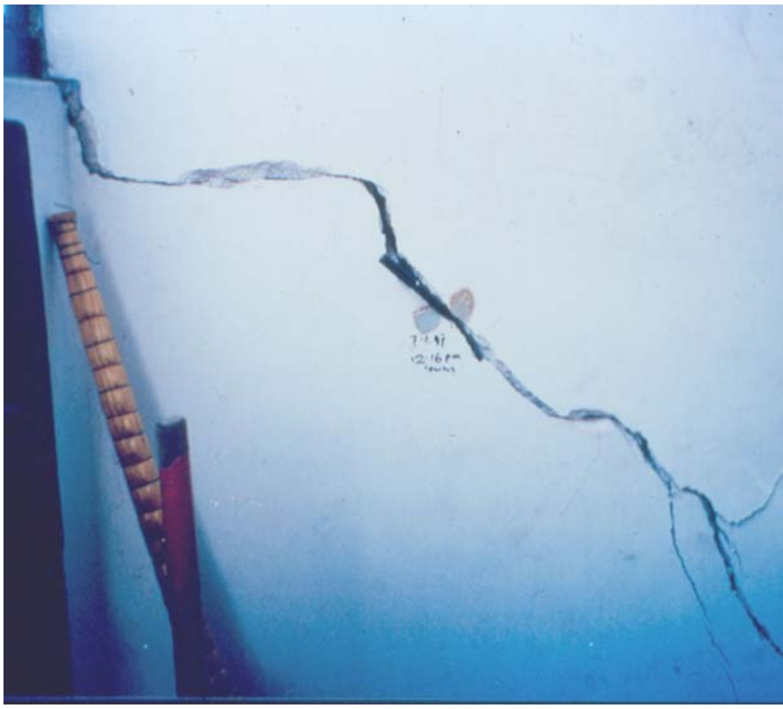
Original Retaining Wall (Insufficient Depth)



The Site after Failure

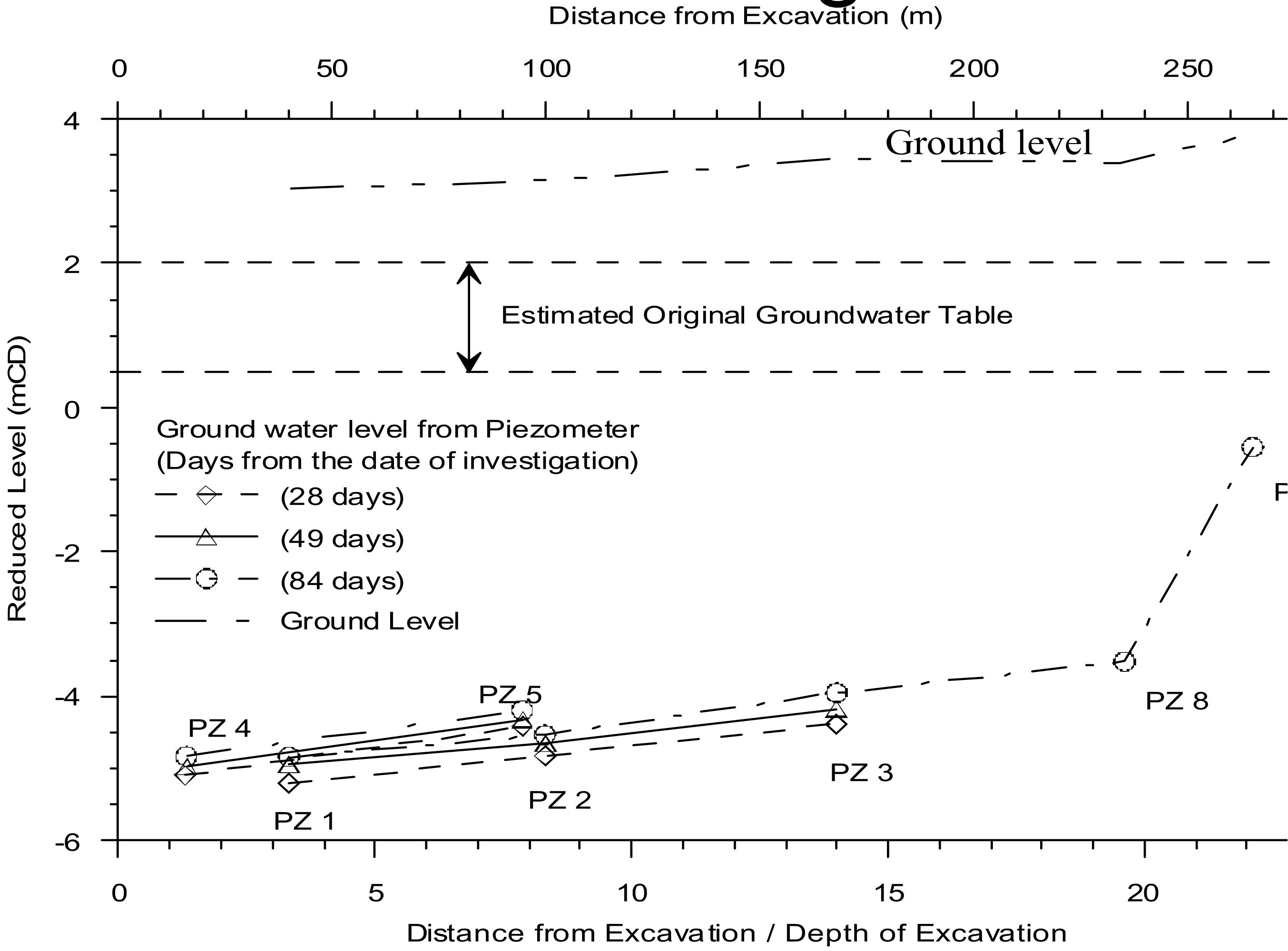
Cracks of Houses



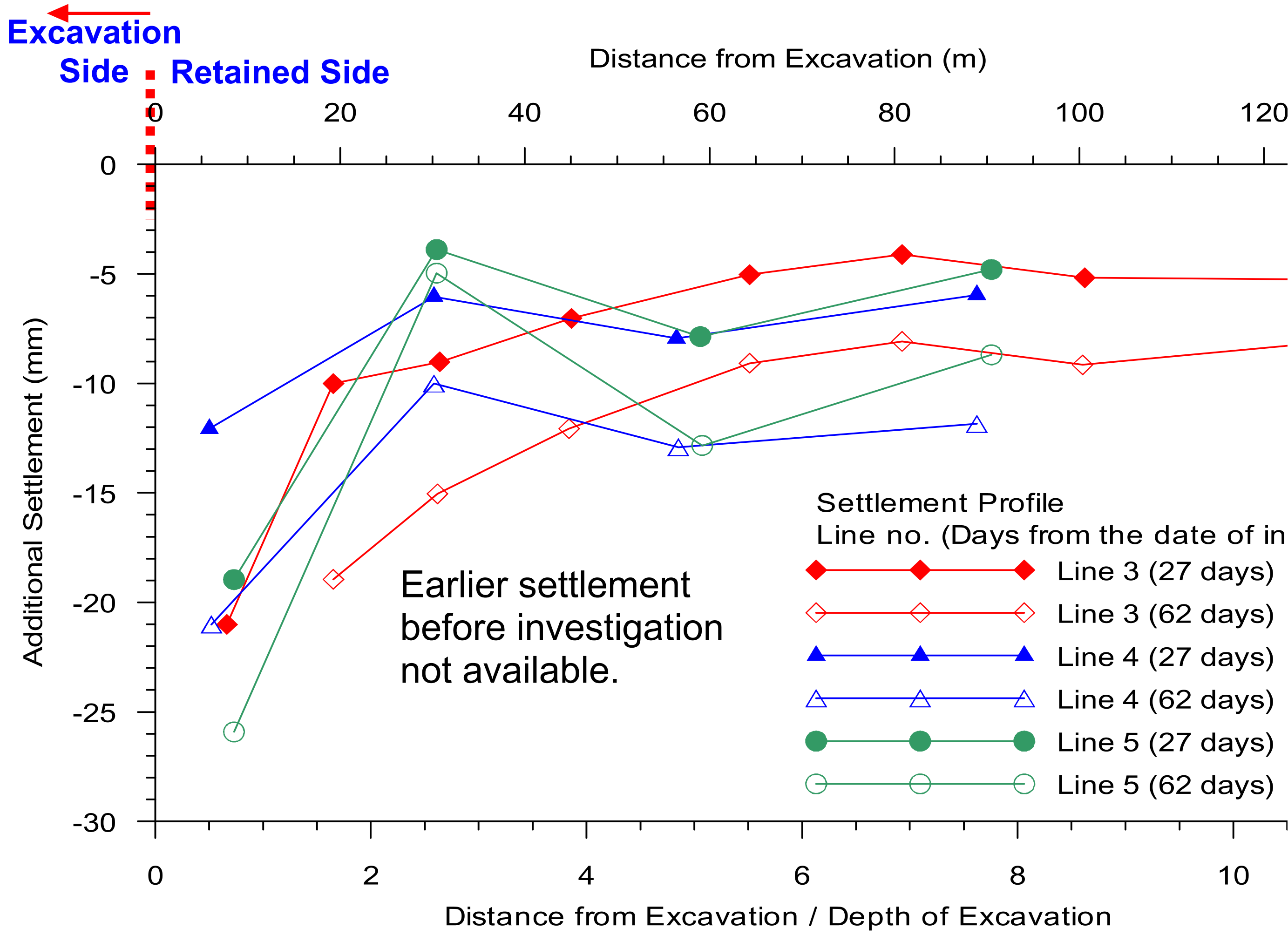


Settlement of Ground

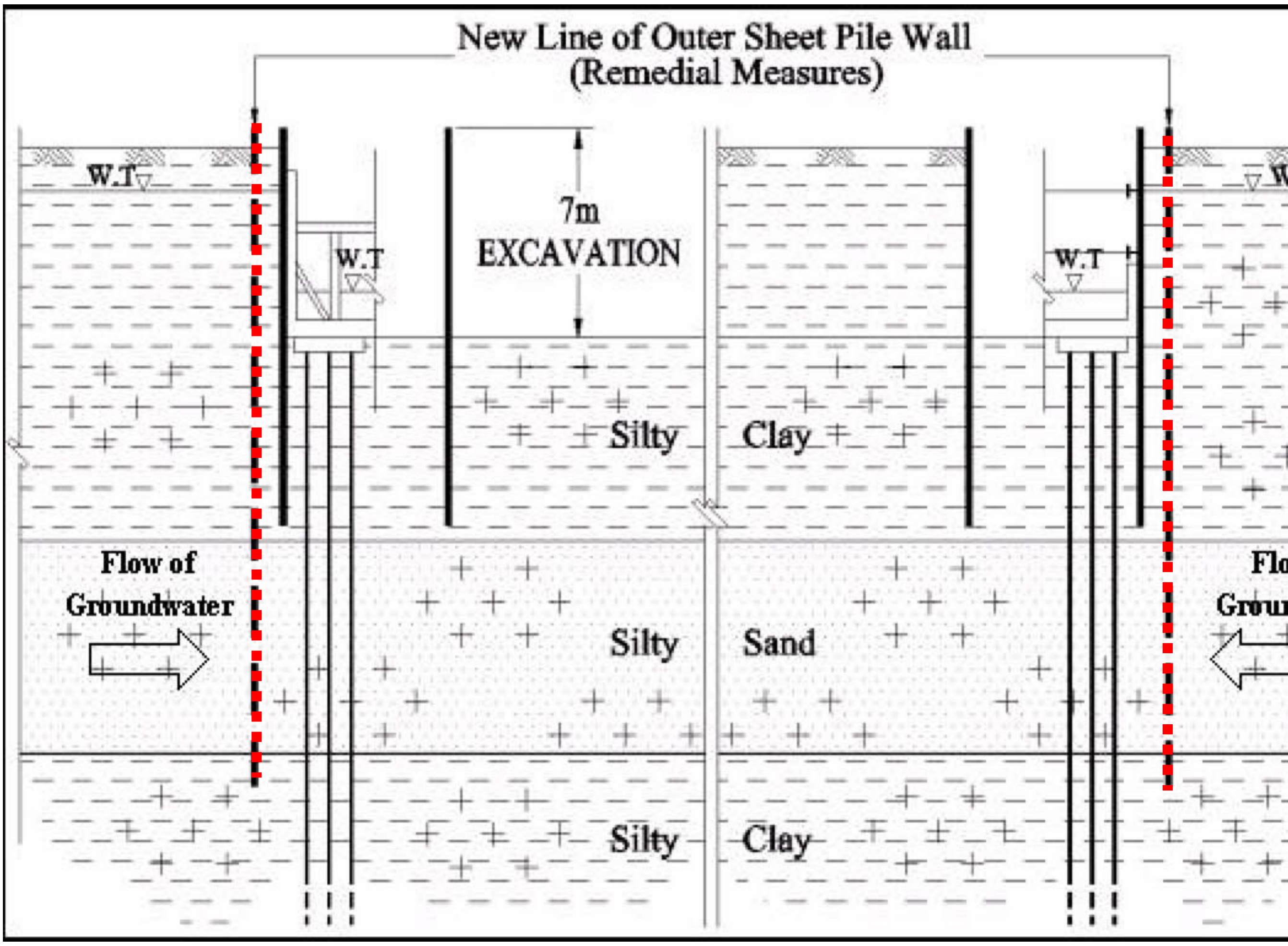
Groundwater Changes



Additional Settlement

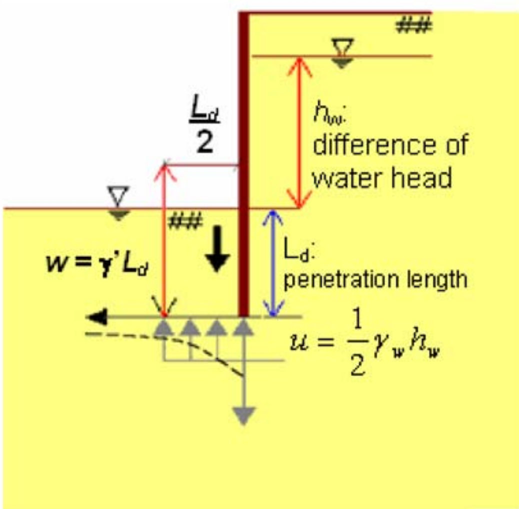
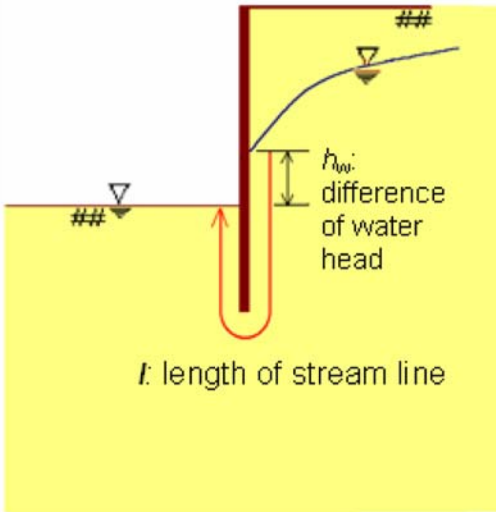


Remedial Works



HYDRAULIC FAILURE

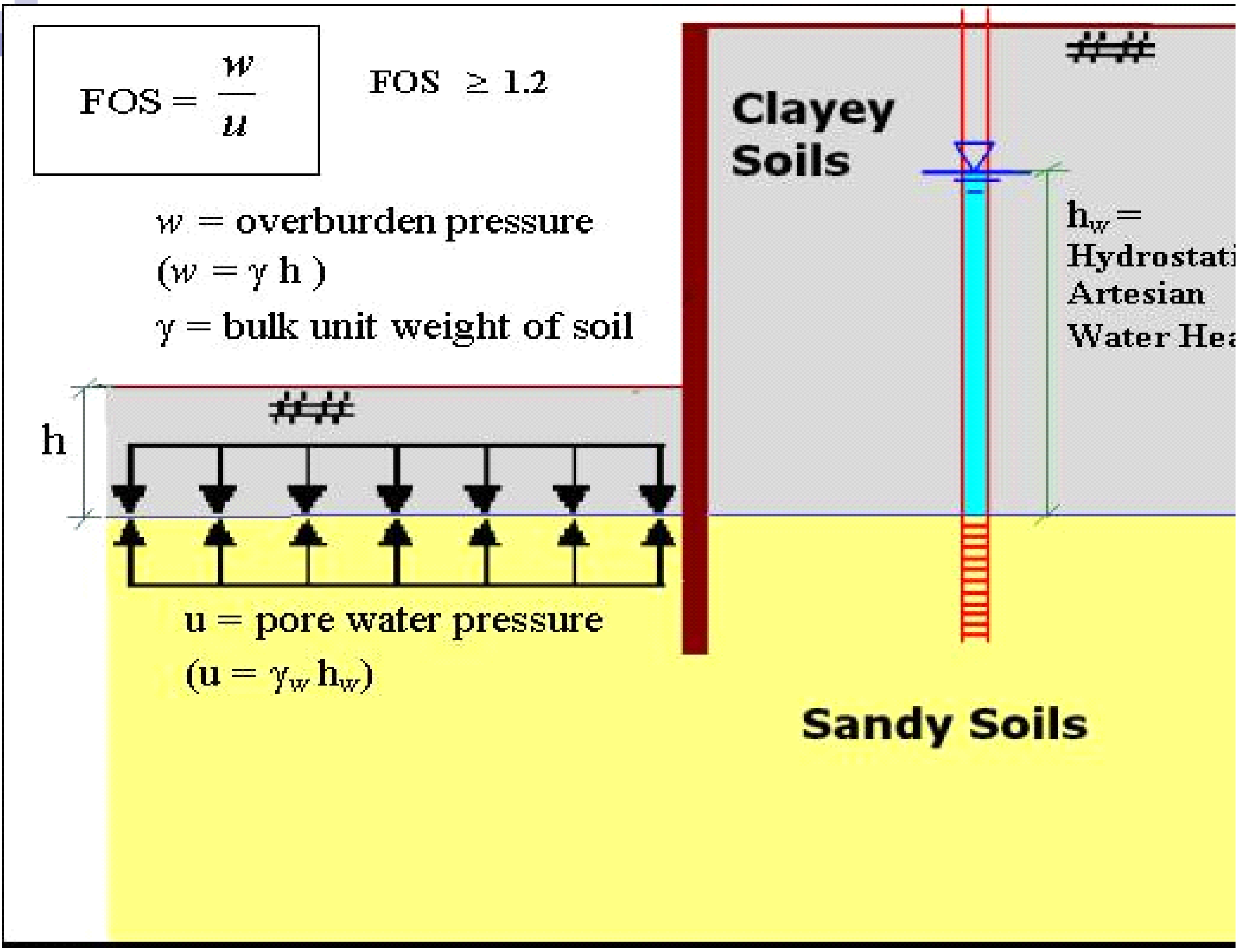
- Base instability caused by piping
  - **Seepage** due to high groundwater level
- Available methods
  - **Terzaghi's method**
  - **Critical hydraulic gradient method**

	Terzaghi's method	Critical hydraulic method
Diagram	 γ': submerged unit weight of soil γ_w: unit weight of water	 G_s: specific gravity of soil particle e : void ratio
Equation	$FOS = w/u = \frac{2\gamma' L_d}{\gamma_w h_w}$ $FOS \geq 1.2$ (temporary works) $FOS \geq 1.5$ (permanent works)	$FOS = i_c/i = \frac{G_s - 1}{1+e} \cdot \frac{l}{h_w} = \frac{\gamma' l}{\gamma_w h_w}$ $FOS \geq 2.0$

HYDRAULIC FAILURE CHECKS

HYDRAULIC FAILURE

- **Terzaghi's method recommended**
  - Based on latest research by Tanaka & Ver (1999)
  - Factor of safety required – **1.2 to 1.5**



HEAVING DUE TO ARTESIAN PRESSU

HYDRAULIC FAILURE

- **Heaving due to artesian pressure**
  - Factor of safety – **1.0 to 1.2**
  - Smaller FOS sufficient as it did not consider shear strength or adhesion strength of the ground and retaining w

Video of Hydraulic Failure

CONCLUSIONS

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Successful deep excavation depends o

- Parameters & calibrations
- Constitutive models
- Impact of lowering water table & Mitigat
  measures

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THANK YOU

Q & A

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