



Ground Movements Associated with the Underground Excavations of the First Bangkok MRT Project

Noppadol Phienwej

Attasit Sirivatchiraporn

Asian Institute of Technology

Suchatvee Suwanrsawat

King Mongkut Institute of Technology-Lad Krabang

Zaw Zaw Aye

Seafco Public Company Limited

Bangkok, Thailand

16th SEAGC - Kuala Lumpur, Malaysia 8-11 May 2007

-
-
-

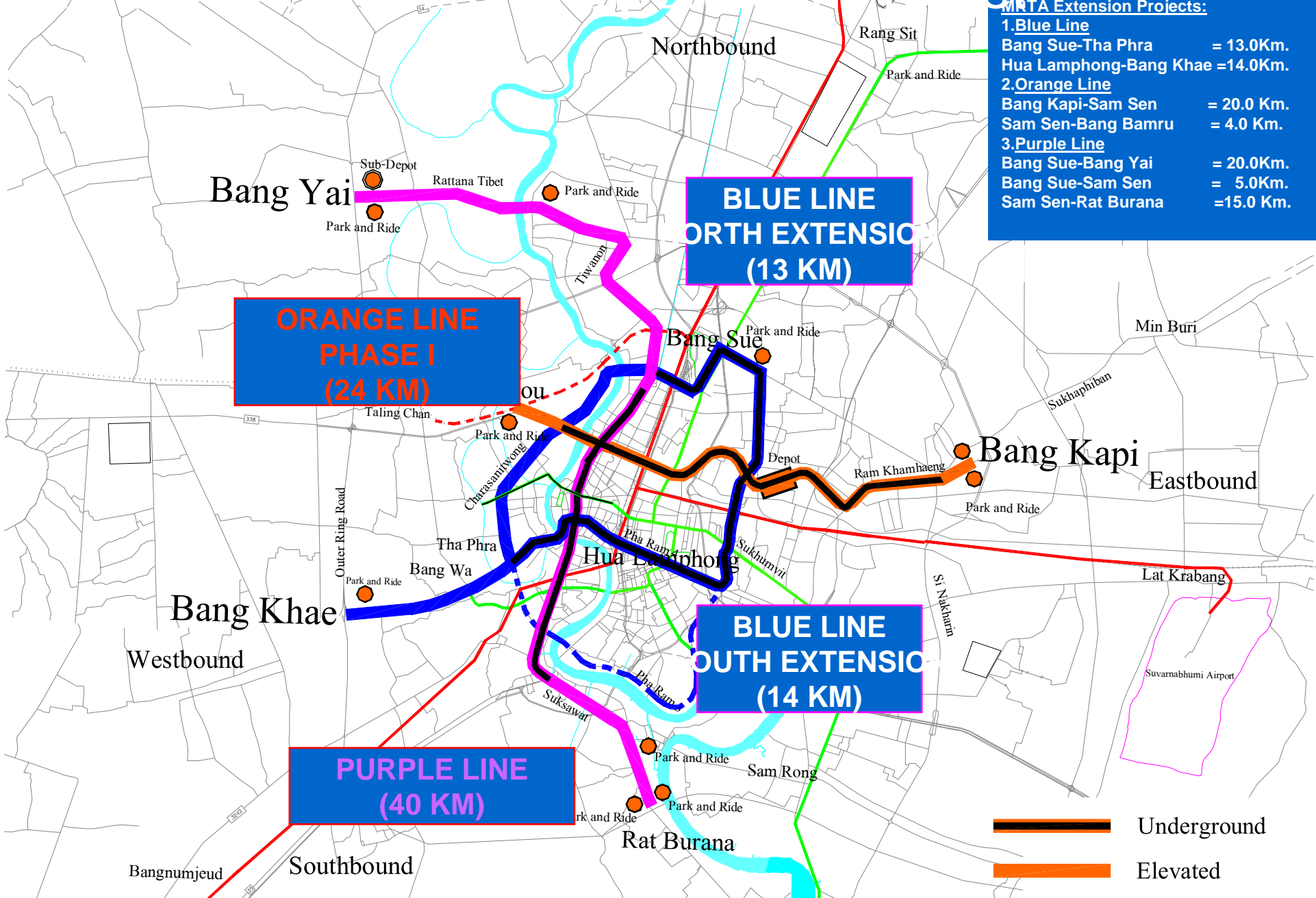
Outline



- Project Outline
- Observation Method and Instrumentation
- Ground Movements in Bored Tunnelling
- Ground Movements in Station Excavation
- Effects on Adjacent Buildings
- Conclusions

The Coming Public Transportation Project

MRTA Extension Projects:

- Blue Line**
 - Bang Sue-Tha Phra = 13.0Km.
 - Hua Lamphong-Bang Khae = 14.0Km.
- Orange Line**
 - Bang Kapi-Sam Sen = 20.0 Km.
 - Sam Sen-Bang Bamru = 4.0 Km.
- Purple Line**
 - Bang Sue-Bang Yai = 20.0Km.
 - Bang Sue-Sam Sen = 5.0Km.
 - Sam Sen-Rat Burana = 15.0 Km.



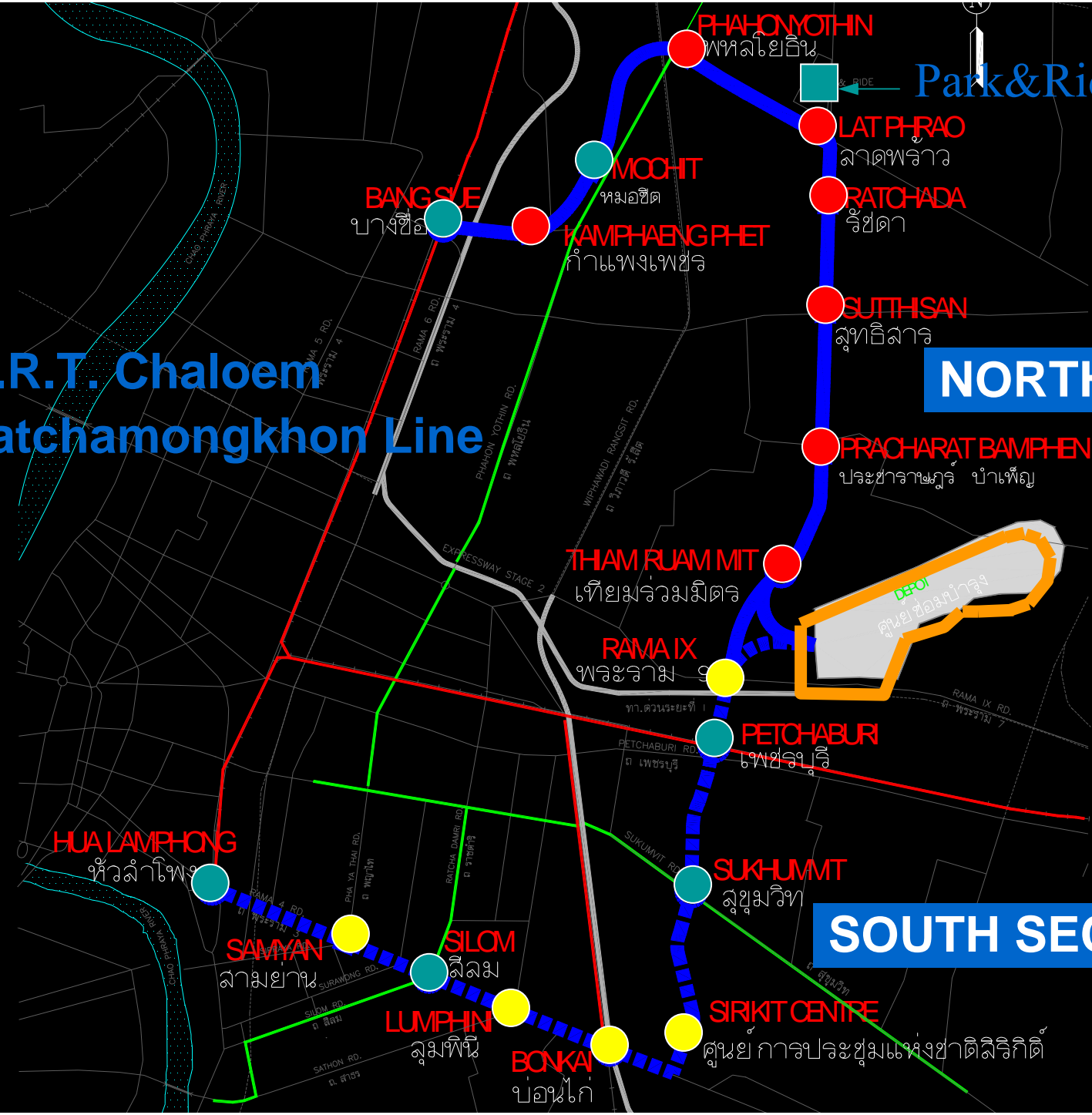
 Underground
 Elevated



M.R.T. Chaloen Ratchamongkhon Line

NORTH SECTION

SOUTH SECTION



-
-
-

Underground Work Contracts

JV BCKT
Underground
Structure -
South Contract

11.5 km twin tunnel
9 stations
3 intervention shafts
1800 m depot
approach

ION JV
Underground
Structure -
North Contract

10.5 km twin tunnel
9 stations
5 intervention shafts
1800 m depot
approach

STATIONS

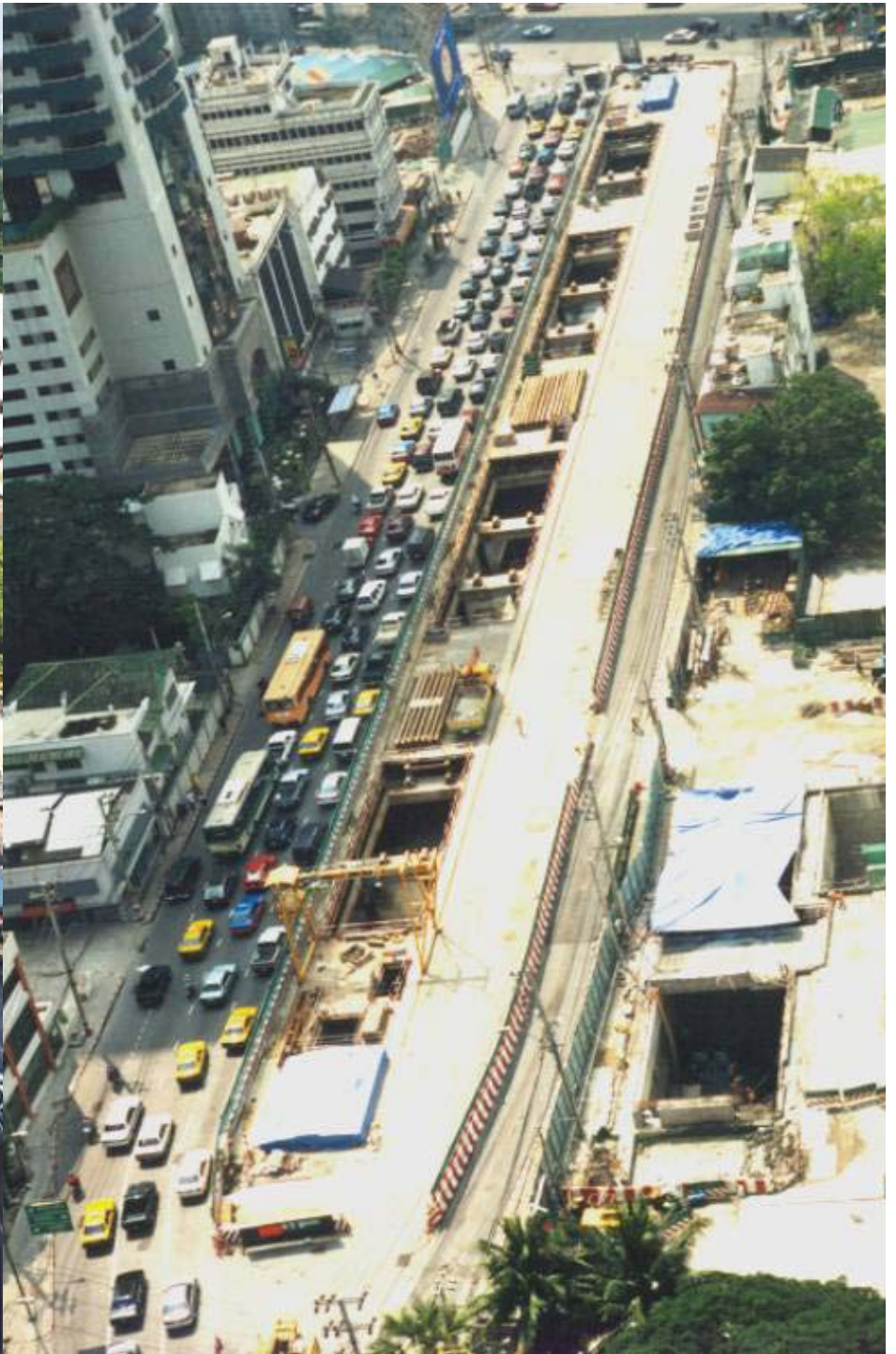


-
-
-

Station Construction

- Cut and cover (top-down method)
- Concrete diaphragm wall using permanent floor slabs as internal support
- Ground treatment - jet grouting/ dewatering
- Monitoring of ground responses







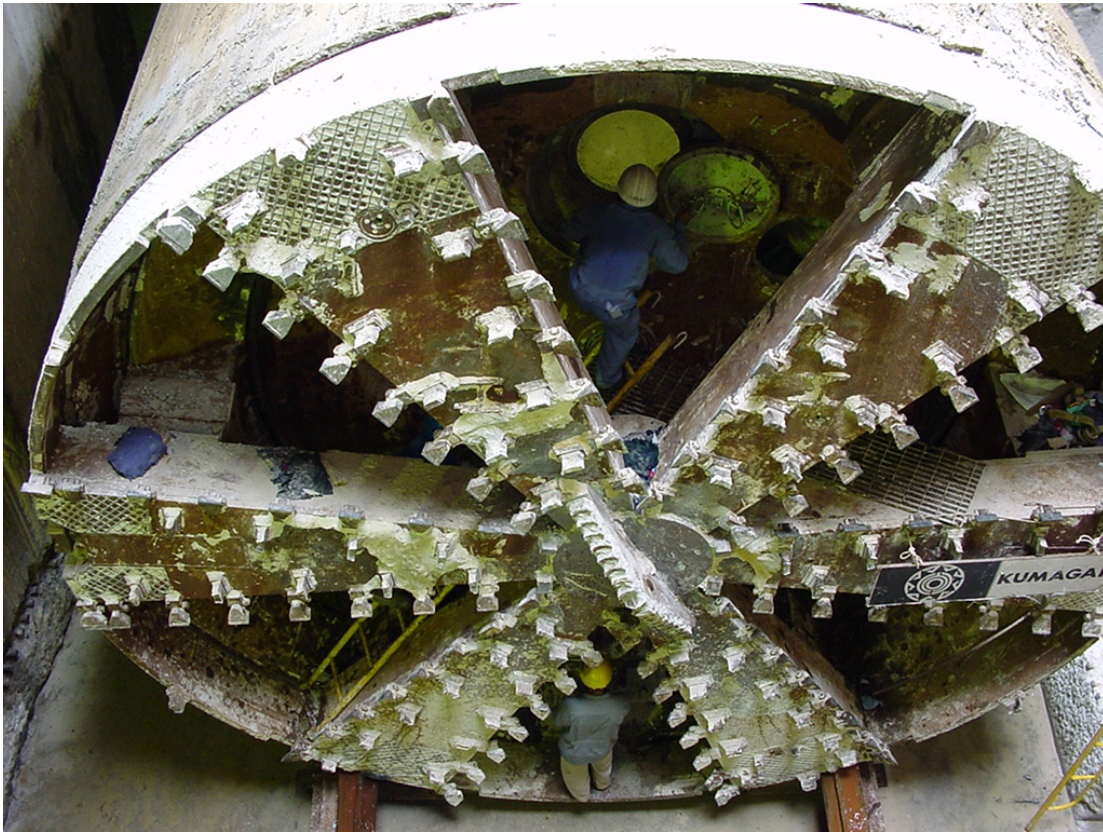
TUNNELLING



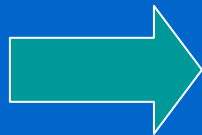
-
-
-

Tunnel Construction

- 5.7-m inside diameter of the single track tunnels
- Shields: Eight 6.46-m-diameter Earth Pressure Balanced (EPB) Shields
- Lining: Precast concrete segmental rings, each 1.2 m long and 0.3 m thick, made up of 5 segments and a keystone
- Backfill grouting



TBM-Kawasaki

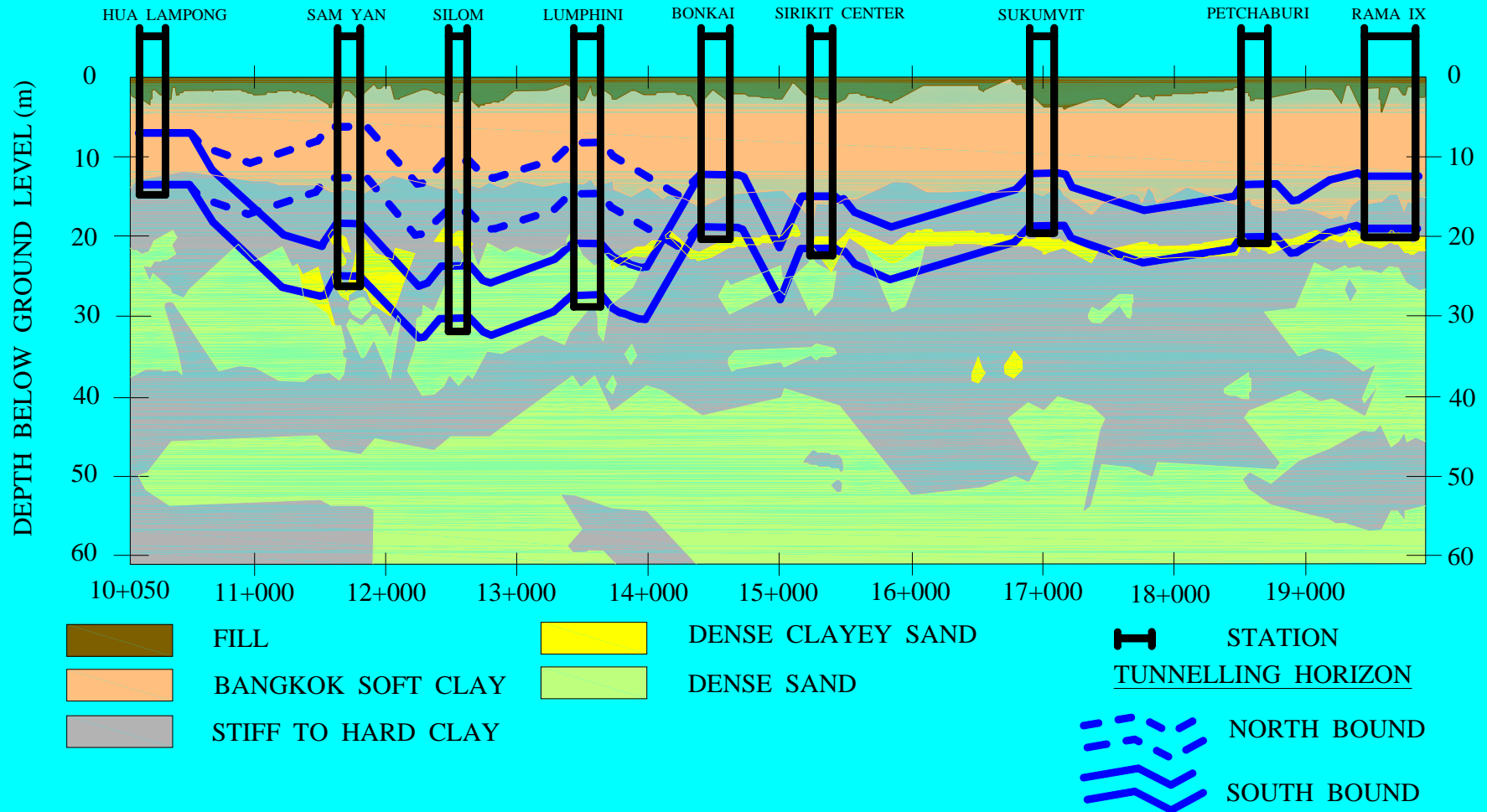




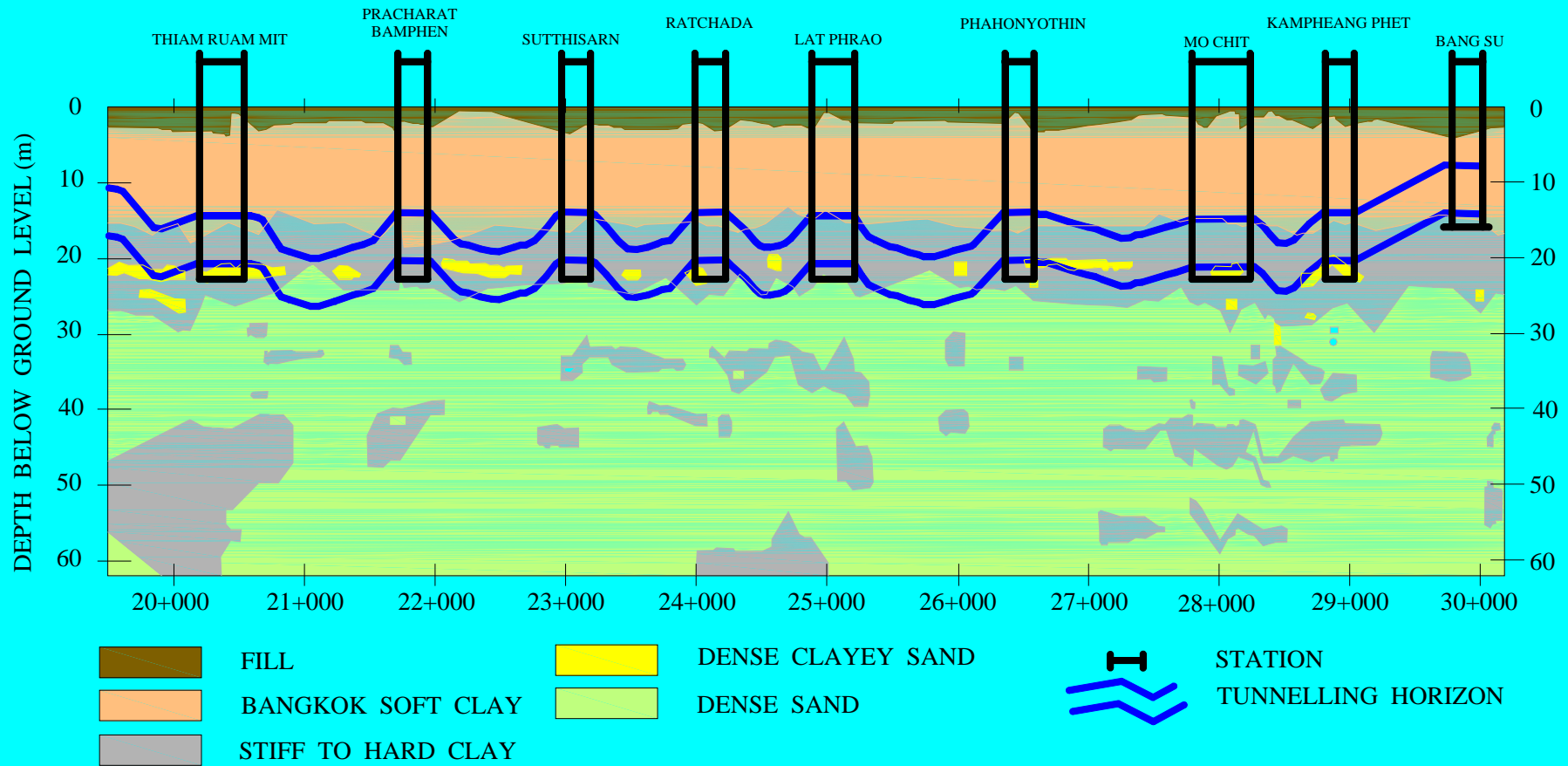
Shield

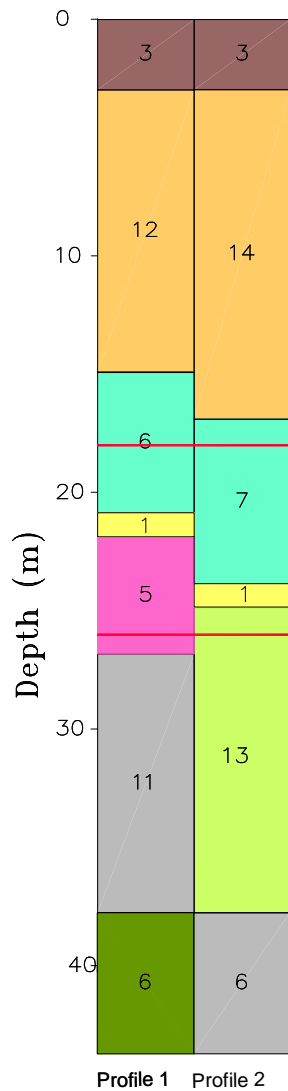


Subsurface Condition of South Section



Subsurface Condition of North Section





- Made ground**
 Loose sands or soft clay and fill, and stiff crust at surface, grey, medium stiff, silty clay 2 –3 m thick

- Bangkok soft clay**
 Very soft to soft, dark grey compressible marine silty clay occ. medium stiff. Evidence of lower mc nearbase

- First Stiff clay**
 Stiff to hard greenish or brownish grey, yellowish brown stiff silty clay often sandy towards base of strata mc =/ PL , fissures observed in clays in north

- Medium dense thin clayey silty sand,**
 light greyish brown continuous, Top of the Bangkok Aquifer

- Very stiff sandy clay**
 greyish brown /light brown (First Bangkok Sand)

- First Bangkok Sand**
 Dense to very dense, light grey brown & yellow, silty fine to medium sand typically 10 to 15 m thick

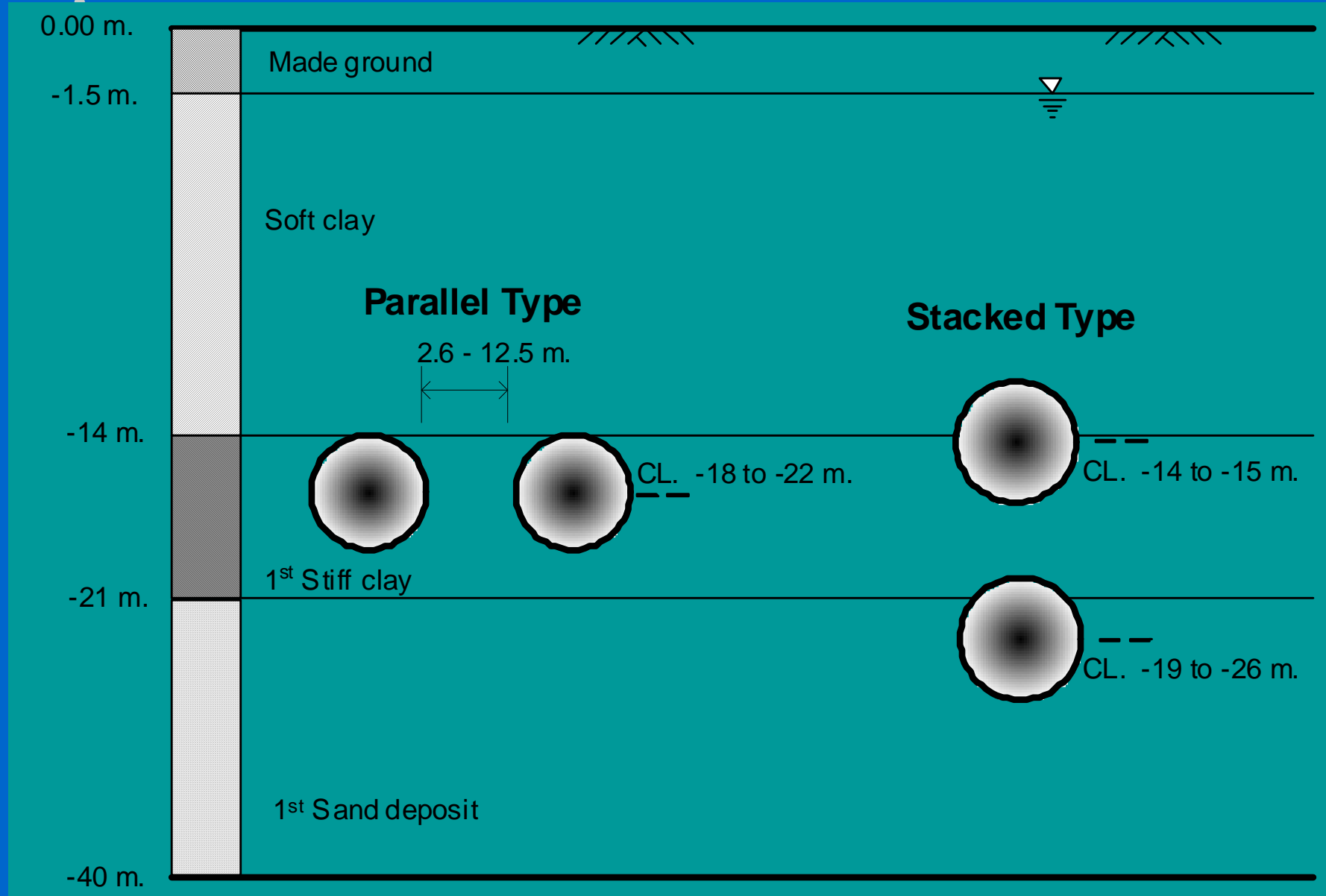
- Second Hard Clay**
 Very stiff to hard greyish brown / light brown sandy clay, occasional zones of stiff, dark grey clay 1 to 3.1 m thick

- Second Sand

- Number Indicate Thickness

- Major tunnelling horizon

Figure 2 Typical Soil Profiles



-
-
-

The Observational Method

- Deepest D-wall excavation ever attempted
- Largest shield tunnelling ever attempted
- Construction in business district of the city
- Need to minimize impacts on adjacent buildings
- Adopted The Observational Method

-
-
-

BUILDING PROTECTION PRINCIPLES

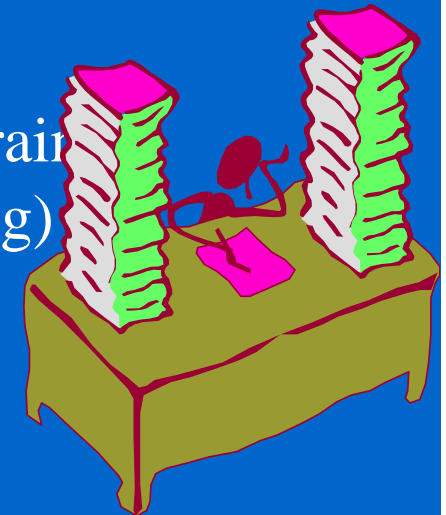
- DESIGN & CONSTRUCTION METHODS
TO MINIMISE GROUND MOVEMENTS
- PREDICTION OF MOVEMENTS IS REQUIRED
- BUILDING CONDITION SURVEY
- 2nd & 3rd STAGE ASSESSMENT IF REQUIRED
- ALERT LEVELS IDENTIFIED BEFOREHAND
- BUILDING PROTECTION IF REQUIRED
- INSTRUMENTATION & MONITORING



-
-
-

STAGED ASSESSMENT

- Check all buildings in influence zone
- No further check if predicted settlement < 10 mm & ground slope $< 1/500$
- Check damage level using the limiting tensile strain approach (Burland et al & Boscardin and Cording)
- Structures placed in Category 3 of damage classification (moderate) or above need further assessment (detailed analyses)
- Establish protective measures requirement
- Monitoring (till 3 months after movement stops)



Typical values of maximum building slope and settlement for damage risk assessment.

Risk Category	Maximum Slope of Building	Maximum Settlement of Building (mm)	Description of Risk
1.	Less than $\frac{1}{500}$	Less than 10	<i>Negligible</i> : superficial damage unlikely
2.	$\frac{1}{500}$ to $\frac{1}{200}$	10 to 50	<i>Slight</i> : Possible superficial damage which is unlikely to have structural significance
3.	$\frac{1}{200}$ to $\frac{1}{50}$	50 to 75	<i>Moderate</i> : Expected superficial damage and possible structural damage to buildings. Possible damage to relatively rigid pipelines
4.	Greater than $\frac{1}{50}$	Greater than 75	<i>High</i> : Expected structural damage to building. Expected damage to rigid pipelines. Possible damage to other pipe lines.

-
-
-

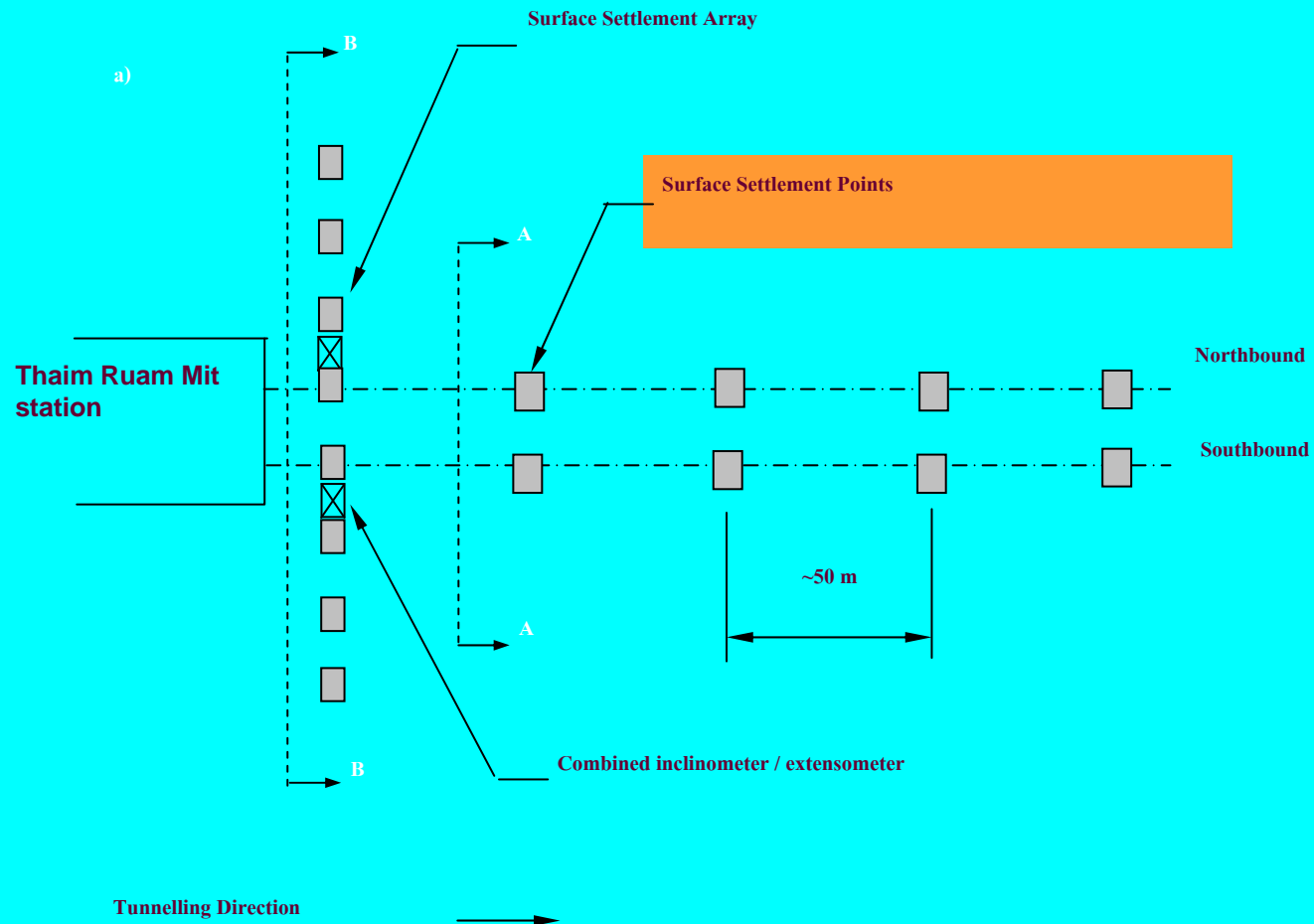
INSTRUMENTATION & MONITORING

- 4 sub-contractors appointed
- Leo Jovian JV and STS-Sol Data JV on South Contract with the work split geographically
- GMT Corp on North Contract
- Each responsible for installation of instruments, monitoring, data input & manipulation of data base, plotting & reporting
- Large range of instrument types with special readout units
- Reading interval to suit work but often daily at critical periods

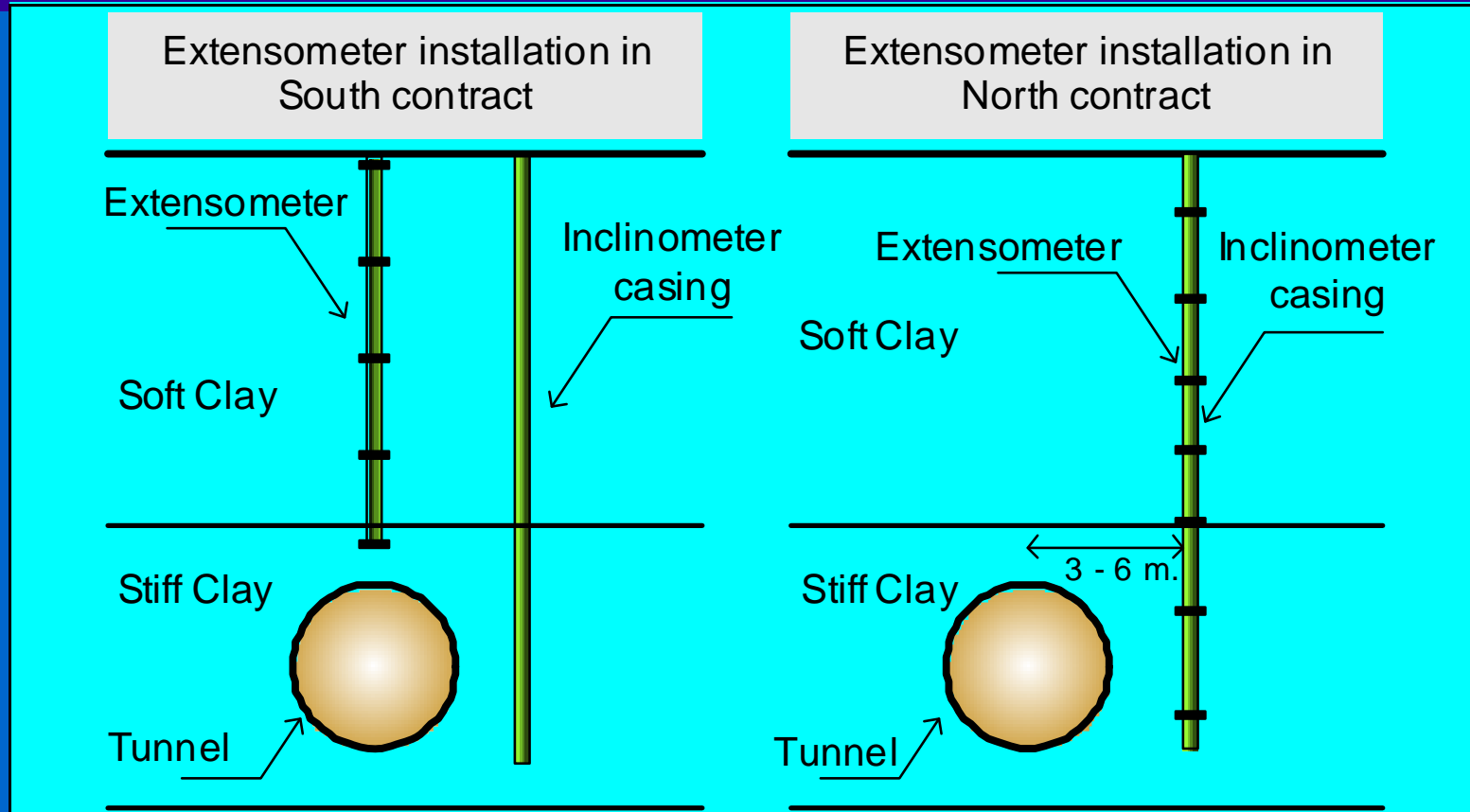
Instrumentation

Type of Instrument	Scope of Use
BM Survey	to monitor BM reference elevation
Surface settlement point	to monitor surface settlement
Building settlement point	to monitor settlement of buildings
Structure settlement point	to monitor settlement of structures
Utility settlement point	to monitor settlement of utilities
Subsurface Heave Indicator	to monitor movement of excavation
Standpipe piezometer	to monitor water level
VW Piezometer	to monitor water pressure
Inclinometer	to monitor diaphragm wall deflection
Extensometer combined with Inclinometer	to monitor settlement and ground movement
Tiltmeter	to monitor changes in inclination of
Crack gauge	to monitor cracks in building/structure
Rebar stress transducer	to monitor stress/strain in D/W steel rebars
Strut strain gauge	to monitor stress/strain in struts
Strut Load Cell	to measure load in strut
Tape Extensometer	to monitor convergence of tunnel

Typical Instrumentation Pattern



Subsurface Movement Instrumentation



-
-
-

Summary of instrumentation for bored tunnelling

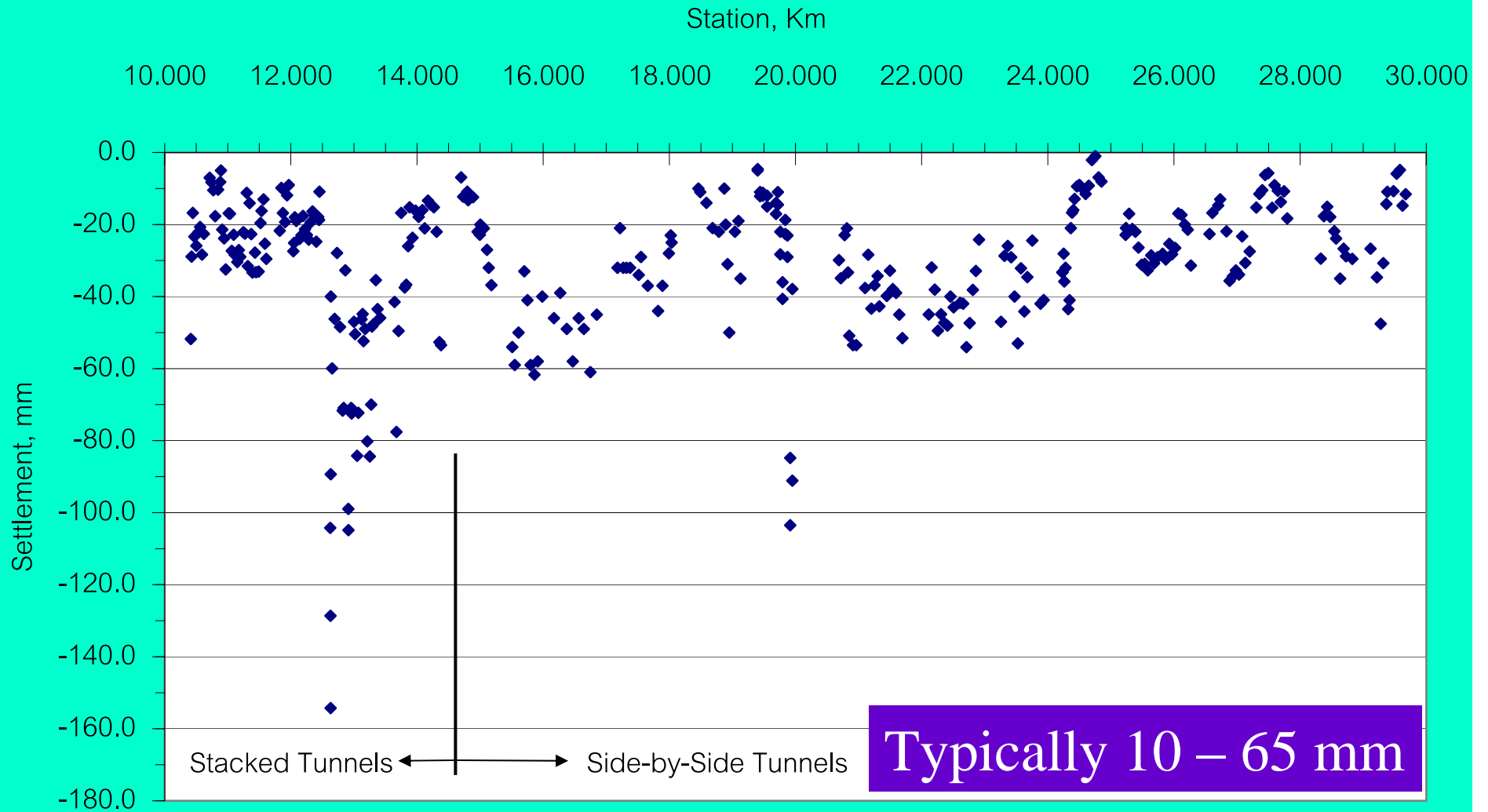
Instrument	quantity
Surface settlement point	1,276
Settlement array	39 arrays
Subsurface instrument	36 set
Building settlement marker	On 339 buildings

-
-
-

Subsurface Ground Movement Instrumentation

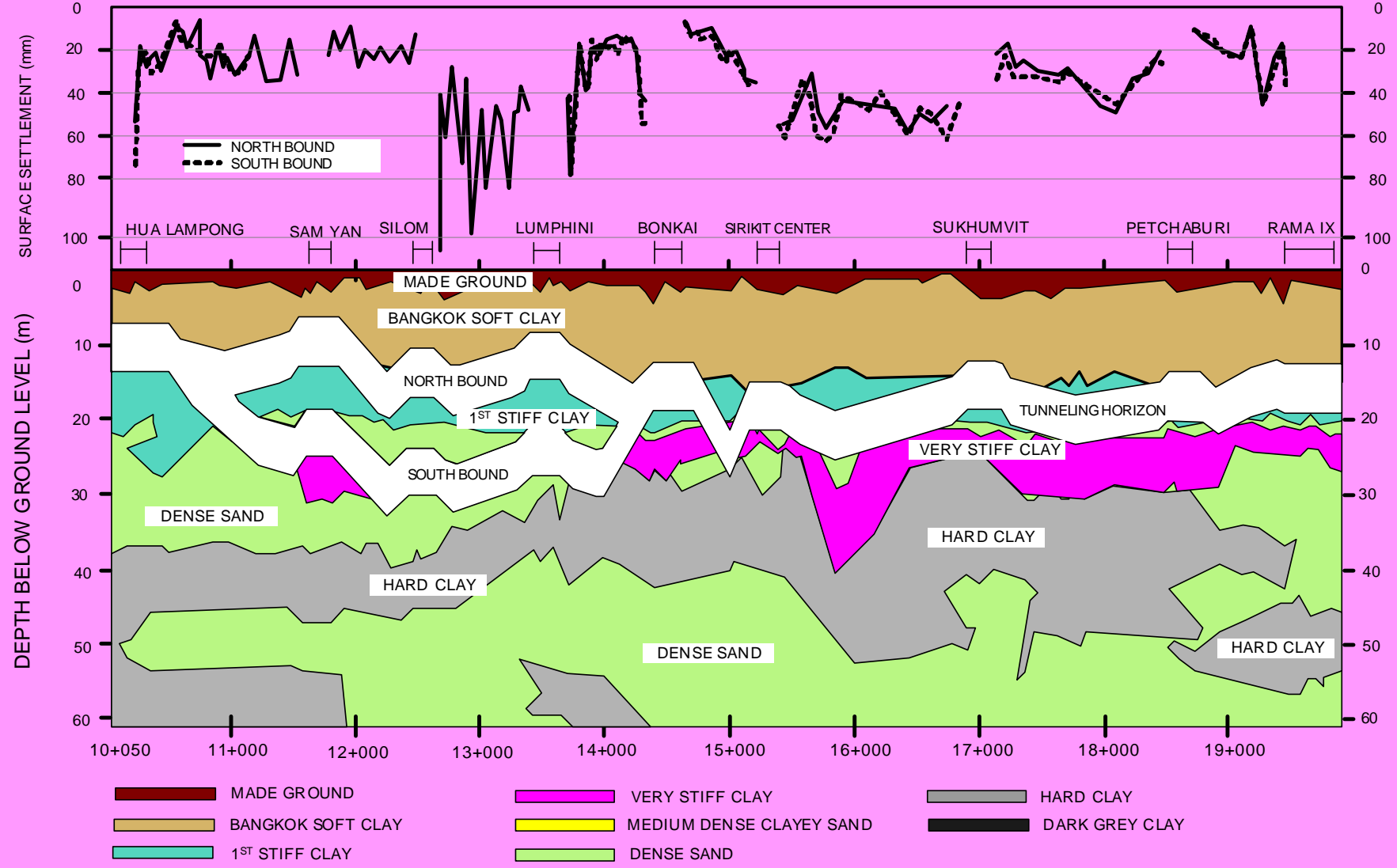
Extensometer	North Contract	South Contract
For tunnel excavation	24	18
- Subsurface settlement type 1	24 of 24	4 of 18
- Subsurface settlement type 2	0 of 24	14 of 18
For shaft excavation	18	0
Total	42	18

SURFACE SETTLEMENT

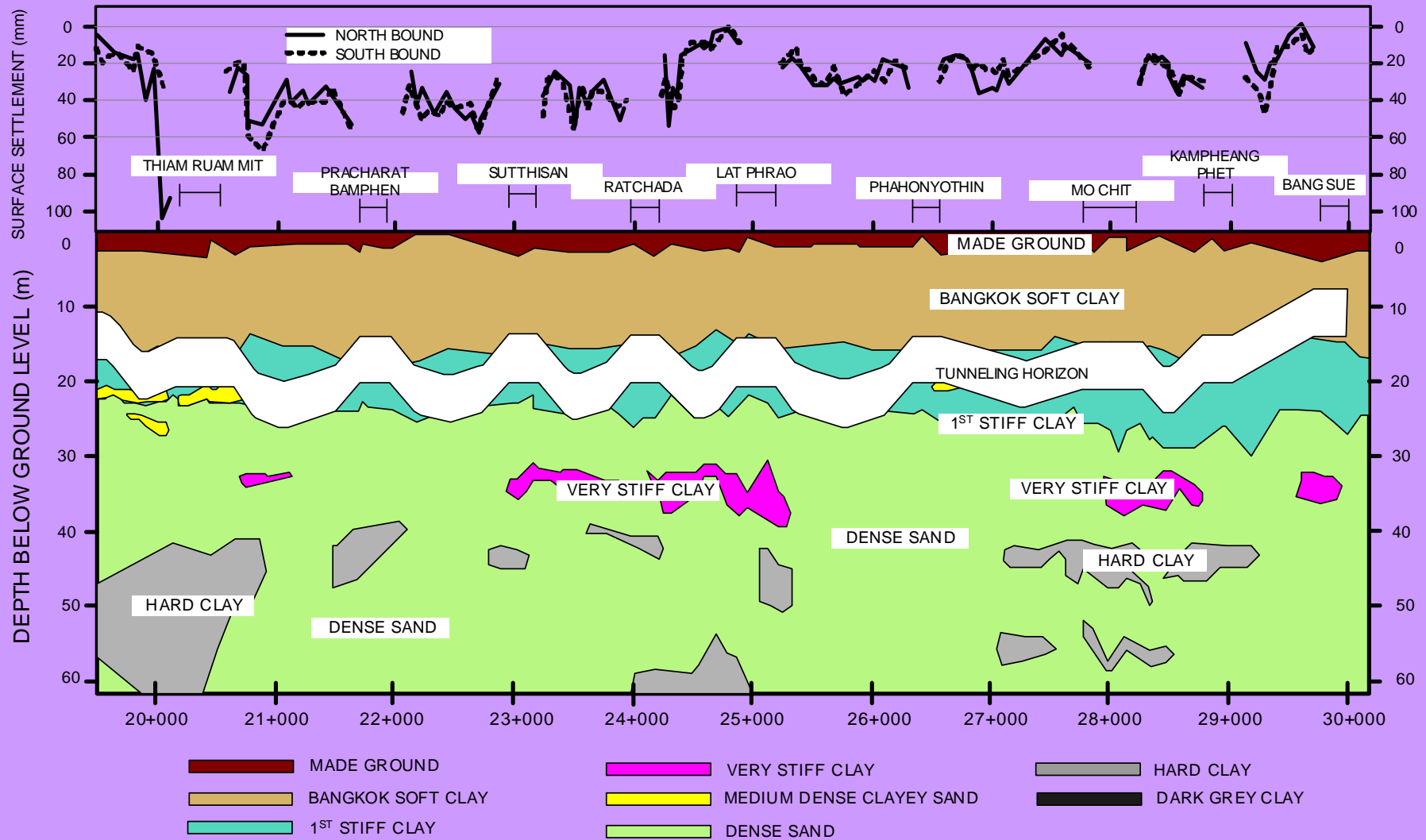


Typically 10 – 65 mm

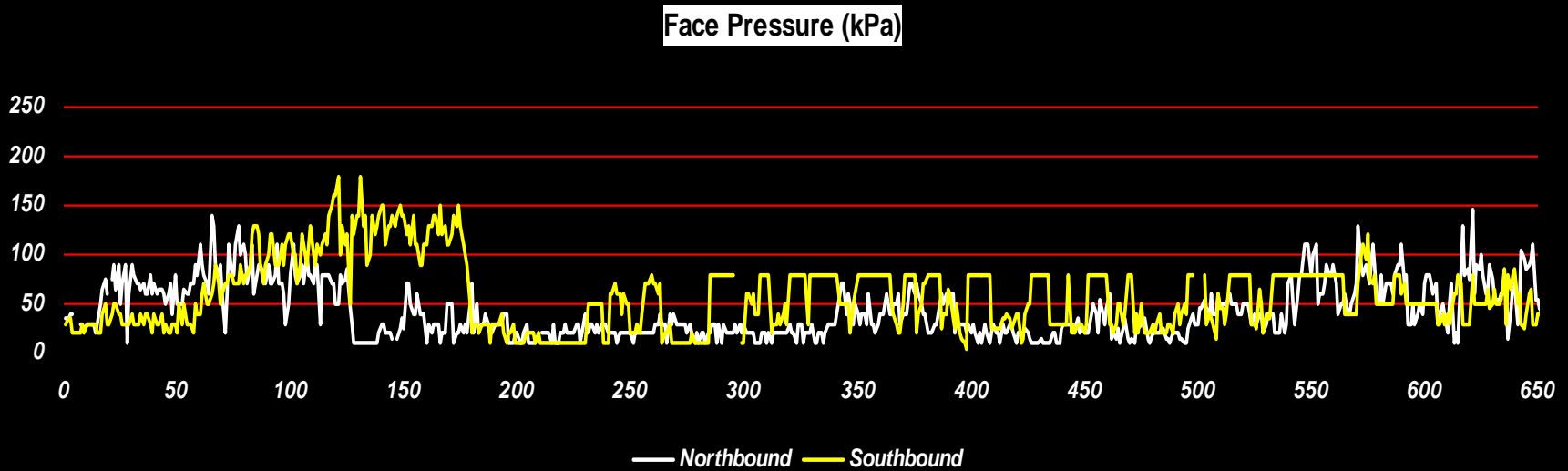
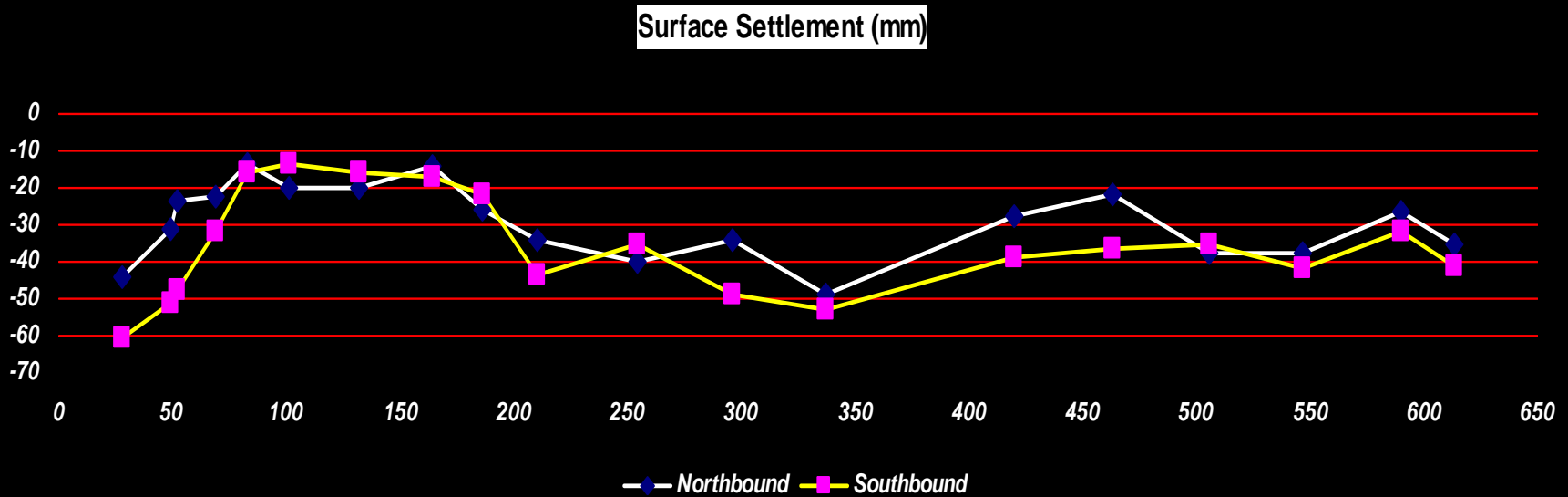
SURFACE SETTLEMENT AND SOIL PROFILE IN SOUTH CONTRACT



SURFACE SETTLEMENT AND SOIL PROFILE IN NORTH CONTRACT



Effect of Face Pressure

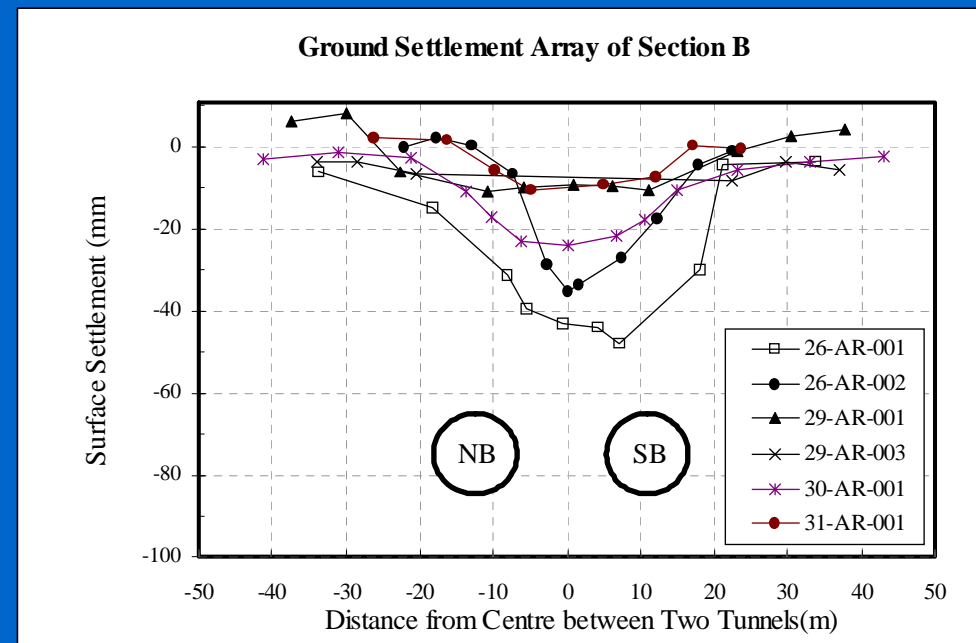
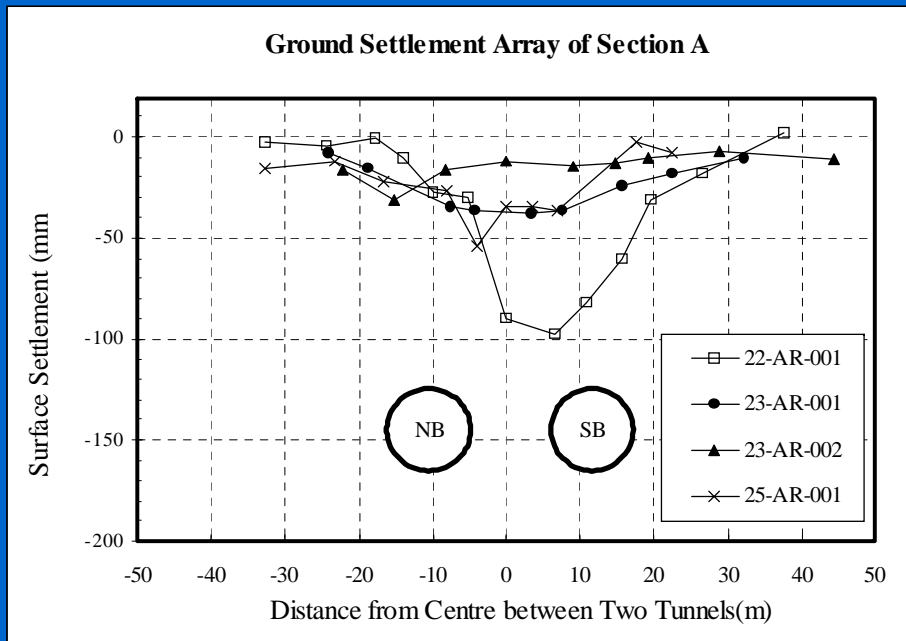


•
•
•

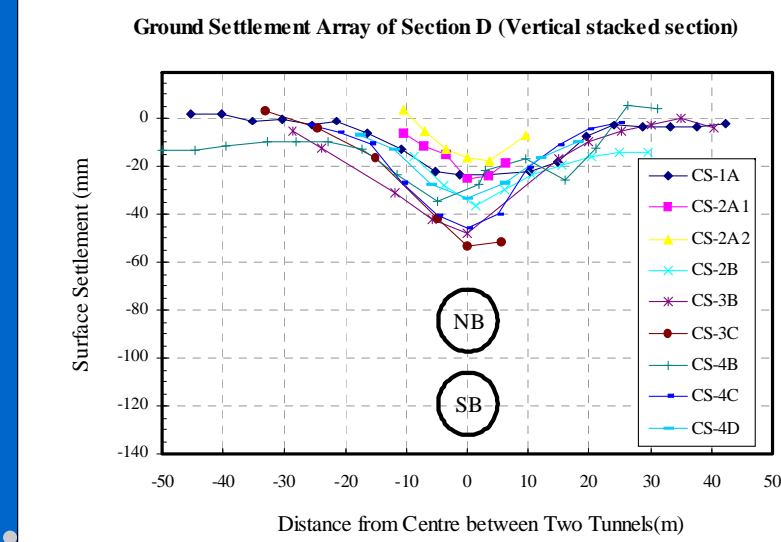
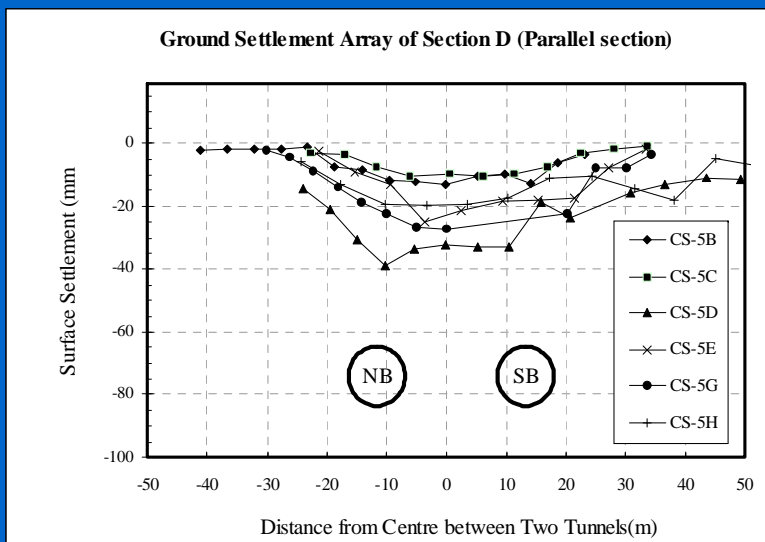
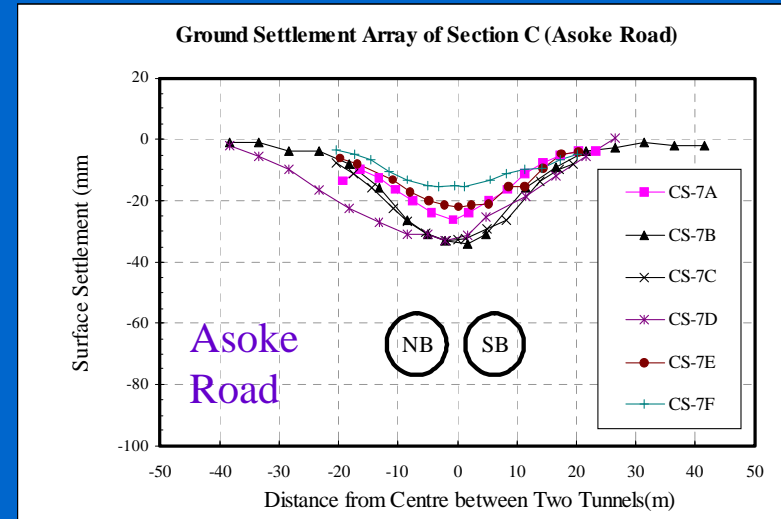
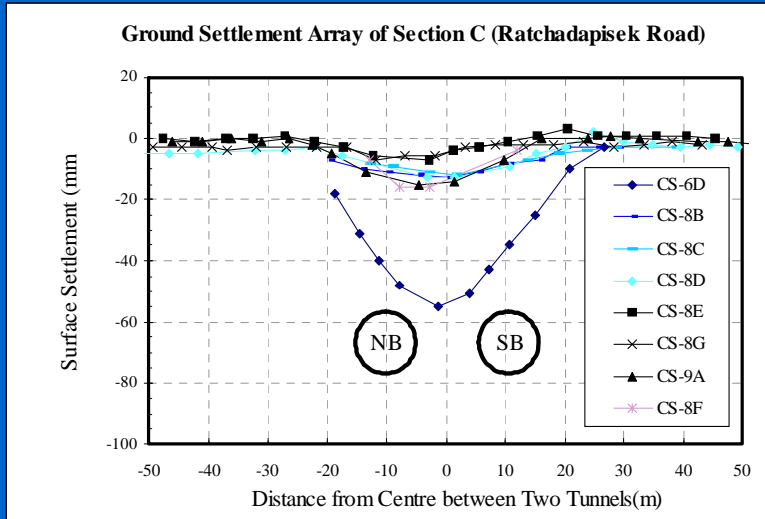
Significant Influencing Factors

- Face pressure
- Rate of advancement - Obstruction & Breakdown
- Soil type - Sand
- Workmanship

Settlement Troughs in North Contract



Settlement Troughs in North Contract



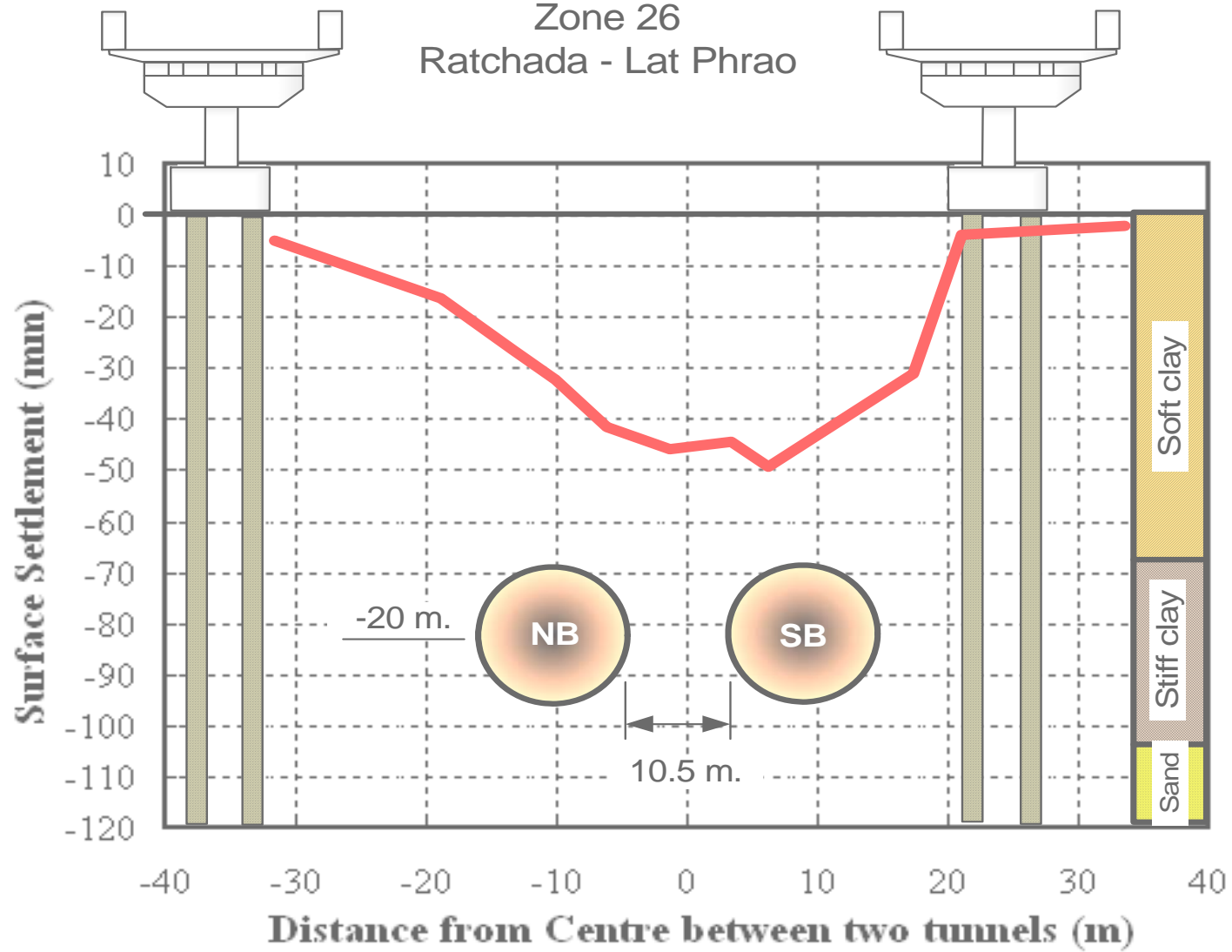
Surface Settlement Arrays

Surface settlement trough for tunnel excavation	North Contract	South Contract
Installed in green-field condition	6	8
- Gaussian fitted	2 of 6	5 of 8
- Non-Gaussian fitted	4 of 6	3 of 8
Installed in existing structure area	4	21
- Gaussian fitted	2 of 4	10 of 21
- Non-Gaussian fitted	2 of 4	11 of 21

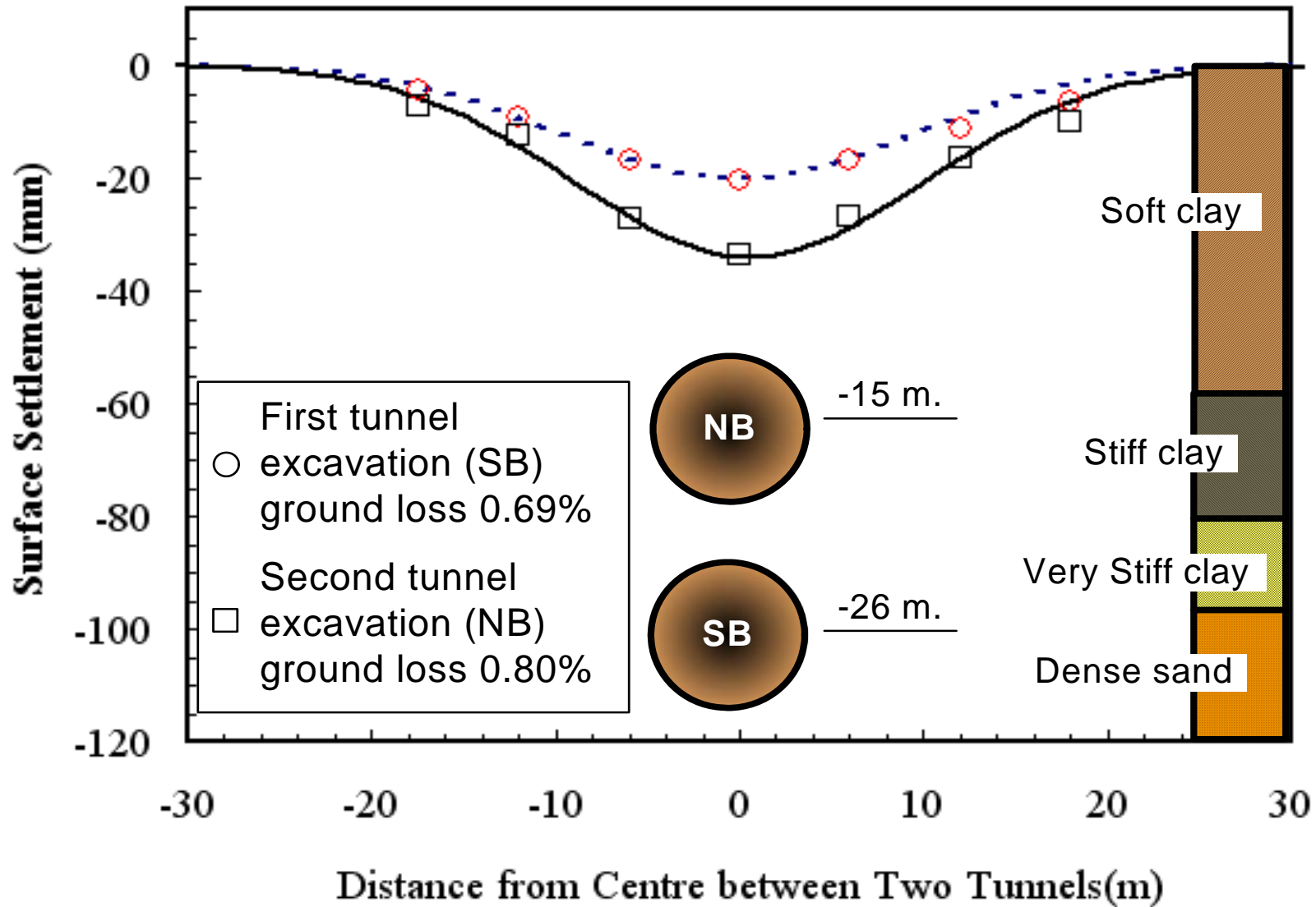
Gaussian Fit : 19 out of 39 arrays

Ground settlement array no. 26-AR-001

Zone 26
Ratchada - Lat Phrao

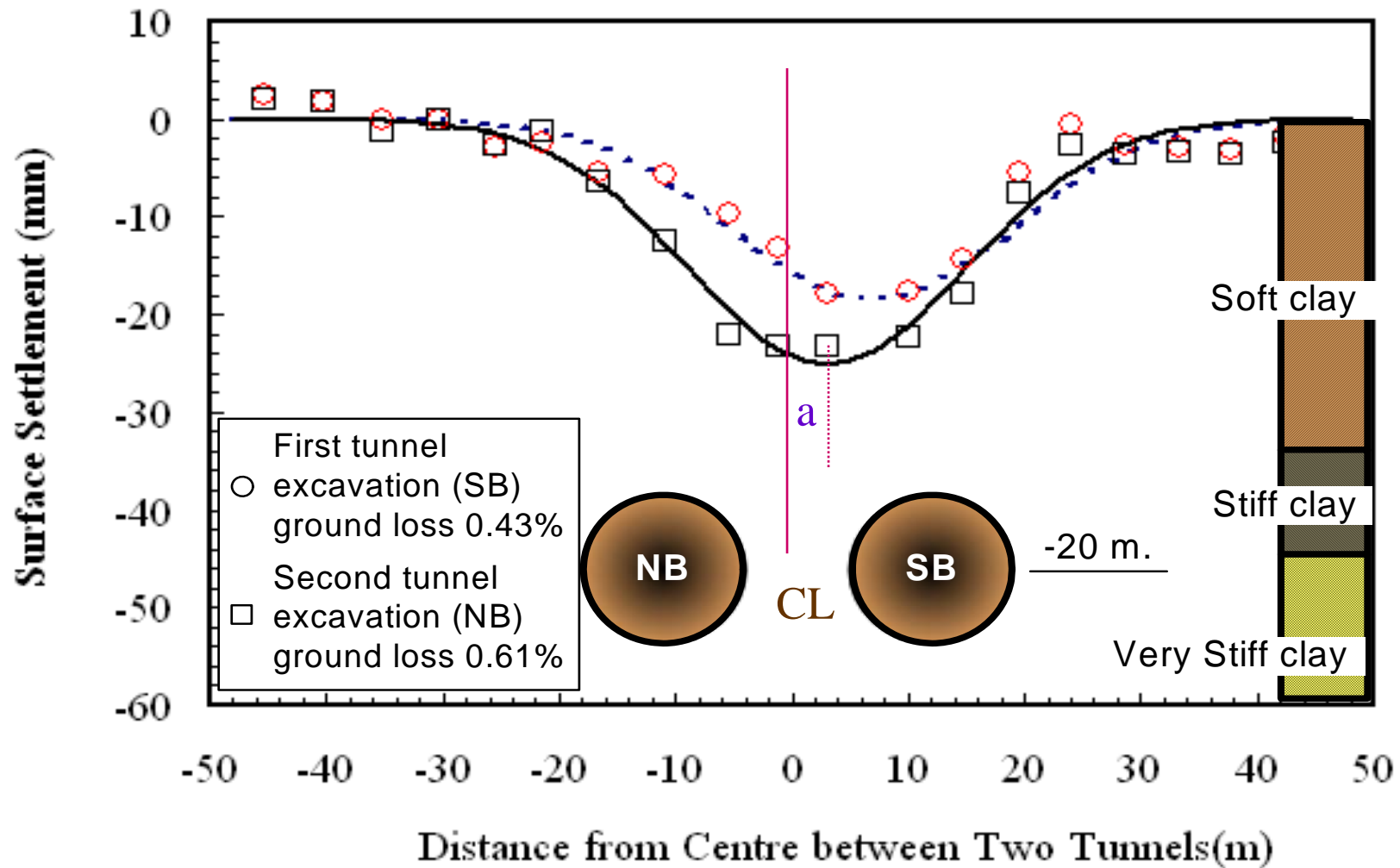


Ground Settlement Array No. CS-4D
(Lumphini - Bon Kai)



Surface Settlement

Ground Settlement Array No. CS-1A
(Hua Lamphong - Sam Yan)



-
-
-

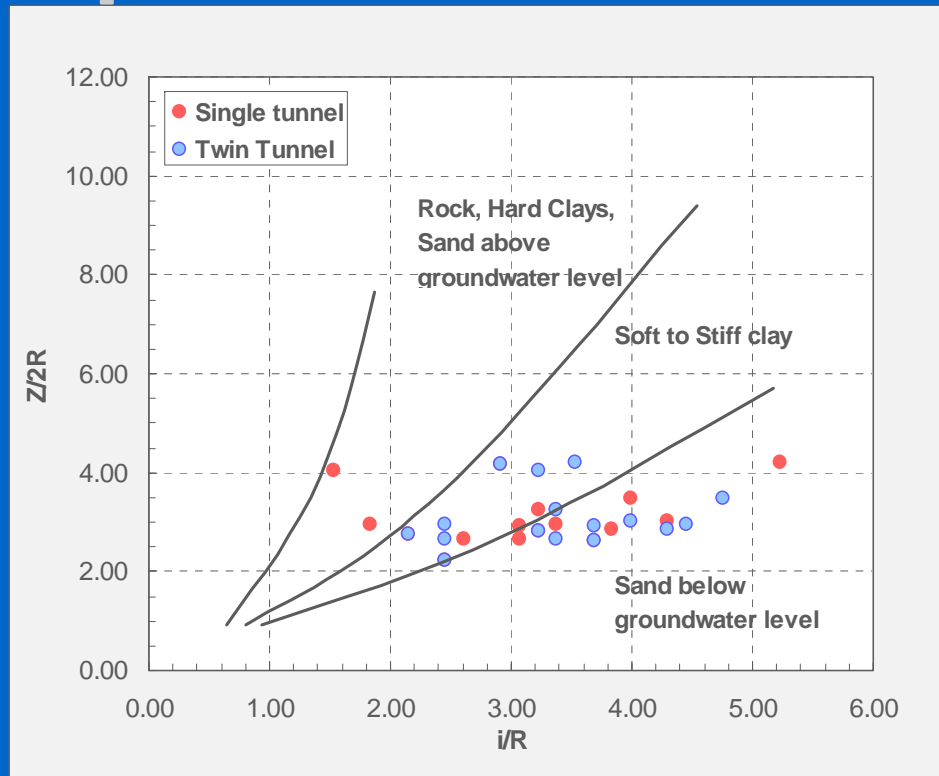
Skew of Settlement Troughs

$$\delta = \delta_{\max} \exp\left[-\frac{(x-a)^2}{2i^2}\right]$$

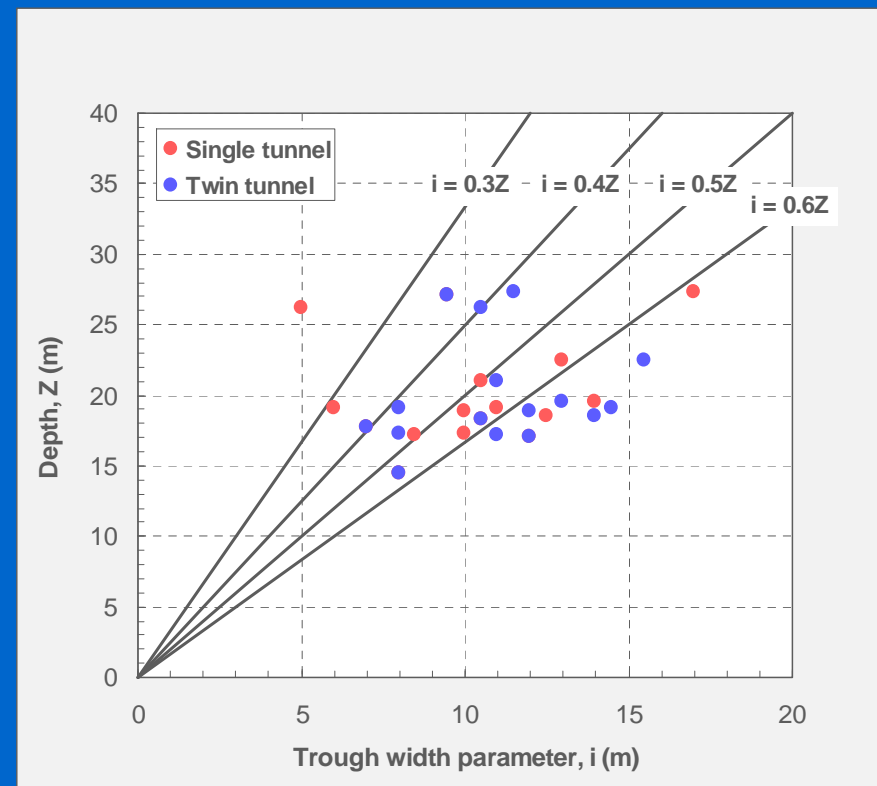
- $a = 0.03-0.58$ of the distance between the two tunnel centerlines (d).
- The mean a/d is 0.16

Width of Settlement Trough

O'Rielly and News (1982)



Peck (1969)



-
-
-

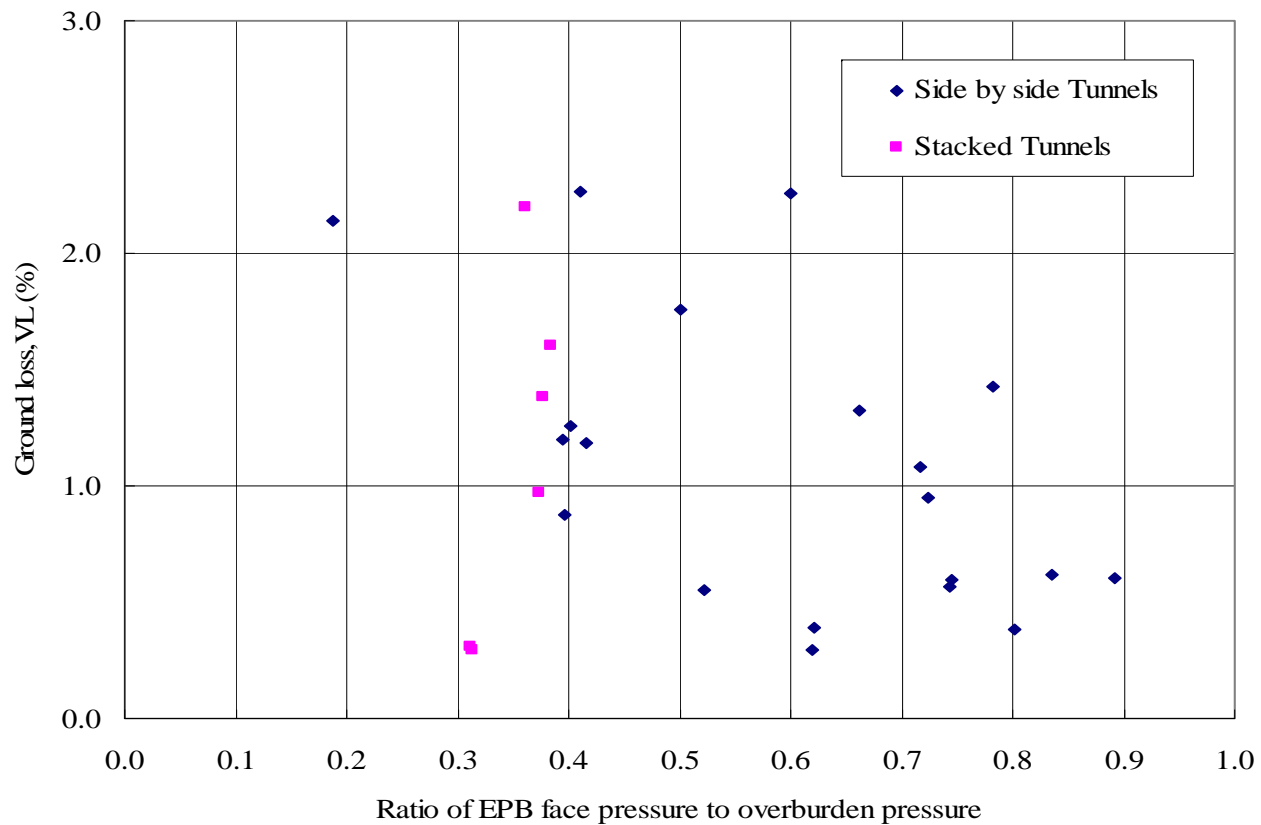
Tunnel Volume Loss

Typically 0.5-2.5%

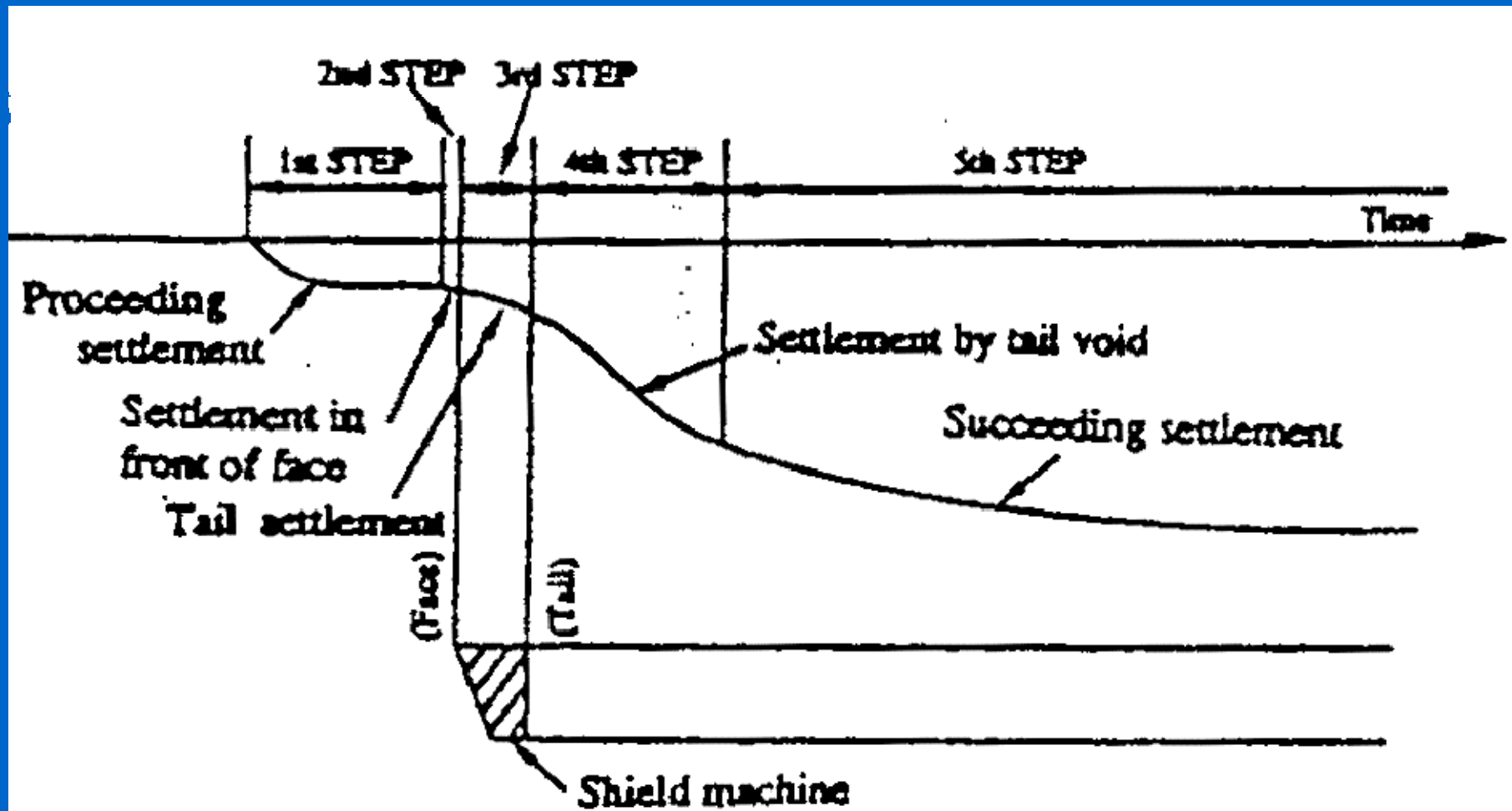
In difficult sections , it was up to 3.5%.

-
-
-

Correlation between Volume Loss and Ratio of Face Pressure to Overburden Pressure



Ground Movements with Shield Advancement

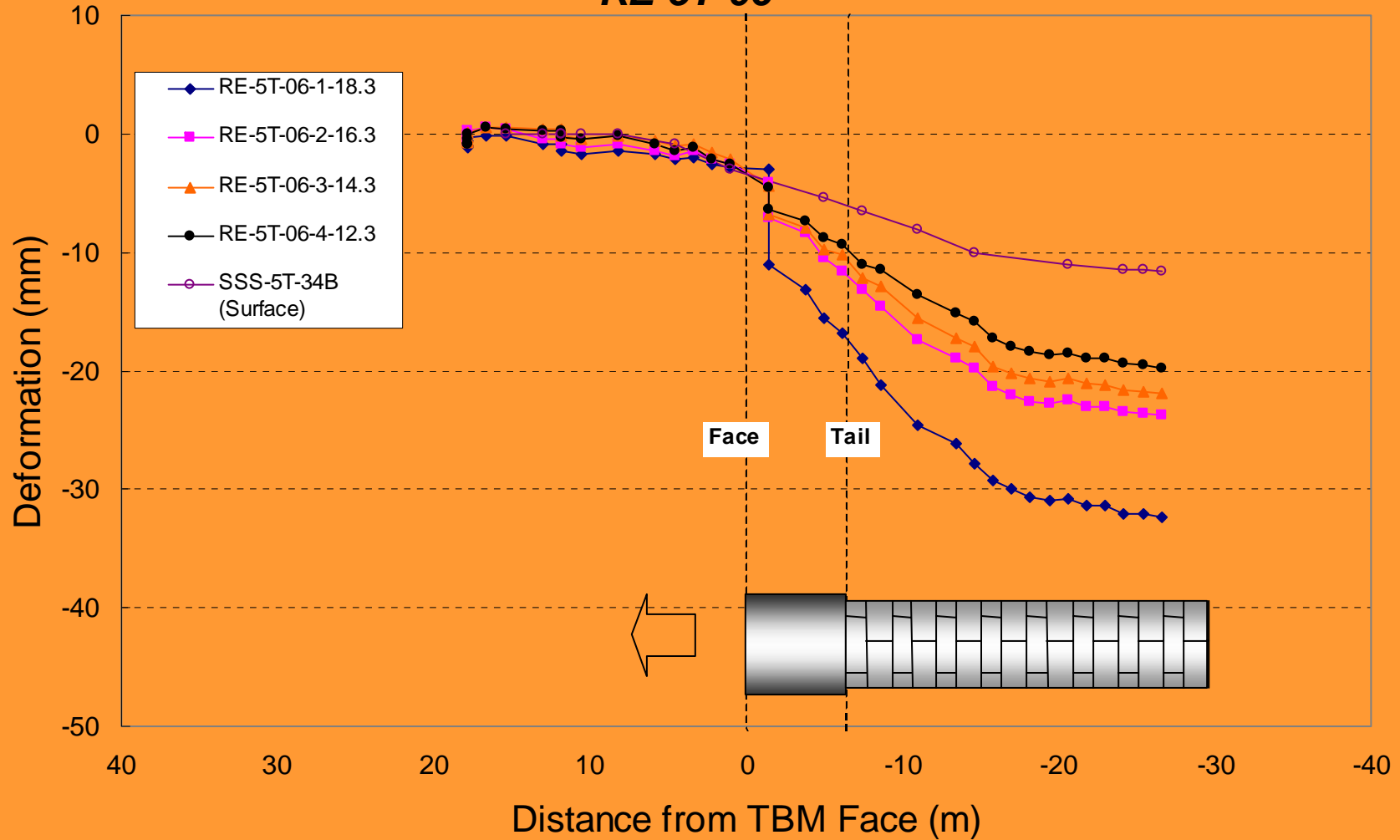


Longitudinal Section

Sirikit Station - Bon Kai Station

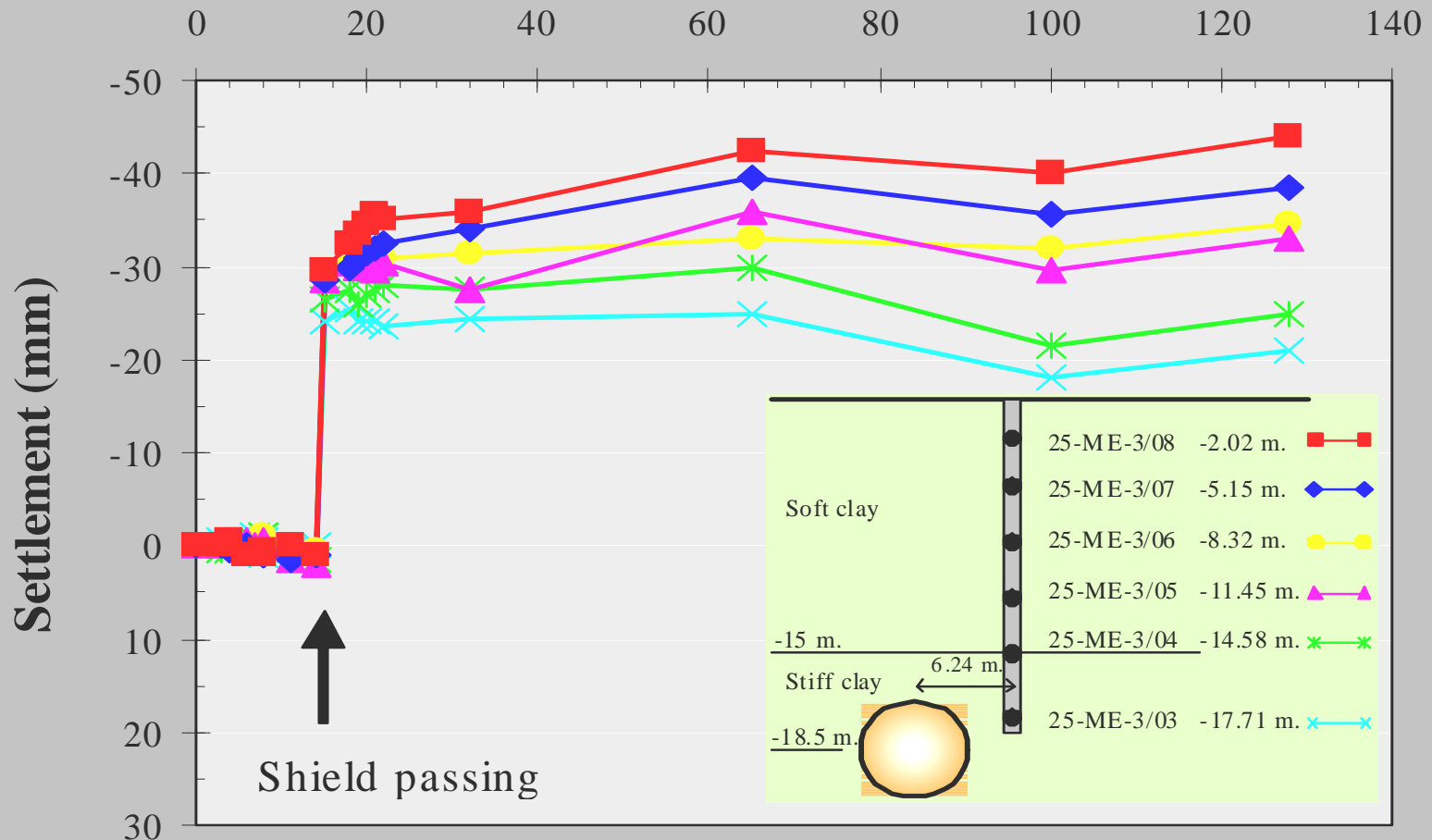
Position - Deformation

RE-5T-06



Extensometer Monitoring Result No. 25-IE-003 Sutthisan - Ratchada

Elapsed time (days)

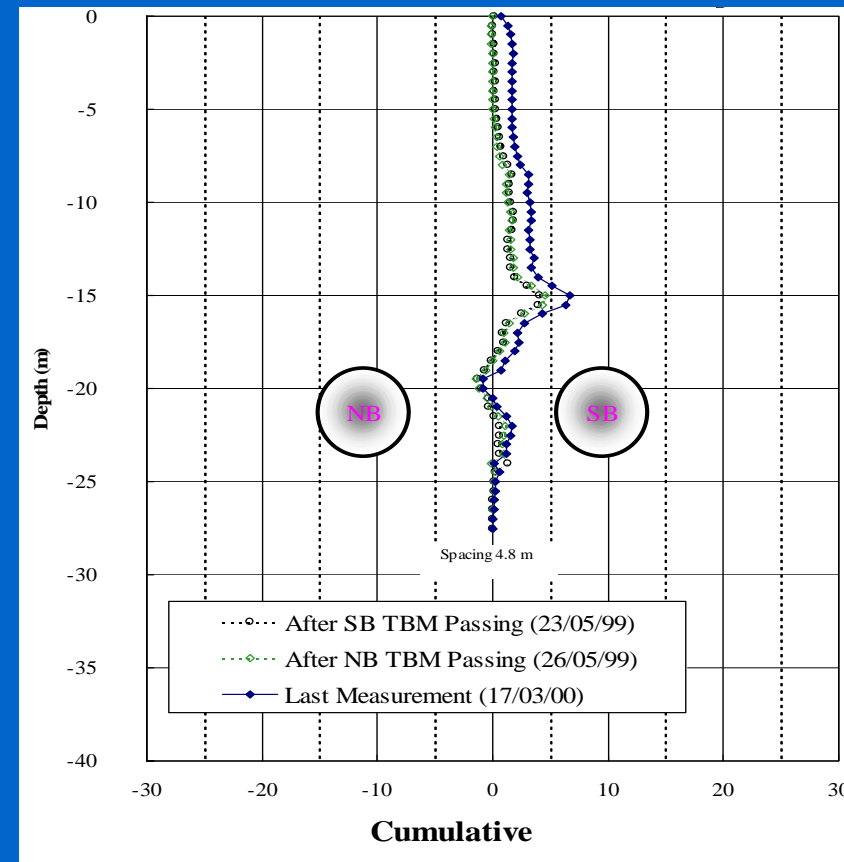
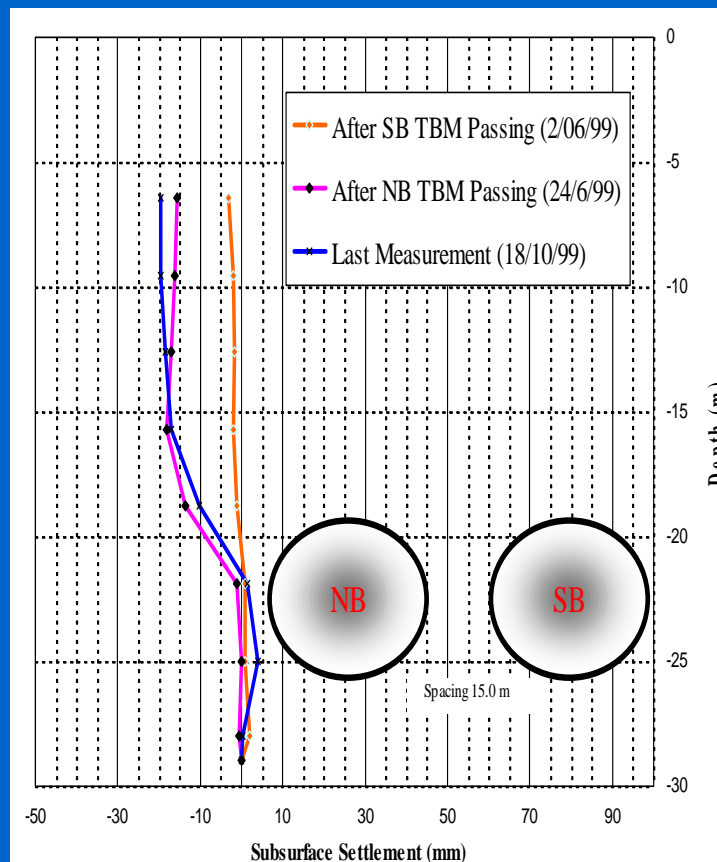


-
-
-

Long-term Ground Movements

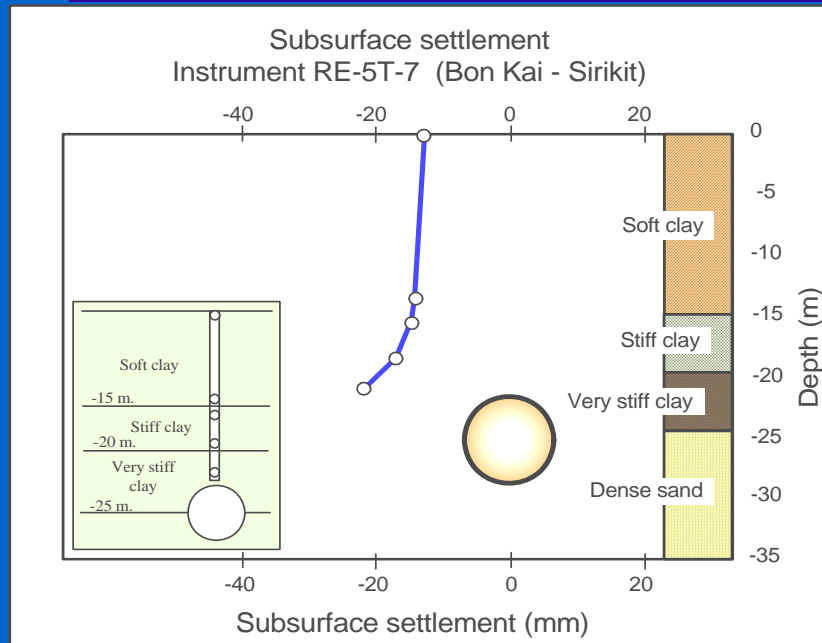
- Most ground movement occurred in the vicinity of shield advancement
- Some long-term movement occurred within soft clay layer
- No significant long-term movement in stiff clay layers

Subsurface movement data

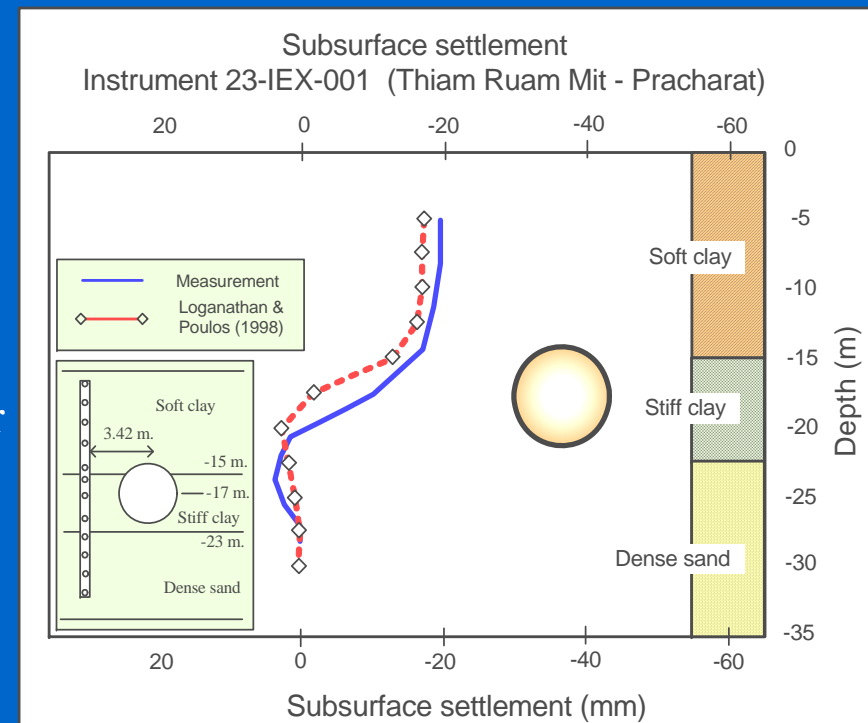


Lateral Displacement (mm)

Subsurface Settlements

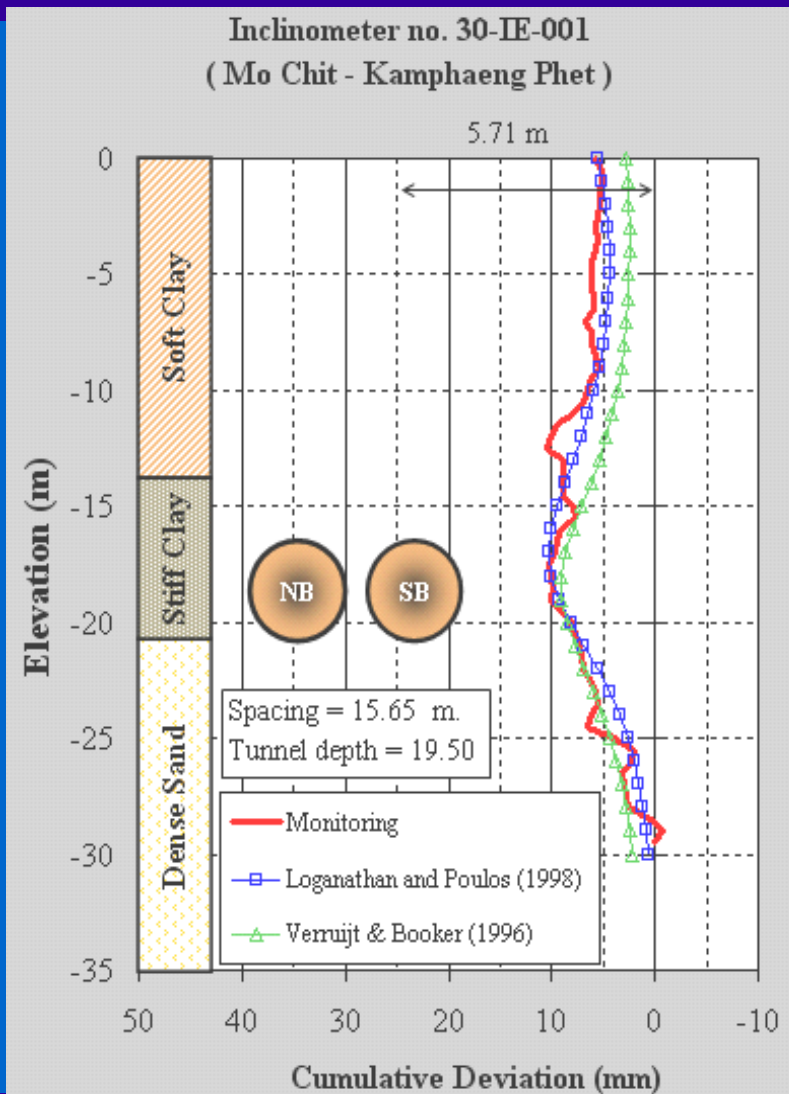


- Largest settlements occurred in soft clay layer
- Some showed in stiff clay layer



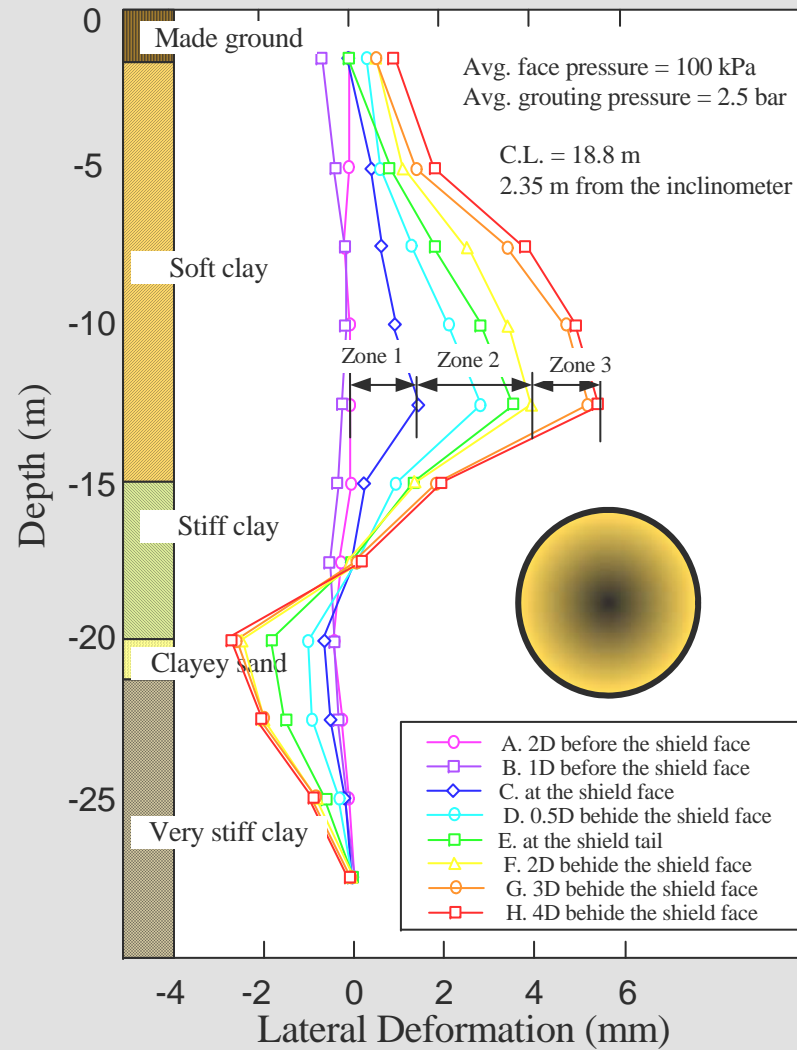
Lateral Ground Movement

Cases of Low Face Pressures

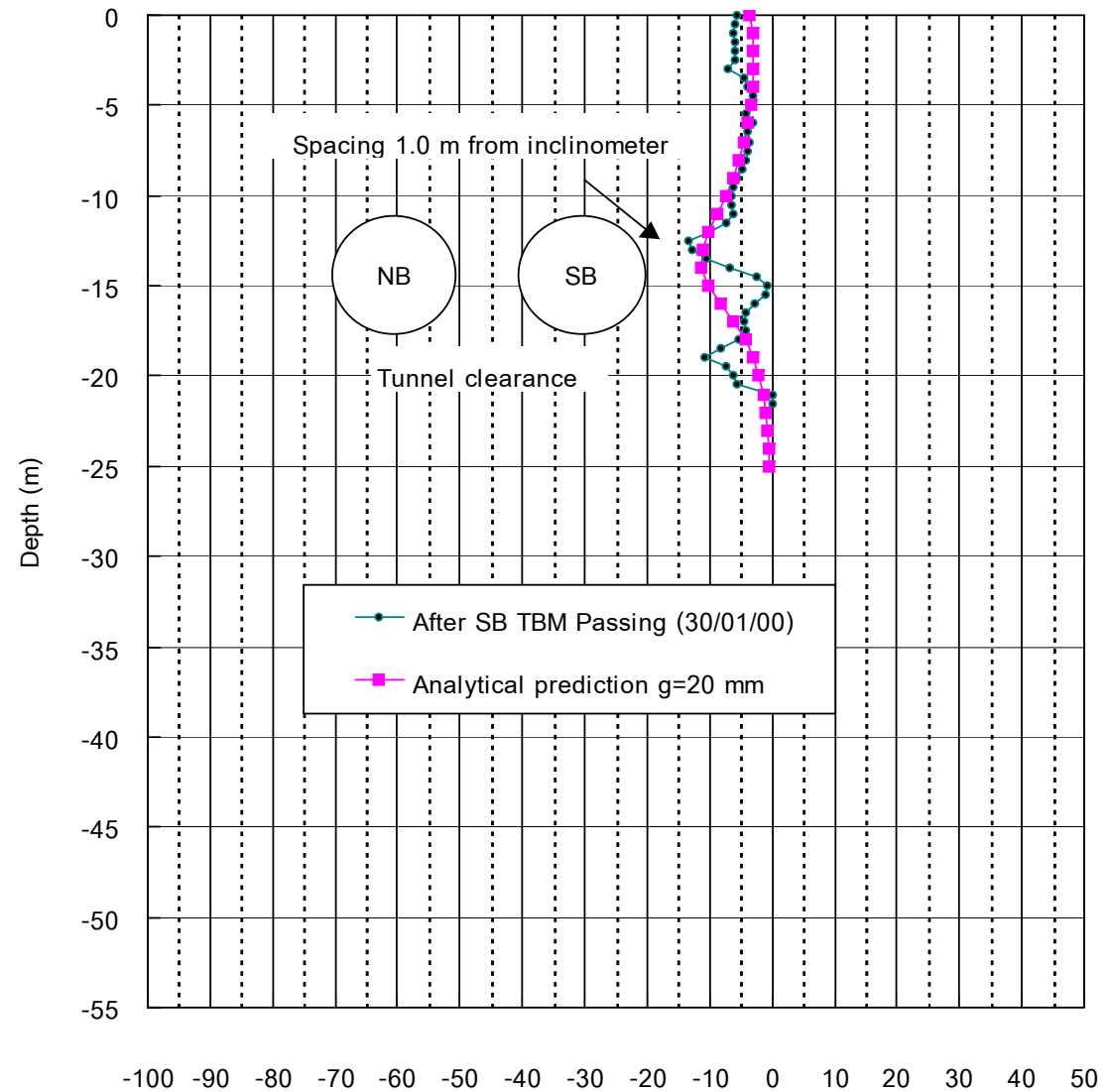
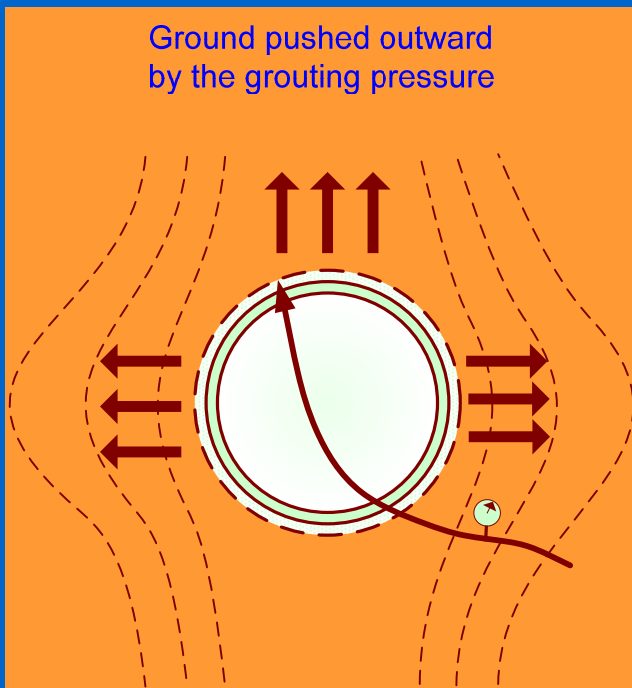


- gap parameter, g , from back calculation was in the range of 20-60 mm (Timpong, 2002).

Inclinometer No. IN-T7-04
(Phetchaburi - Sukhumvit stations)



Lateral movement predicted by Longanathan and Poulos (1998) at 31-IE-001 (Kampkaeng Phet - Bang Su)



-
-
-

Analysis of Subsurface Ground Movements

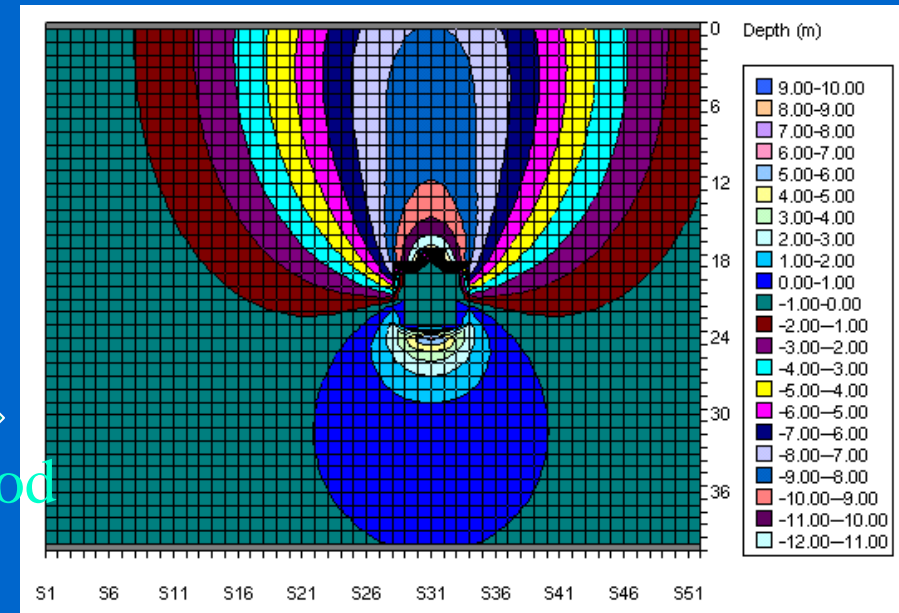
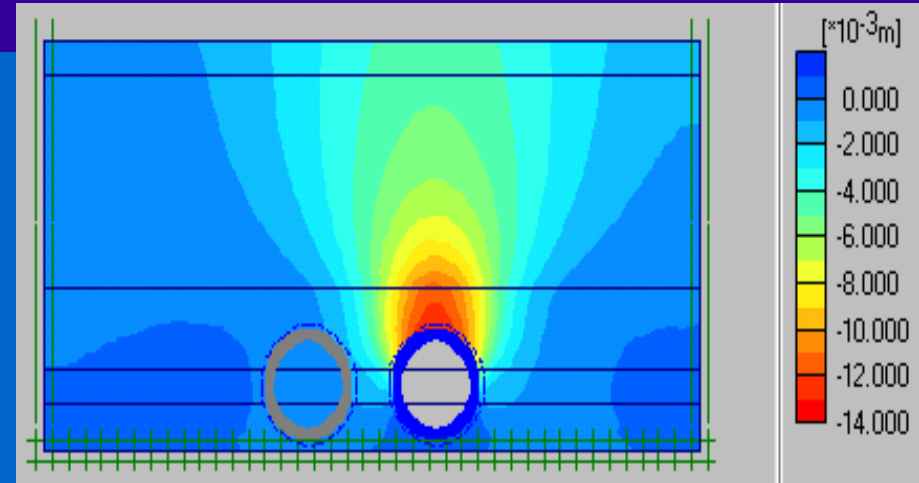
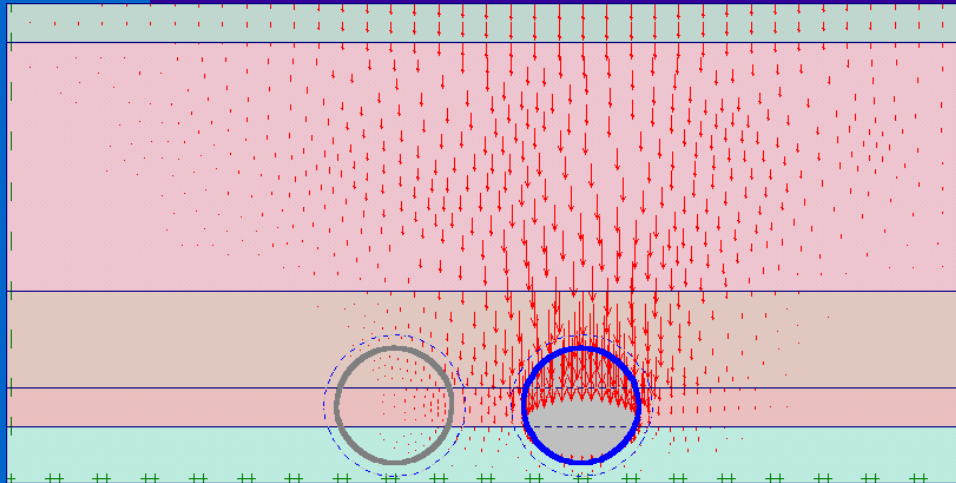
Two methods

Empirical and
Analytical methods

Numerical methods

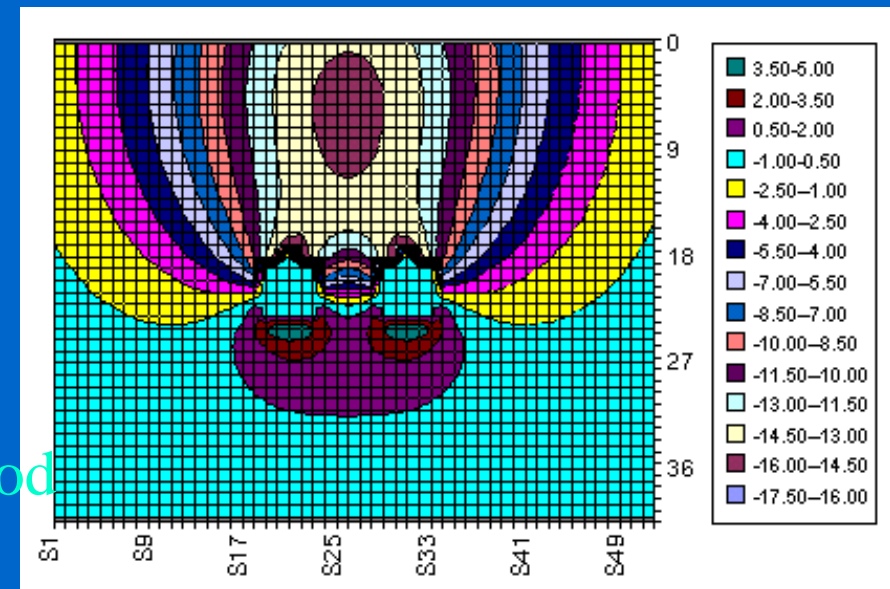
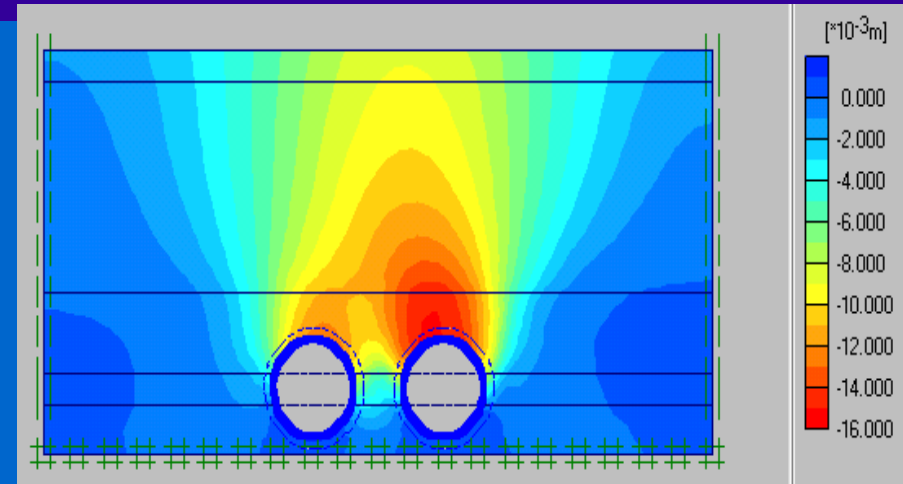
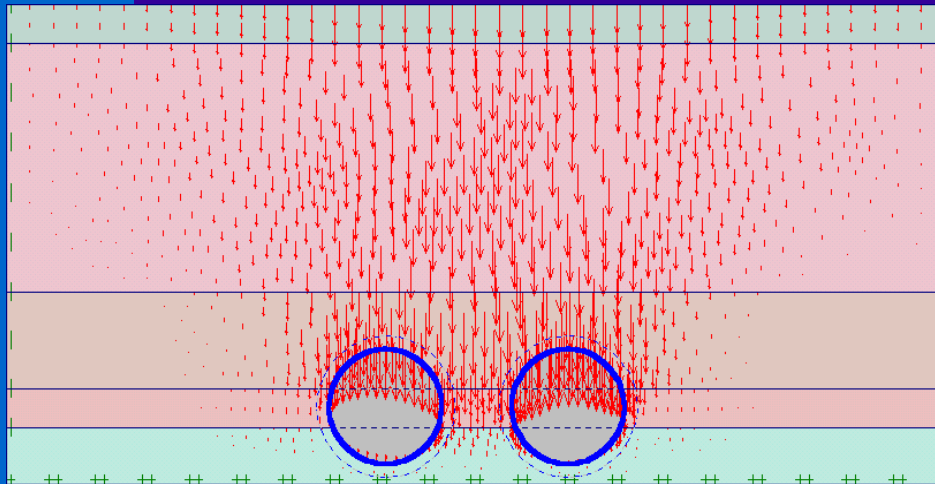
PLAXIS
and FLAC

Vertical Movement Contour for Single Tunnel



Loganathan and Poulos (1998)'s method

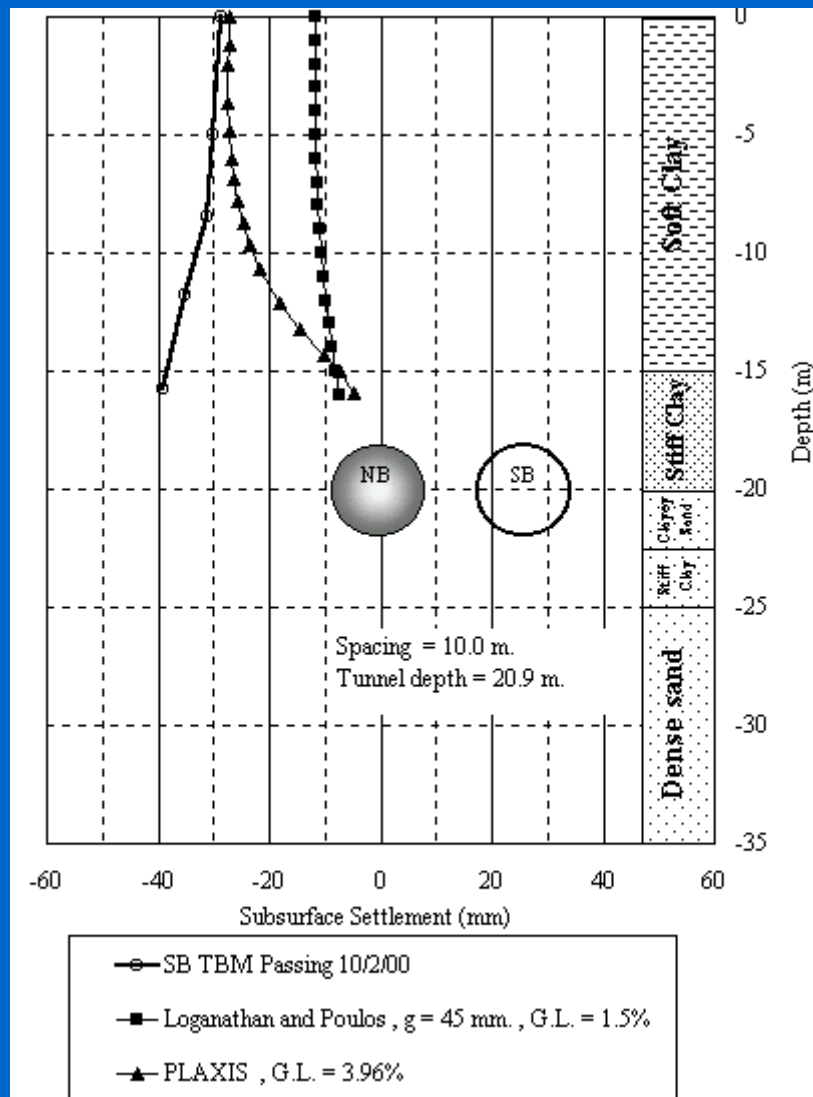
Vertical Movement Contour for Twin Tunnels



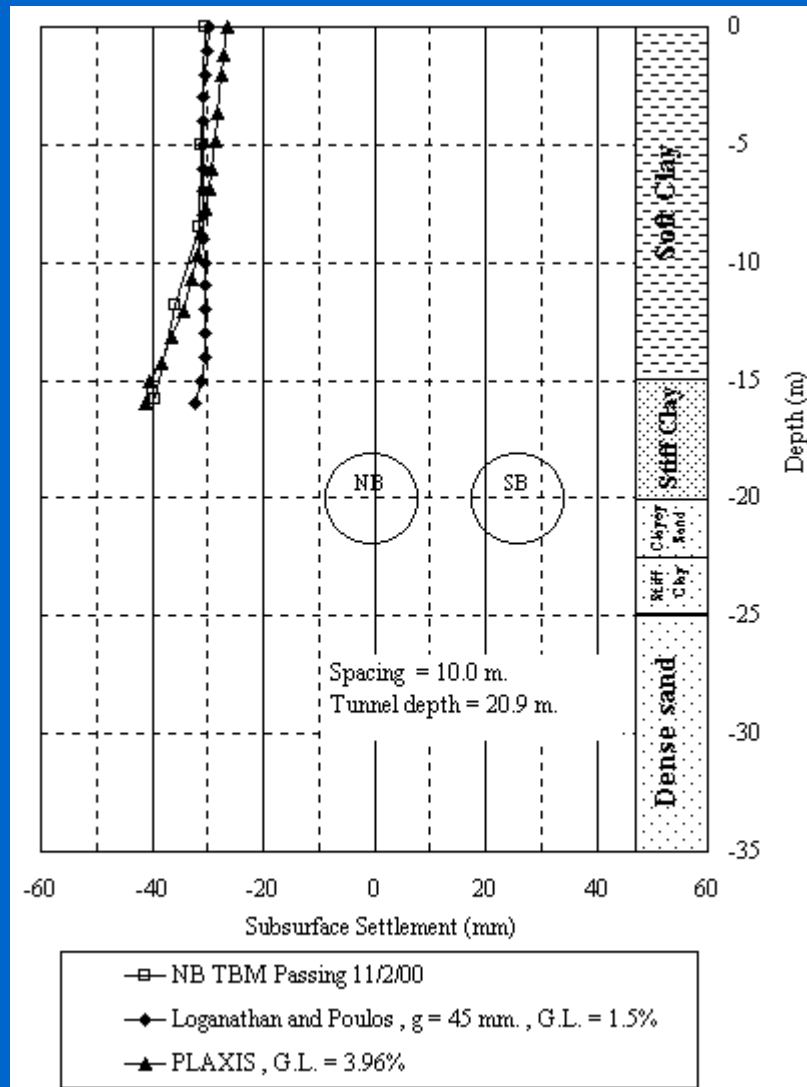
Loganathan and Poulos (1998)'s method

Subsurface Vertical Movement

Single tunnel



Twin tunnels



-
-
-

Prediction of subsurface movement

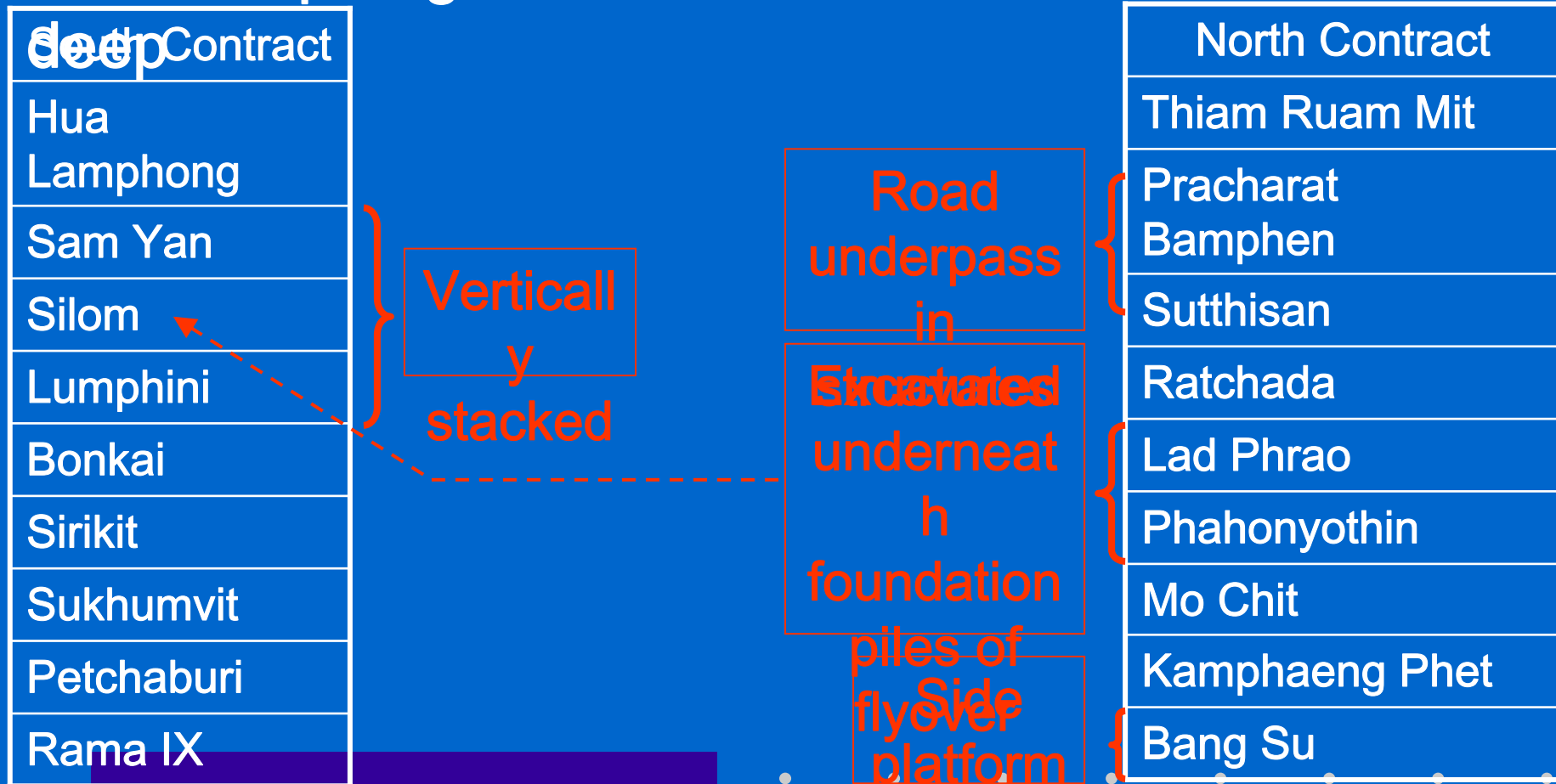
Limited ability in case of high face pressure

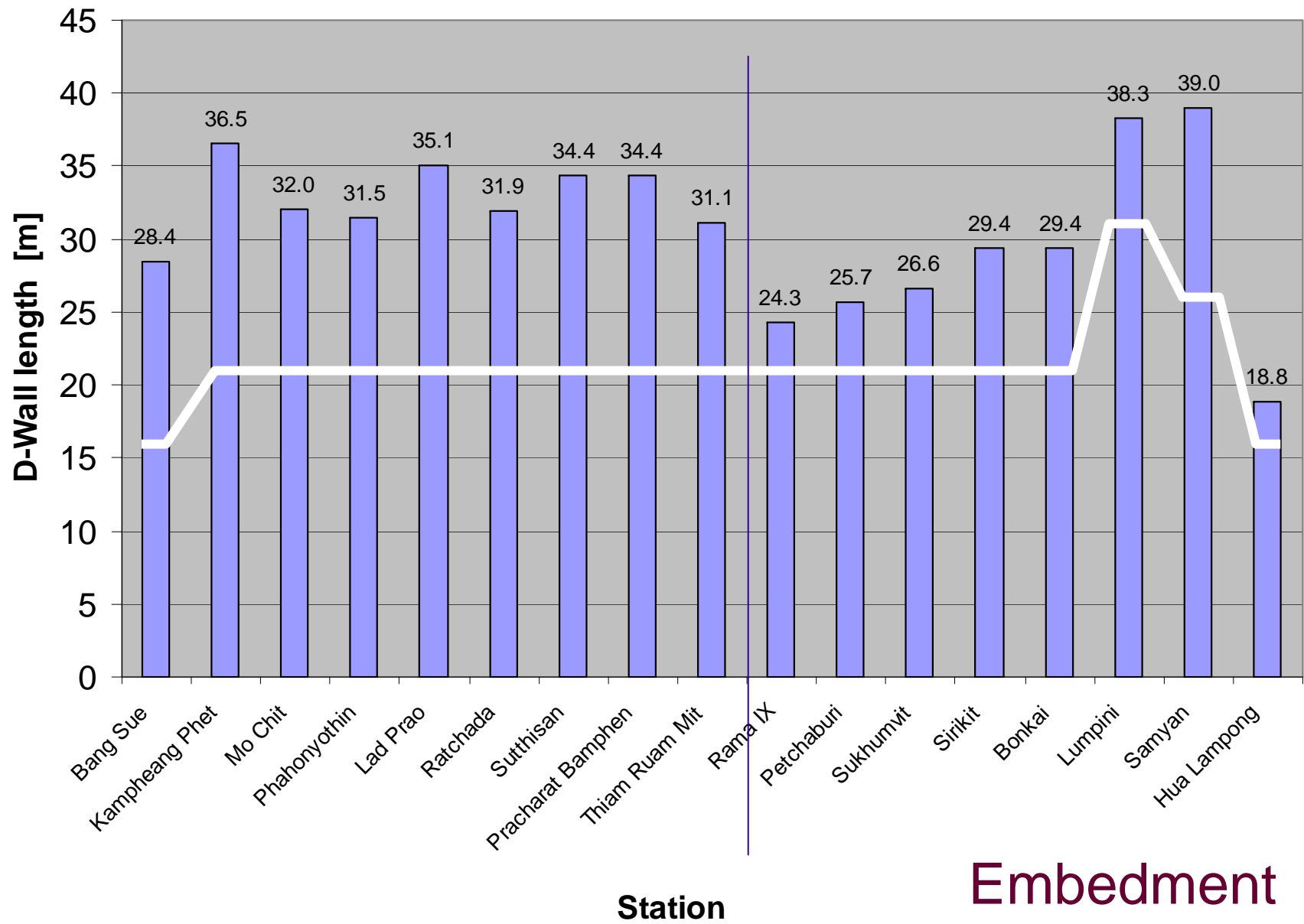
-
-
-

Ground Movements in Station Excavations

Station Boxes- Hazel Hooi 2003

- 18 station box excavations
- Typically Centre Island Platform with 3 levels
- 230 m x 25 m, excavation depth of 20 – 30 m
- Diaphragm walls 1.0 m thick and 30 to 35 m

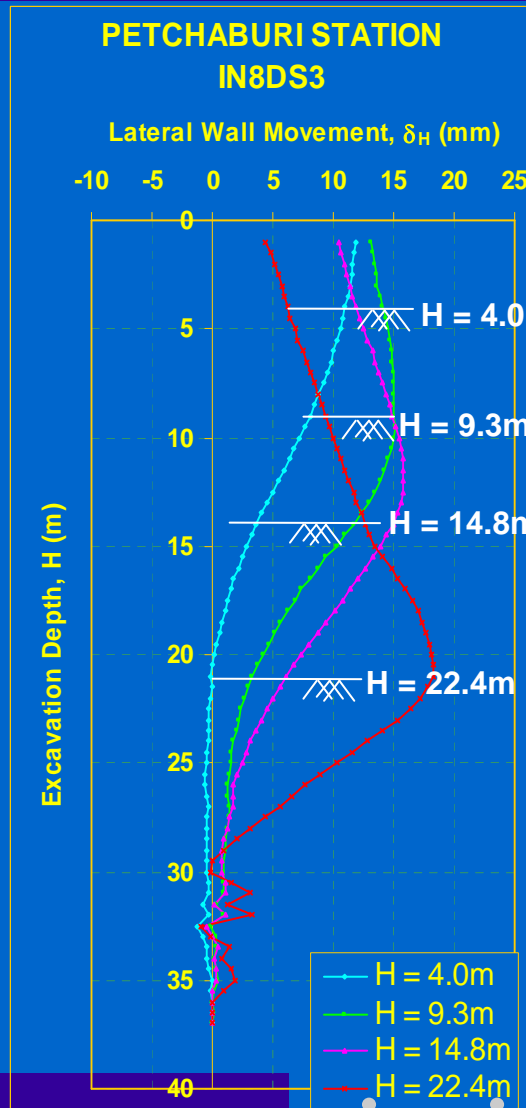
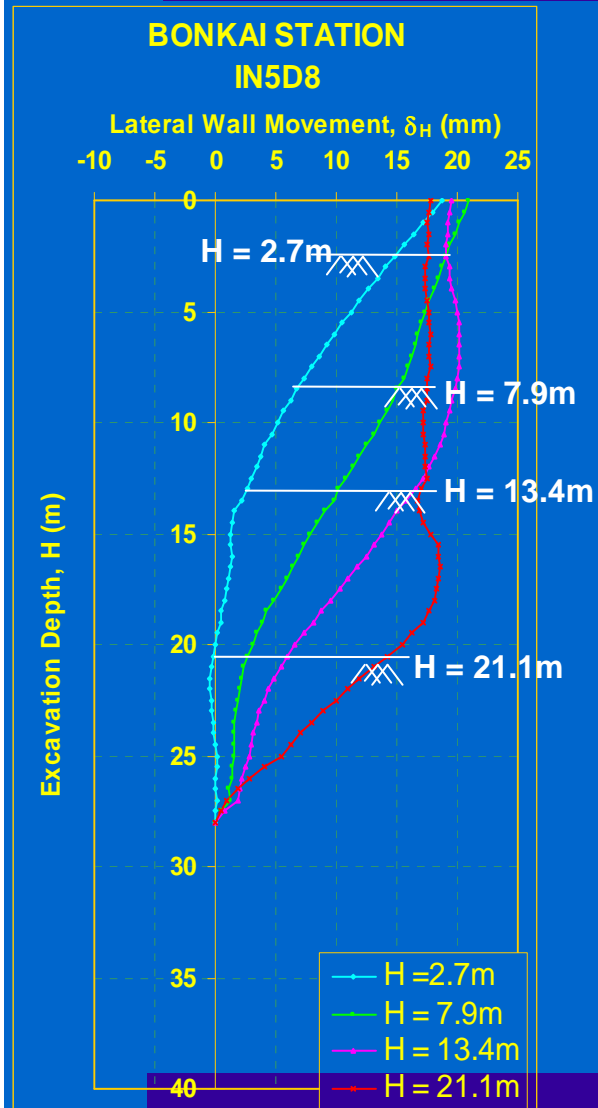




Embedment
Depth of D-
Wall

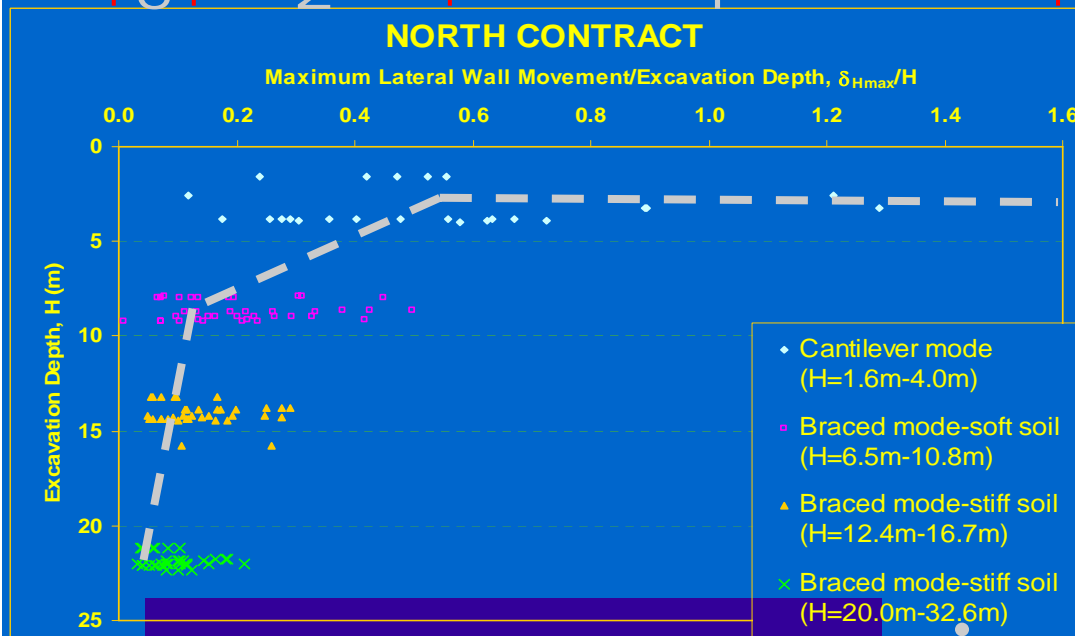
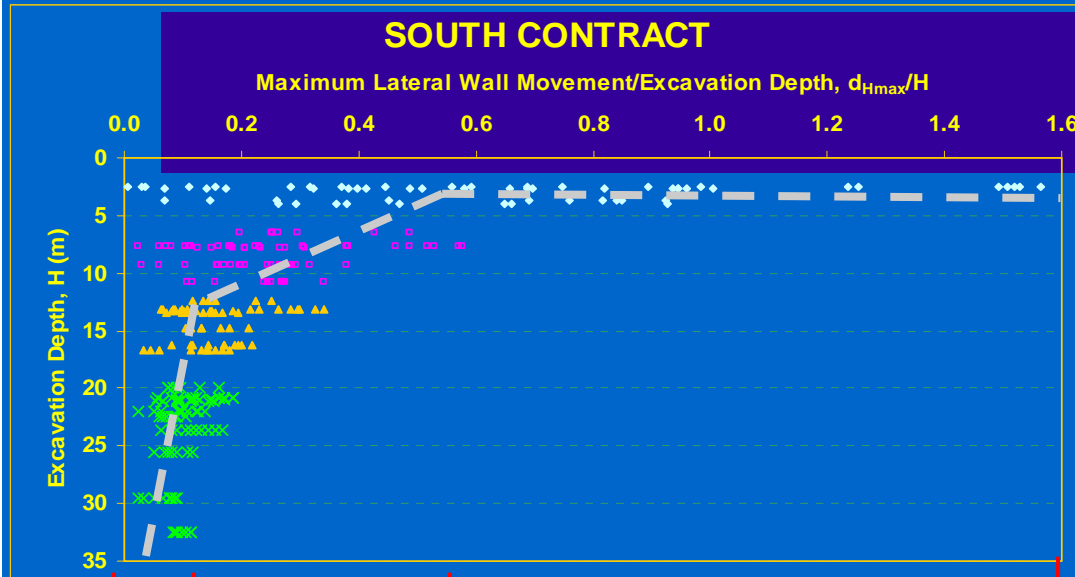
• Interpretation of Measurement Data

(1) Lateral Wall Movement



→ Cantilever Mode
→ Braced excavation mode bulge in soft soil
→ Braced excavation mode bulge in stiff soil

Plot of $\delta_{H_{max}}/H$ vs H



(1) Cantilever mode

H = 1.6 m – 4.0 m

$d_{H_{max}}/H = 0.20 - 1.60$

(2) Braced excavation mode

(soft soil)

H = 6.5 m – 10.8 m

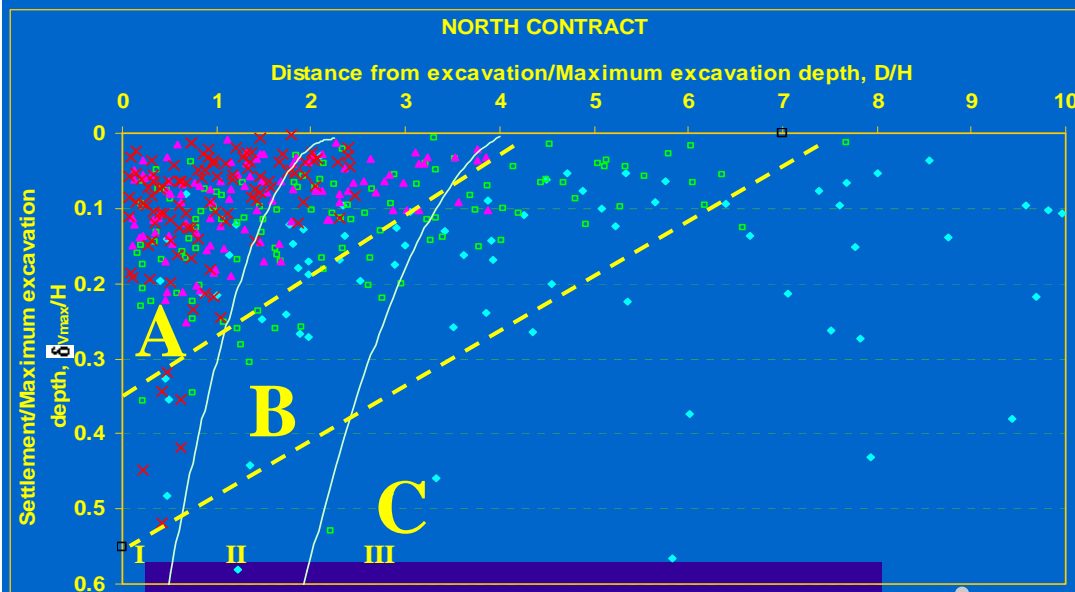
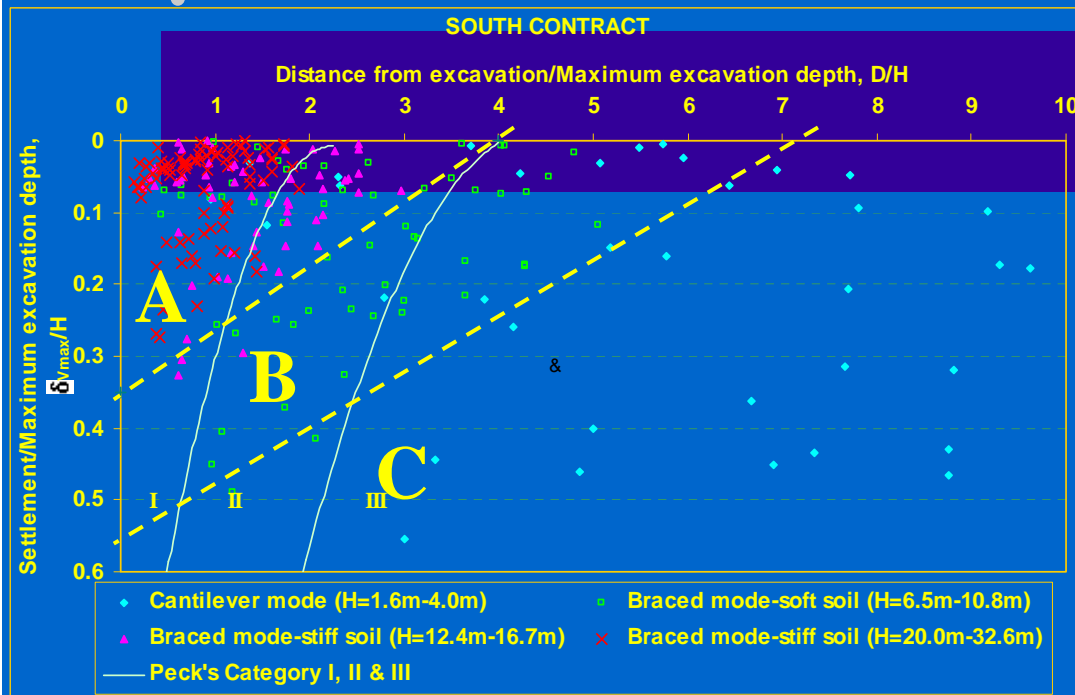
(3) Braced excavation mode

stiff soil

H = 12.4 m – 32.6 m

$d_{H_{max}}/H = 0.05 - 0.40$

Dimensionless Settlement Data



- Category A
Braced excavation mode
(stiff soil)
- Category B
Braced excavation mode
(soft soil)
- Category C
Cantilever mode
D/H > (7 - 10)

Used as
general guide
only

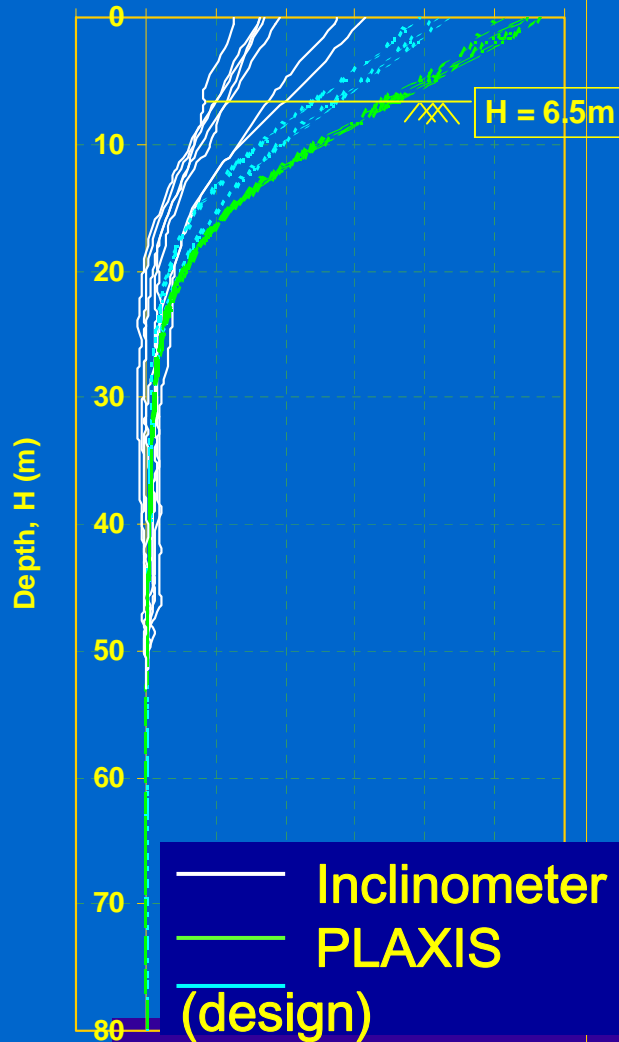
Design Parameters vs Adjusted Parameters

Silom Station

Roof

Lateral Wall Movement, δ_H (mm)

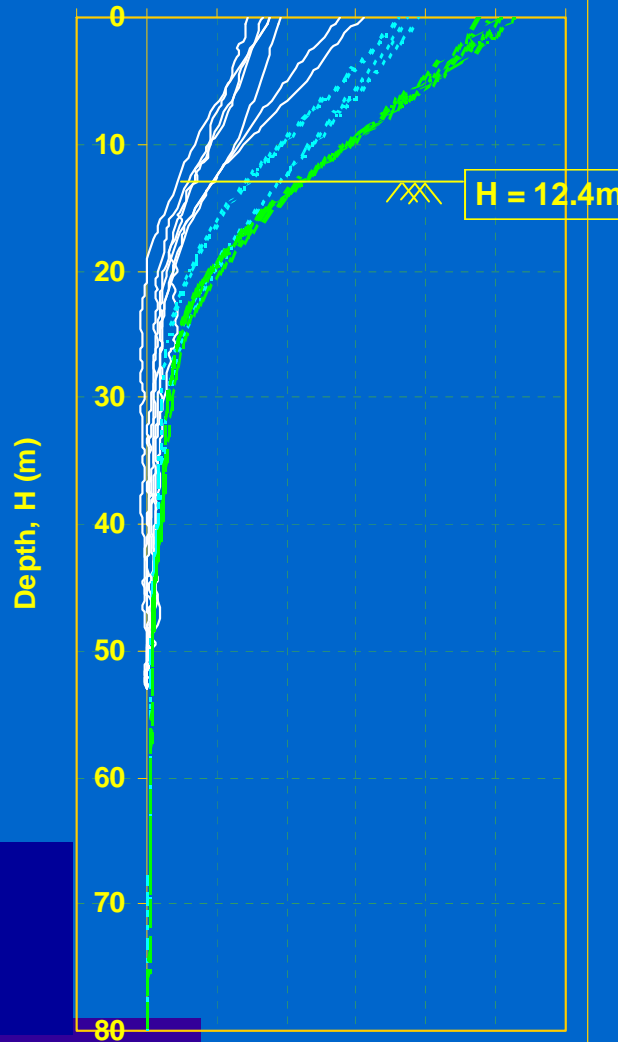
-10 0 10 20 30 40 50 60



Concours

Lateral Wall Movement, δ_H (mm)

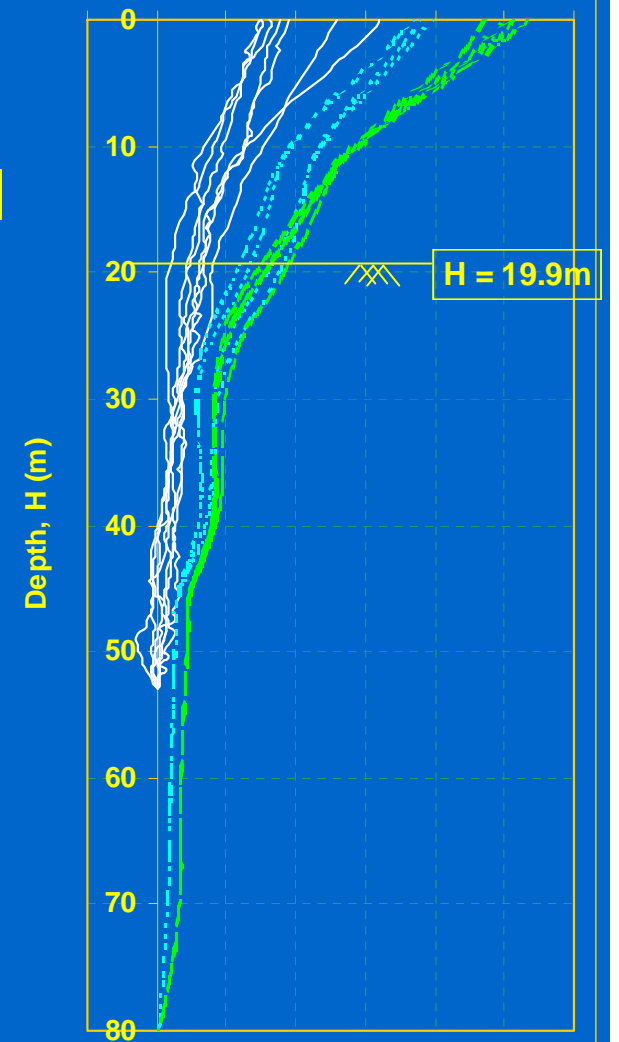
-10 0 10 20 30 40 50 60



Upper Platform

Lateral Wall Movement, δ_H (mm)

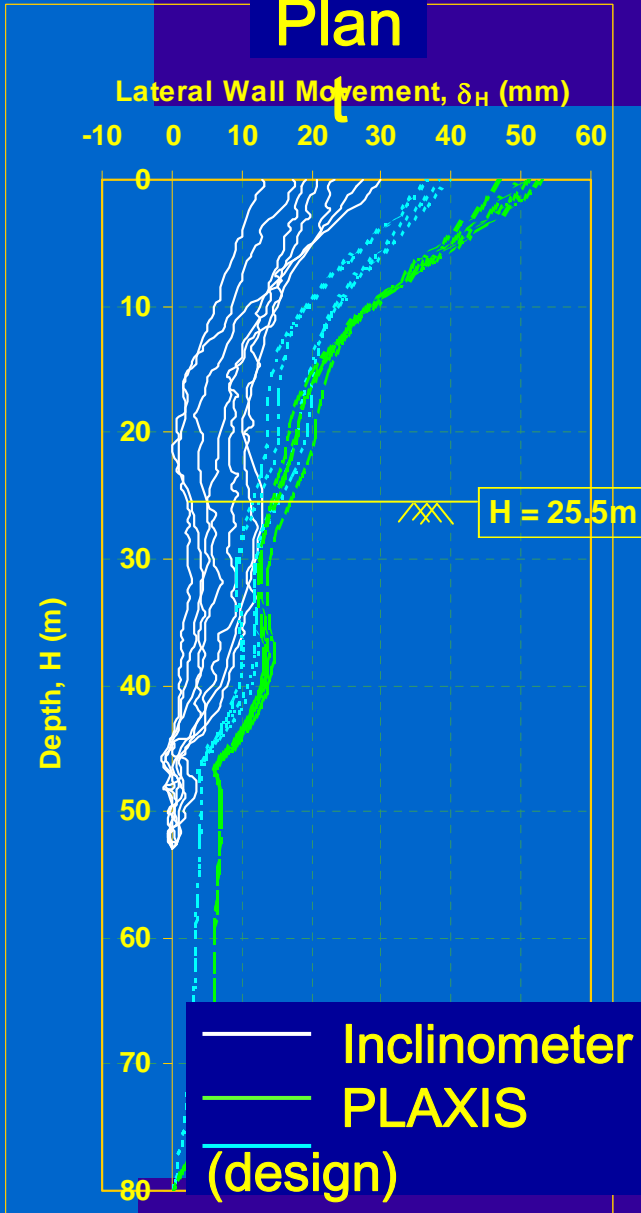
-10 0 10 20 30 40 50 60



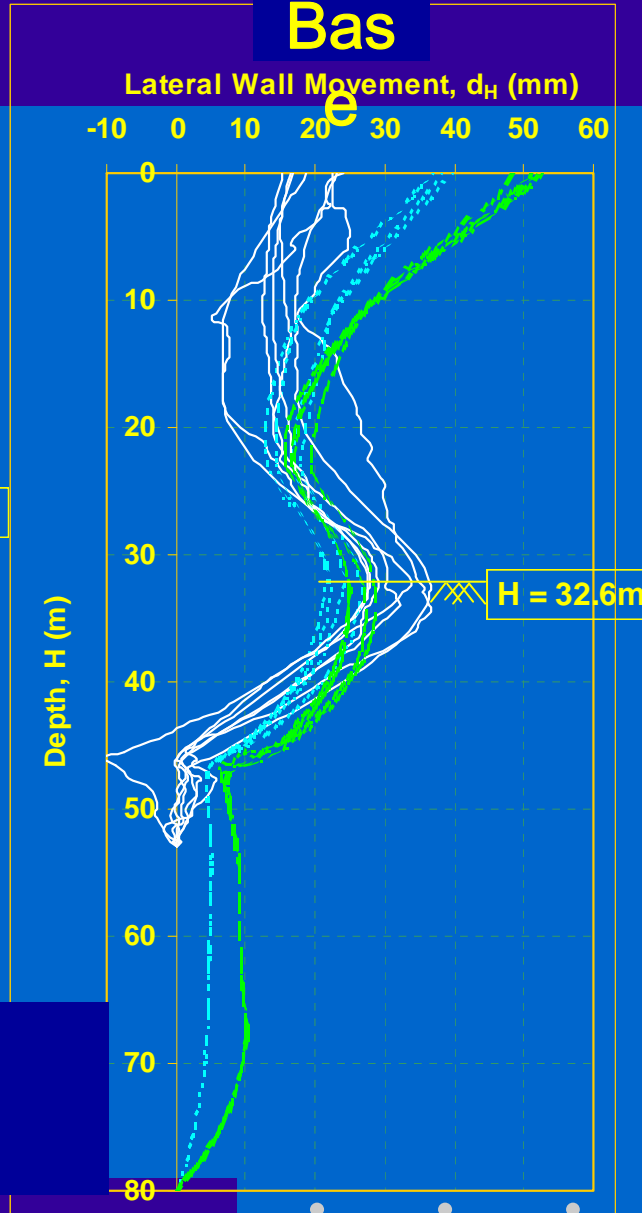
Design Parameters vs Adjusted Parameters

Silom Station (cont'd)

Plan



Bas



Base

excavation stage reveal large bulge due to delayed base casting works Adjusted parameters



Slightly closer

predictions

Derived Soil Modulus for Linear Elasto-Plastic Analysis

A horizontal fictitious load applied at top of wall to model:

- Lateral confinement due to road pavement 

• The adjusted stiffness parameters used were predictions

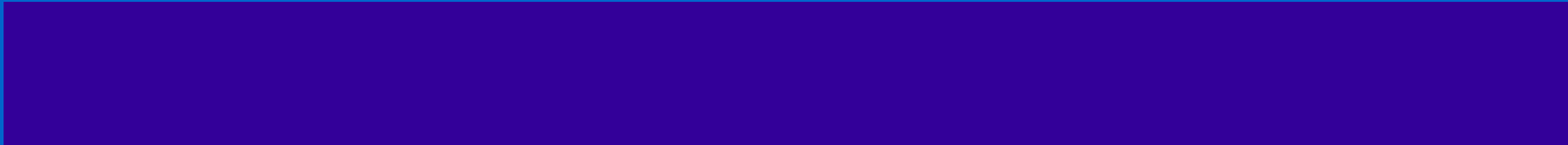
- Soft/Medium Clay : $E_u = 500c_u$ kN/m²
- 1st Stiff Clay : $E_u = 700 N_{60}$ kN/m²
- Clayey Sand & Sandy/Silty Clay : $E_u = 900 N_{60}$ kN/m²
- 2nd Hard Clay : $E_u = 1600 N_{60}$ kN/m²

• 3rd Hard Clay : $E_u = 2500 N_{60}$ kN/m²

Soil This Study Gan (1997) Reparaksia (1999)
 where c_u is the corrected field vane test and N_{60} is the
 corrected SPT N_u value

Soft clay	$500c_u$	$500c_u$	$500c_u$
Stiff clay	$700N_{60}$	$720N_{60}$ or $1200c_u$	$1200N_{60}$ or $2000c_u$

-
-
-

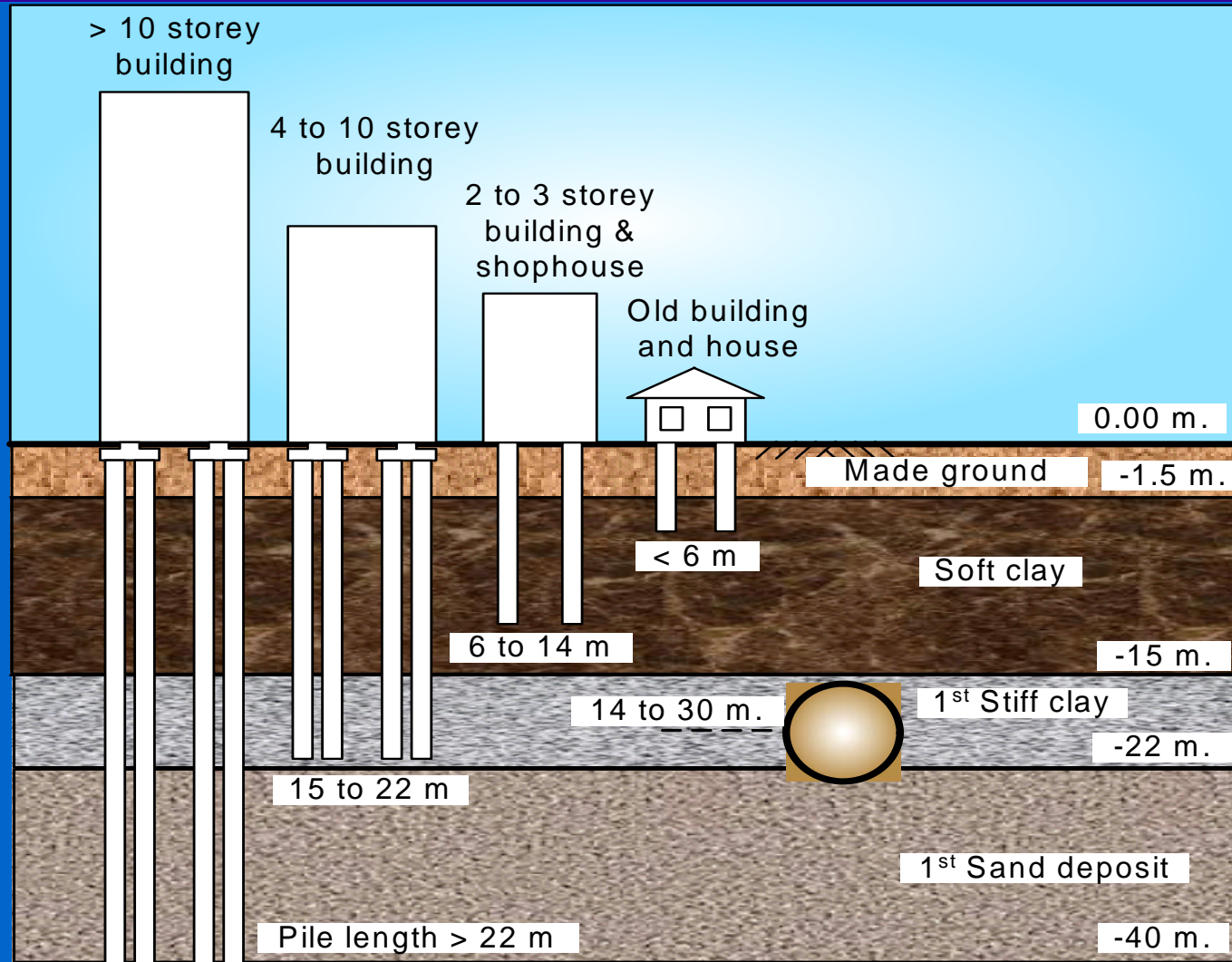


Effects on Adjacent Buildings

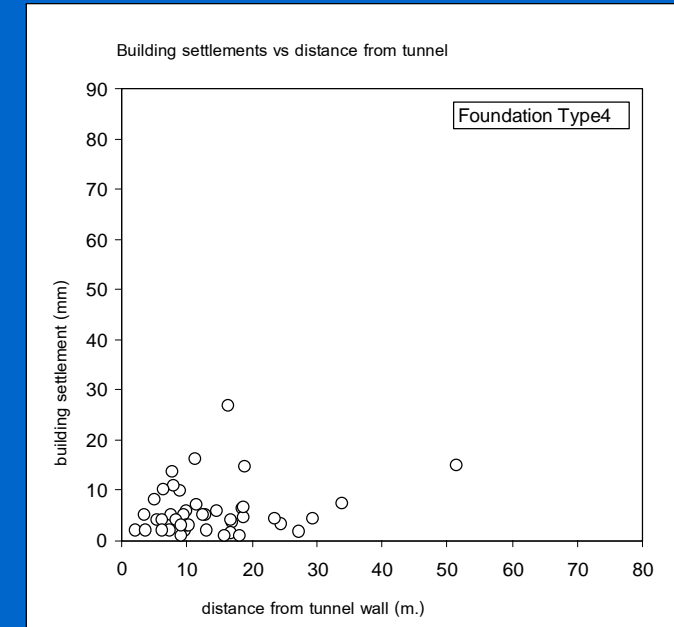
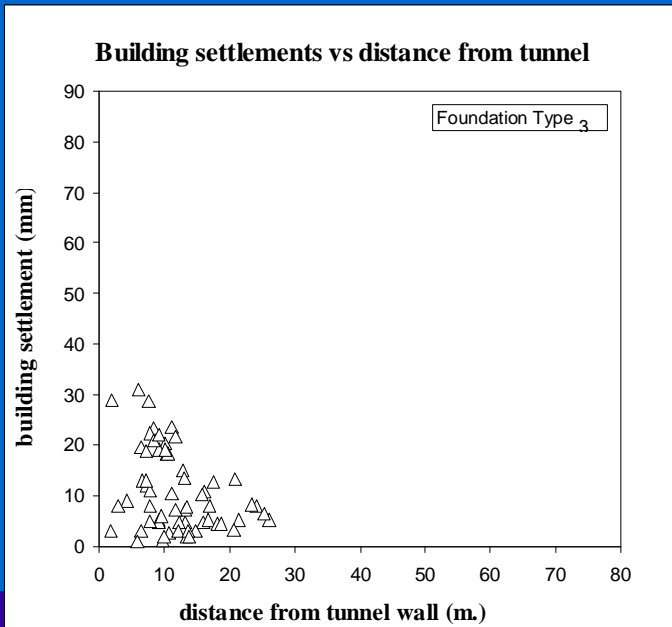
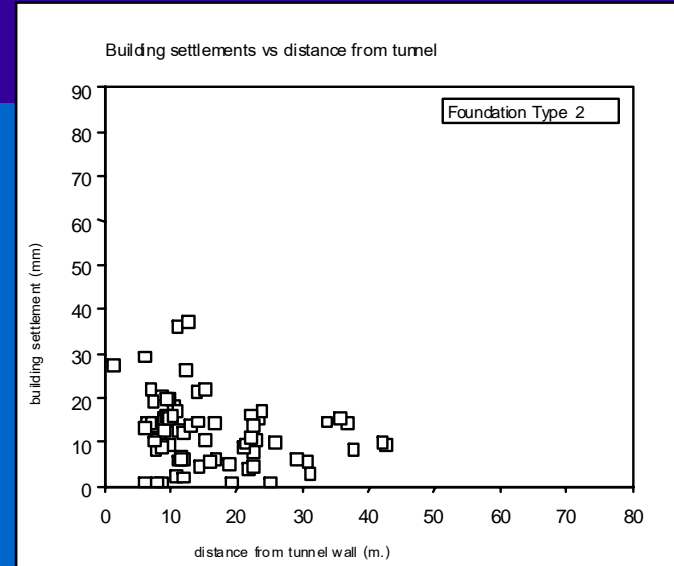
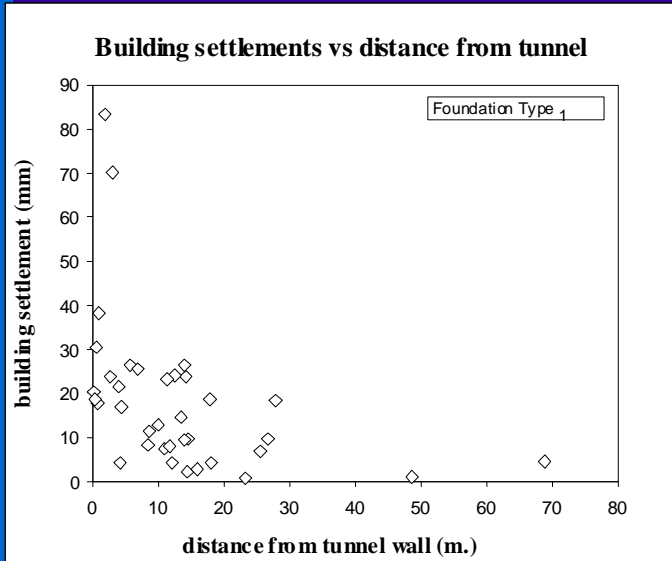


-
-
-
-
-
-
-
-

Typical Foundations of Buildings in Bangkok

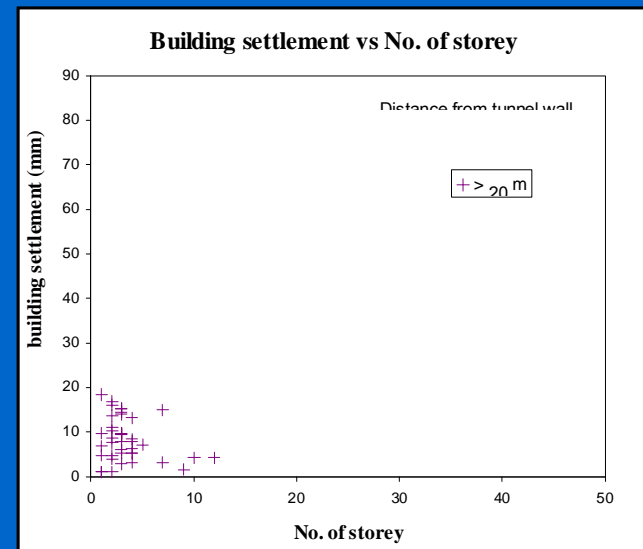
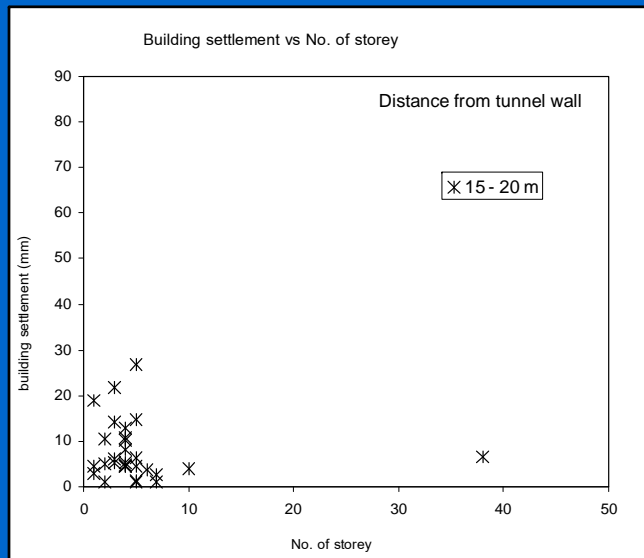
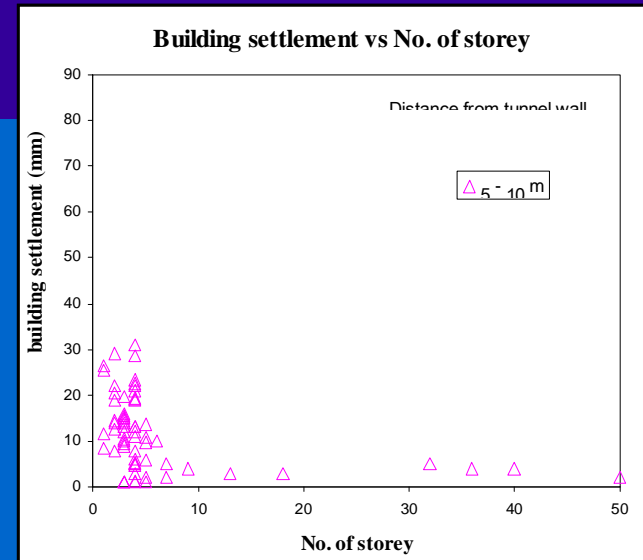
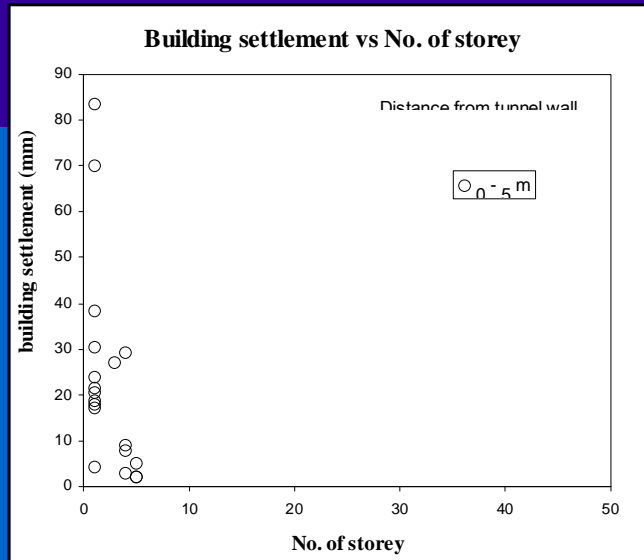


Building settlement versus distance from tunnel wall.



339
buildings

Building Settlement versus Number of Storey



Conclusions

- Maximum surface settlement ranged from 5 mm to 120 mm, mostly 20-60 mm. The corresponding volume loss was 0.4-2.50%.
- Influencing factors are :- Face pressure,
Rate of advancement - Obstruction & Breakdown,
Soil type - Sand, and Workmanship
- Most ground movement occurred in the vicinity of shield advancement. Some long-term movement occurred within soft clay layer. No significant long-term movement in stiff clay layers
- Outward lateral ground movement and heave from the tunnel excavation occurred for depths below the tunnel roof in sections where high face pressure was used in EPB excavation. This make prediction of subsurface movement difficult.
- Only few cases of damages to adjacent building from tunnelling.
- Settlement of buildings from tunnelling showed correlation with the height of building (depth of foundation piles) and distance from tunnels.
- Typical characteristics and range of lateral wall deflection and ground settlement in station excavation using D-wall were derived from the monitoring data.

-
-
-



Thank You



-
-
-
-
-
-
-
-