AIT Technology Event

Innovative Solutions for Foundations and Deep Basements

Dr. Noppadol Phienwej

Geotechnical and Earth Resources Engineering Field

AIT
Asian Institute of Technology

Geotechnical & Earth Resources Engineering

School of Engineering and Technology

Asian Institute of Technology

Established in 1967

Produced 800+ master graduates and 30+ doctoral graduates

Areas of Specialization

- *Soil Engineering*
- *Engineering Geology*
- *Rock Engineering*
- *Geo-system Exploration and Petroleum Geo-engineering*

SOIL ENGINEERING

Soft Soil Properties

Pile Foundation

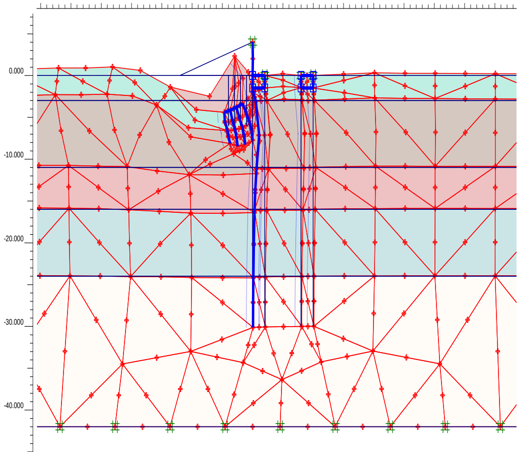
Slope Stability

Ground Improvement

Geosynthetic Engineering

Deep Excavation & Tunneling

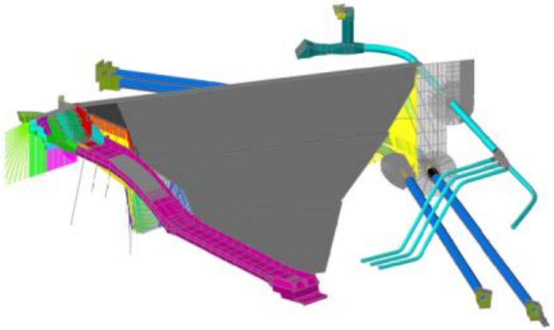
Numerical Computation



ENGINEERING GEOLOGY & ROCK ENGINEERING

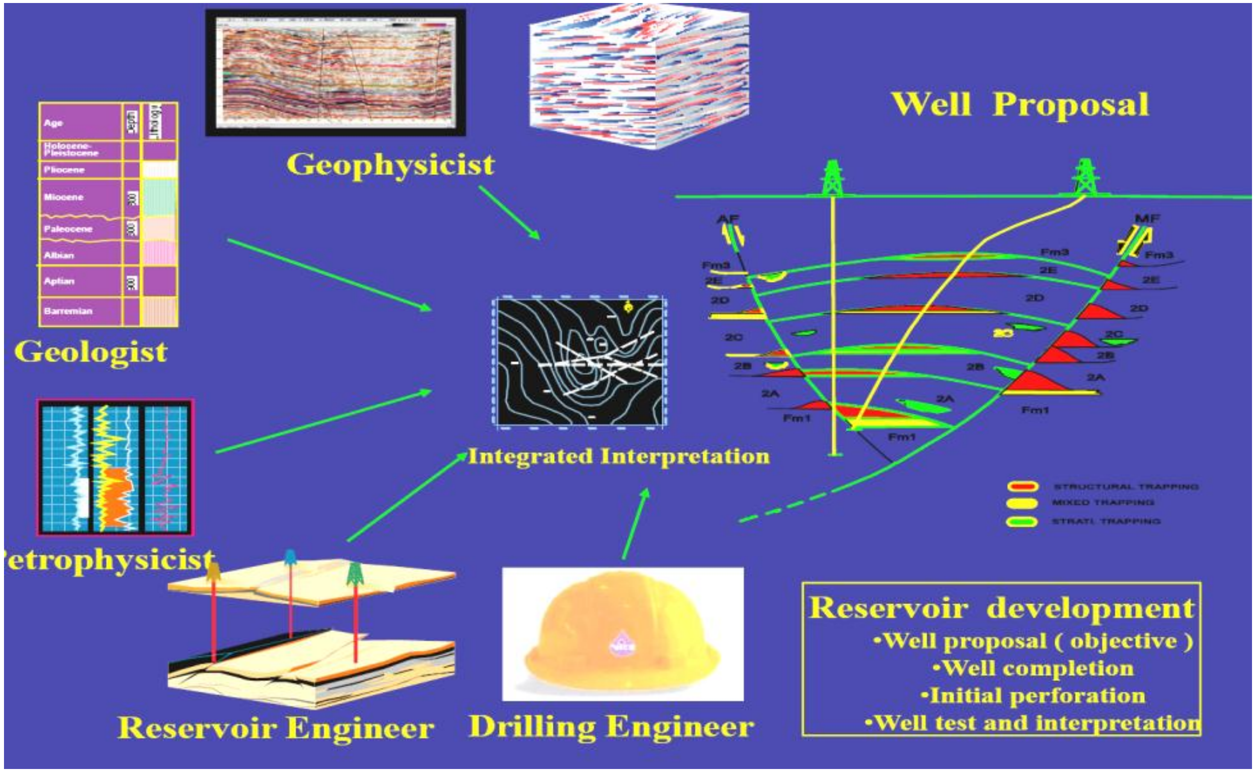
- Site Characterization
- Geological Hazards
- Hydrogeology

- Underground Rock Excavation
- Rock Slope Engineering
- Dam Engineering
- Hydro-power Engineering Application



Geosystem Exploration and Petroleum Geoengineering

- Exploration for Natural resources/Site Characterization
- Exploration and Production of Oil and Gas Fields



Presentation Contents

- Overview of Foundation and Excavation Works in Soft Soil
- Constraints in Construction in – Bangkok as an Example
  - Bangkok Geology & Soft Subsoil
  - Land Subsidence
  - Groundwater condition & effect
- Deep Excavations
  - Method of Deep Excavations
  - Deep Excavations for Mass Rapid Transit System
- Foundation
  - Pile Capacity & Pile Foundation Design
  - Pile Capacity Improvement
  - New Trend of Piled Foundation Design for Highrise Buildings
- Conclusions

CITIES – URBAN DEVELOPMENT

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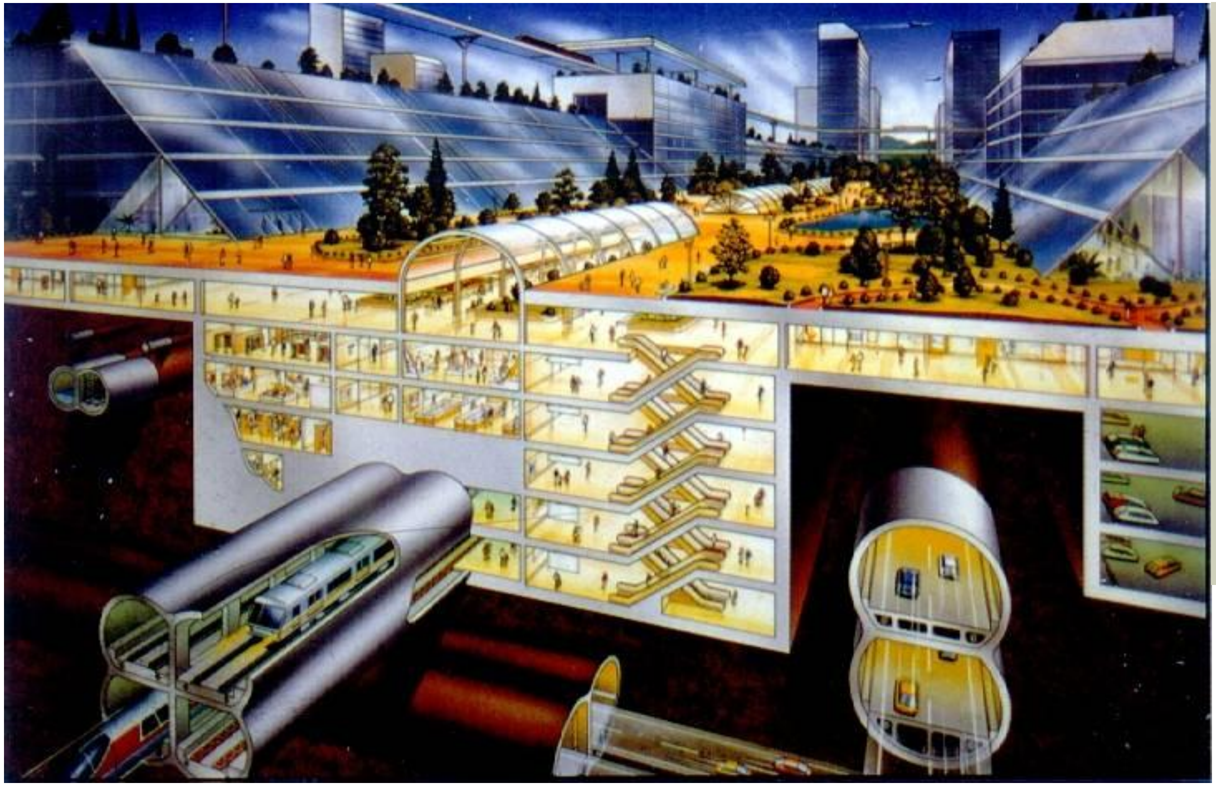
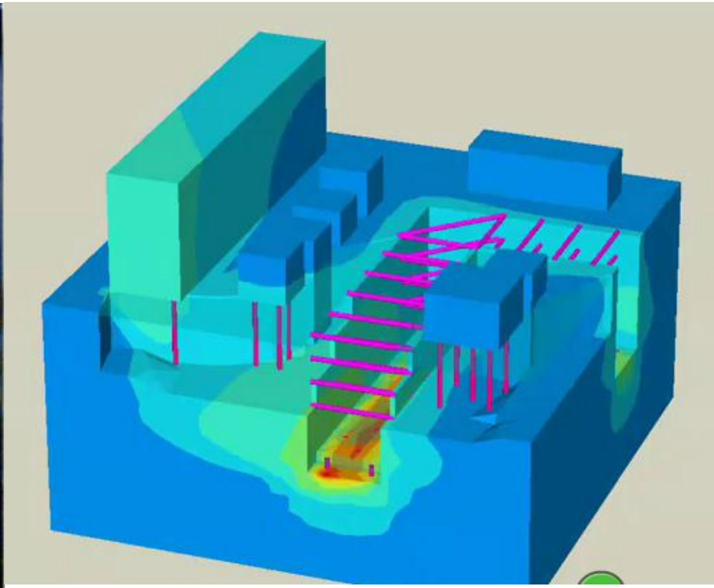
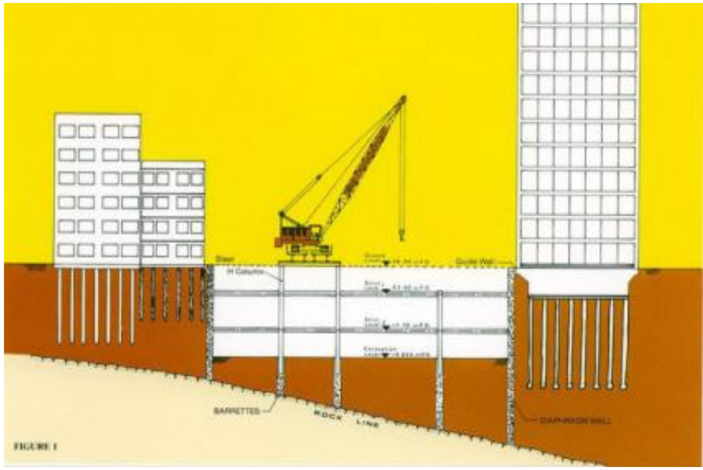
Necessity of Underground Space Use







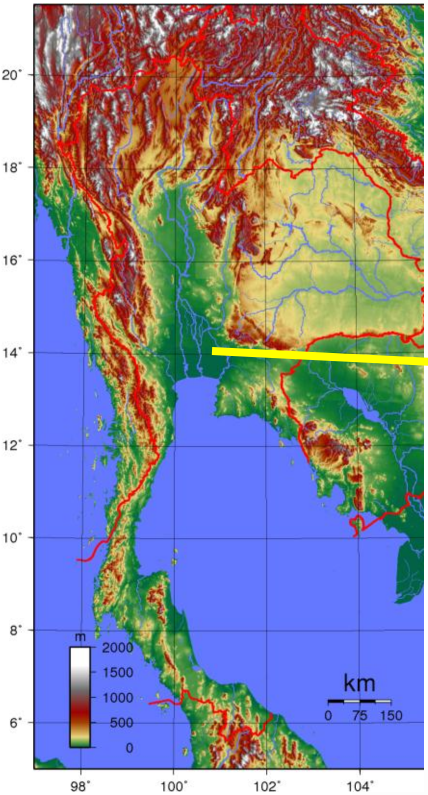
Deep Foundation & Excavation

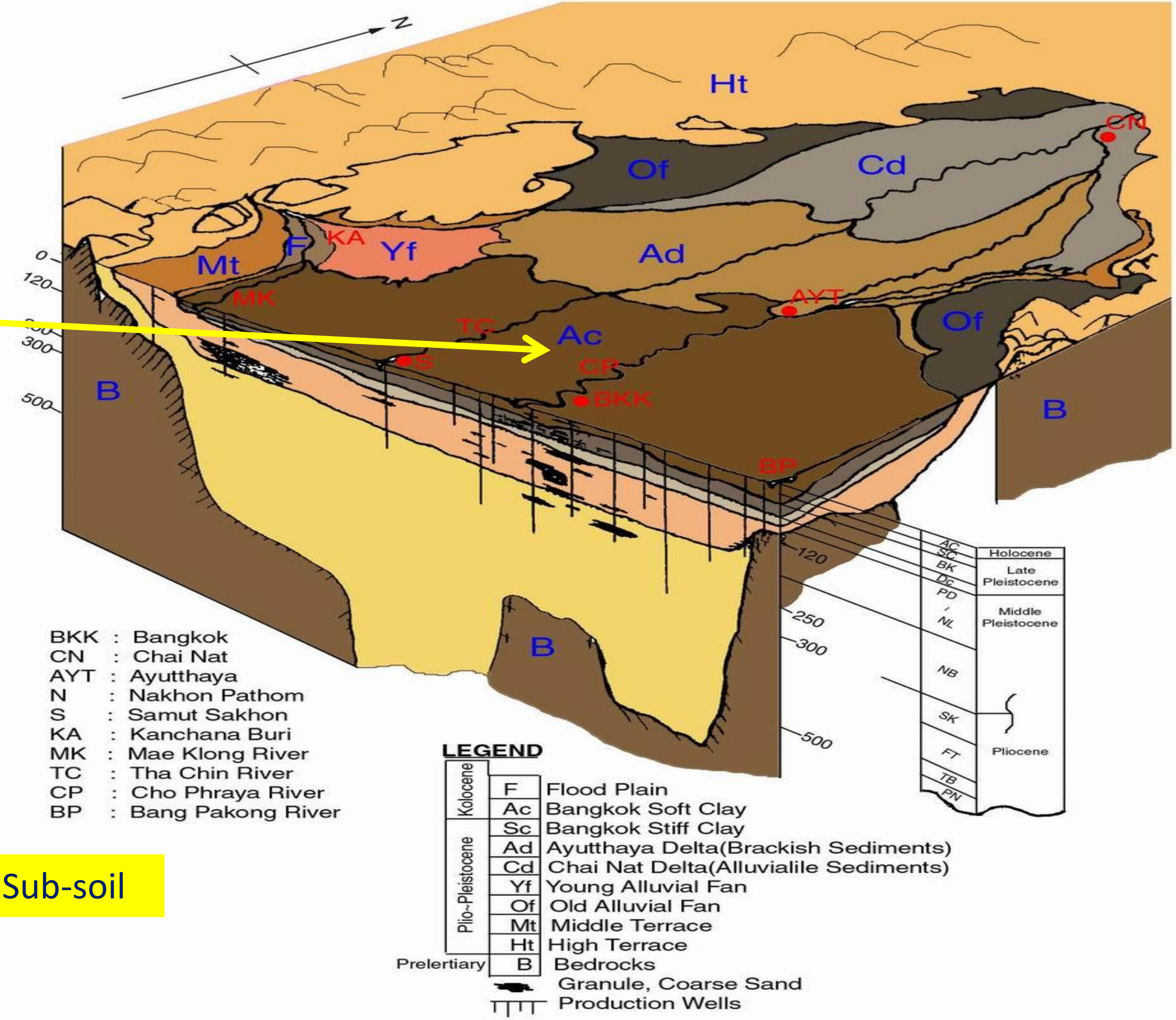
Pile Foundation & Deep Excavation

Method, Technology and Design

Case of Bangkok

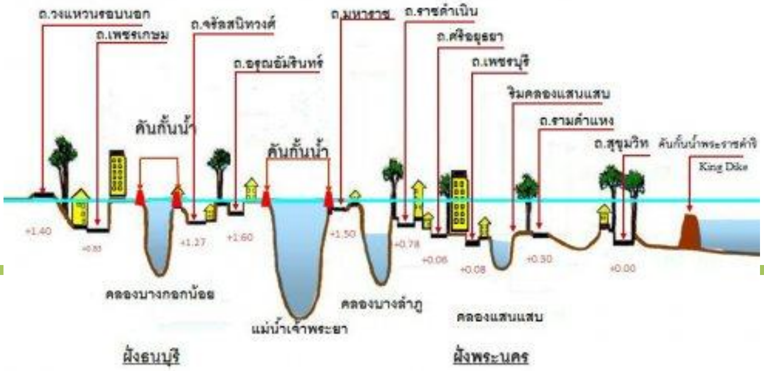
Geology





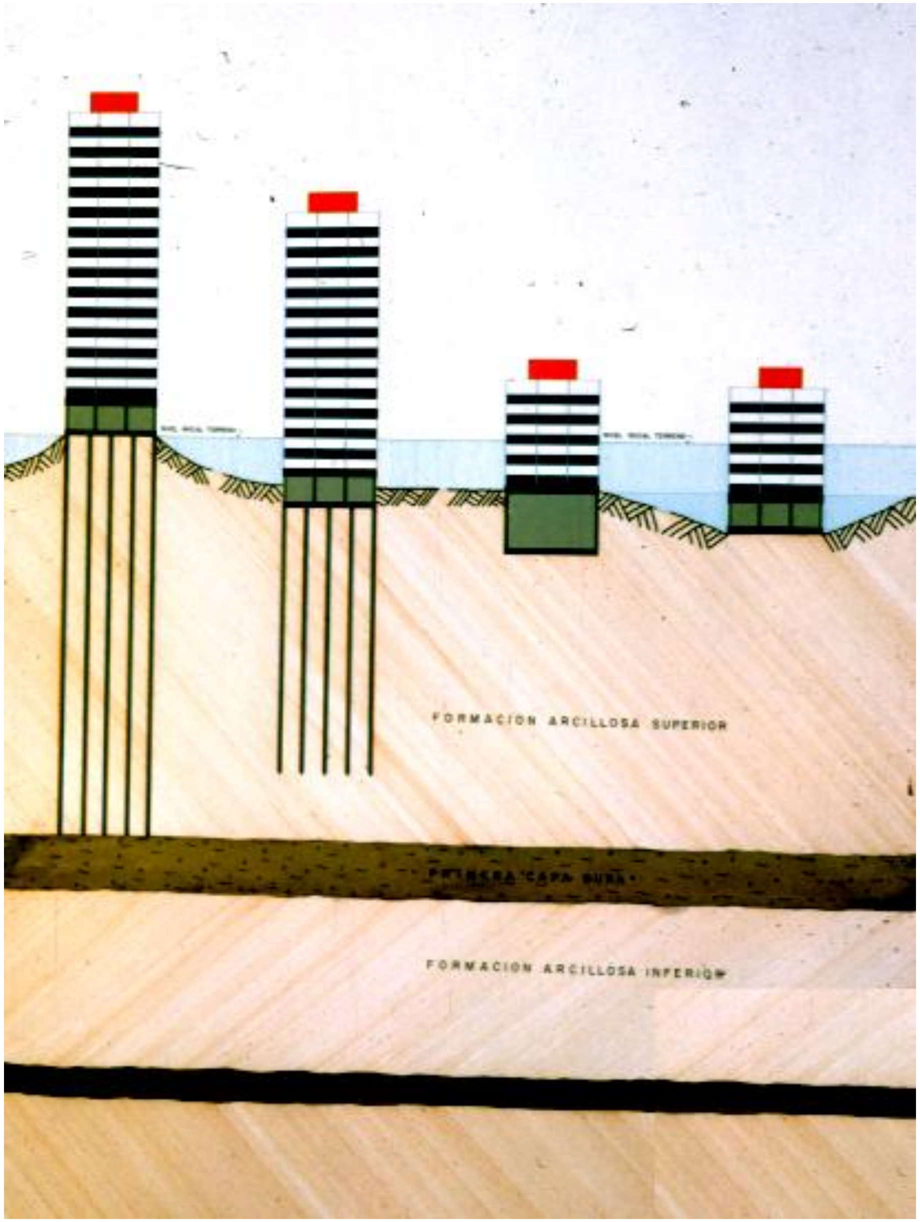
Soft Foundation Sub-soil

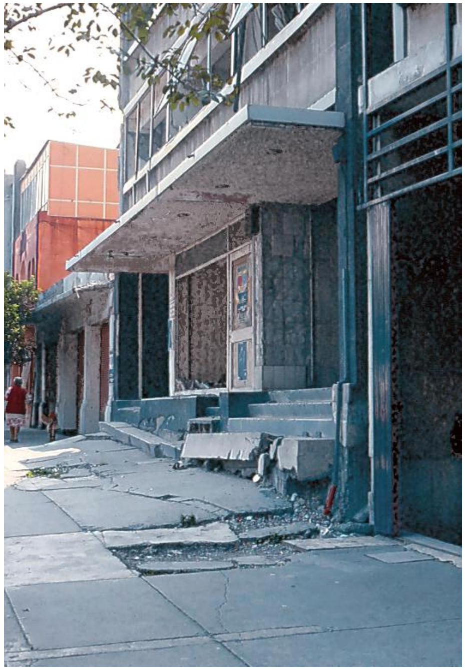
Low Lying and Risk of Flooding



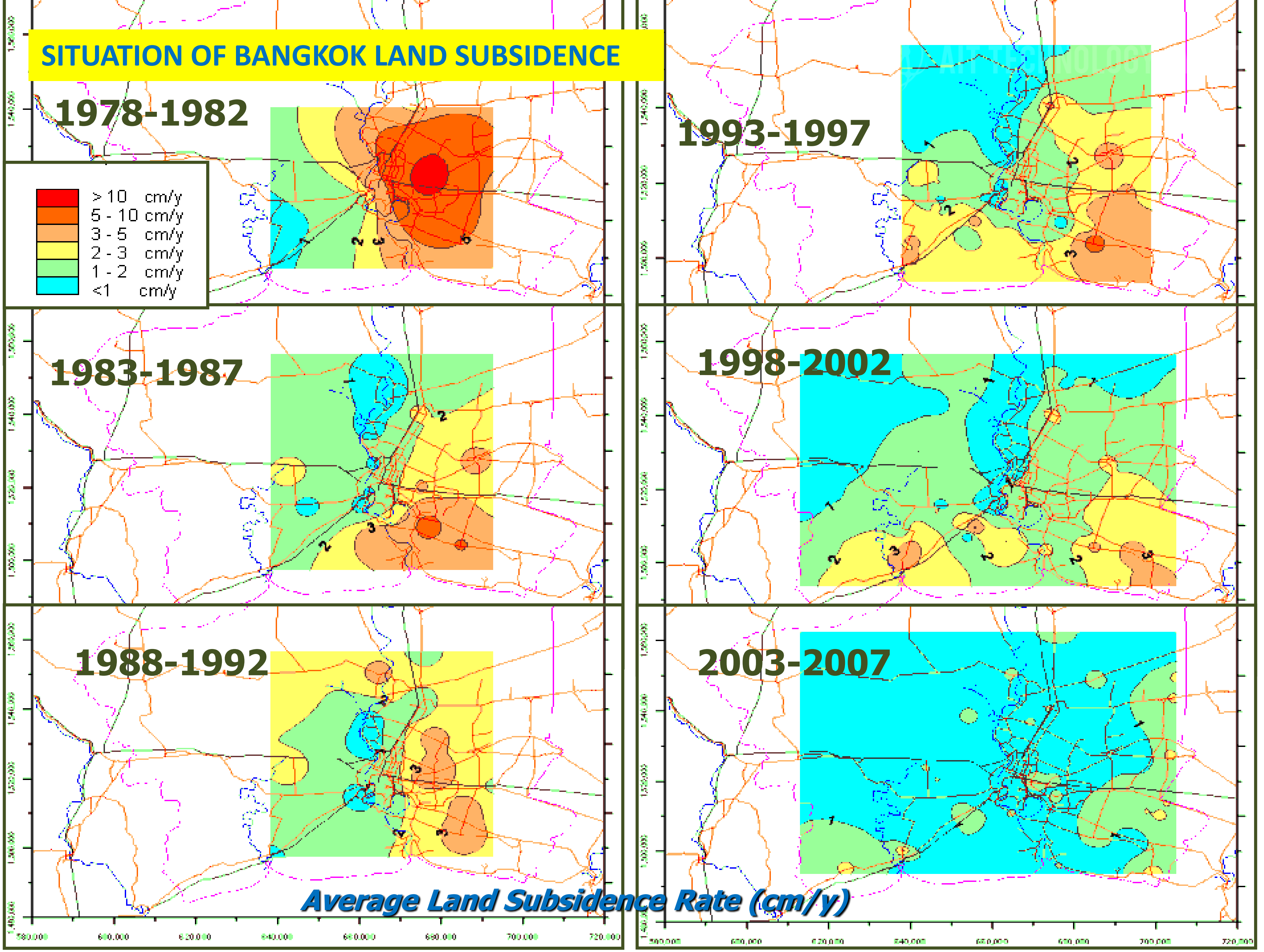
EFFECTS OF SOFT FOUNDATION SOIL AND LAND SUBSIDENCE

EFFECTS OF SOFT FOUNDATION SOIL AND LAND SUBSIDENCE ON FOUNDATION DESIGN



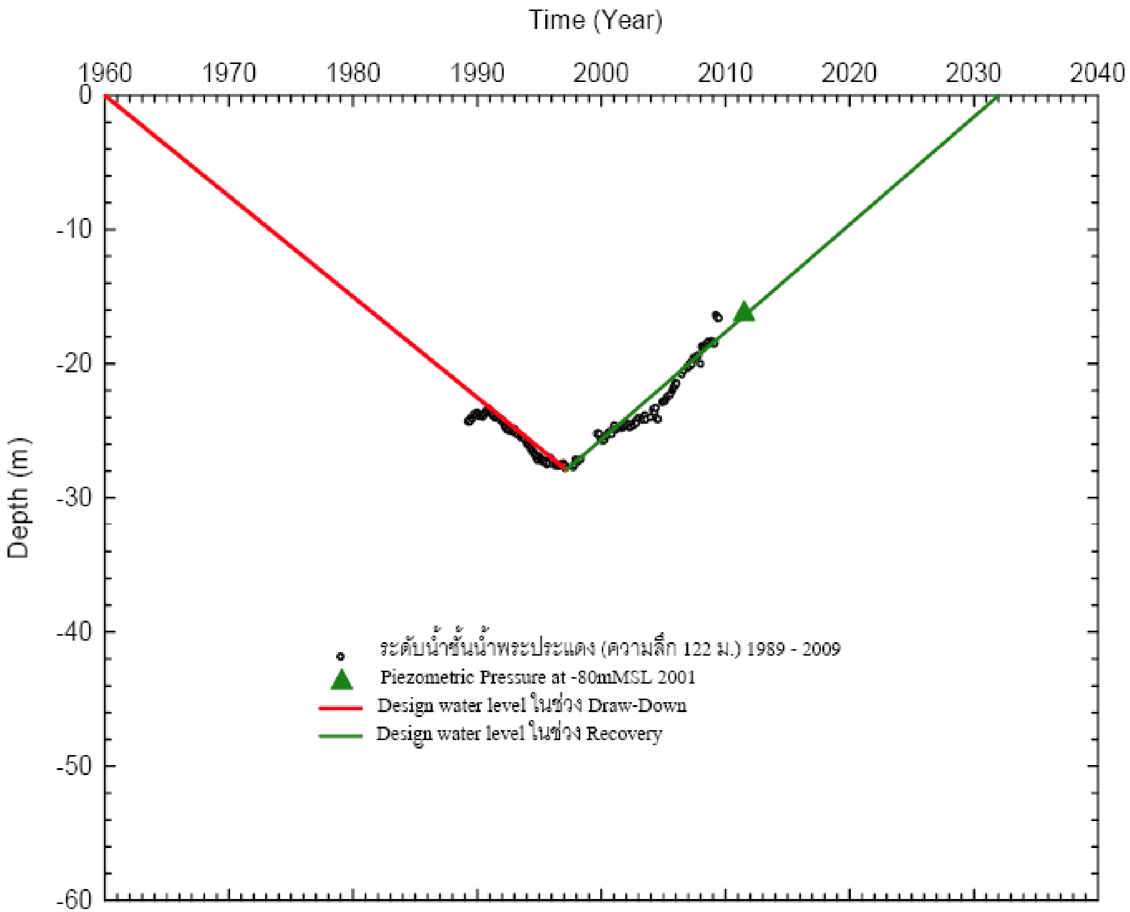


SITUATION OF BANGKOK LAND SUBSIDENCE



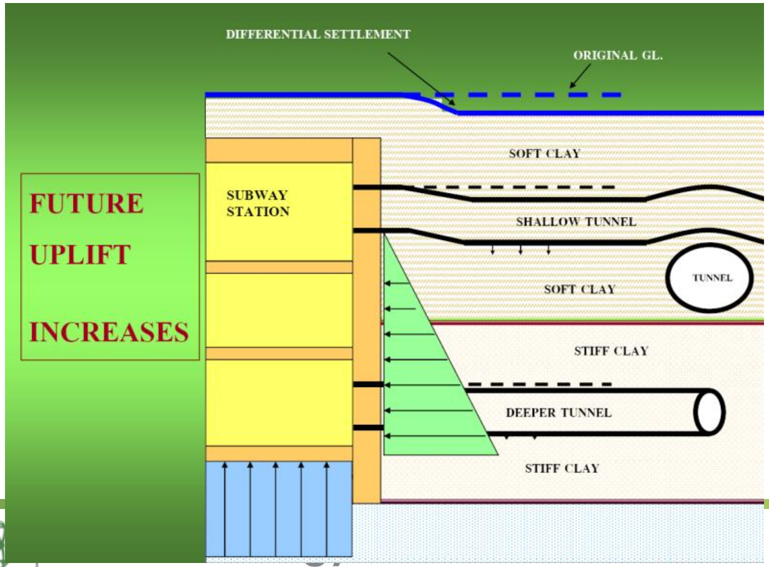
Average Land Subsidence Rate (cm/y)

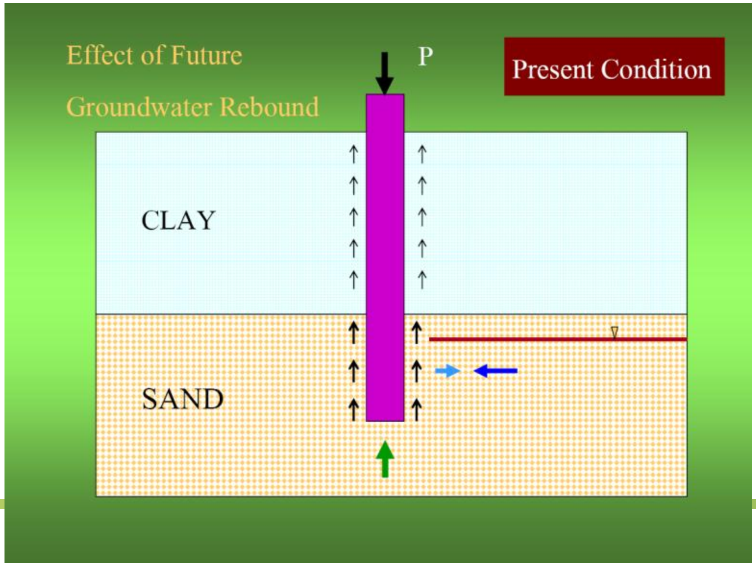
Piezometric Level in (Shallow) PD Aquifer at Jatujak Park



THERE IS A NEED TO STOP LAND SUBSIDENCE BY MINIMIZING GROUNDWATER PUMPING TO PREVENT IMPACTS ON ENVIRONMENTAL ISSUES AND BUILDING FOUNDATION

BUT ON THE OTHER HAND THE AMOUNT OF GROUNWATER REBOUND NEEDS BE CONTROLLED FOR SAFETY OF EXISTING STRUCTURE FOUNDATIONS





Deep Excavations

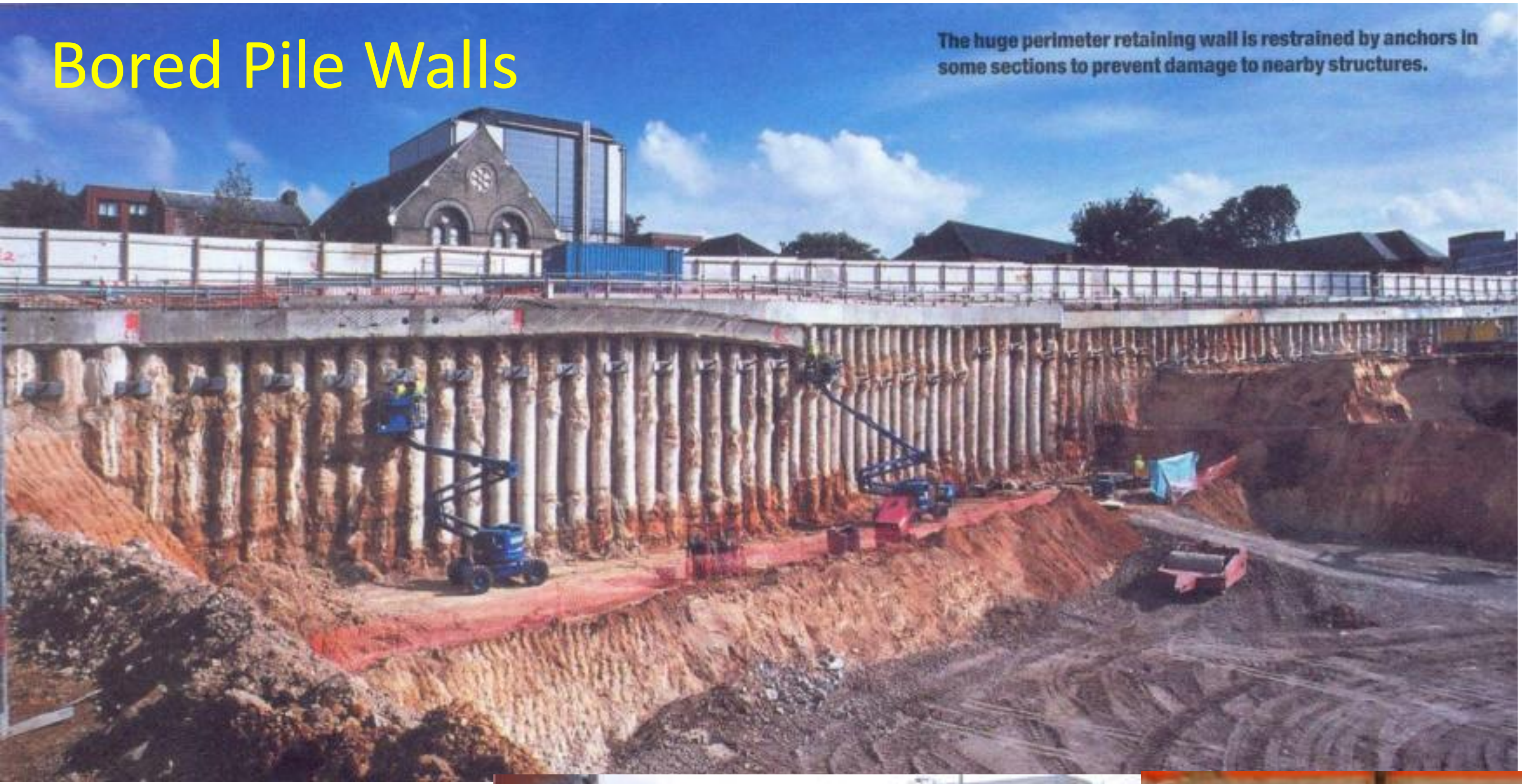
- **Type of wall**
- **Wall and lateral support design**
- **Stability of base of excavation**
  - Water seepage or soil upheave from uplift
  - Basal heave instability of clayey soil
- **Control of ground movements - Prevent damages to third party's properties**
- **Optimize construction time schedule**
  - Means to reduce lateral support members
  - Bottom-up versus top-down basement construction

Steel Sheet Pile Walls

32 m deep Excavation in Soft clay, Singapore

Concrete Diaphragm Walls – Tie Backs

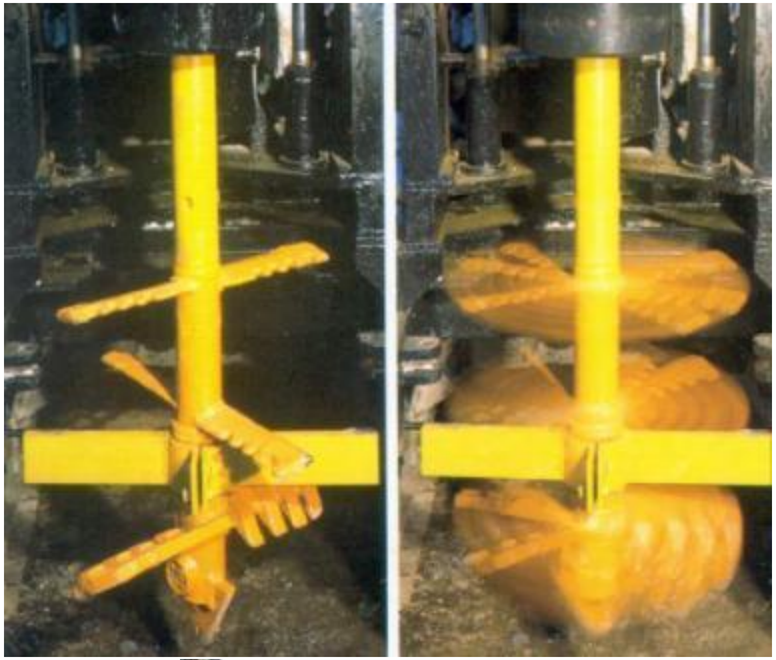
Bored Pile Walls



Soil-Cement Columns- Methods of Construction

Deep Cement Mixing (DCM)

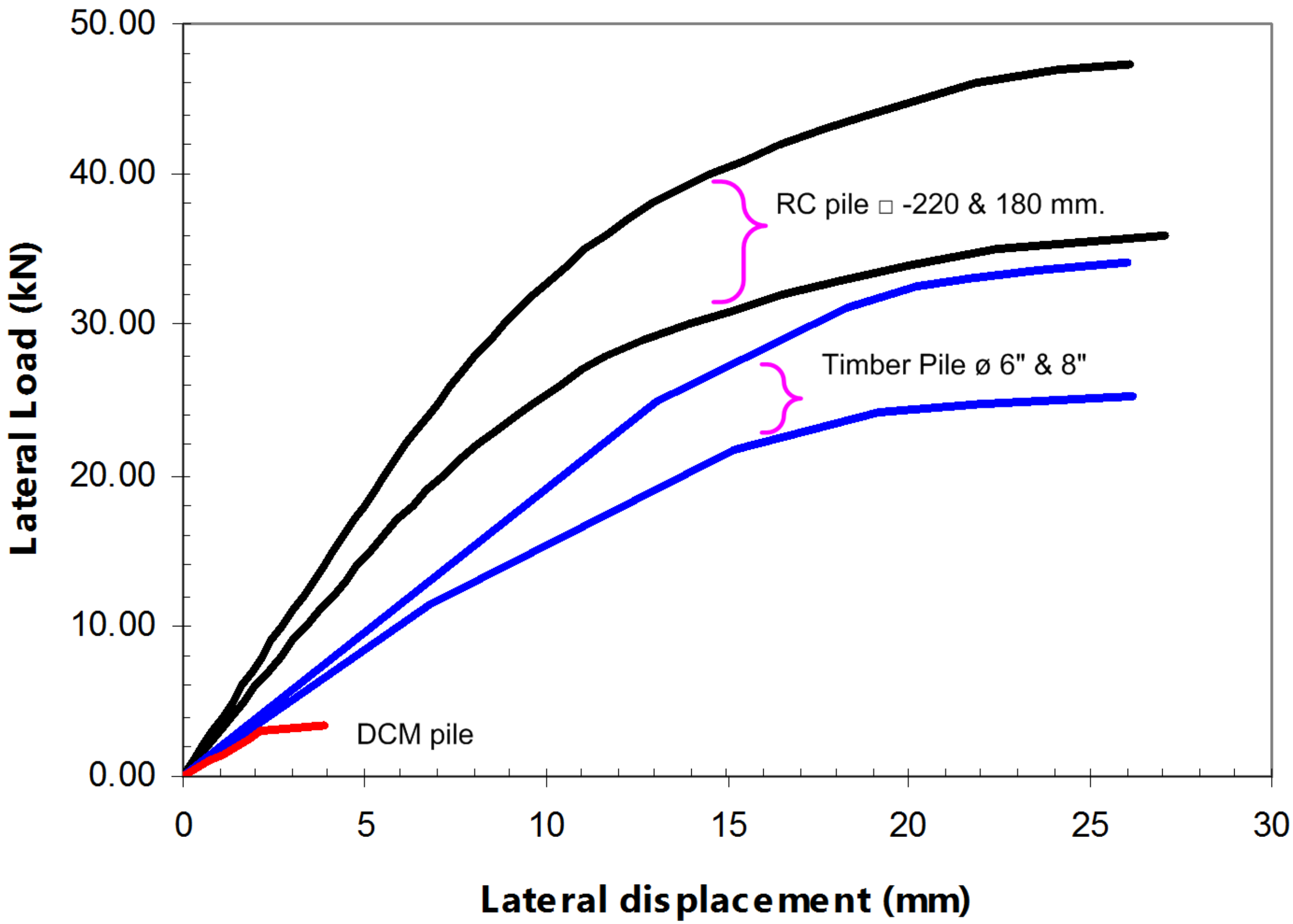
Jet Cement Grouting (JCG)



Soil-Cement Column/Jet Grout Walls

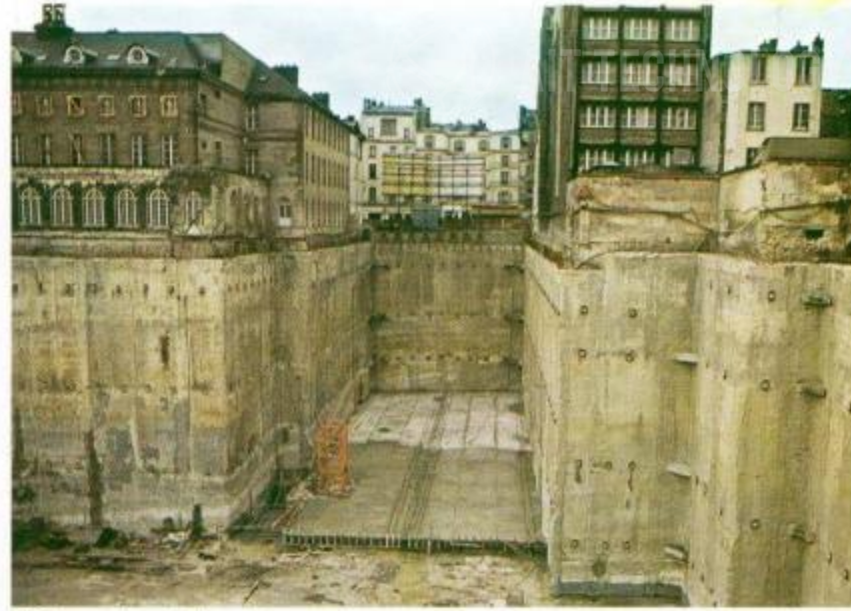
Improvement of DCM pile on Lateral capacities in Bangkok Clay by adding RC pile or timber core

AIT Research – Noppadol&Bergado



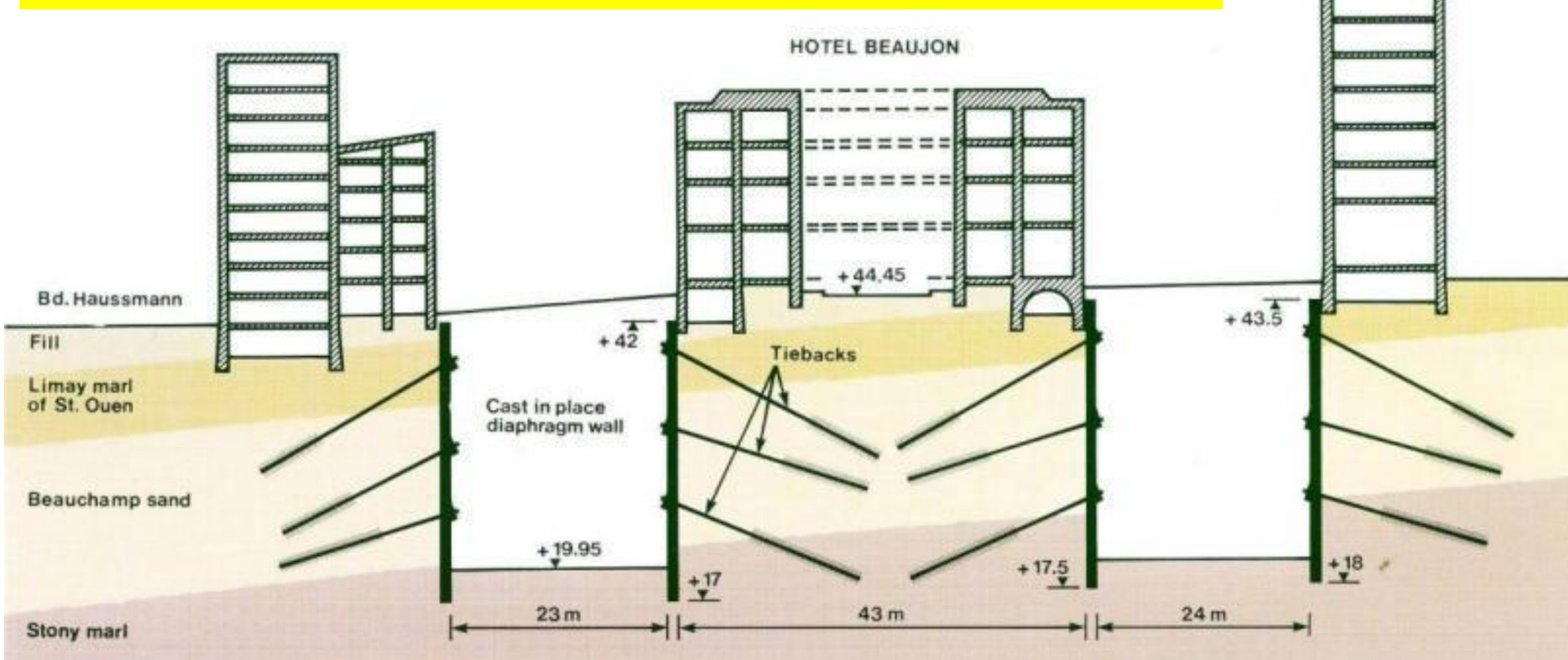
Internal Lateral Support: Bracing System or Struts

Concreting of the infrastructure



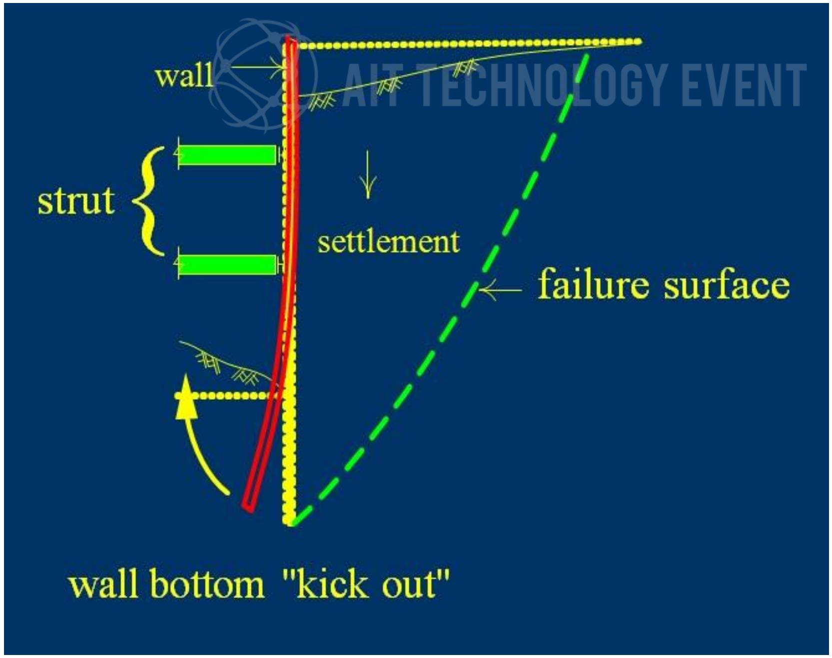
** Concreting of the raft

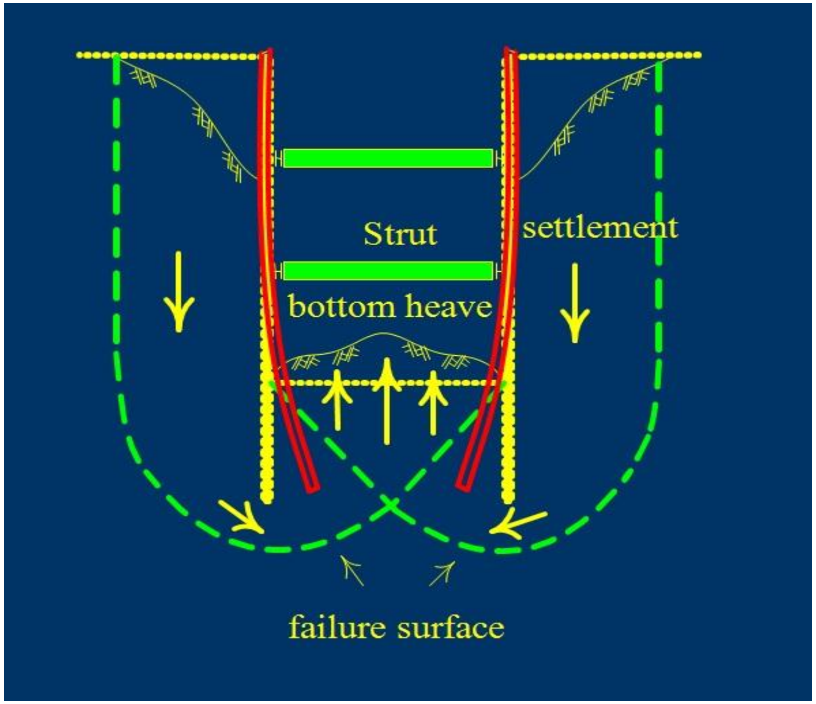
External Lateral Support: Ground Anchors> Tied-back Wall

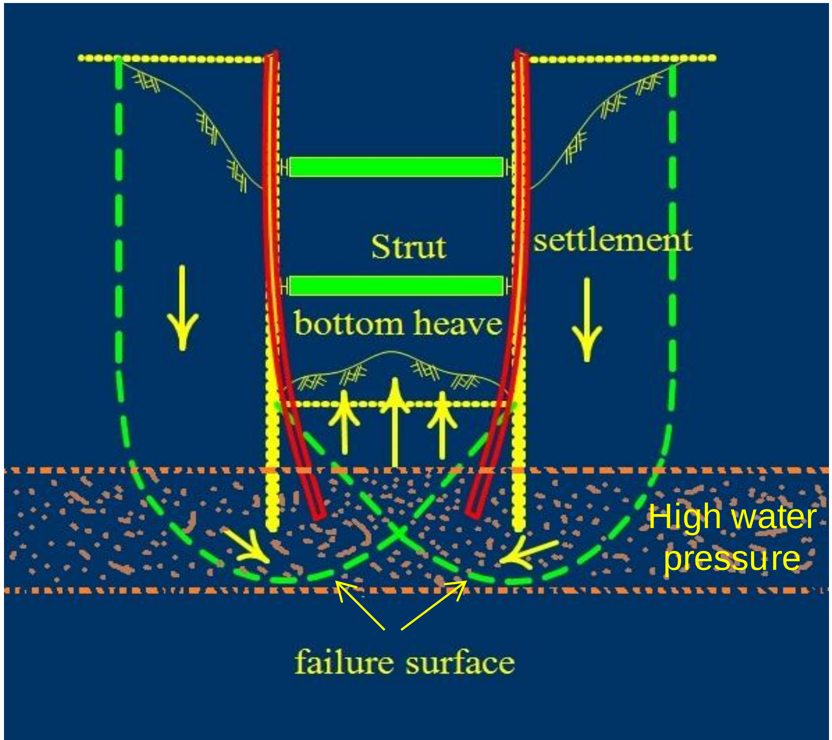


Modes of failure

- Overall shear failure
  - Push in
  - Basal heave
- Hydraulic Uplift- Bottom heave of overlying clay



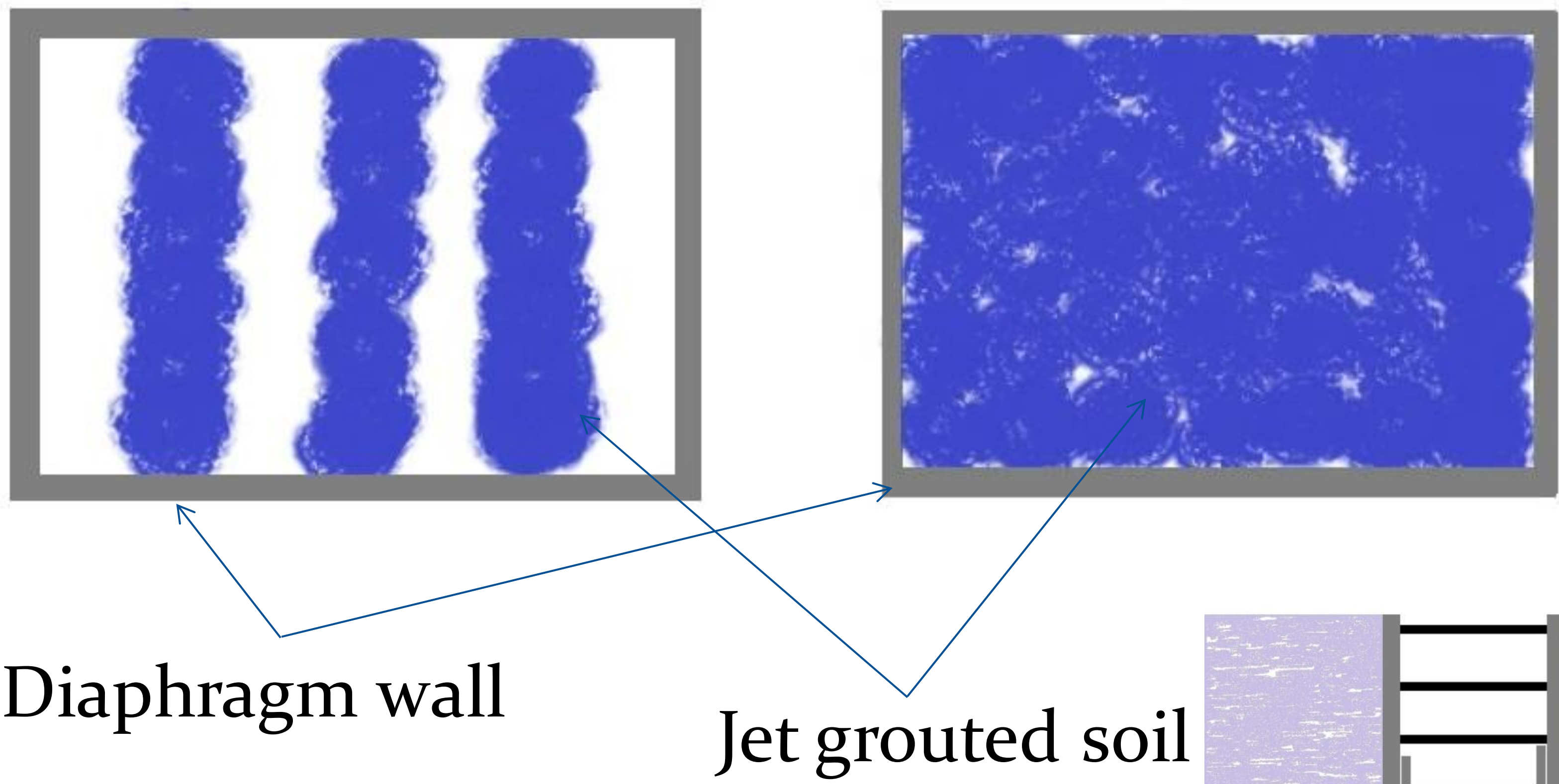


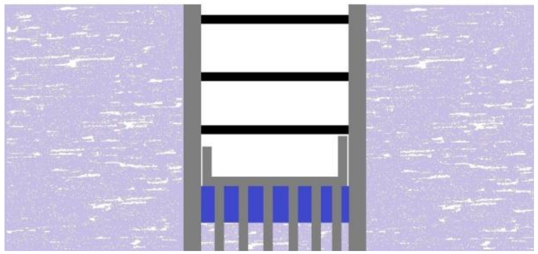


Prevention of Basal Instability

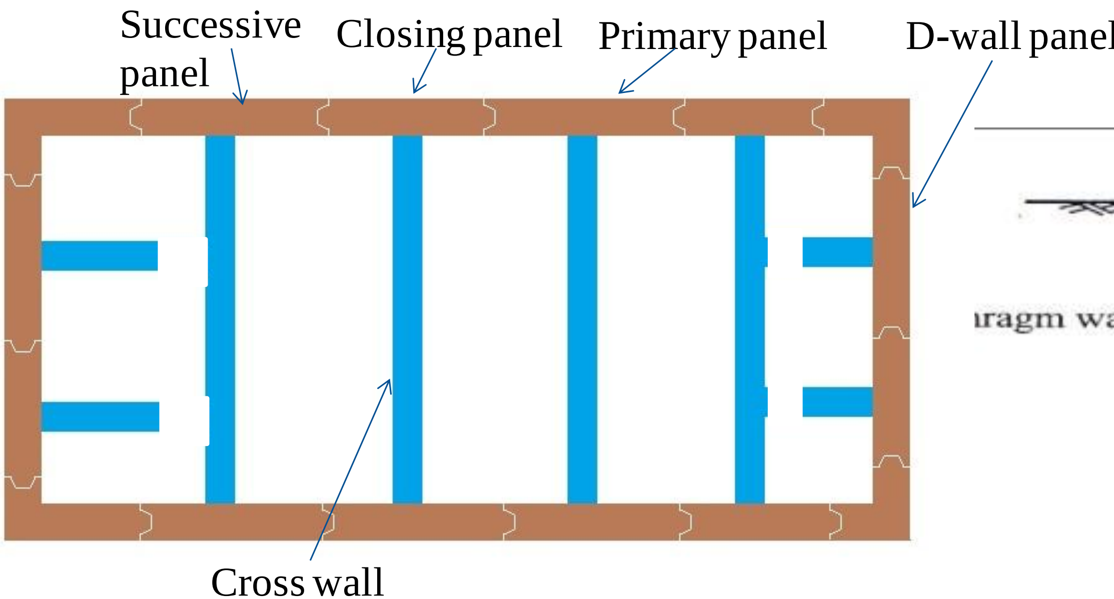
- Base strut by jet grouting
- Cross wall
- Soil Berm

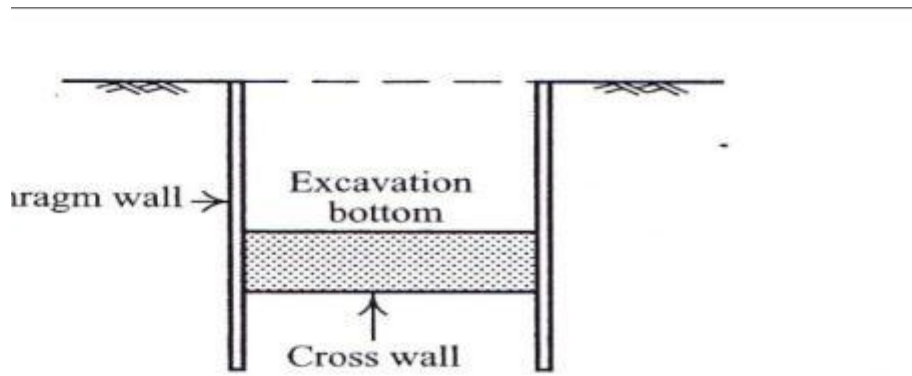
Soil Base improvement – Jet grouting – Base struts





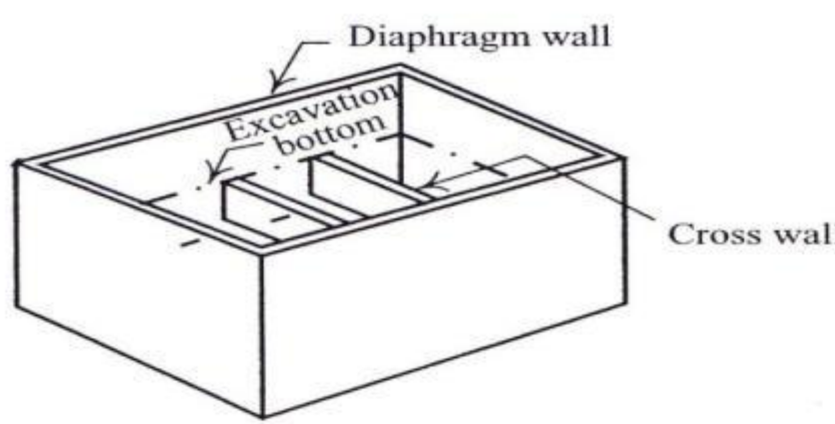
Cross Wall





(a)

(b)

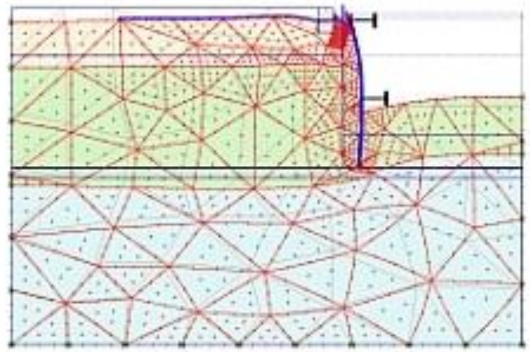


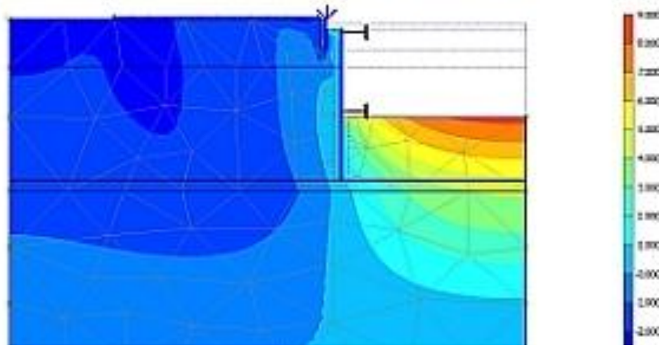
Selection of Wall Types for Deep Excavations

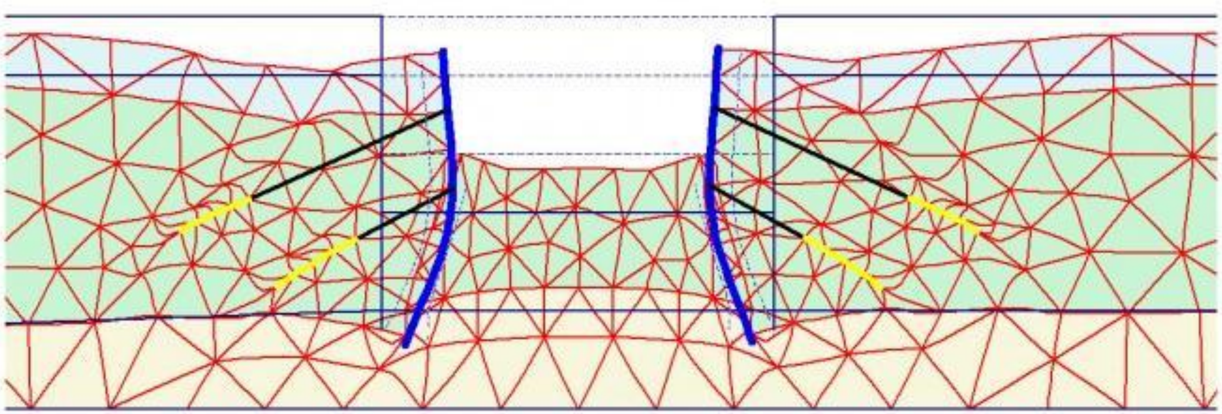
- Depth
- Size of Area
- Subsoils – Groundwater Conditions
- Conditions of Surrounding Buildings/Structures
- Cost
- Construction Time

Flexible versus Rigid Walls

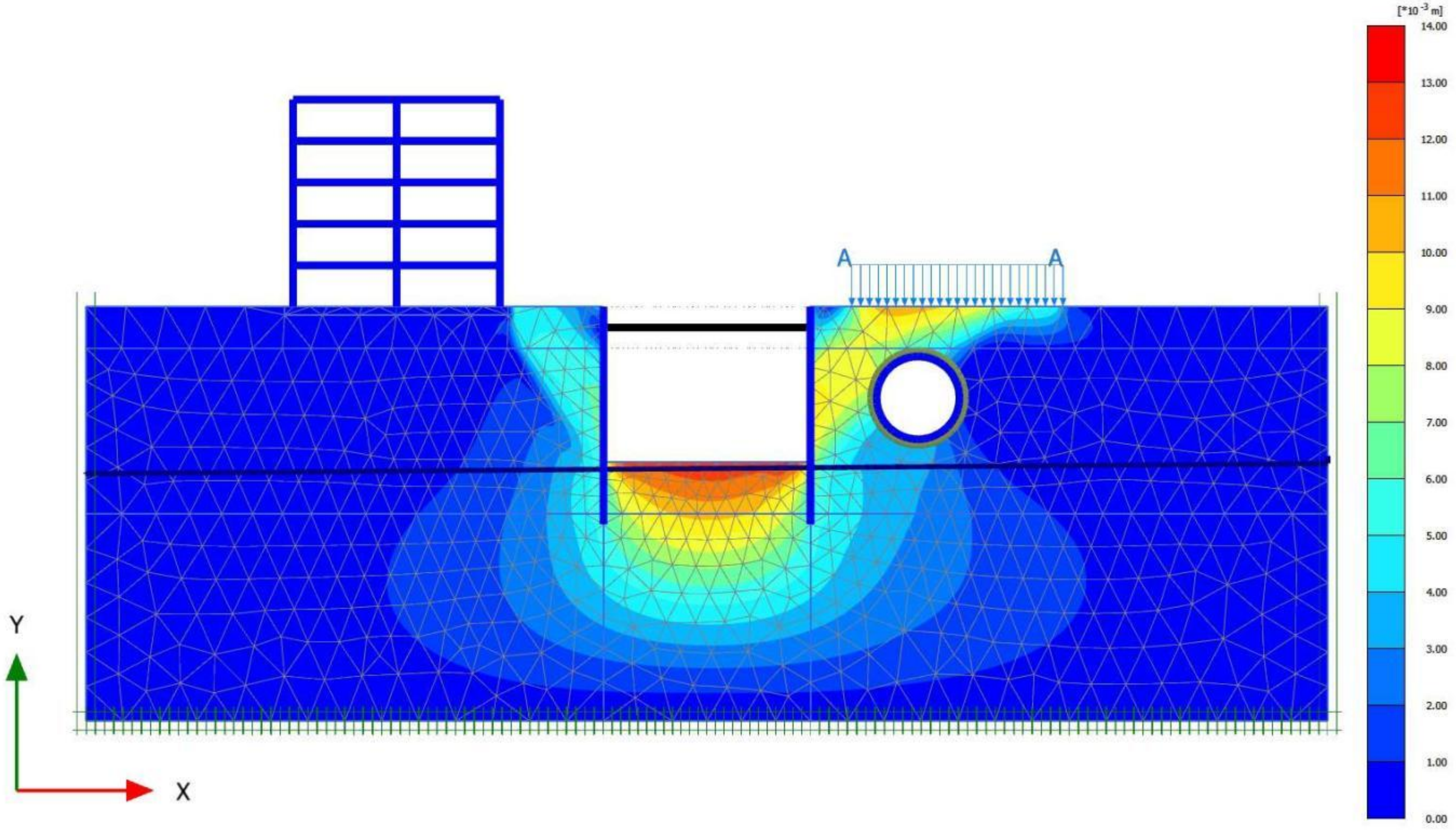
Numerical Analysis is an Indispensible Tool in Design of Deep Excavations





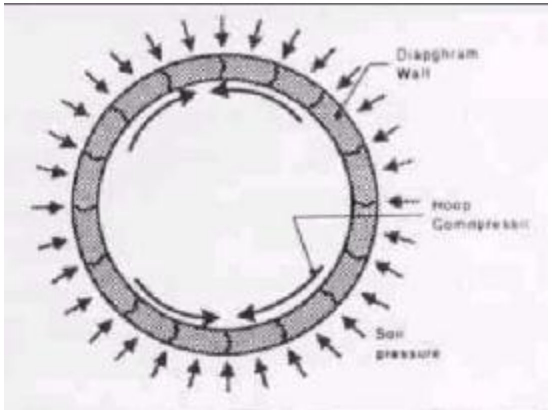


Effect of Excavation on adjacent Buildings and Structures



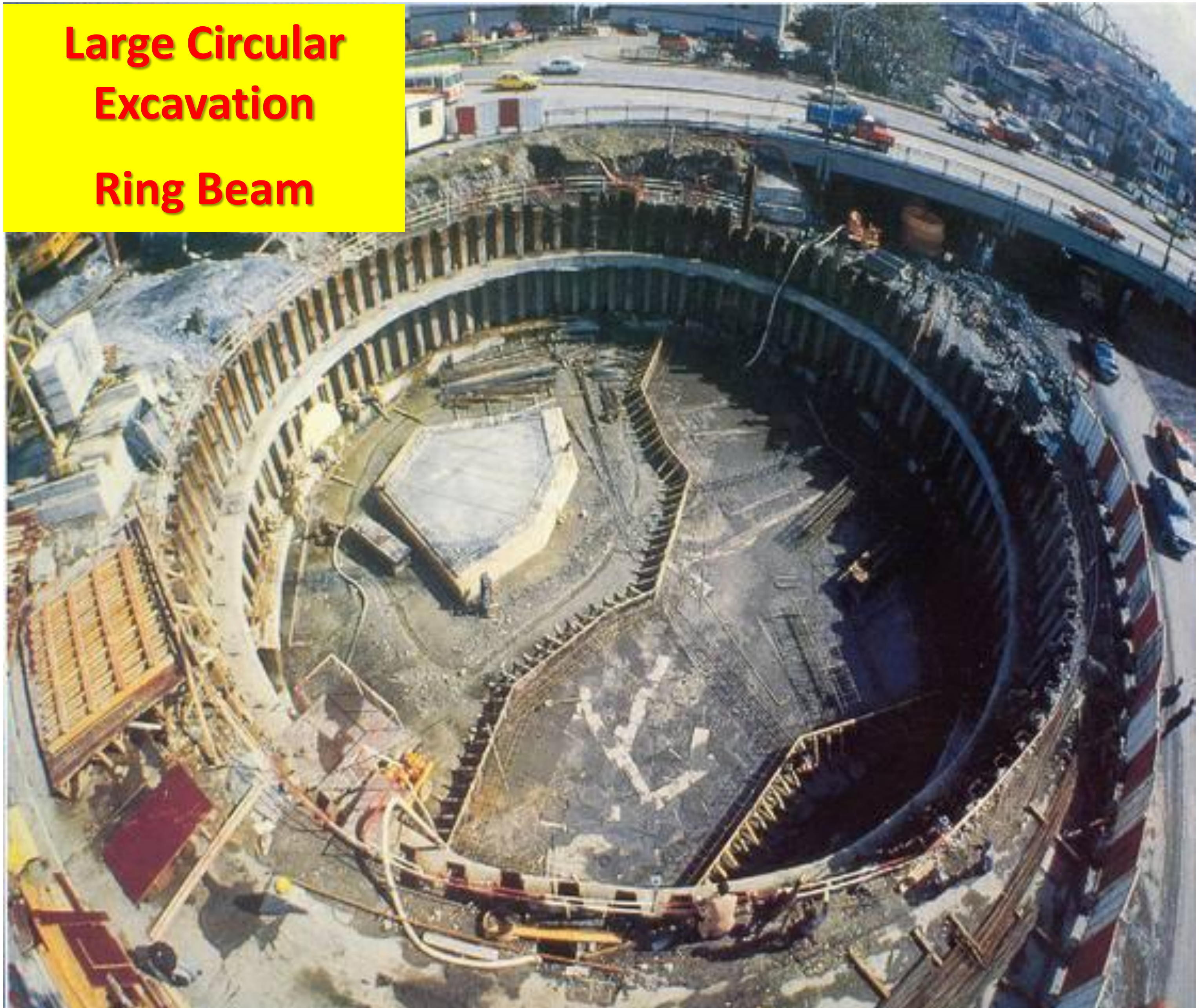
Circular Excavation

Ring Structure



Large Circular Excavation

Ring Beam



Numerical Study on a new Strut-Free Counterfort Embedded Wall in Singapore

(by: Er. SS Chuah and Er. Prof. Harry Tan) - National University of Singapore

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1. Other Examples of Strut-Free excavation system used in Singapore with regular shapes


Fig. 1 Peanut shape formed by 30m diameter diaphragm wall panels at The Sail @ Marina Bay


Fig. 2 2 levels of RC circular ring slab and beam (50m diameter each) constructed at SOHO @ Eu Tong Seng Street


Fig. 3 2 levels of RC circular ring slab and beam (78m diameter each) constructed at La Salle College at Prinsep Street


Fig. 4 Circular shape formed by 130m diameter diaphragm wall panels at City Square residential project at Jalan Besar/Kitchener Road

Fig. 5 Marina Bay Sands Integrated Resort South Podium Donut of 120m diameter excavation site

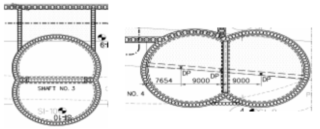


Fig. 6 Downtown Line C912 peanut shape temporary shafts no. 3 and 4 formed by secant pile walls for excavation in close proximity to the existing light rail transit (LRT) viaducts

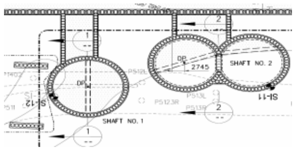


Fig. 7 Downtown Line C912 circular and peanut shape temporary shafts no. 1 and 2 respectively to suit the existing LRT structure and its foundation piles

2. New strut-free counterfort embedded diaphragm wall scheme and inclinometer readings


Fig. 8 Tribeca residential project with 2 basements using counterfort diaphragm wall panels and counterfort slab with perimeter diaphragm wall

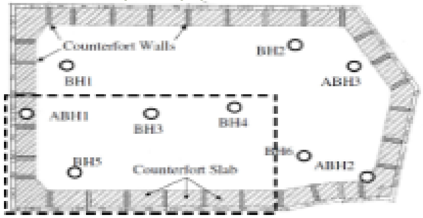


Fig. 9 Tribeca site investigation boreholes, counterfort walls and slab and a quadrant model for numerical study

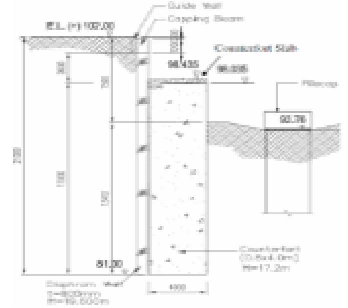


Fig. 10 Typical cross sectional view of diaphragm wall, counterfort wall and slab

3. 3D Quadrant Model study and Twin Counterfort Wall model

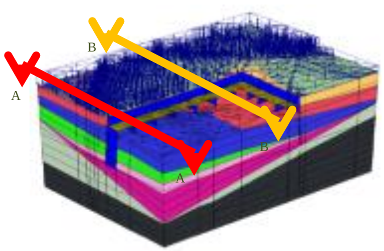


Fig. 13 One quadrant of 3D counterfort model showing the geological profiles based on various boreholes information

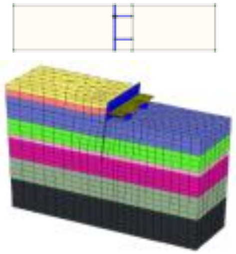


Fig. 14 3D twin counterfort walls model (plan and isometric views)


Fig. 15 These are site photos of Strut-Free counterfort diaphragm walls system adopted in South Korea

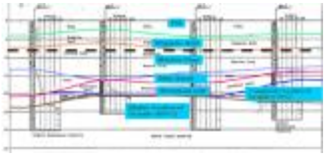
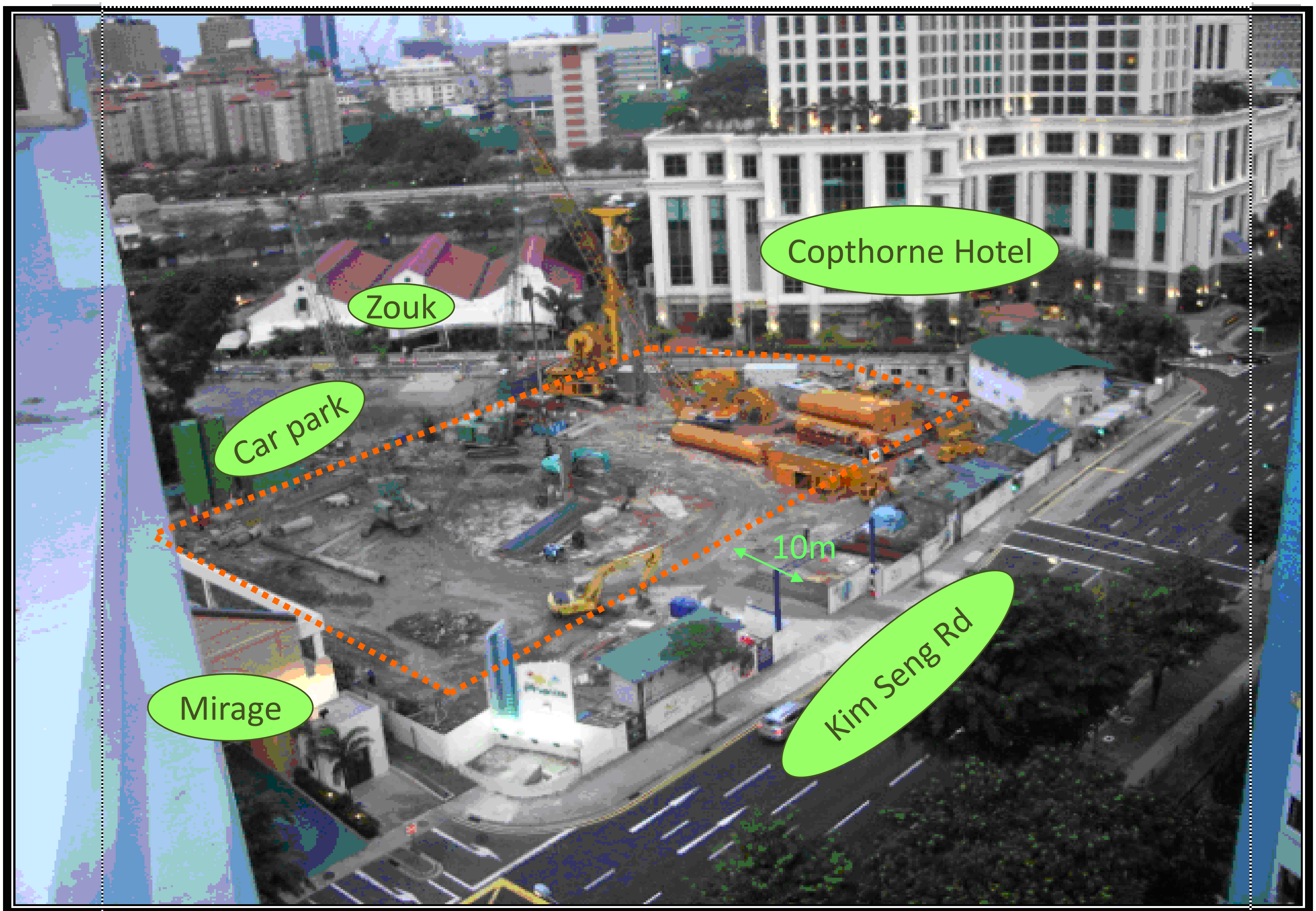


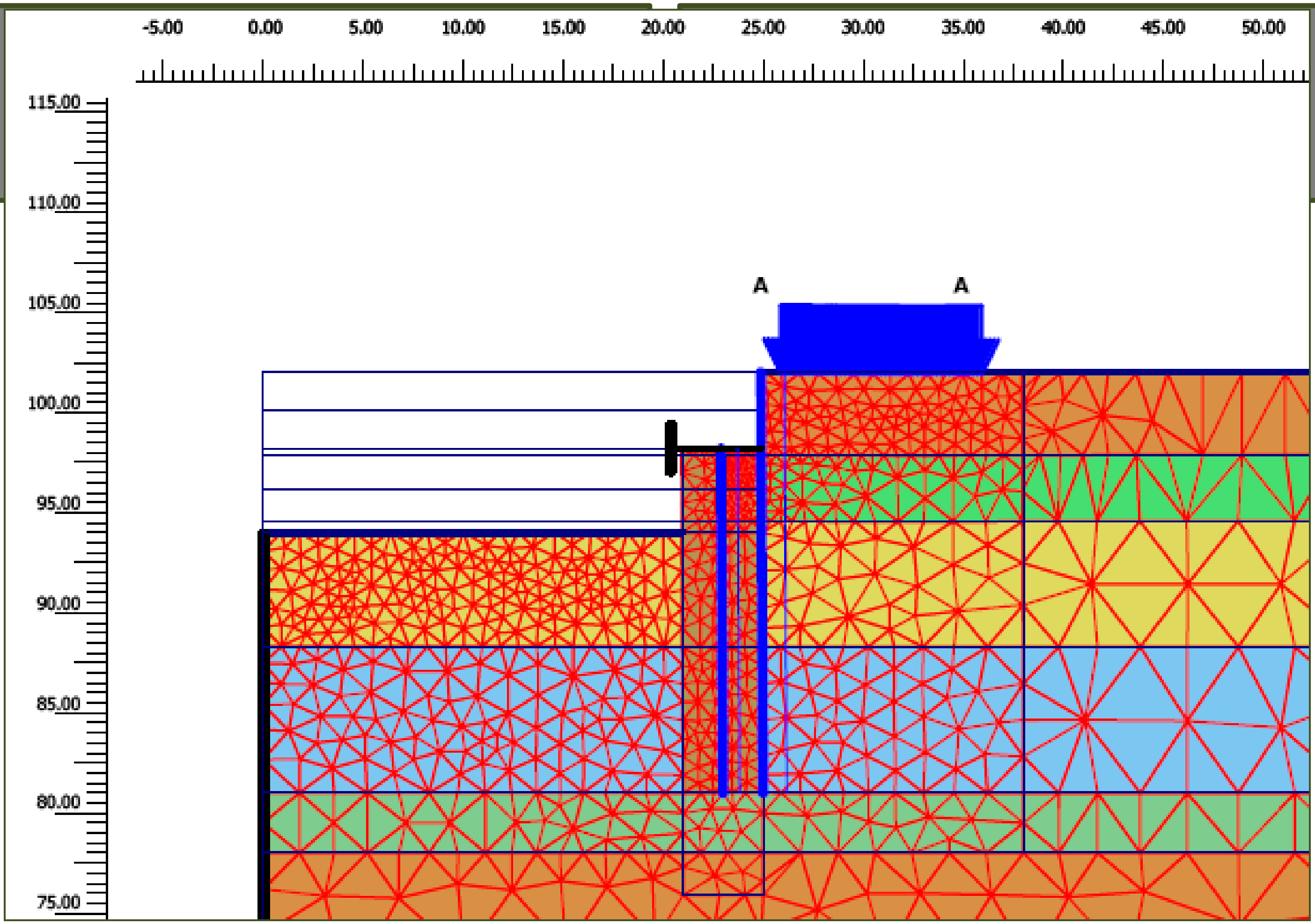
Fig. 16 Typical geological profile at Tribeca site

Minimizing Lateral Support Singapore Case Study



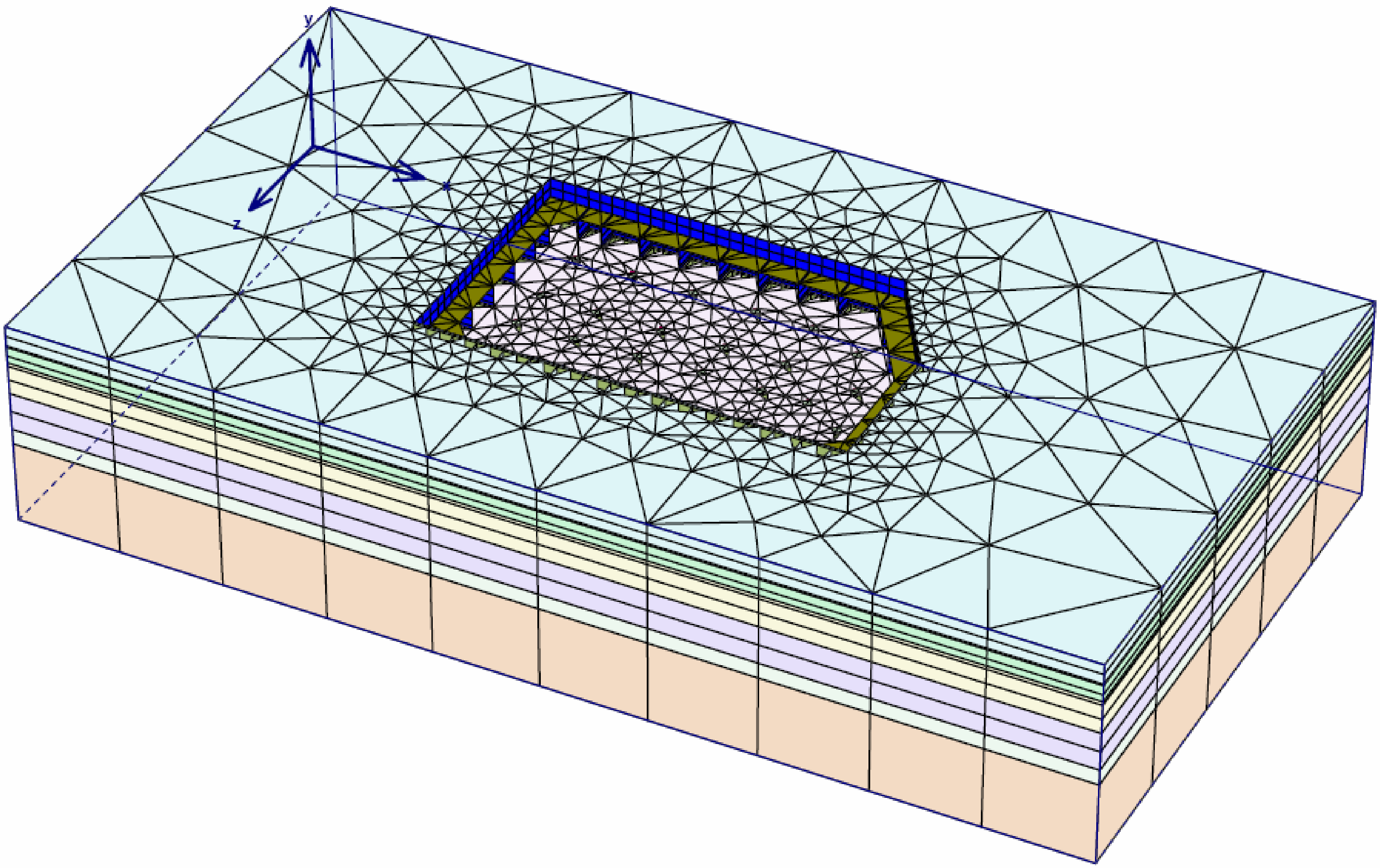
Geotechnical Design for Deep Excavations

2D FEA Borehole adopting worst relevant borehole BH5



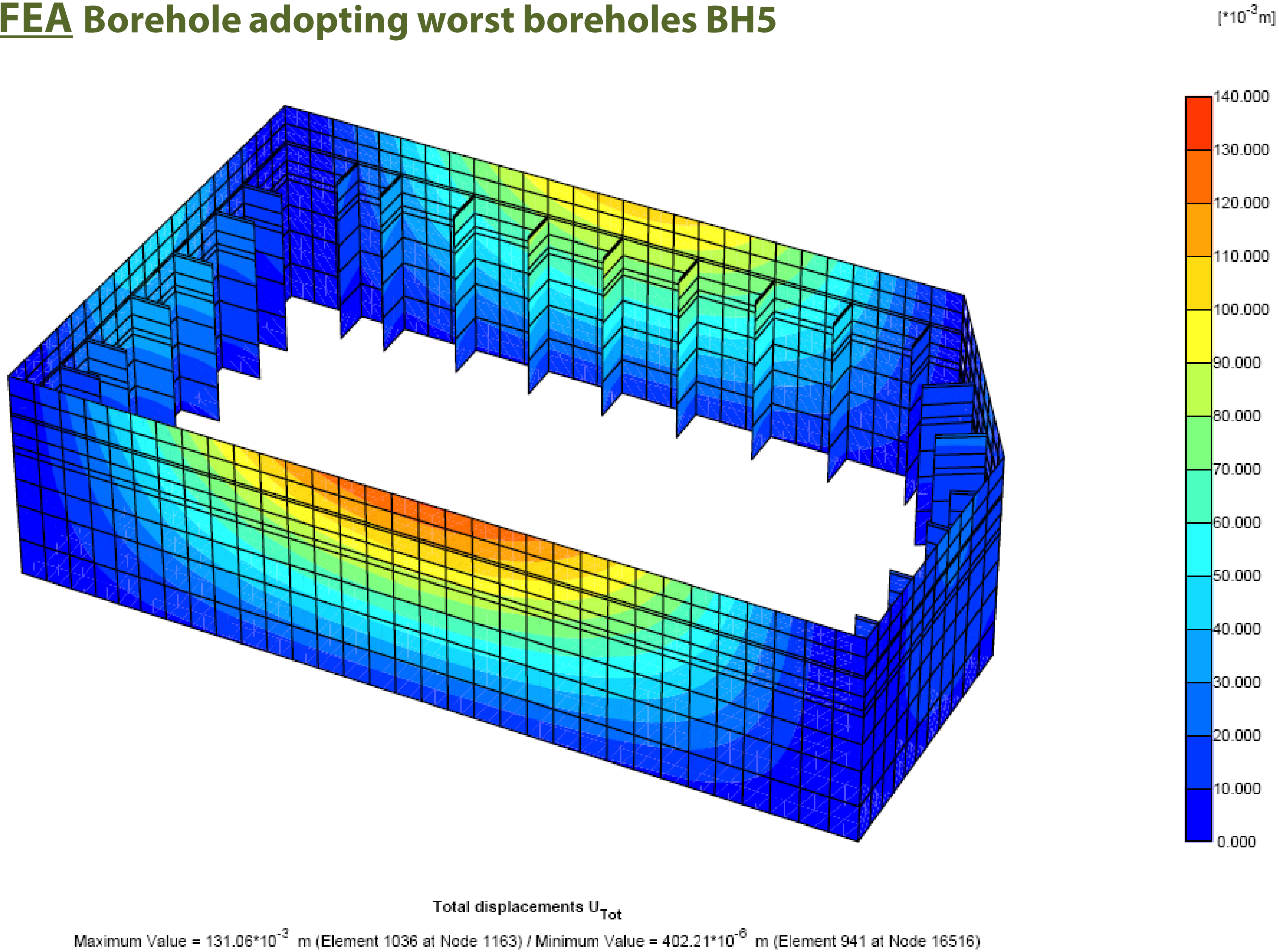
Geotechnical Design for Deep Excavations

3D FEA Borehole adopting worst relevant borehole



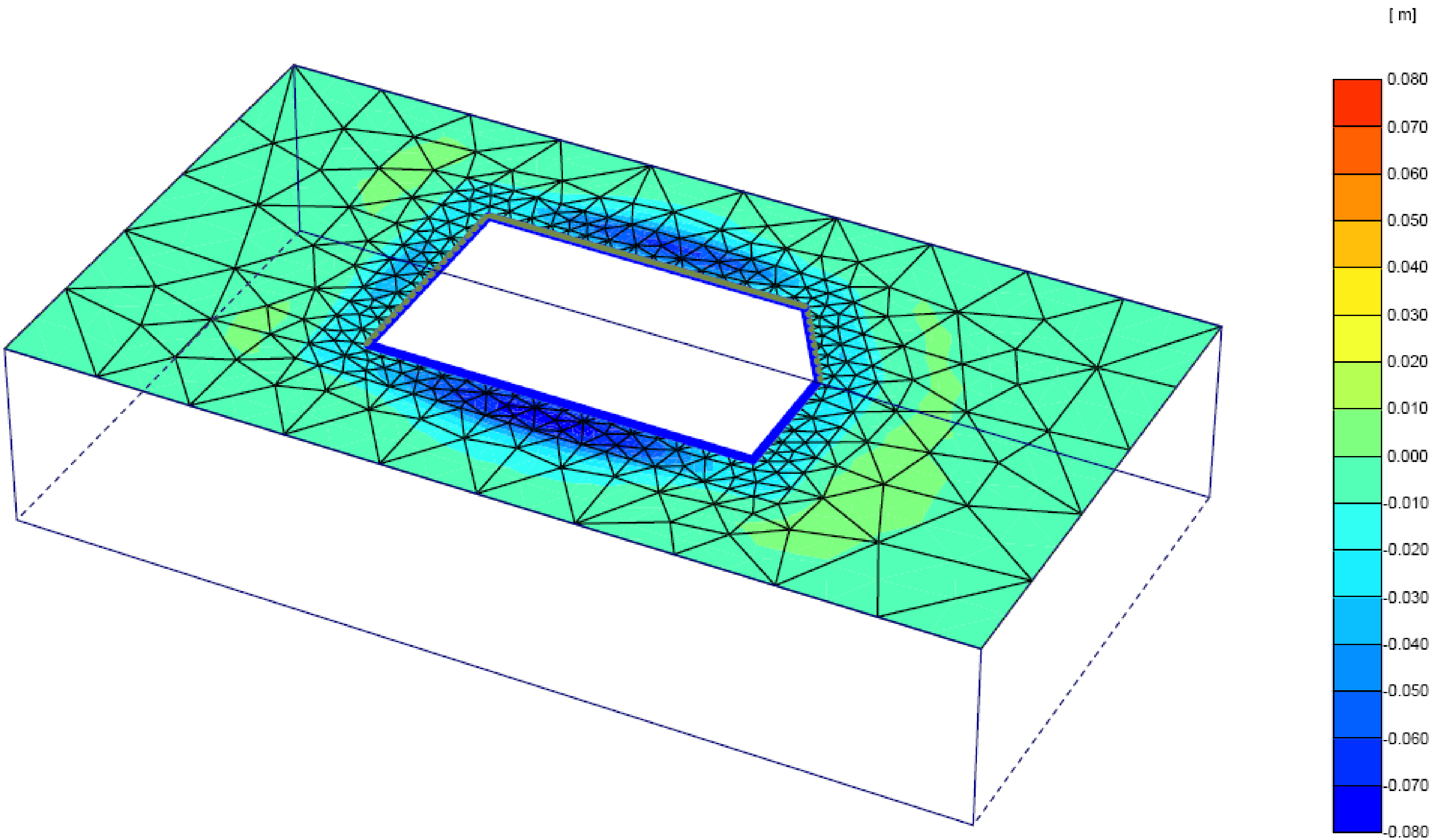
Wall Deflection

3D FEA Borehole adopting worst boreholes BH5



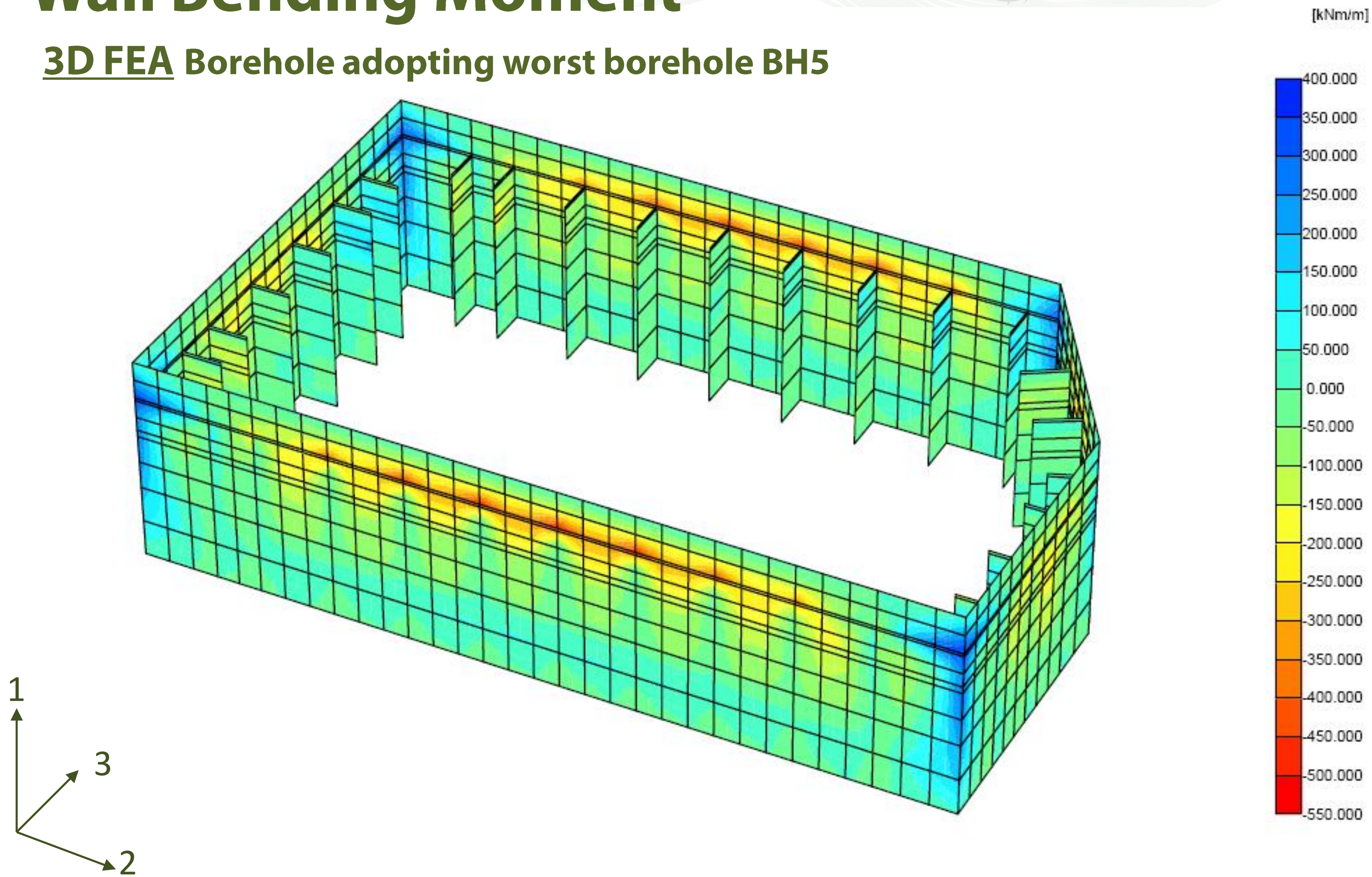
Ground Settlement

3D FEA Borehole adopting worst borehole BH5



Wall Bending Moment

3D FEA Borehole adopting worst borehole BH5



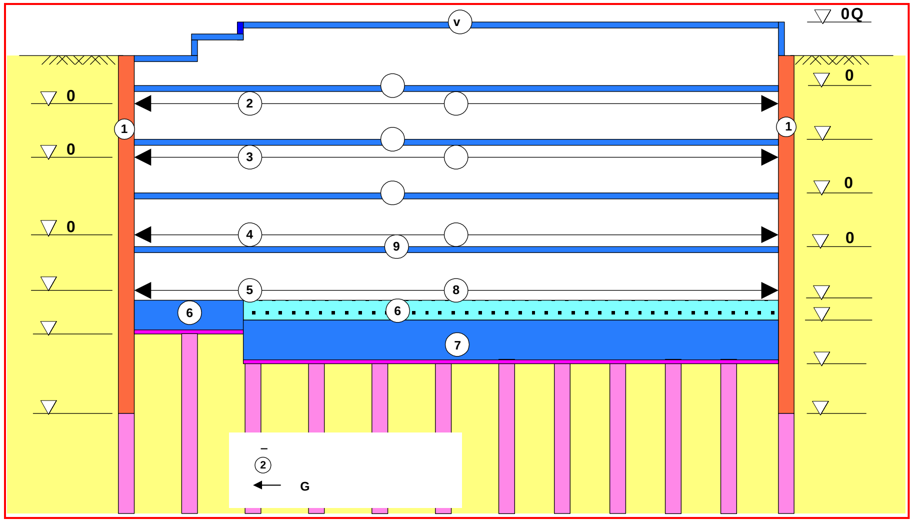
Bending moments M_{11}

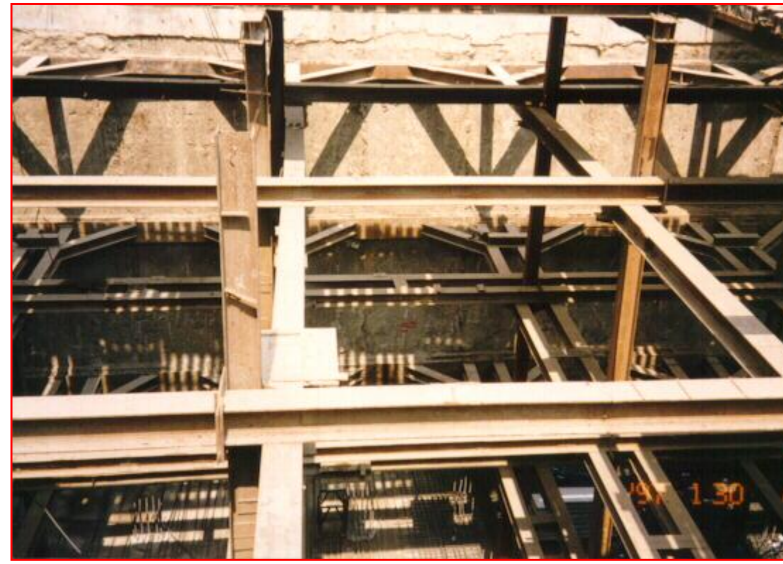
Maximum Value = 374.23 kNm/m (Element 856 at Node 8584) / Minimum Value = -502.90 kNm/m (Element 421 at Node 9312)

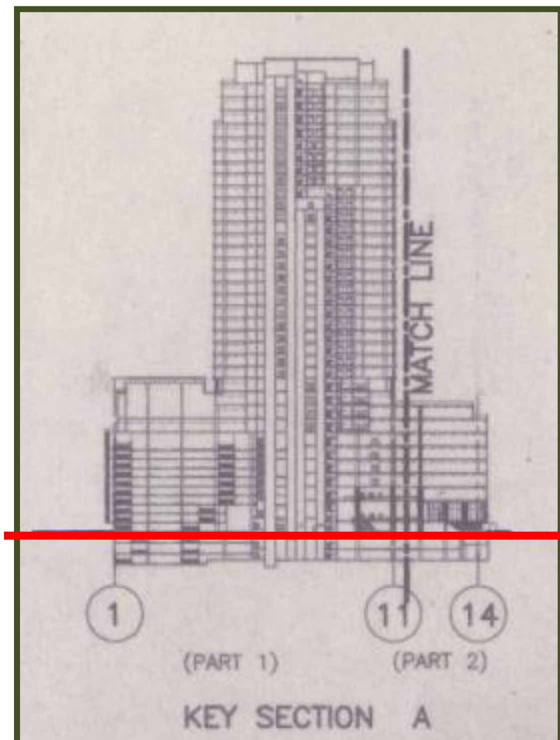
Top down construction versus Bottom up construction

- Time versus Cost
- Depth, Soil
- Substructure
- Preformed column

Bottom-Up Construction







APPLICATION OF TOP-DOWN CONSTRUCTION METHOD

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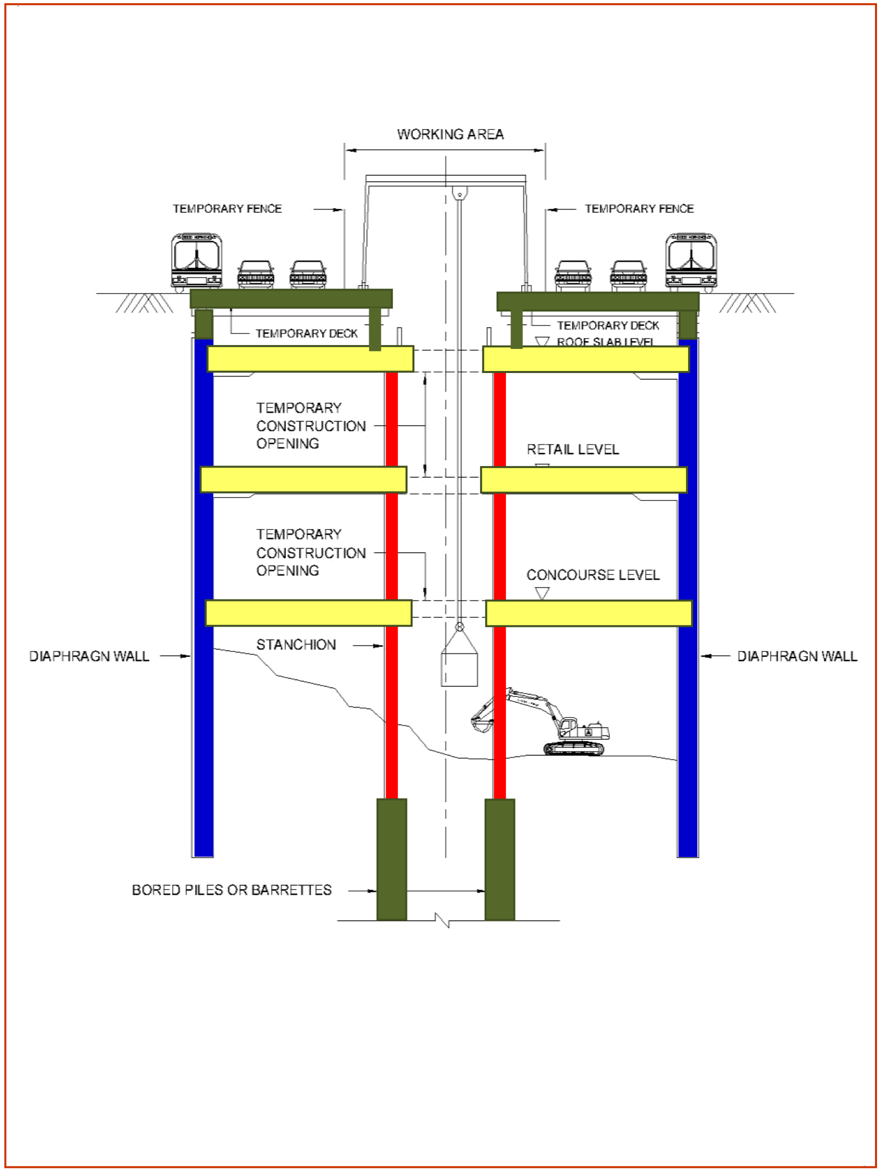
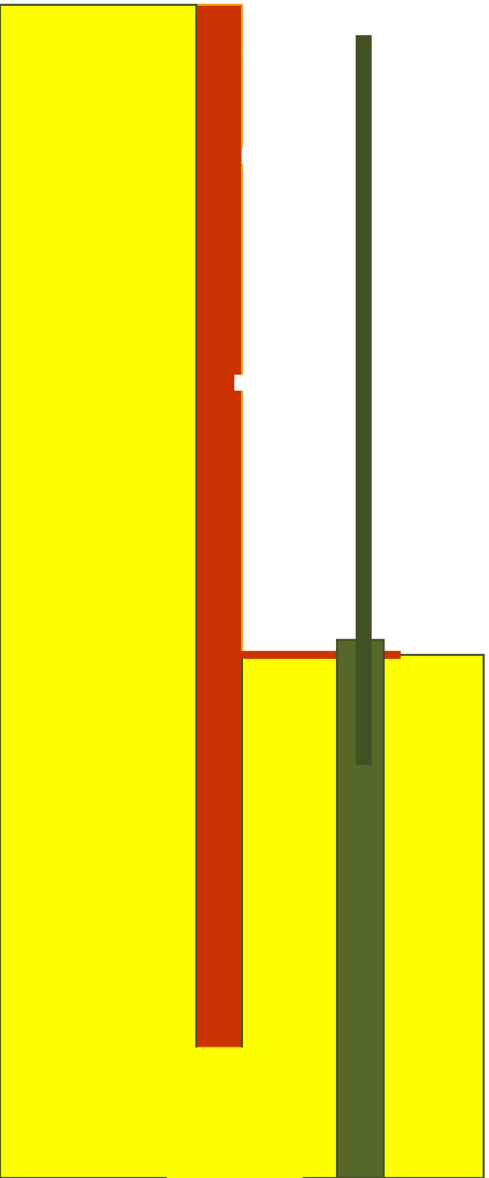
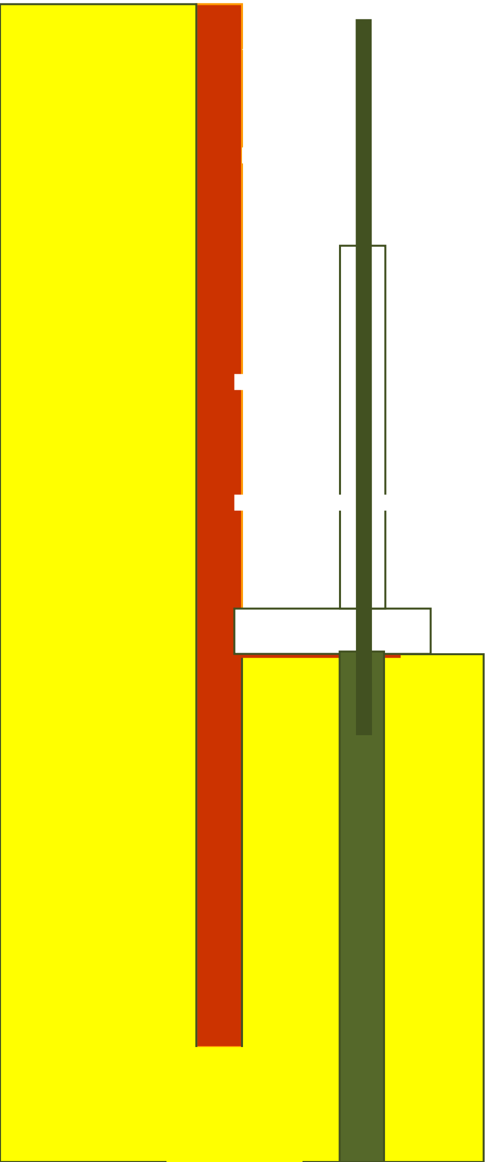


View of stanchion embedded in bored pile at base slab level

Excavation Reached to Final Depth -19.10m



Casting RC Column Encasing Stanchion

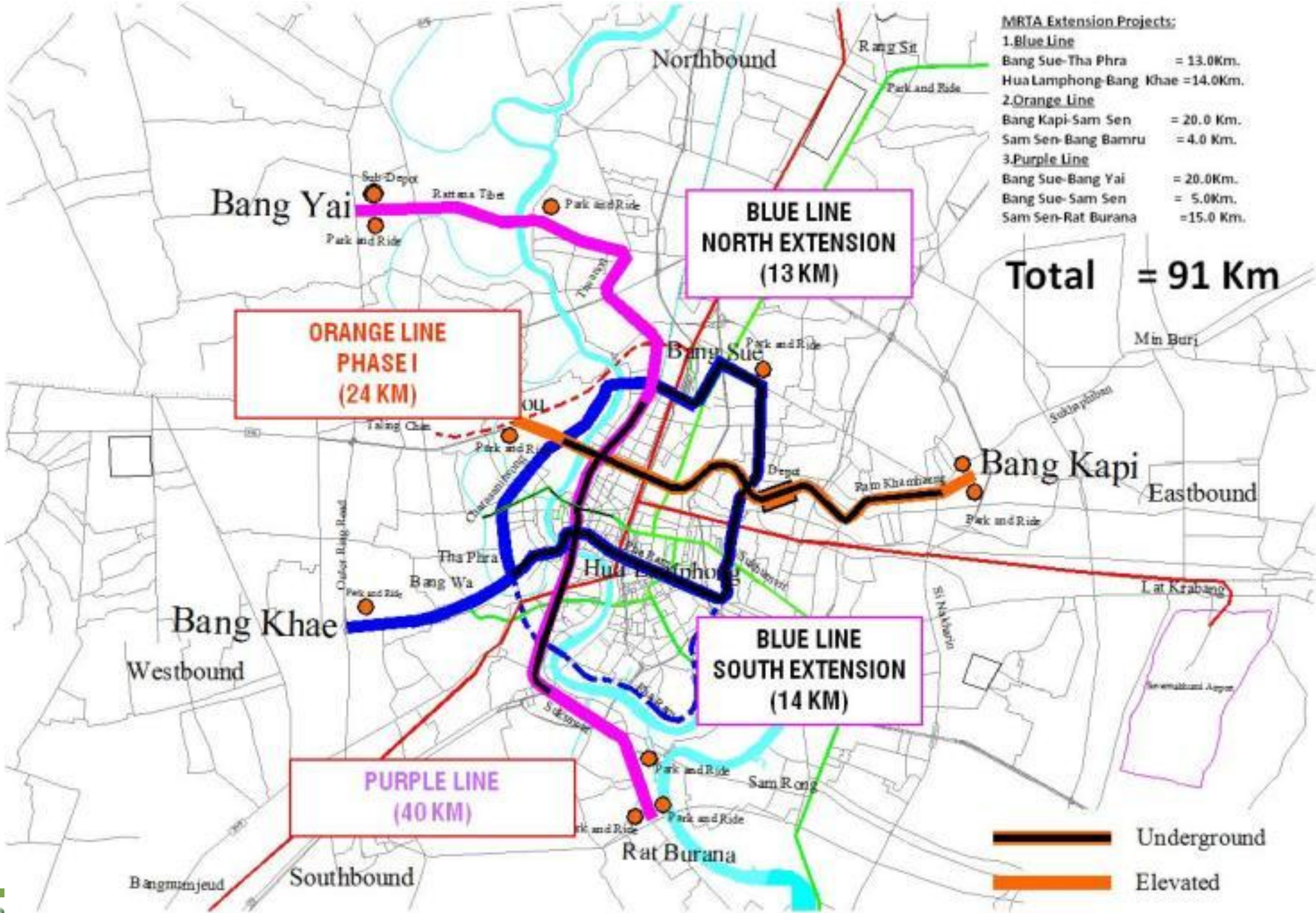


Master Schedule of Construction Comparison between Top-down and Bottom-up Method

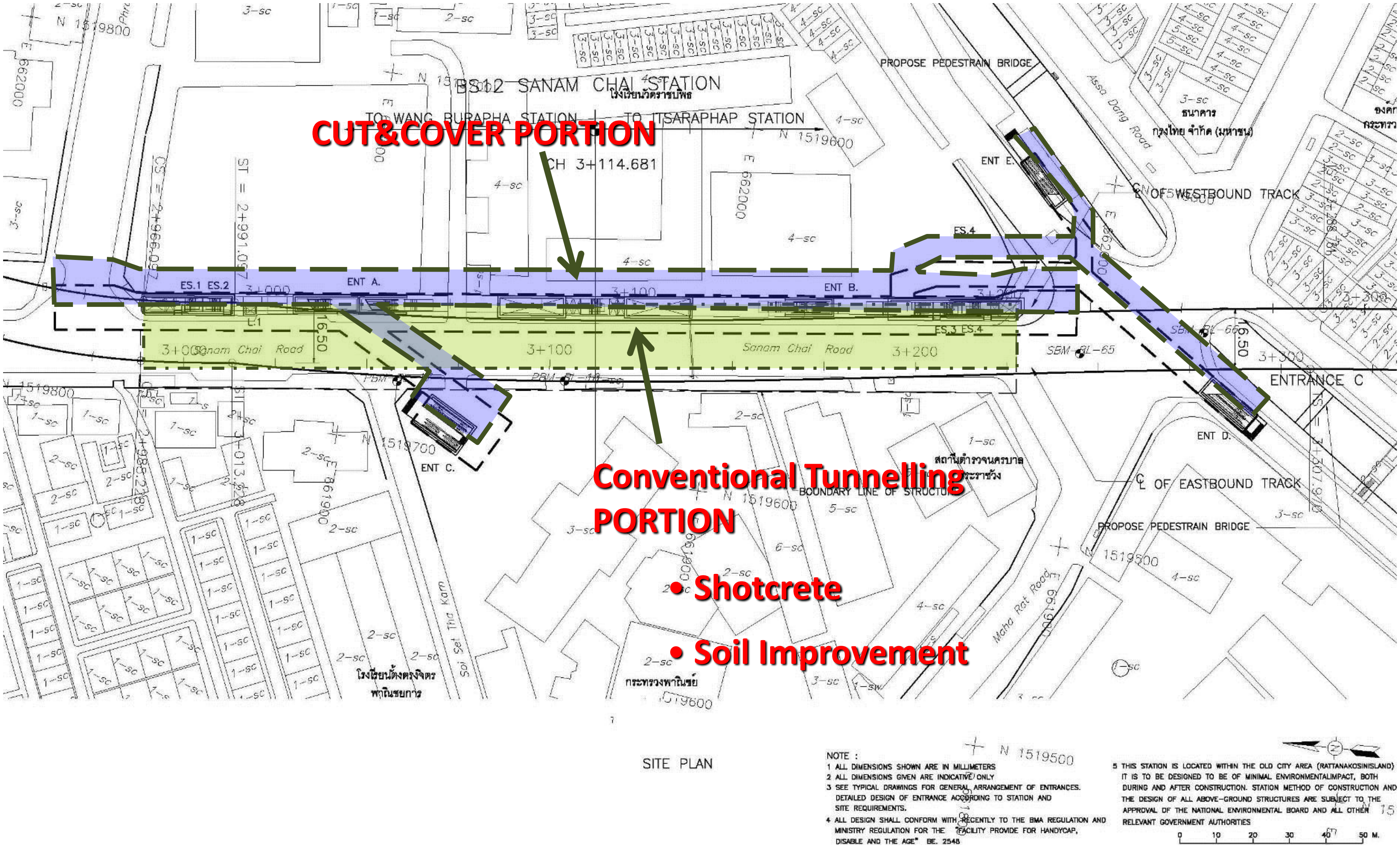
- **Significant time saving by Top-Down Method**

Method	Major Activity	Duration (month)	Construction Period (Month)							
			4	8	12	16	20	24	32	36
Top-down	D-wall and piling	4.5								
	Sub-structure	10								
	Super-structure	12								
Bottom-up	D-wall and piling	4.5								
	Sub-structure	16								
	Super-structure	13								

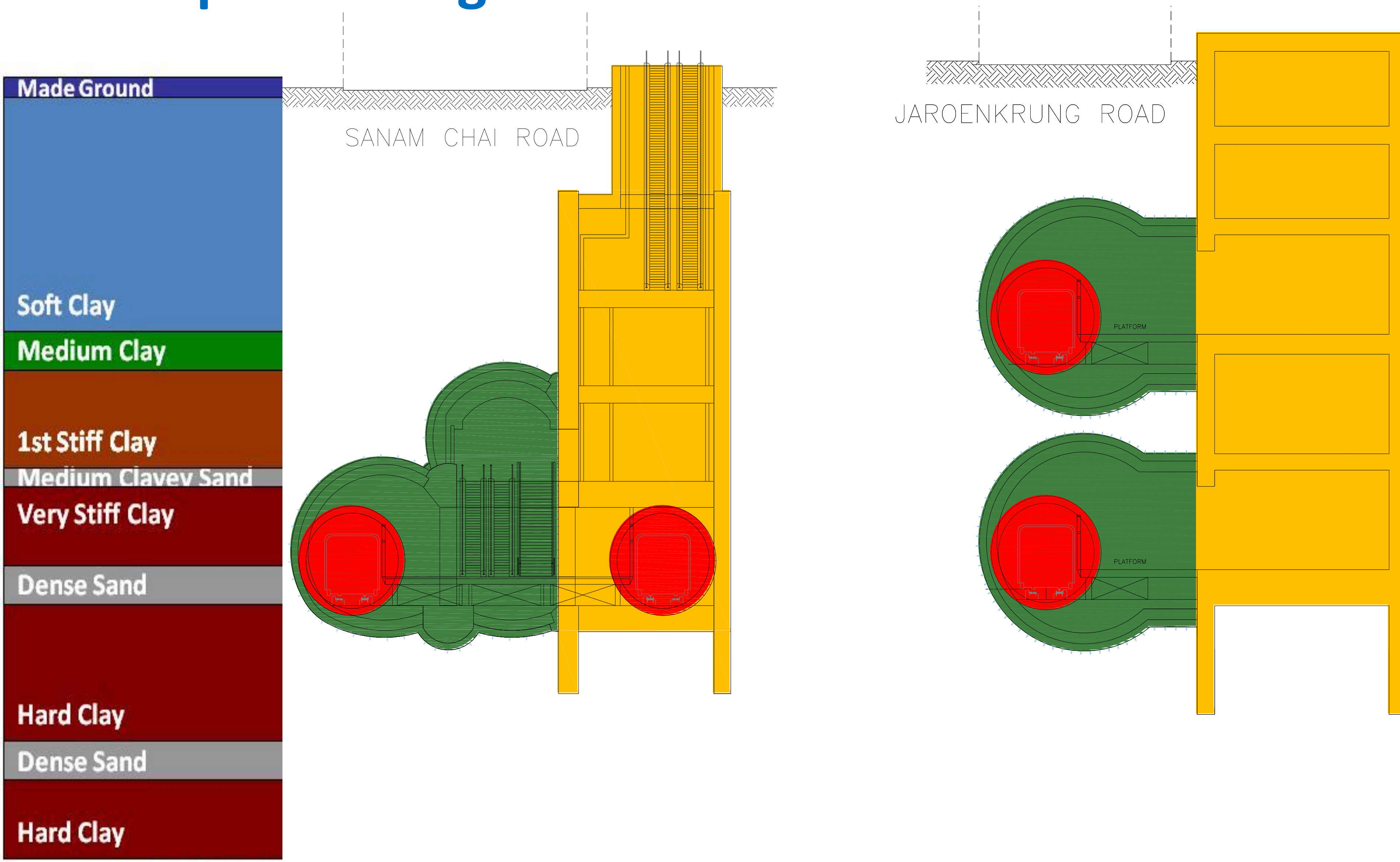
On Going and Upcoming Subway Construction in Bangkok



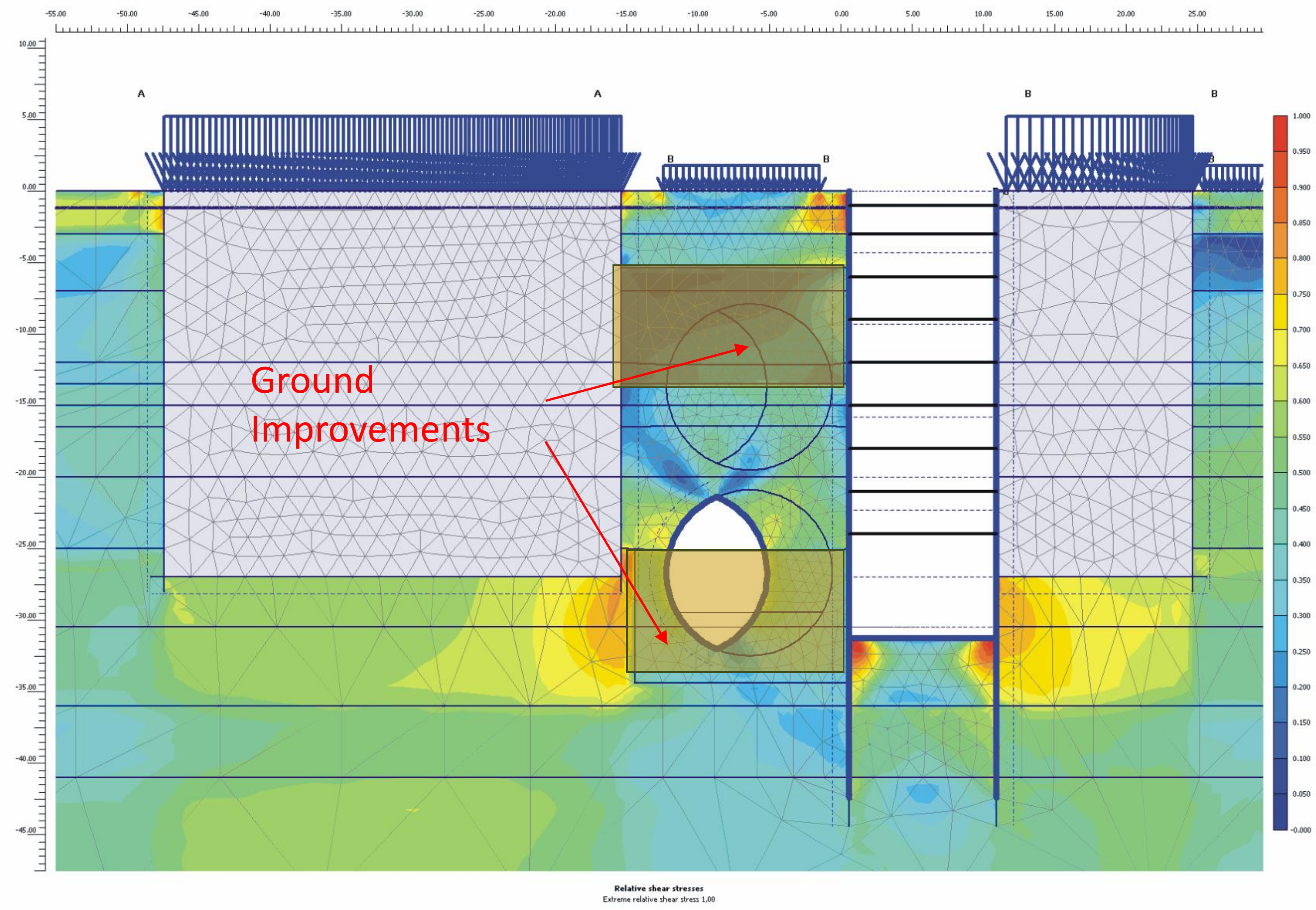
Combined Methods of Station Excavation



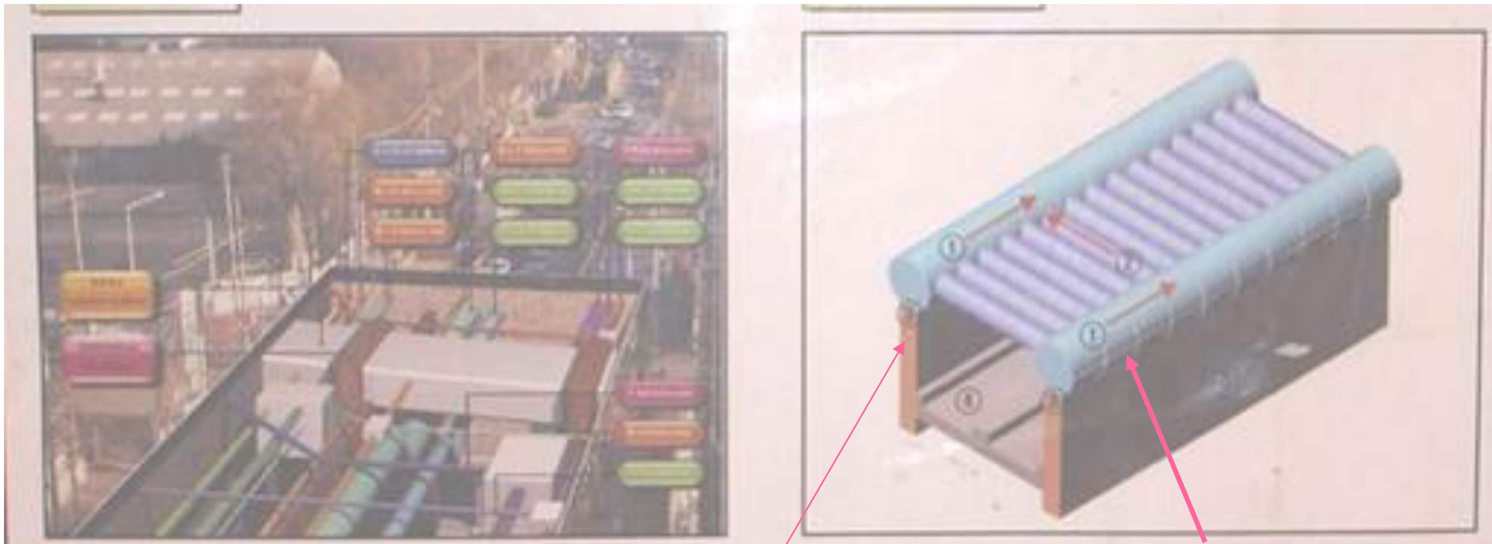
Conceptual Design of Station Excavation



FEM Analysis



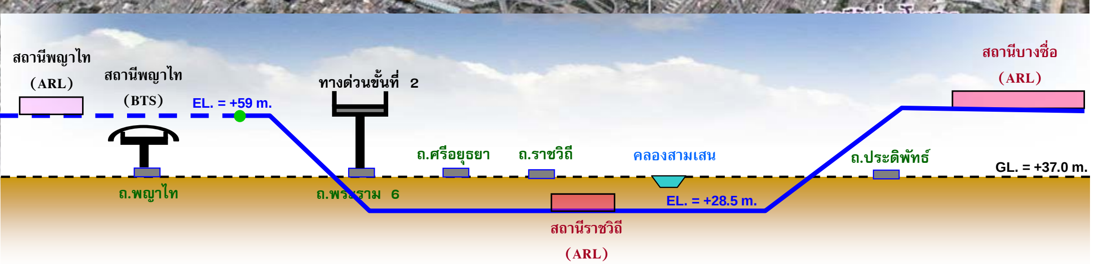
Alternative construction method actually adopted by Contractors

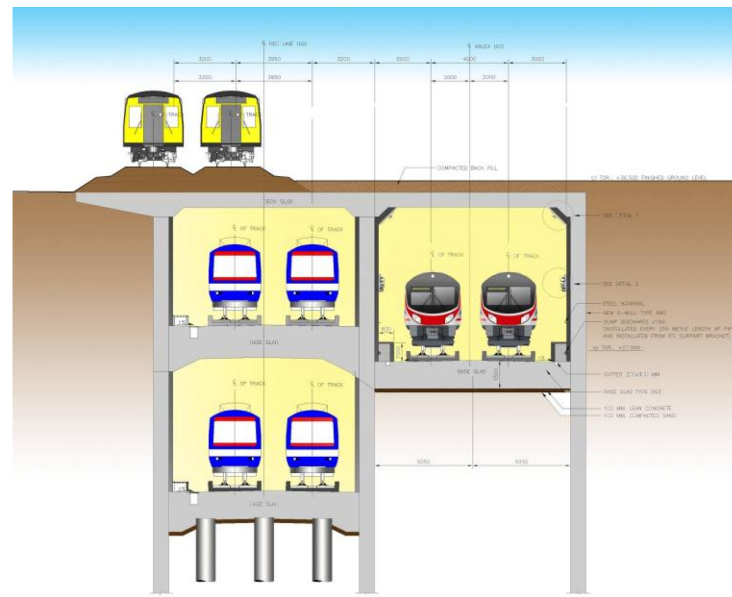


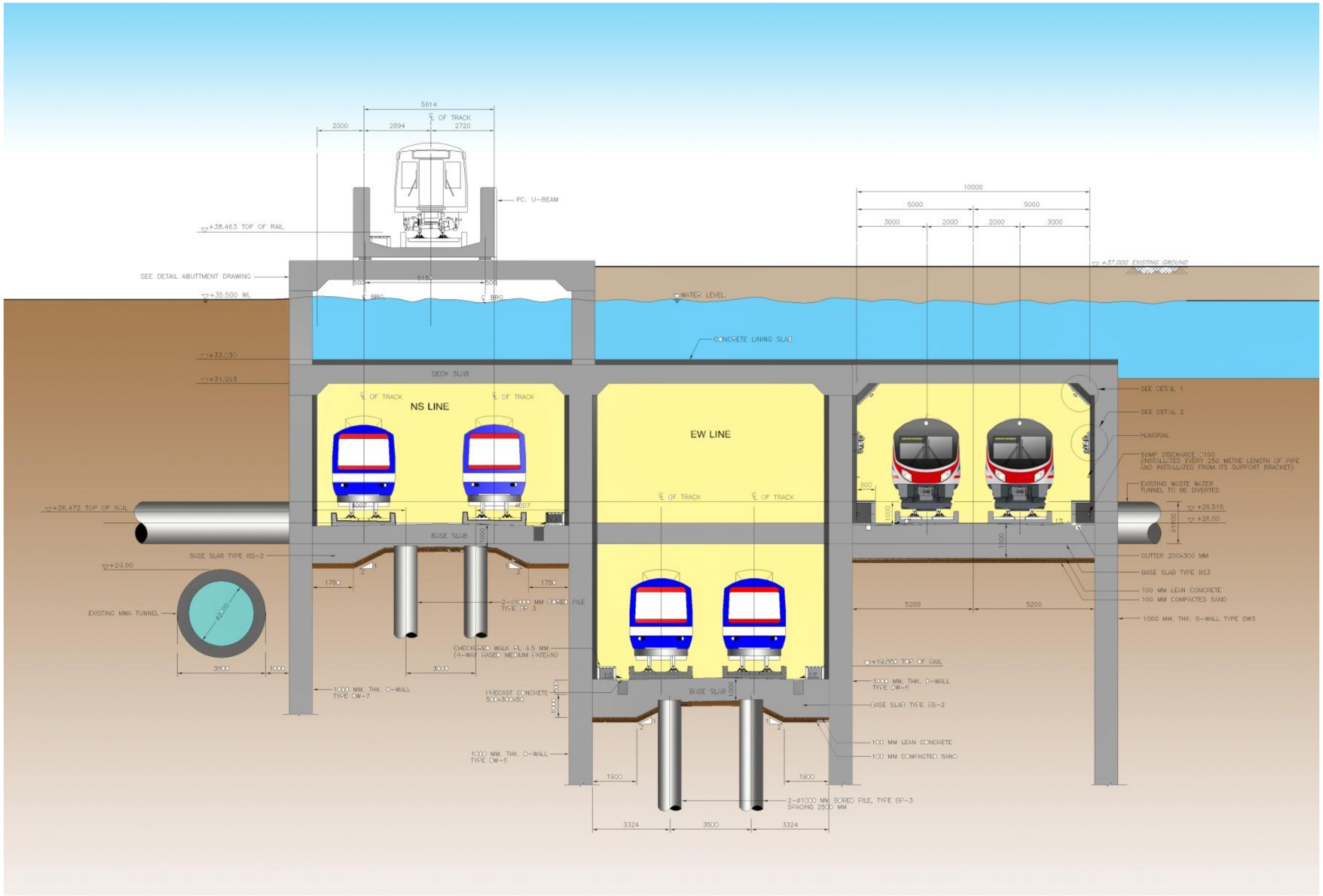
Difficult & Expensive

Risk Management

Missing Link Project SRT Railways and Red Line-MRT

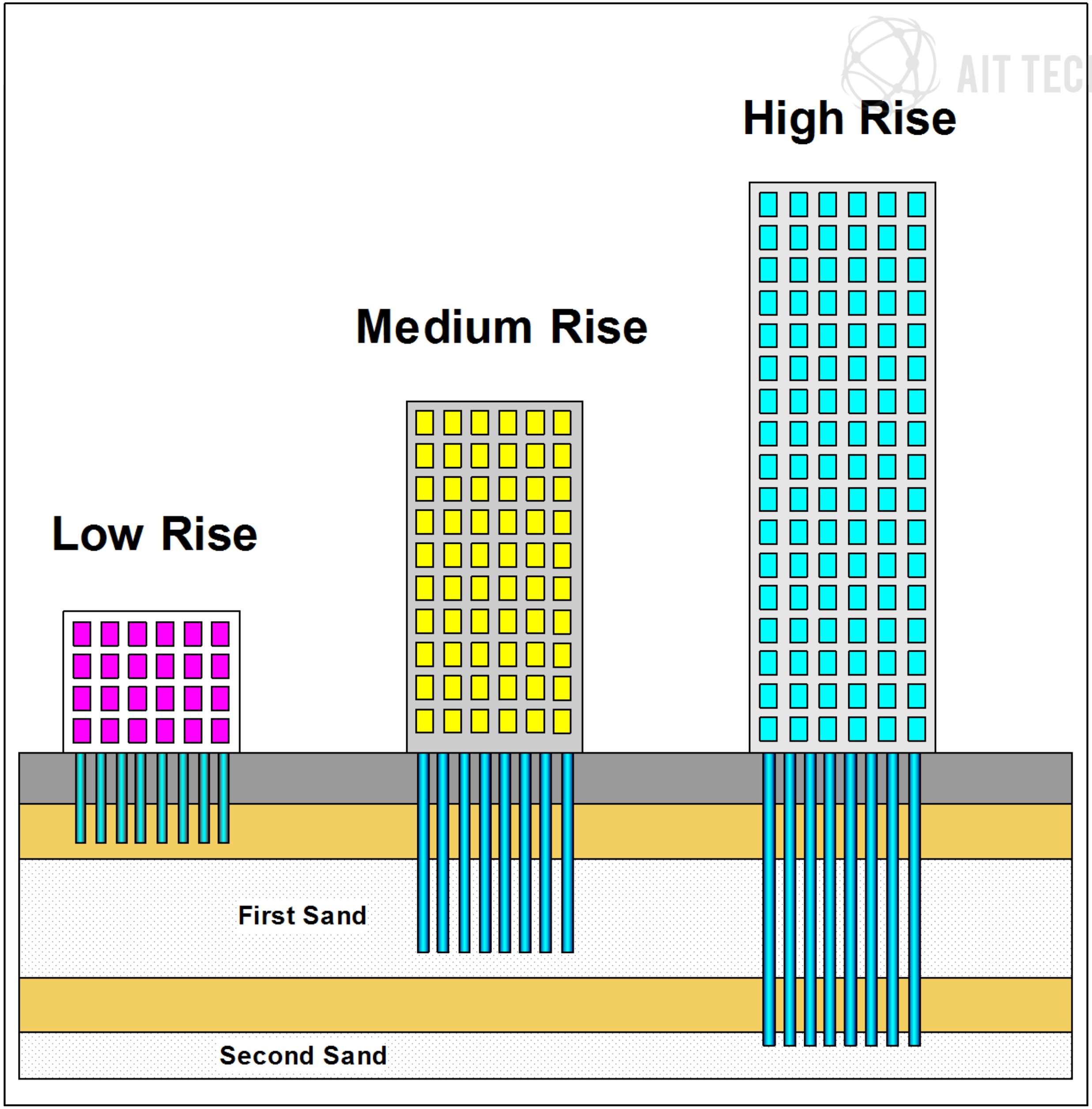






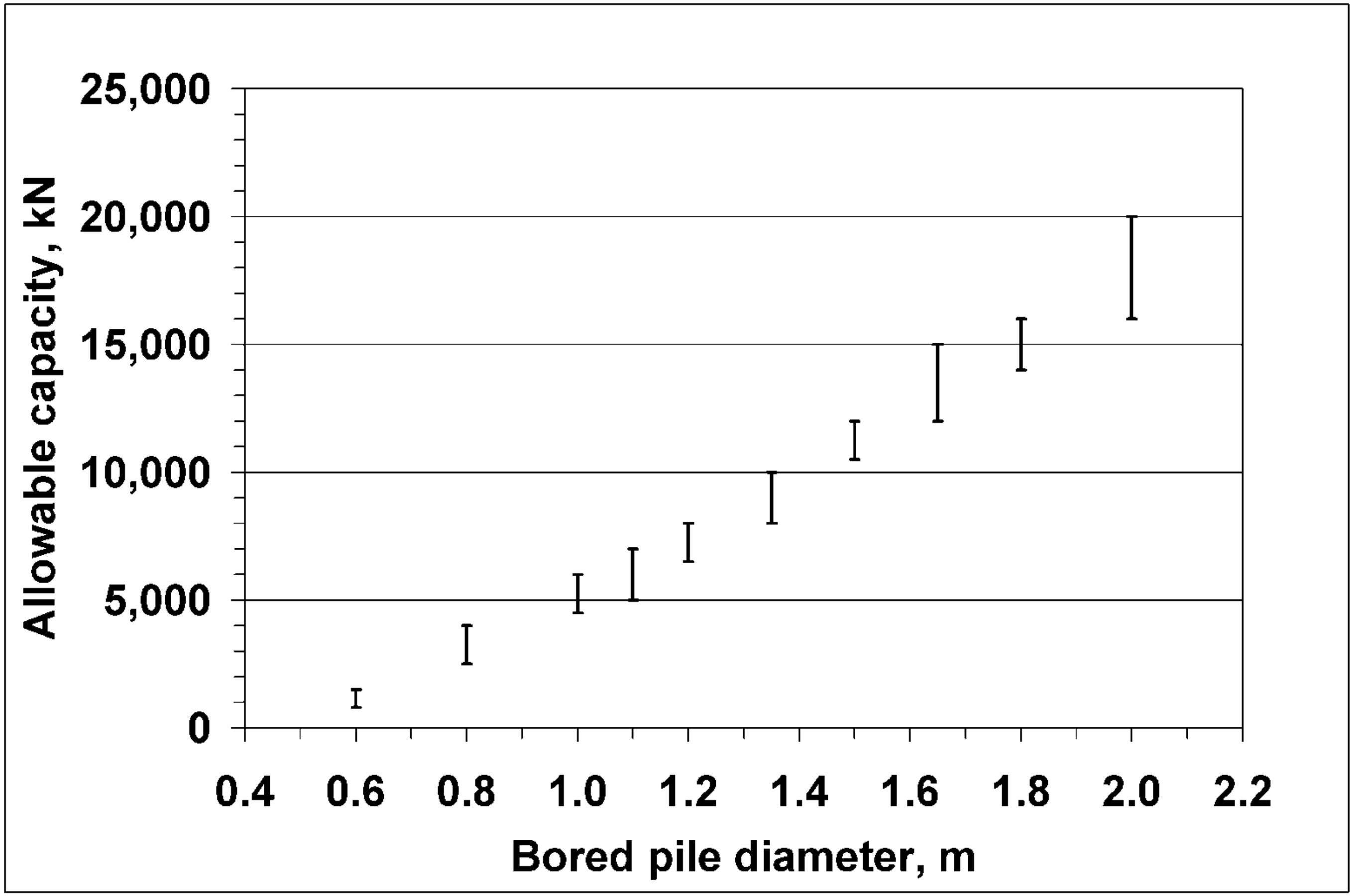
Layout of SRT Missing Link underground section for Red Line and rails for normal intercity trains

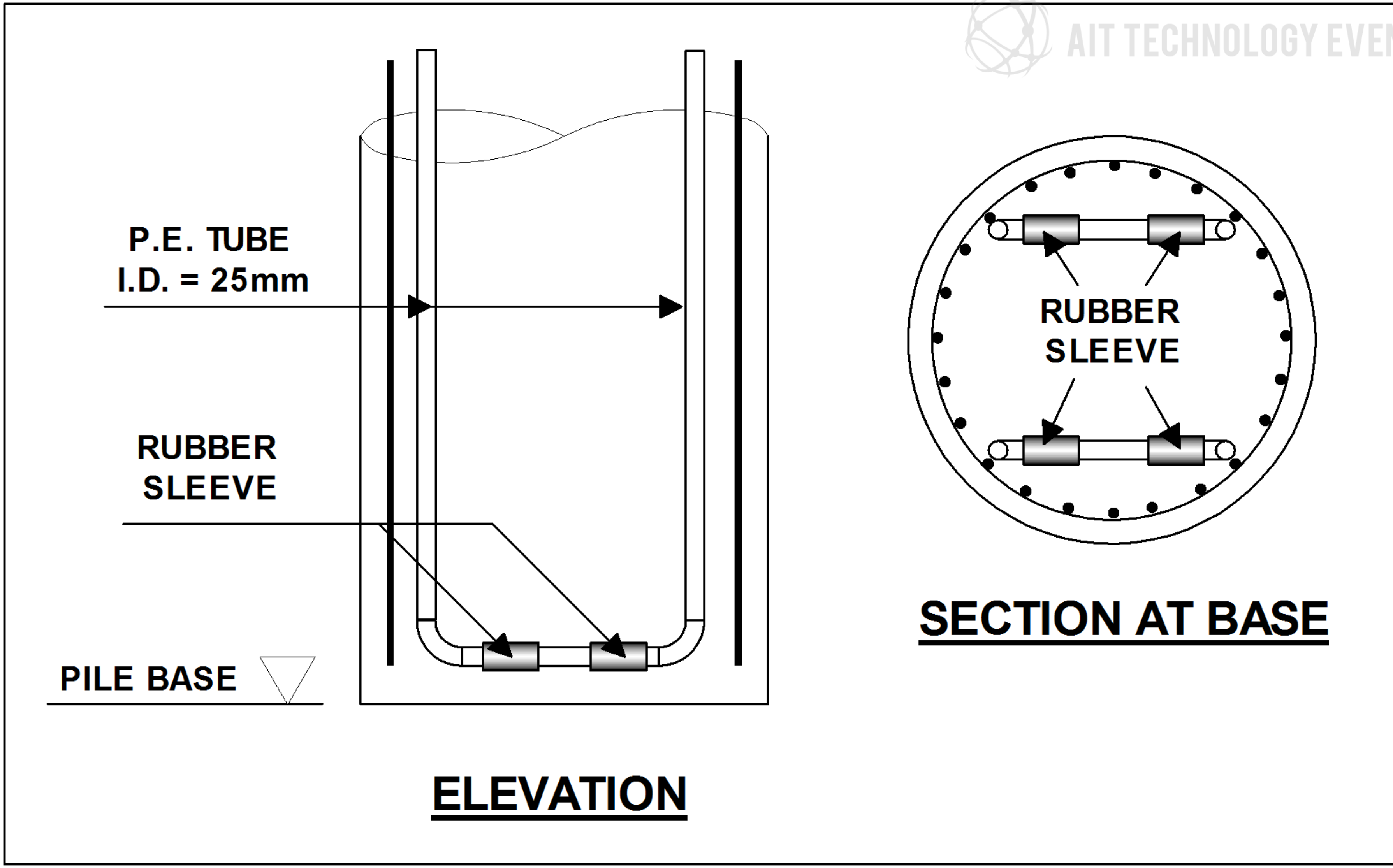
Pile Foundation in Bangkok



Bored Piles for Different Sized Buildings

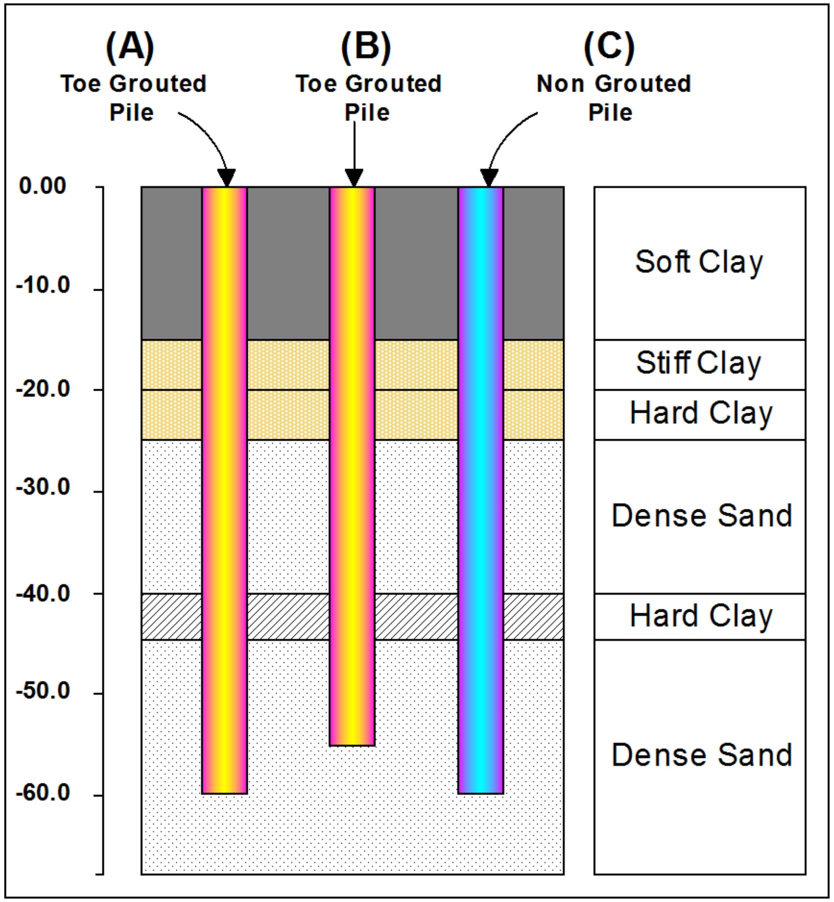
Bored Pile Capacity in Bangkok

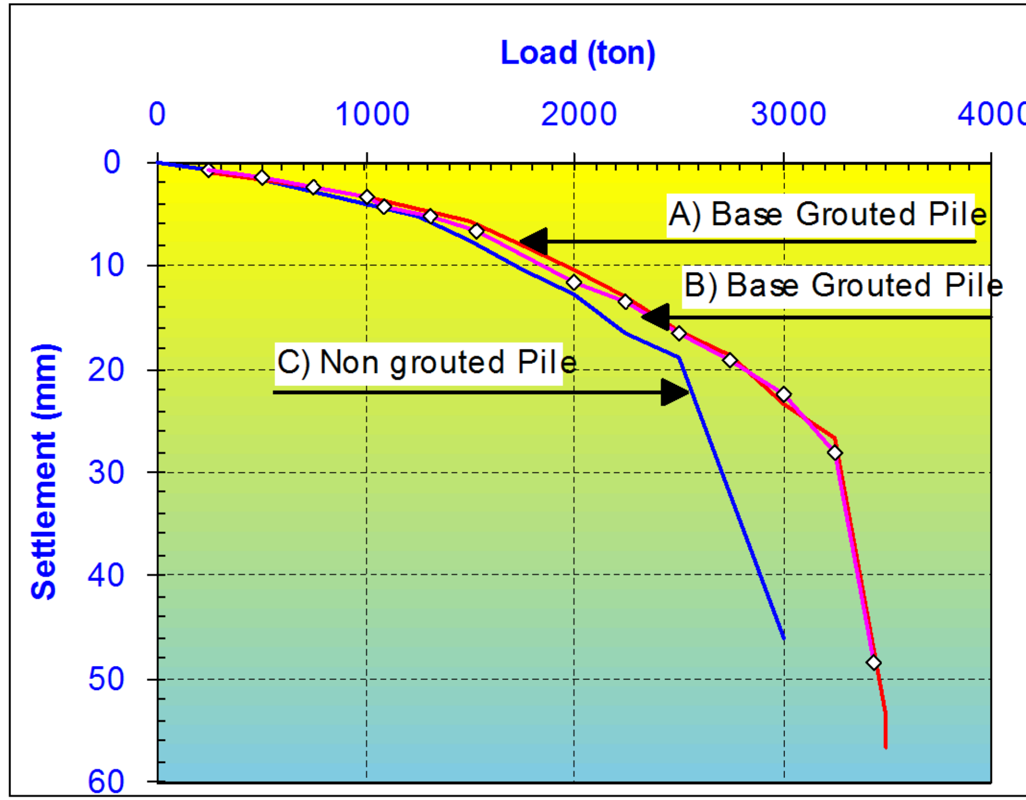




Increasing Capacity by Grouting of Bored Piles

Toe Grouting & Shaft Grouting



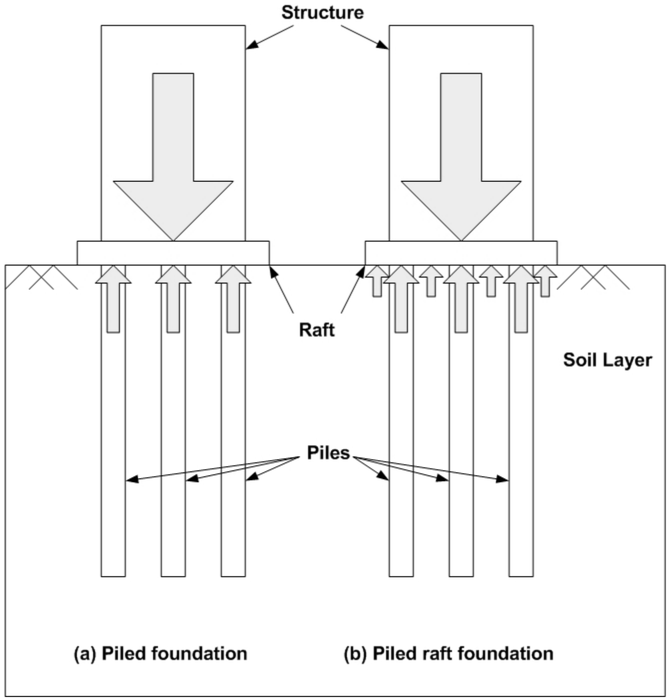


Bored Piles, Tips in Second Sand

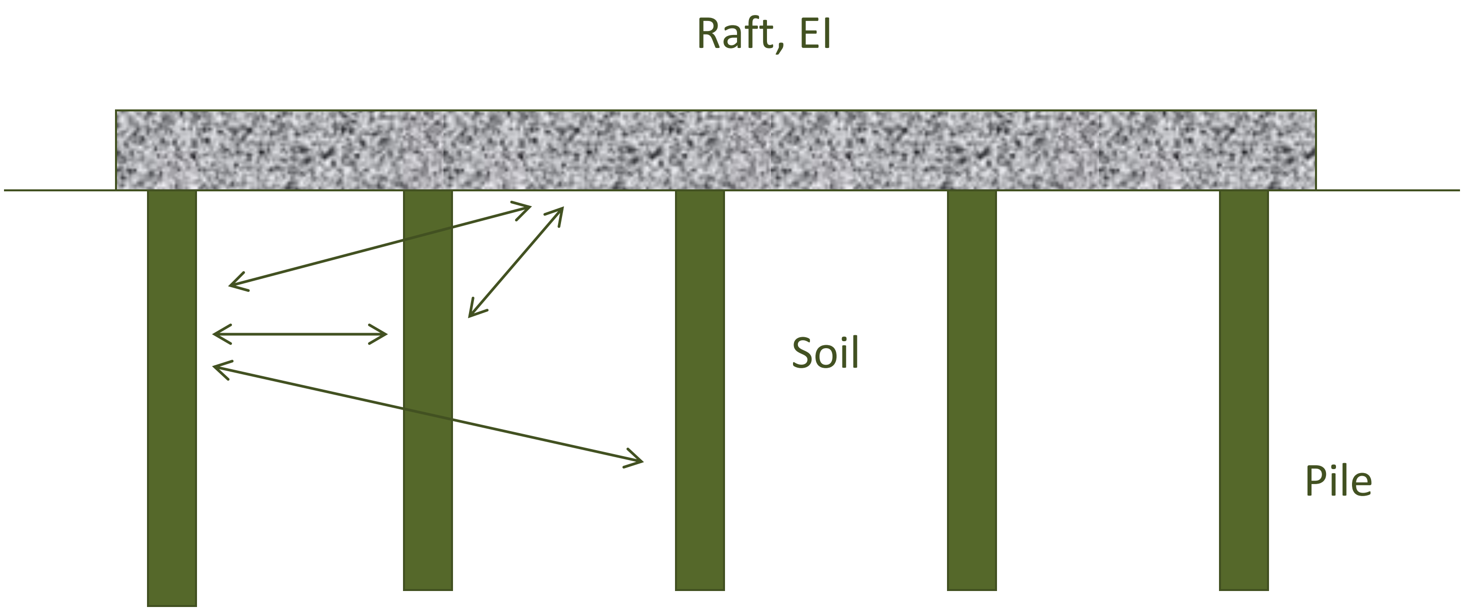
1990, Silom Precious Tower (After Seafco)

PILED RAFT FOUNDATION CONCEPT

- Piled foundation concept
  - the piles are designed to carry the total weight of the structure.
  - any contribution of the raft being ignored
- Piled raft foundation concept
  - Some proportion of total load may be transferred directly from the raft to the soil.
  - Load carried by the piles is reduced and the number of piles may be minimized.



Pile Raft Design Analysis



Interactions:

Pile & Pile

Raft & Soil under-raft

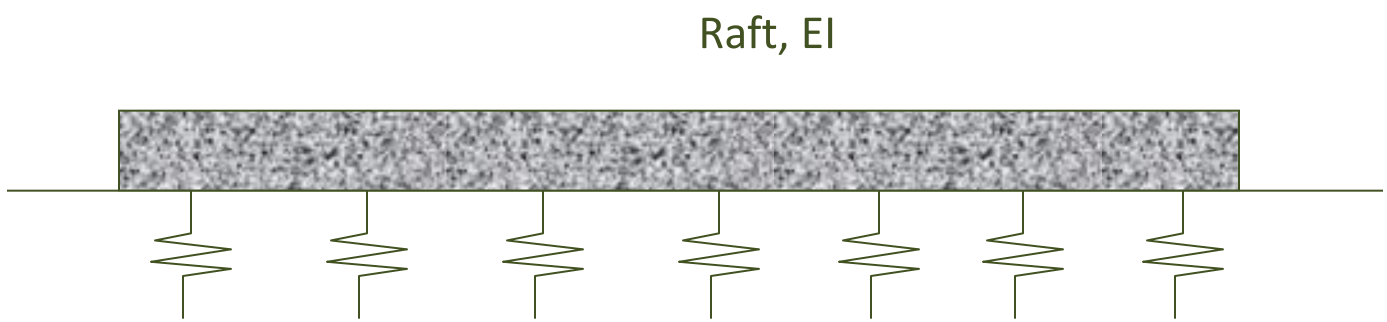
Soil under- raft and pile

Complicated.

See Randolph, Wood

Piled Raft Design Analysis

Simplified Method of Plate on Spring Analysis



Model Piles as a series of springs => Unrealistic

NO INTERACTION CONSIDERED

NO CONSIDERATION OF SOIL (ASSUME PILES TAKE ALL LOADS)

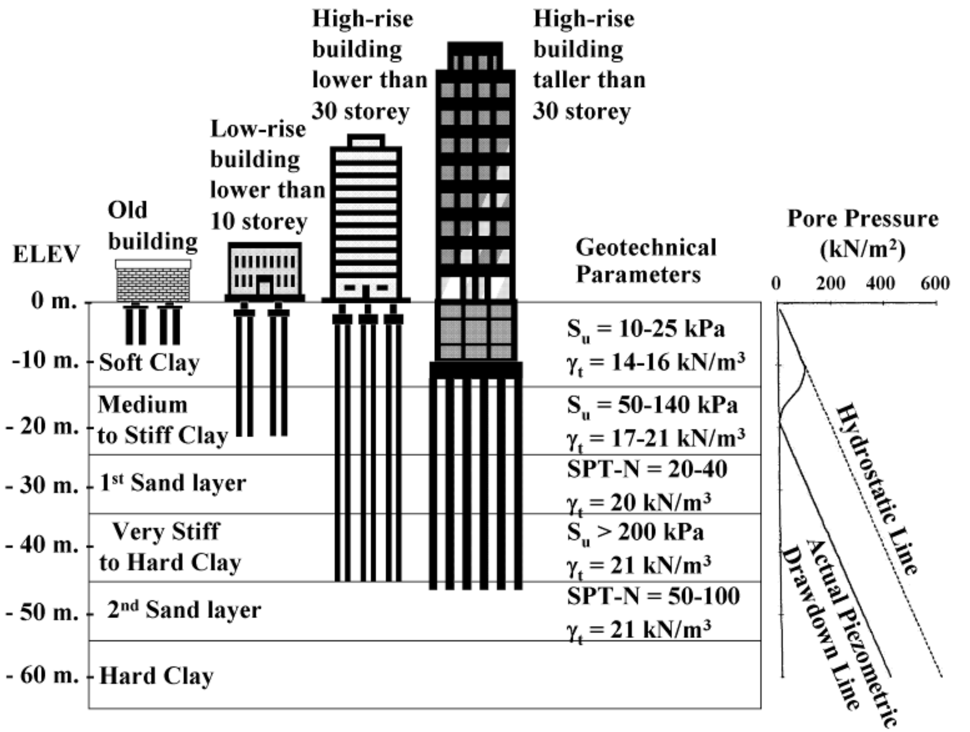
ERROR IN MOMENT AND SETTLEMENT OF RAFT

Piled Raft Design Analysis
Plate on Elastic Spring Approach

- Spring constant from pile load test (single pile !).
- Use reduced values of spring stiffness for inner pile to account for pile interaction effect. Subjective?
- Complicated when superstructure load is not uniform. Use thick raft)how much?)
- How to account for effect of superstructure stiffness?

BANGKOK SUBSOIL CONDITION

- In Bangkok, the subsoil consists of thick deposit of clays.
- Tall buildings are founded on piles with raft foundation.
- The conventional concept may not be cost-effective
- Piled raft foundation concept should be considered
  - Raft is resting on Stiff clay layer (not soft clay)



Application of a piled raft foundation in Bangkok is not yet well developed.

Case Histories

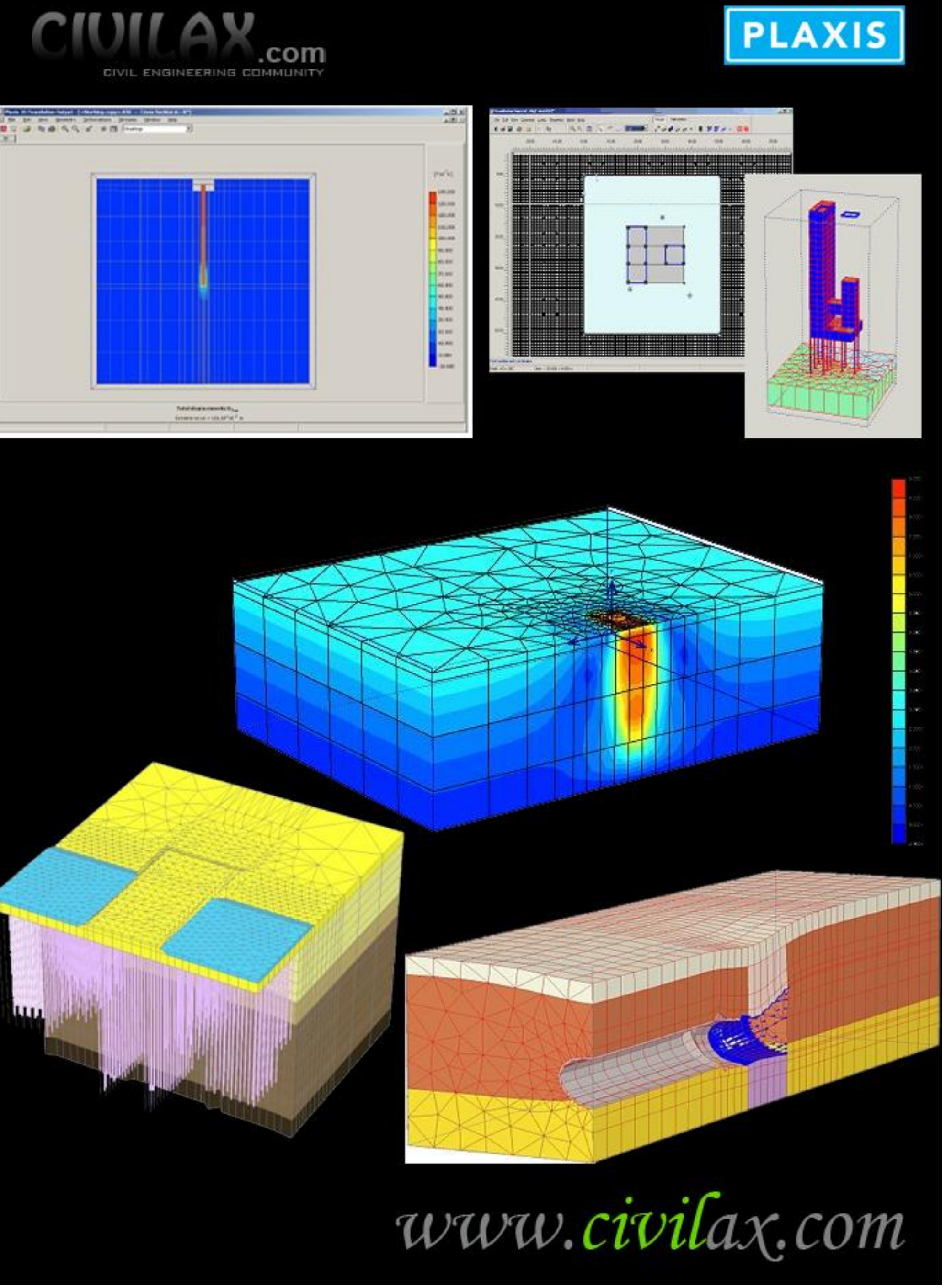
- For the period of the last two decades, number of high-rise buildings has been rapid increasing in the cities all over the world. And piled raft foundation concept has been successful applied in many countries.

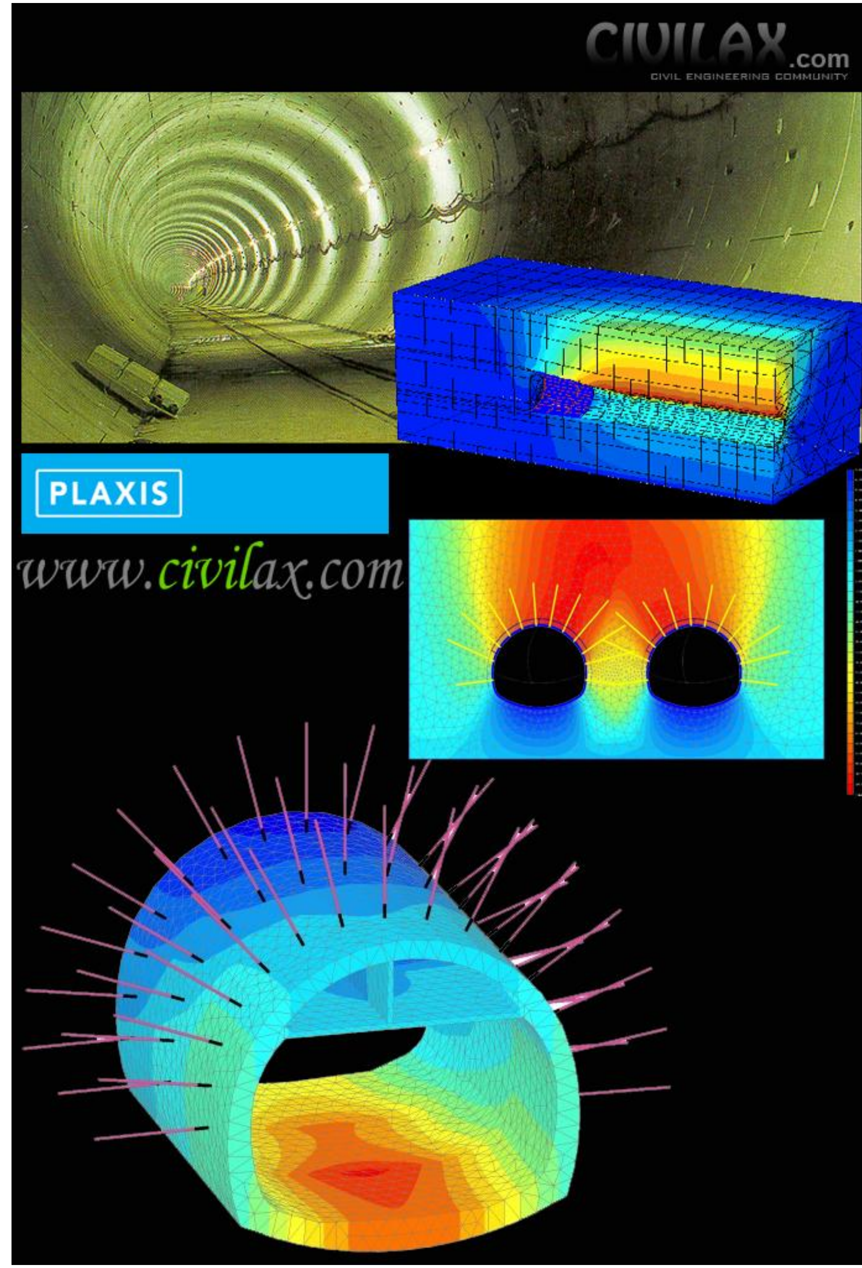
No	Tower	Structure (height/storeys)	Load share (%)		Instru-mentations	Settlement s_{max} (mm)
			Piles	Raft		
1	Messe-Torhaus, Frankfurt	130m, 30-storey	75	25	Yes	N.A.
2	Messeturn, Frankfurt	256m, 60-storey	57	43	Yes	144
3	Westend 1, Frankfurt	208m	49	51	Yes	120
4	Petronas, Kuala Lampur[PF)]	450m, 88-storey	85	15	Yes	40
5	QV1, Perth, West Australia	42-storey	70	30	N.A.	40
6	Treptower, Berlin	121m	55	45	Yes	73
7	Sony Center, Berlin	103m	N.A.	N.A.	Yes	30
8	ICC, Hong Kong	490m, 118-storey	70[D)]	30[D)]	N.A.	N.A.
9	Commerzbank, Frankfurt[PF)]	300m	96	4	Yes	19
10	Skyper, Frankfurt	153m	63	27	Yes	55

Piled raft foundations-Case histories (Phung, 2010)

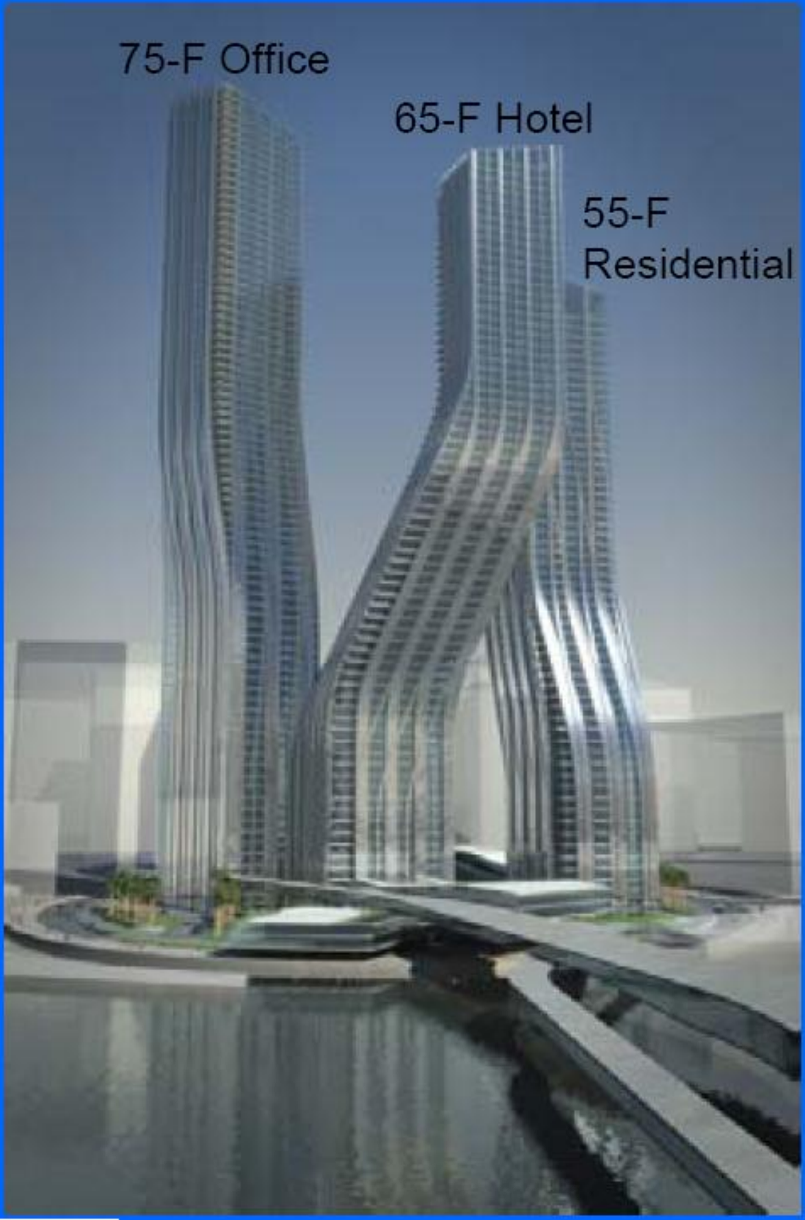
Numerical Geotechnical Software

AIT TECHNOLOGY EVENT





Complex Piled Raft Foundation Analysis



- Nicknamed "Dancing Towers"
- Office 351 m, Hotel 305 m, Residential 251 m high
- Piled raft foundations
- Bored piles 483 nos., 1.5 m dia, 45 m long
- Ground conditions:

0-10 m: Sand

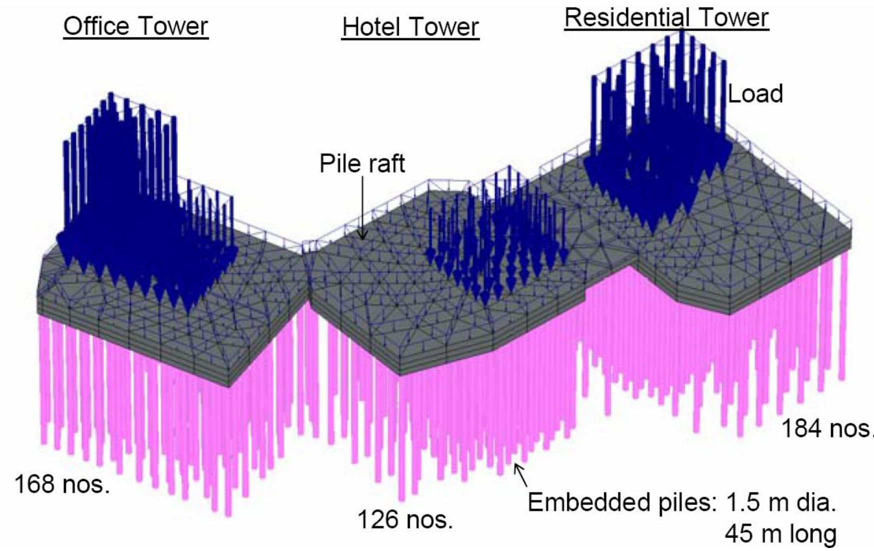
10-25 m: Very/Weak Sandstone

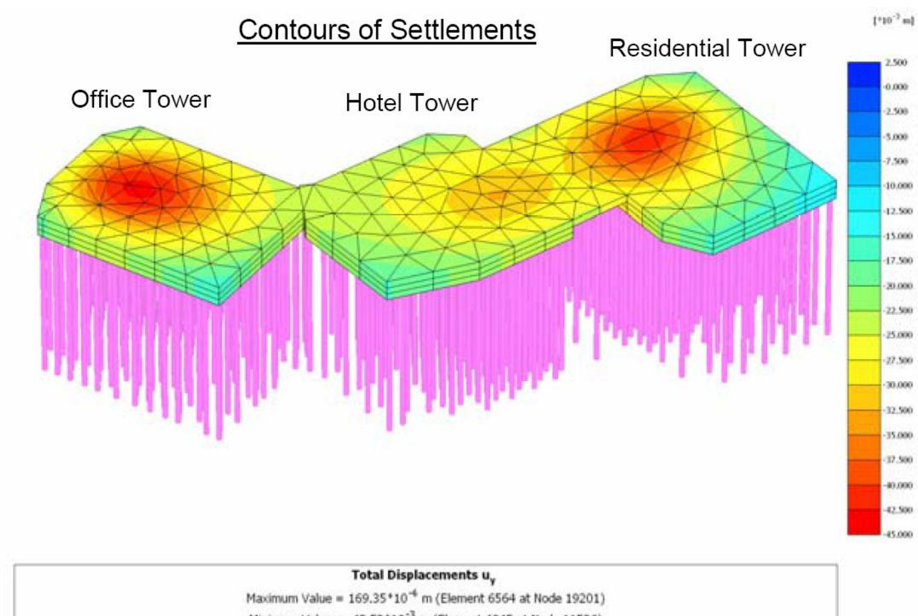
25-30 m: Very/Weak Siltstone

30-40 m: Very/Weak Conglomerate

>40m: Very/Weak Claystone

PLAXIS 3D FOUNDATION





To be the tallest building in Bangkok

Piled-Raft-Foundation Design Check

CONCLUSIONS

- **Application of piled raft foundation for high-rise buildings in Bangkok**
  - Comparison of results given by different methods
    - The 3D FEM gave more realistic results. The load shared by piles via 3D FEM were only 70-80%. Therefore, plate on springs method, as current practice, seem to have significant error.
    - In addition, if piled raft foundation concept is applied, the number of piles can be reduced up to 50% and load shared by piles still remains around 70%. The analysis shows that settlement would increase around 50% which is not significant.

CONCLUSIONS

- **Application of piled raft foundation for high-rise buildings in Bangkok**
  - For case study analysis
    - The use of Beam on spring analysis assuming no bearing contribution of stiff clay below the raft yields huge inaccuracy in load on piles, bending moment, settlement in comparison with the actual behavior revealed by the rigorous 3D FEM foundation analysis.
    - Based on the piled raft foundation concept using the 3D FEM, the load shared by piles was only 85%. Subsequently, an adjustment could be made by reducing raft size, number of pile by one half, and raft thickness, in overall would yield a significant cost reduction from the design using the Beam on spring analysis and the piled foundation concept.

CONCLUSIONS

- **Application of piled raft foundation for high-rise buildings in Bangkok**
  - The piled raft foundation design concept can be used to reach the most optimal design.
  - It will also help solving problem with the large number of piles at close spacing for high-rise buildings constructed in small piece of land.

Kob Kun Krub

Thank You