Deep excavations

- **Observational method**
  - Sir Alan Muir Wood
  - Used where detailed analysis very difficult
  - Principles
    - Make non-conservative estimates of forces
    - Consider implications of error
    - Plan monitoring of forces and deflections
    - Plan contingency in case of error

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Deep excavations

- **Marina Bay Station**
  - Soil profile
    - Hydraulic fill over soft marine clay
  - Heavy sheet piles with I-beams
  - Excavation by backhoe
  - Strutting
  - Fill with water

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- **Marina Bay Station**
  - Excavate by grab
  - Bored piles
  - Tremie slab
  - Lower water and monitor strut loads and deflections

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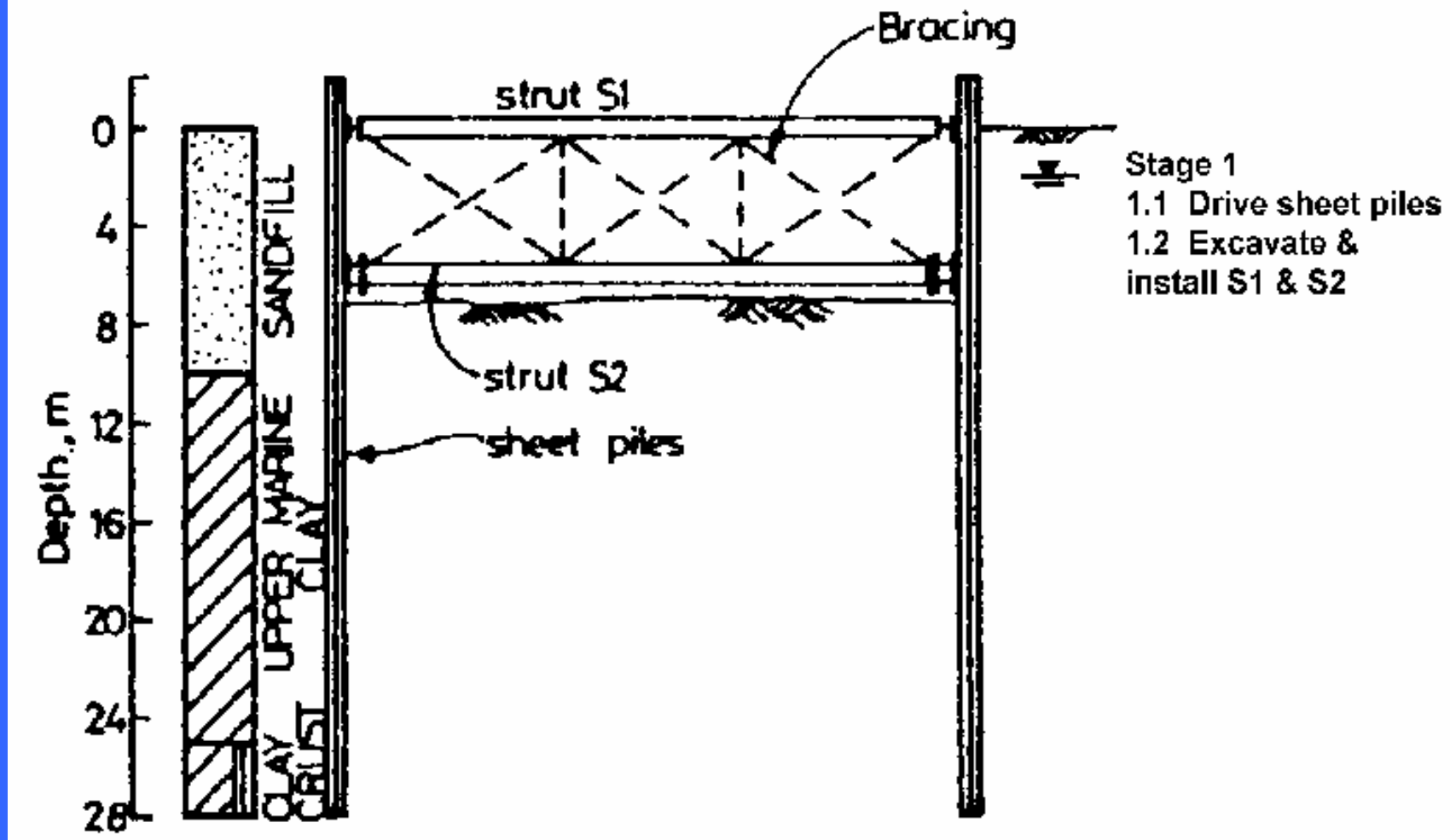
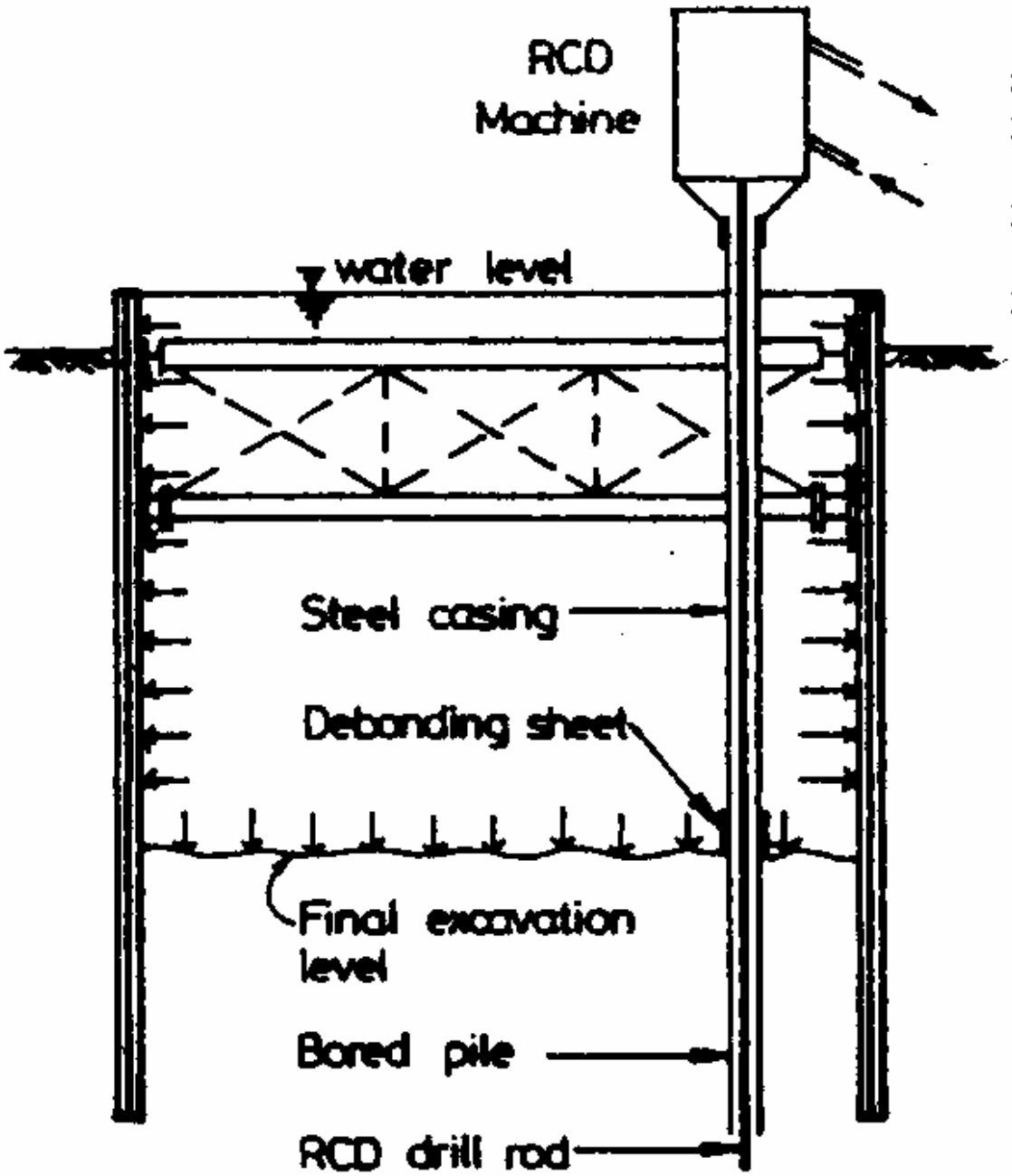

Bracing
strut S1
strut S2
sheet piles
Depth, m
0
4
8
12
16
20
24
28
SANDFILL
UPPER MARINE CLAY
CLAY CRUST
Stage 1
1.1 Drive sheet piles
1.2 Excavate & install S1 & S2

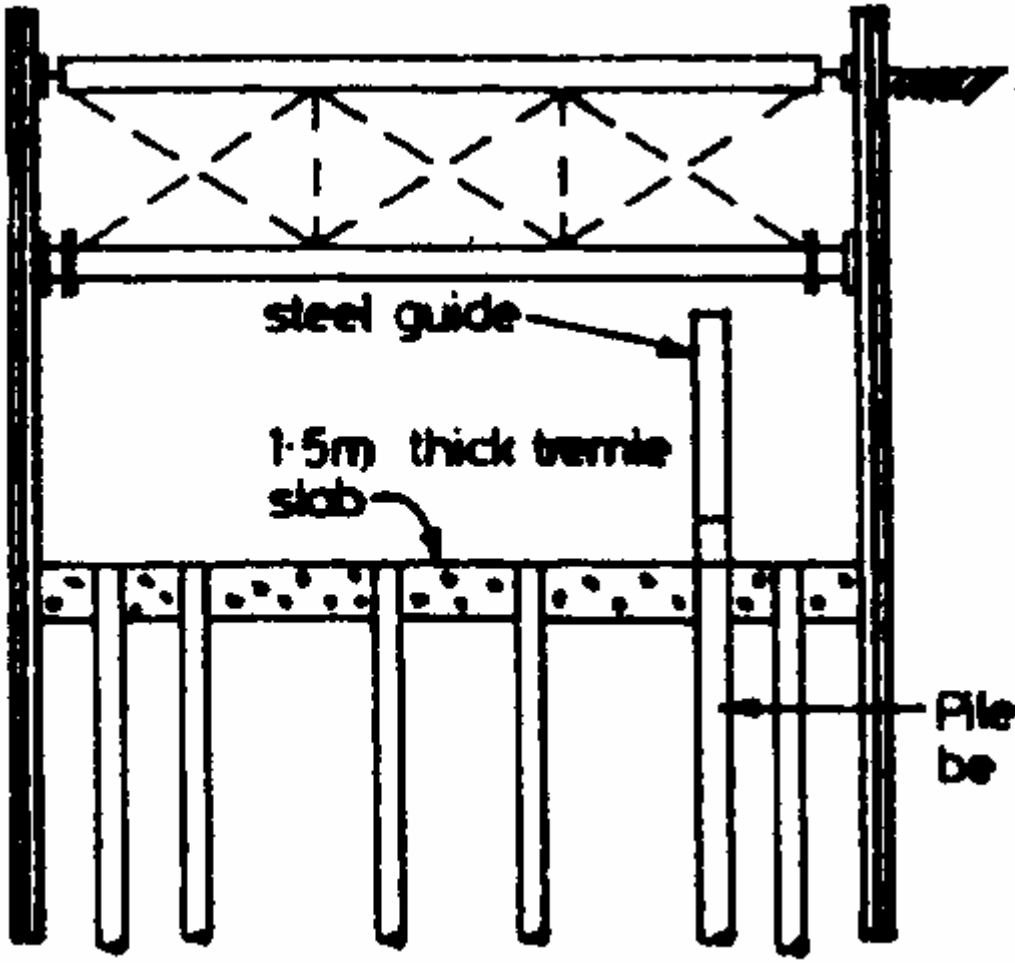


Stage 2

2.1 Flood cofferdam up to top level

2.2 Excavate under water down to base

2.3 Install bored piles by RCD method



Stage 3

3.1 Cast tremie slab

3.2 Pump out water

3.3 Monitor strut loads and wall deflections

3.4 Build station

Deep excavations

- **Instrumentation and monitoring**
  - Loads/stresses
    - strain gauges
    - pressure cells
  - Deformations
    - Extensometers
    - Inclinometers
    - Survey

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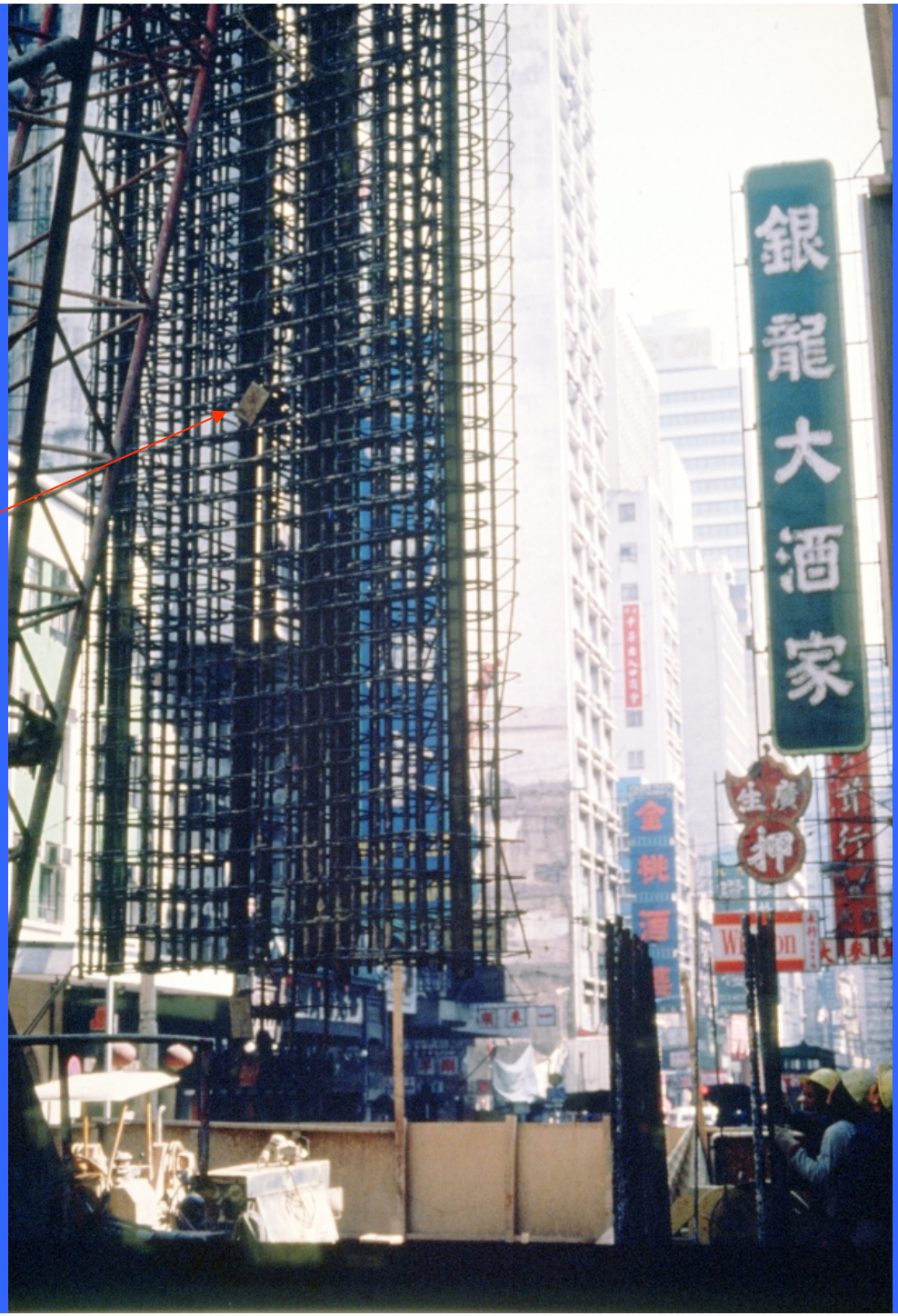
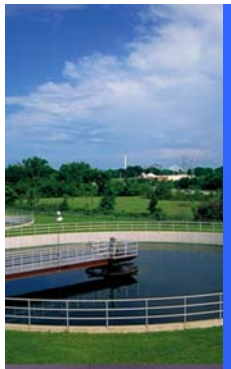
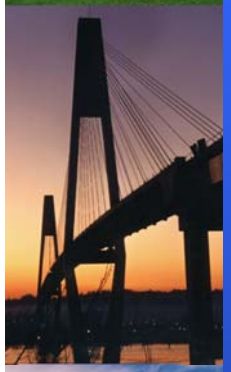
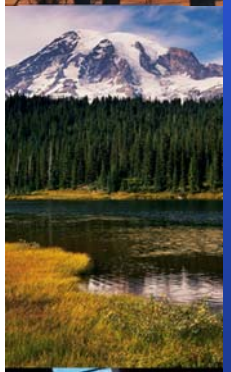
PROTECTOR

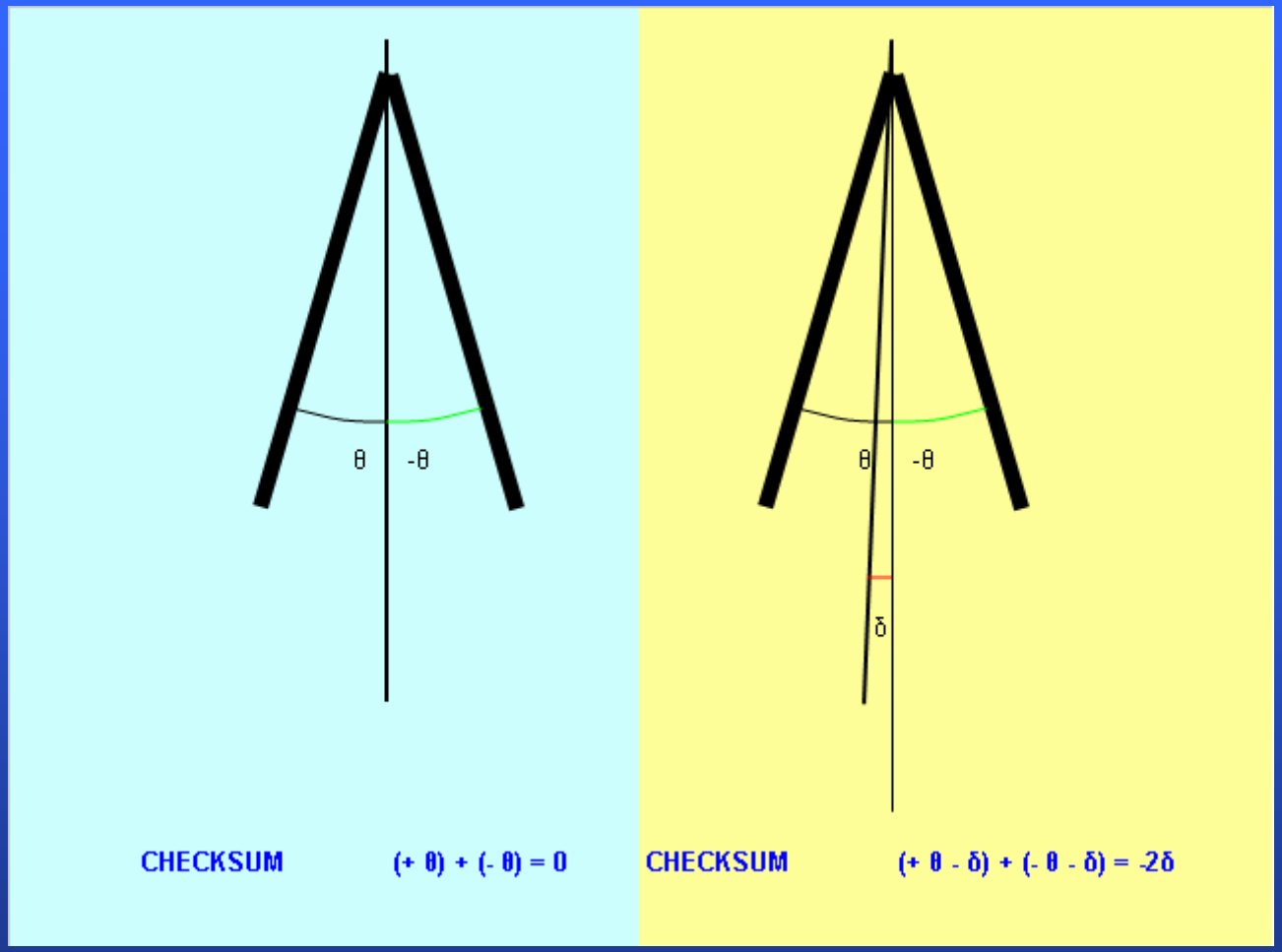
Pressure cell











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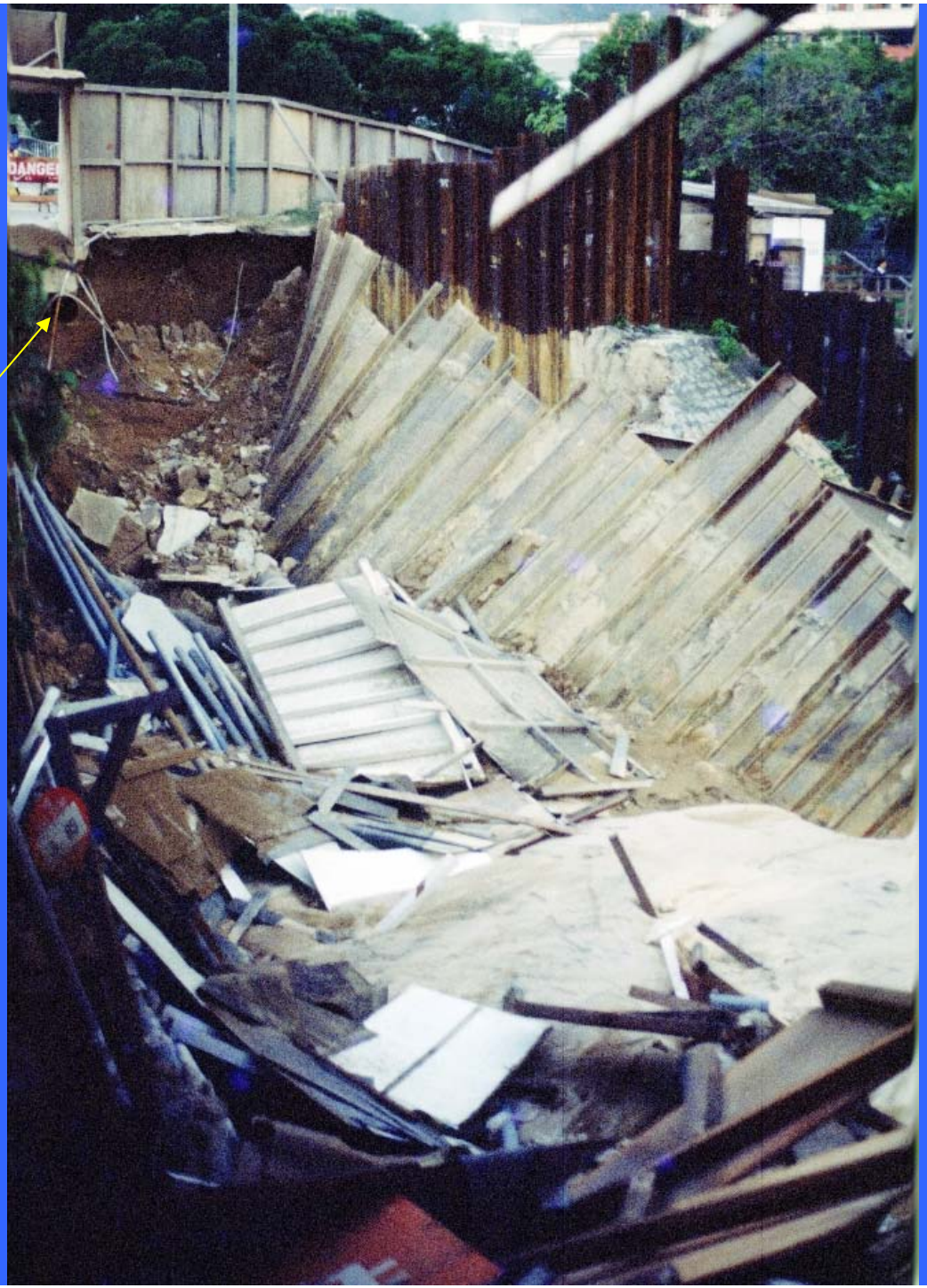
Deep excavations

- **Collapse at Lok Fu Station, HKMTRC**
  - Checkers queried strutting design
  - Designers would not respond
  - Checkers insisted on monitoring
  - Collapse occurred
  - Monitoring survey data in desk drawer
  - When plotted showed progressive wall movement
  - Firewater main behind wall with T-branch across road
  - Firewater main failed in tension

End of
water pipe



Deep excavations

- **City Hall Station, Singapore MRTC**
  - Two level soil profile
    - Anchored sheet piles at upper level
    - Anchored pads at lower level
  - Anchors failed on Whit Sunday 1985
  - Backfill to stabilise
  - Dewatering surface sands
  - Contiguous pile wall through backfill
  - Anchors with vertical and horizontal walings

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GEHO
DEWATERING
SYSTEM

Deep excavations

- **Failure of sheet piled cofferdam in Bangkok**
  - Extrapolation of strutting system from small rectangles to large excavation
  - Reentrant corners

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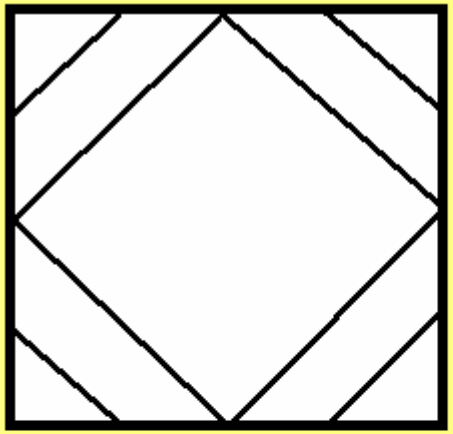
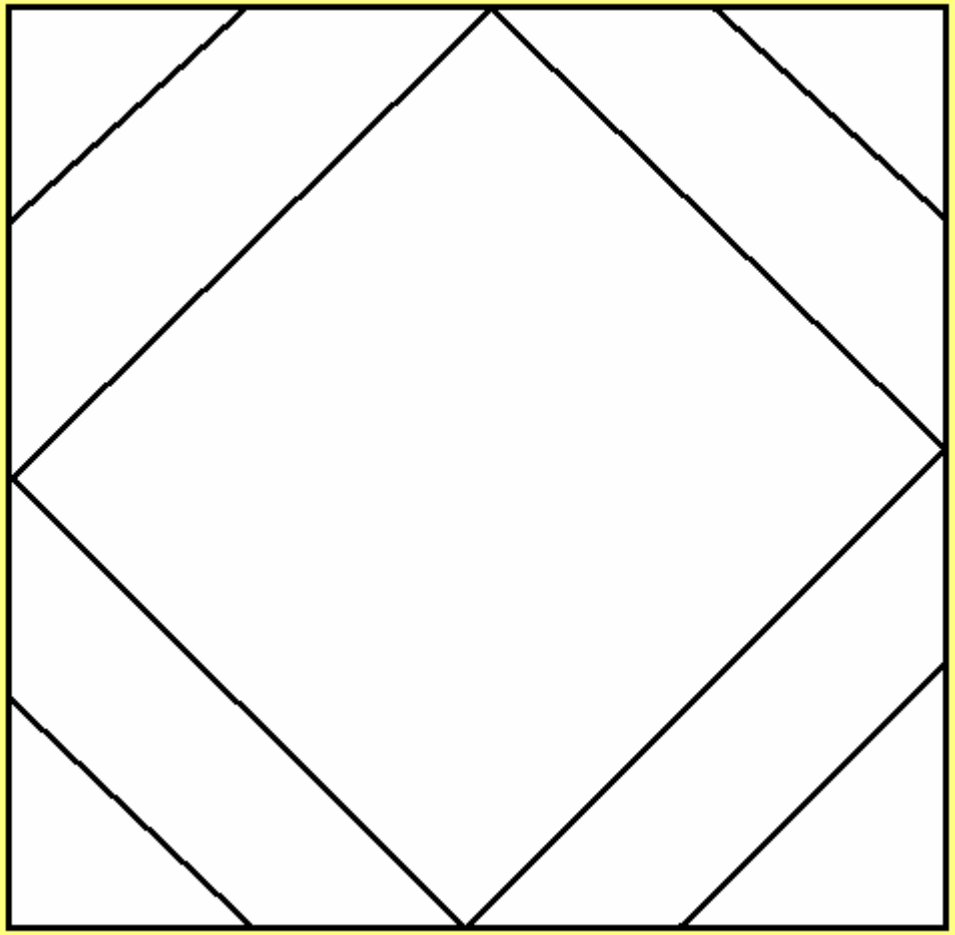
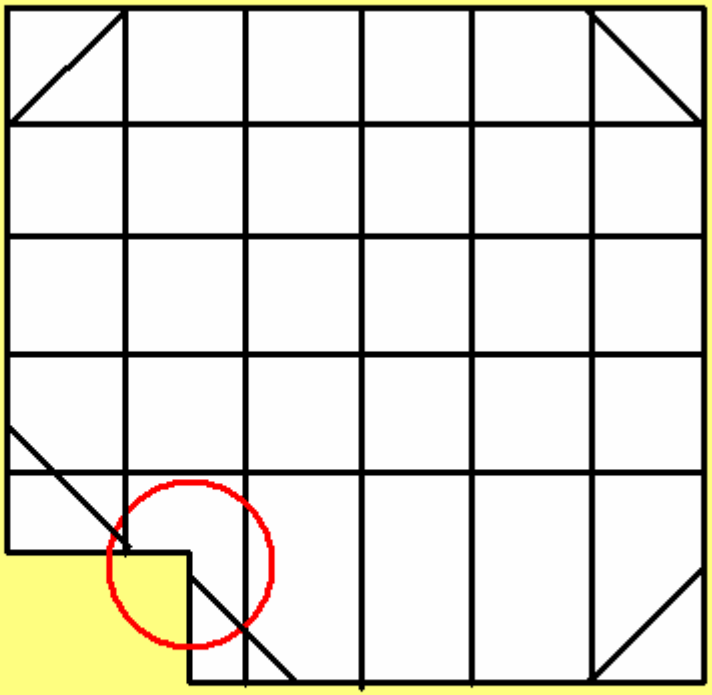


20 m

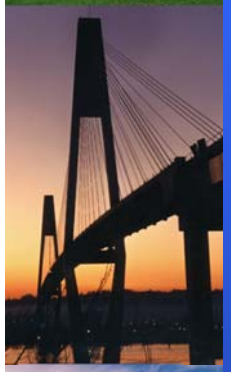


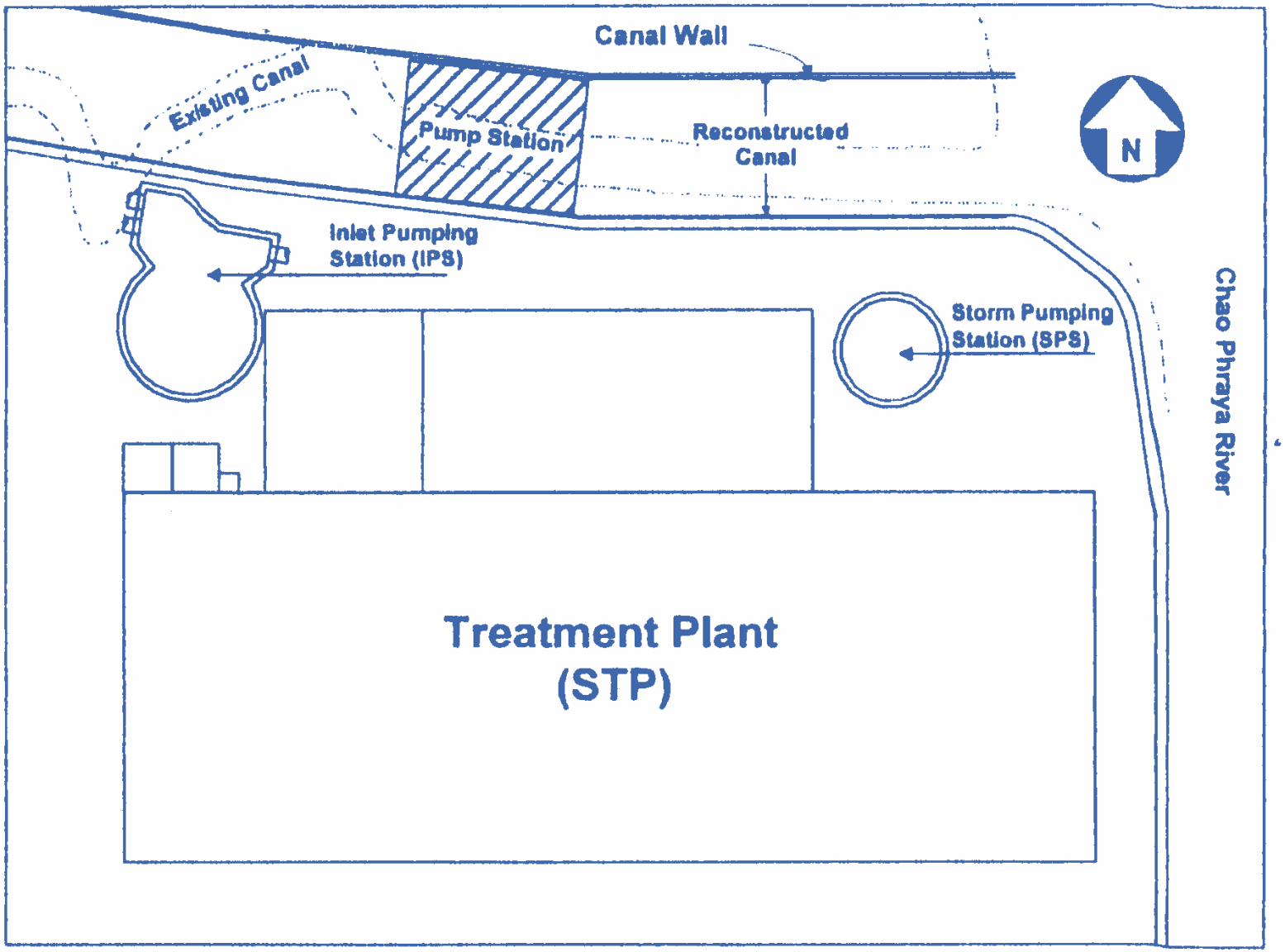
200 m



Deep excavations

- **Yannawa Wastewater Treatment Plant**
  - Inlet Pumping Station
  - Collapse of diaphragm walled shaft on 17 August 1997
  - Difficult, restricted site
  - Circular PS shaft and “rectangular” inlet/bypass chamber
  - Poor strut detail
  - Poor strutting installation
  - Lack of monitoring





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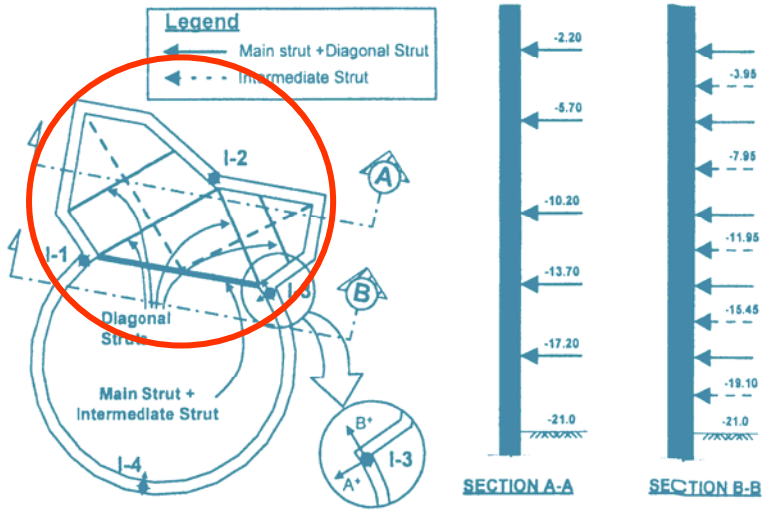


Figure 2. Temporary bracing system (Initial design)

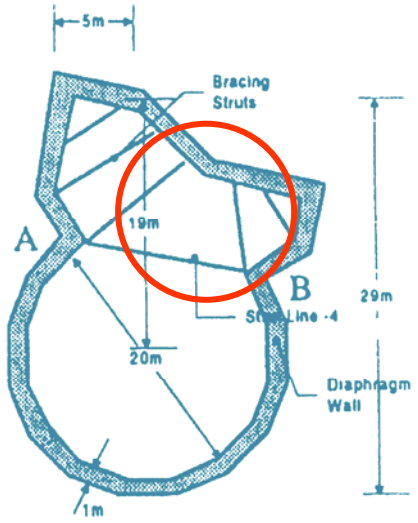
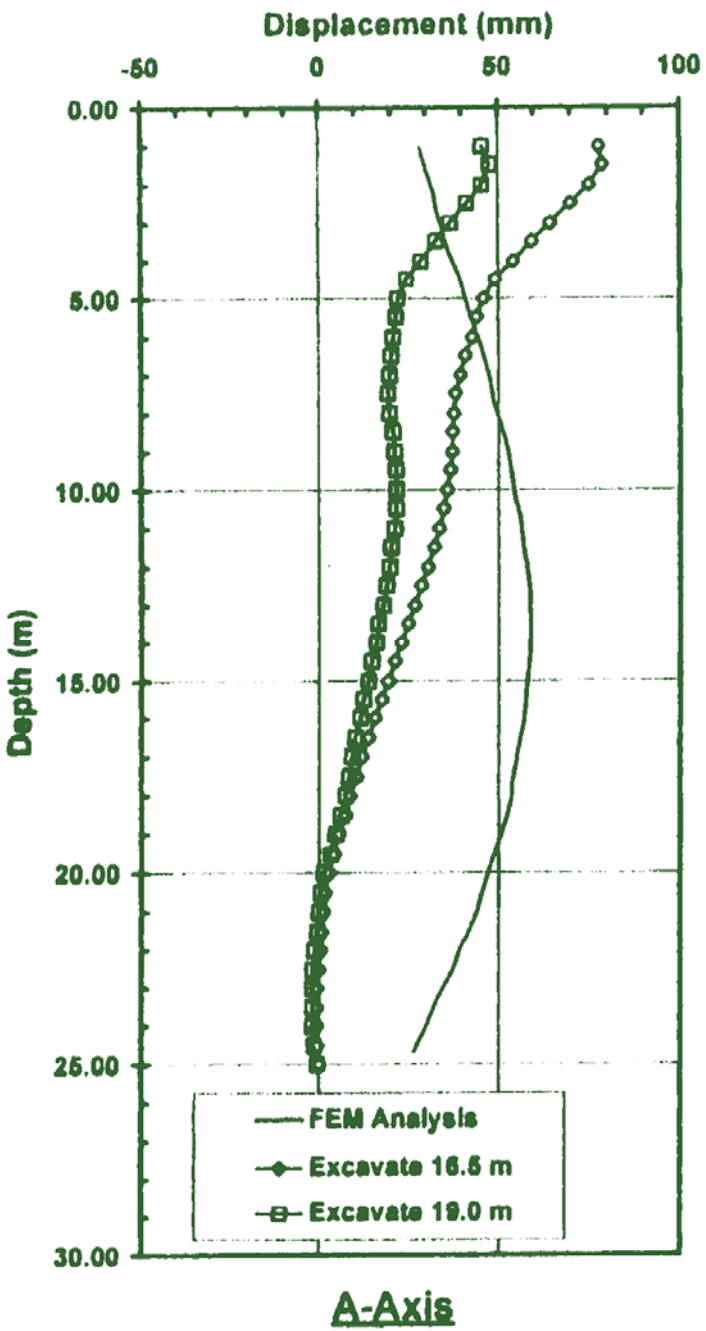
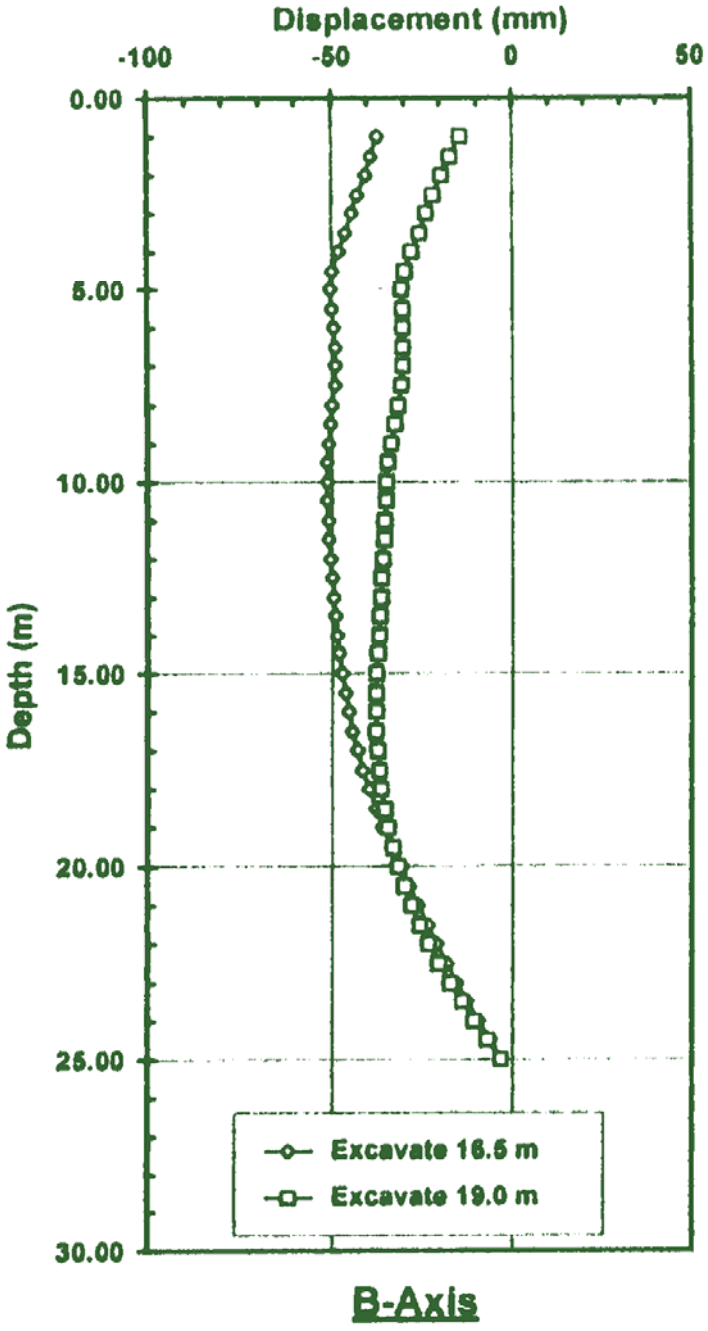


Figure 3. Final Temporary bracing system (after Kanok-Nukulchai et al., 1998).

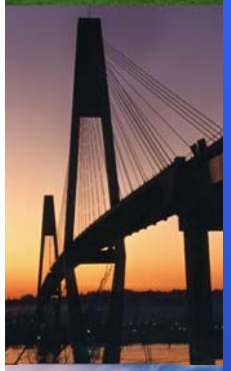
aged

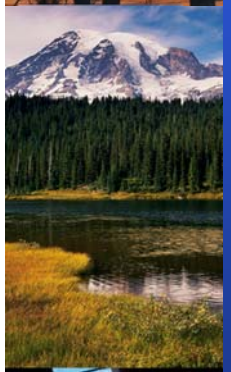
king

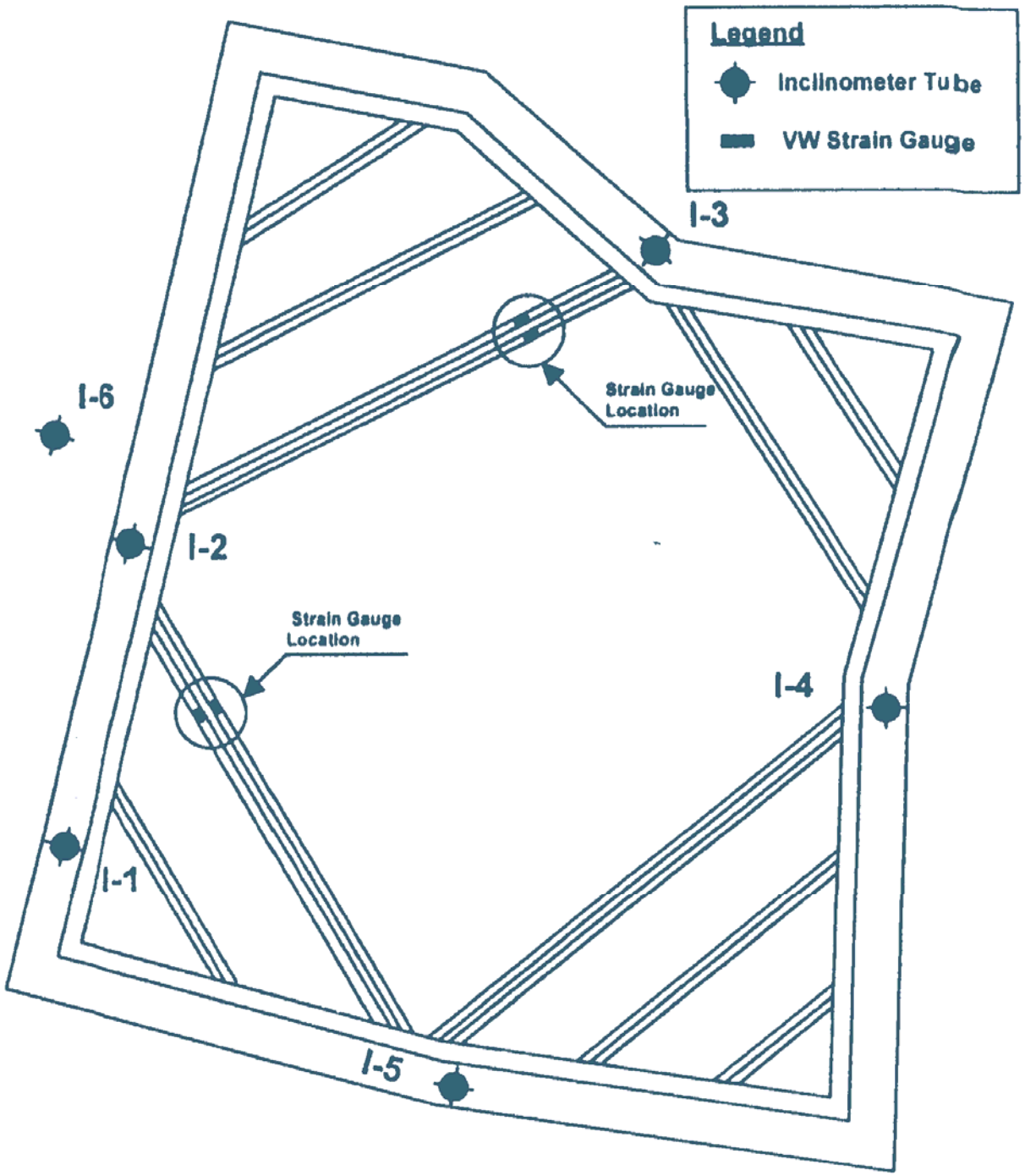

Displacement (mm)
-50
0
50
100
0.00
5.00
10.00
15.00
20.00
25.00
30.00
Depth (m)
FEM Analysis
Excavate 16.5 m
Excavate 19.0 m
A-Axis

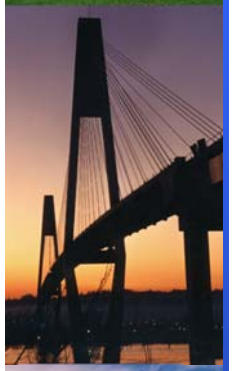

Displacement (mm)
-100
-50
0
50
0.00
5.00
10.00
15.00
20.00
25.00
30.00
Depth (m)
Excavate 16.5 m
Excavate 19.0 m
B-Axis

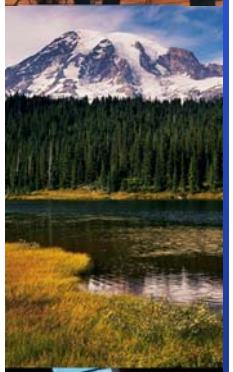

Cracks in capping beam

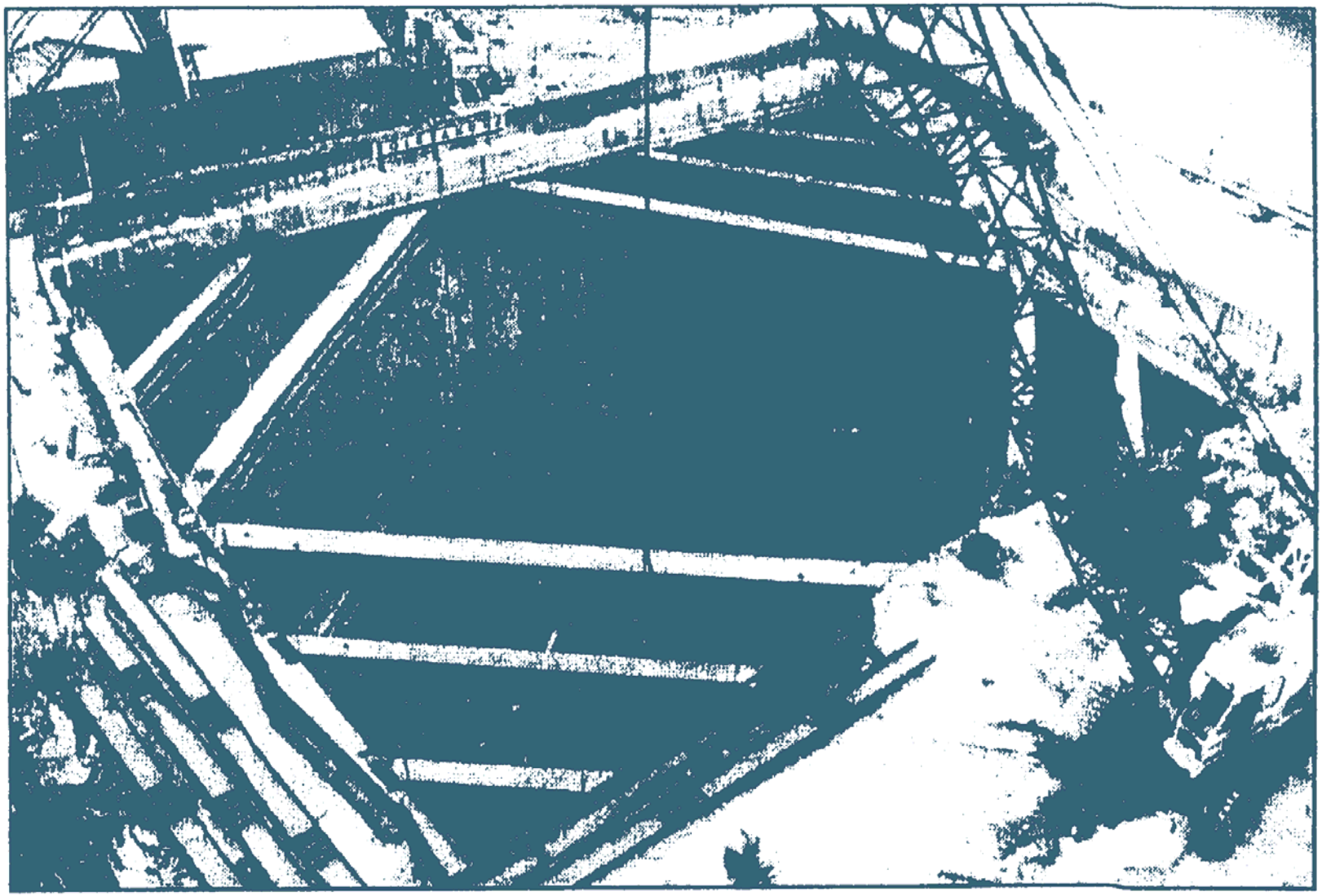





Legend
Inclinometer Tube
VW Strain Gauge
I-3
I-6
Strain Gauge Location
I-2
Strain Gauge Location
I-4
I-1
I-5







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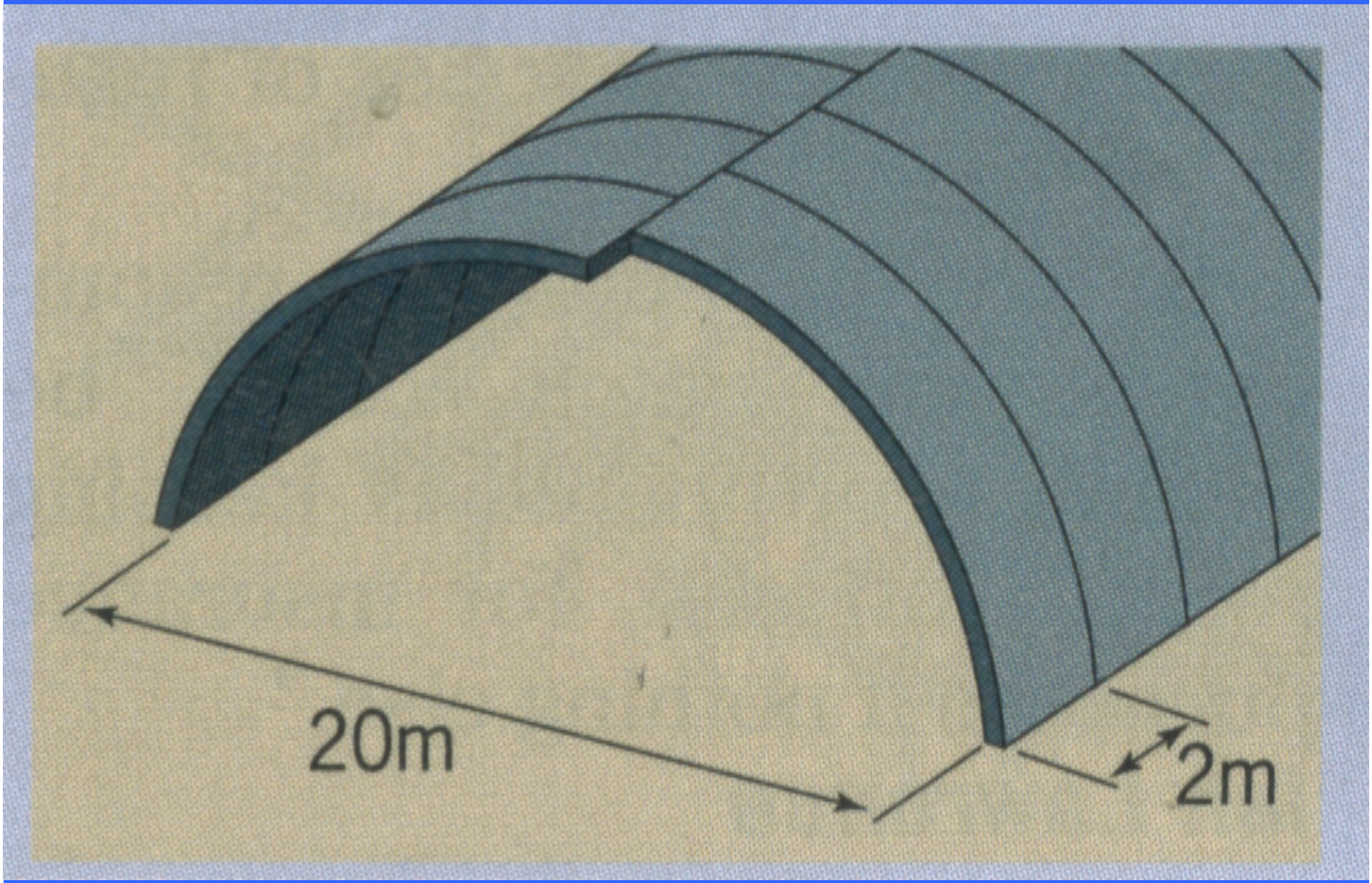
Deep excavations

- **Collapse of cut and cover tunnel at Gerrards Cross, UK**
  - Existing railway line in cutting
  - Land being reclaimed for Tesco superstore
  - Precast “pinned” arches built on piled ground beams
  - Backfill over
  - Collapsed on 30 June 2005 at 7:30pm – no injuries


20m
2m

The collapse happened because not enough fill had been placed to the sides of the tunnel before material was placed on the crown.

Deep excavations

- **Collapse of Nicoll Highway on 20th April 2004, caused by incident at MRT Circle Line Worksite**
  - Contract 824 included
    - NCH Station, 3-level underground 327 m long
    - BLV Station, 3-level partly underground 246 m long
    - 800 m of twin bored tunnels
    - 2 km of cut-and-cover tunnels, mainly in soft marine clay

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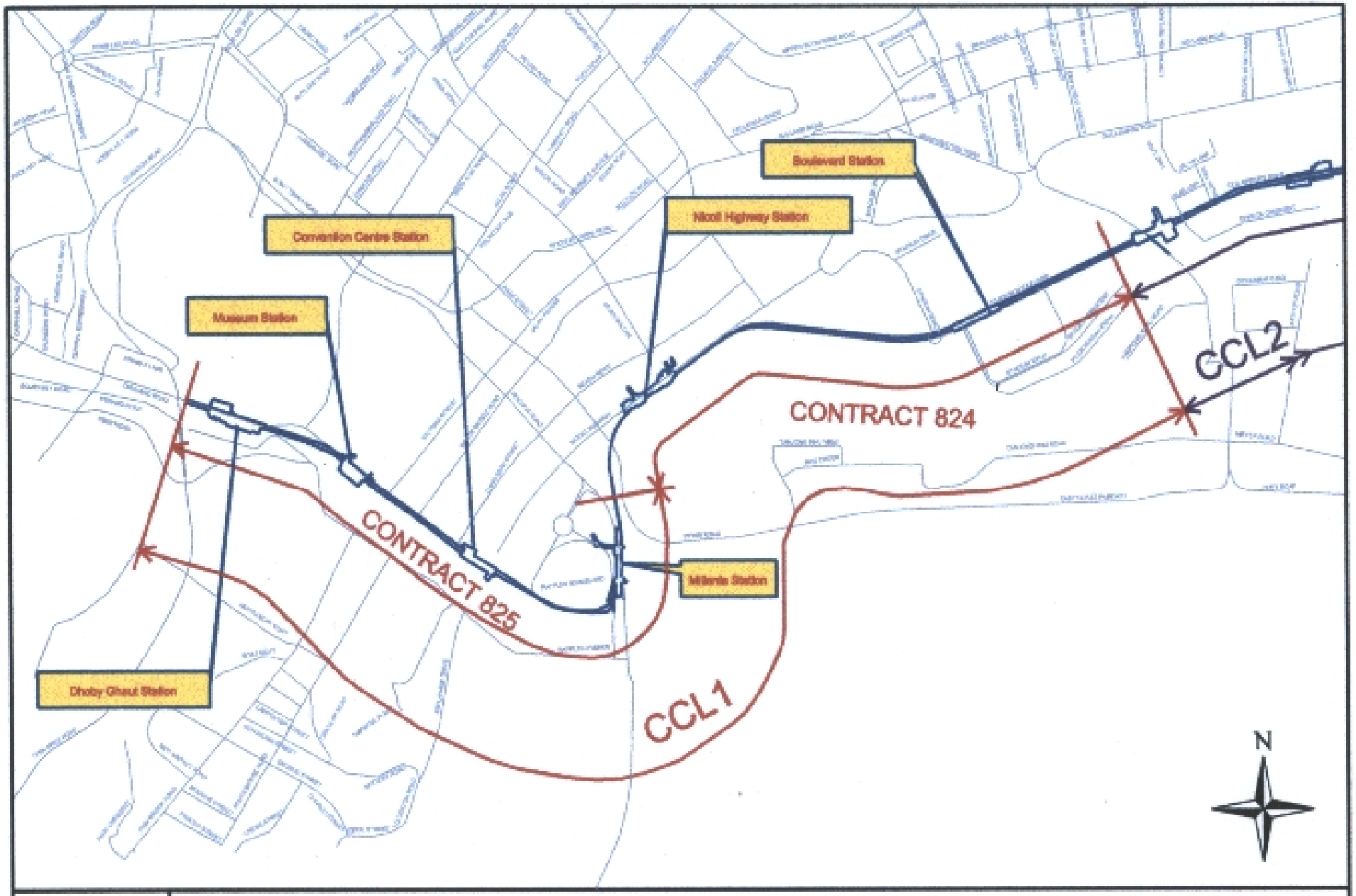
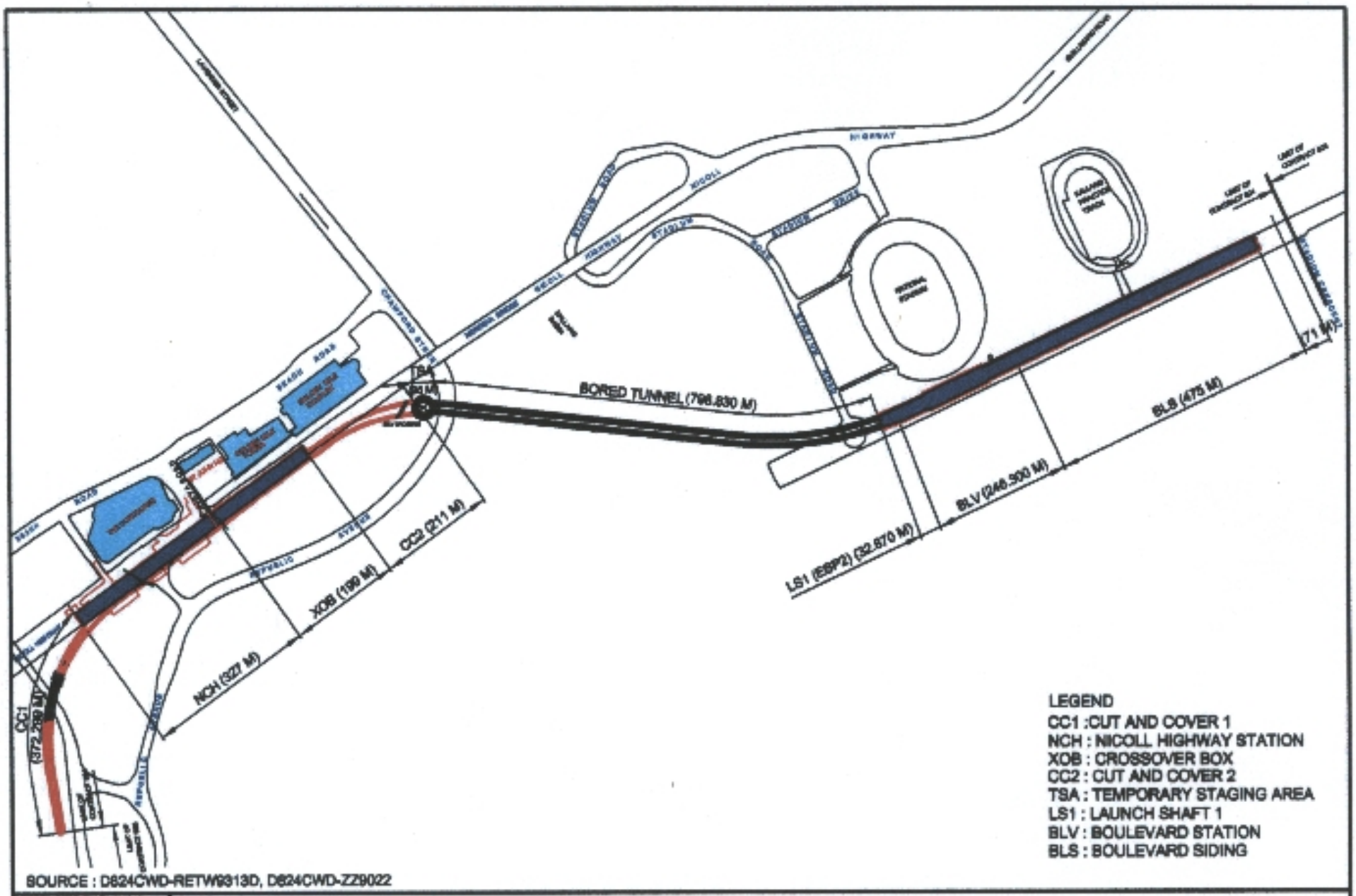


FIGURE 1.5 OVERVIEW OF CIRCLE LINE STAGE 1 (CCL1)



SOURCE : D824CWD-RETW9313D, D824CWD-ZZ9022

FIGURE 1.6 OVERVIEW OF CONTRACT 824 (A)

Deep excavations

- 2 km of cut-and-cover included CC2 (211 m)
  - Type L – 46 m
  - Type M1 – 44 m
  - Type M2 – 88 m
  - Type M3 – 33 m
- Tender design based on
  - excavation depth 34.5 m
  - Soft Clay thickness 35 m
  - 9 levels of struts
  - Single JGP slab beneath 9th layer

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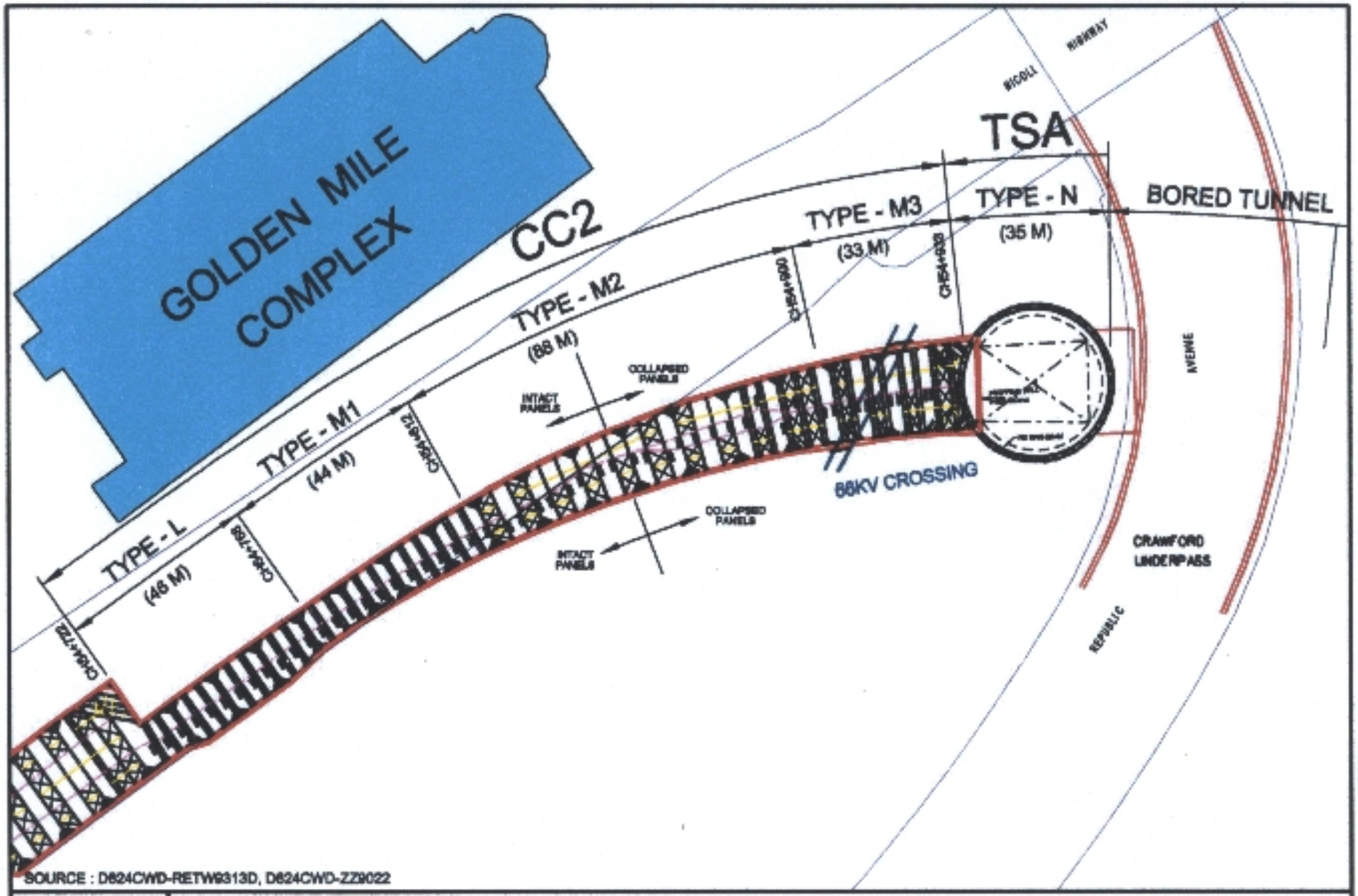

SOURCE : D624CWD-RETW9313D, D624CWD-ZZ9022

FIGURE 1.8 OVERVIEW OF CC2 (TYPE L, M1, M2 AND M3)

Deep excavations

- Developed design
  - 10 levels of struts
  - 2 levels of JGP slab, upper level between 9th and 10th strut levels sacrificial
- Very difficult conditions
  - ~ 35 m deep
  - Soft clays to about 40 m
  - Hard ground beneath walls

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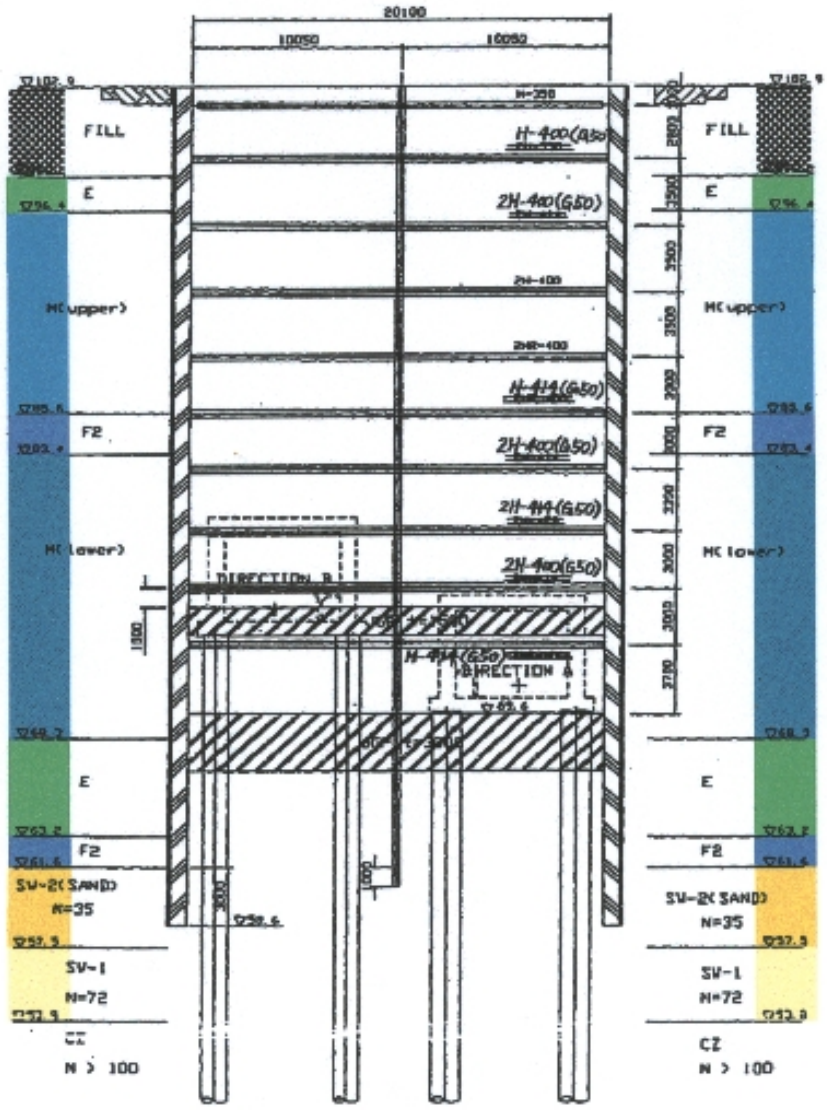
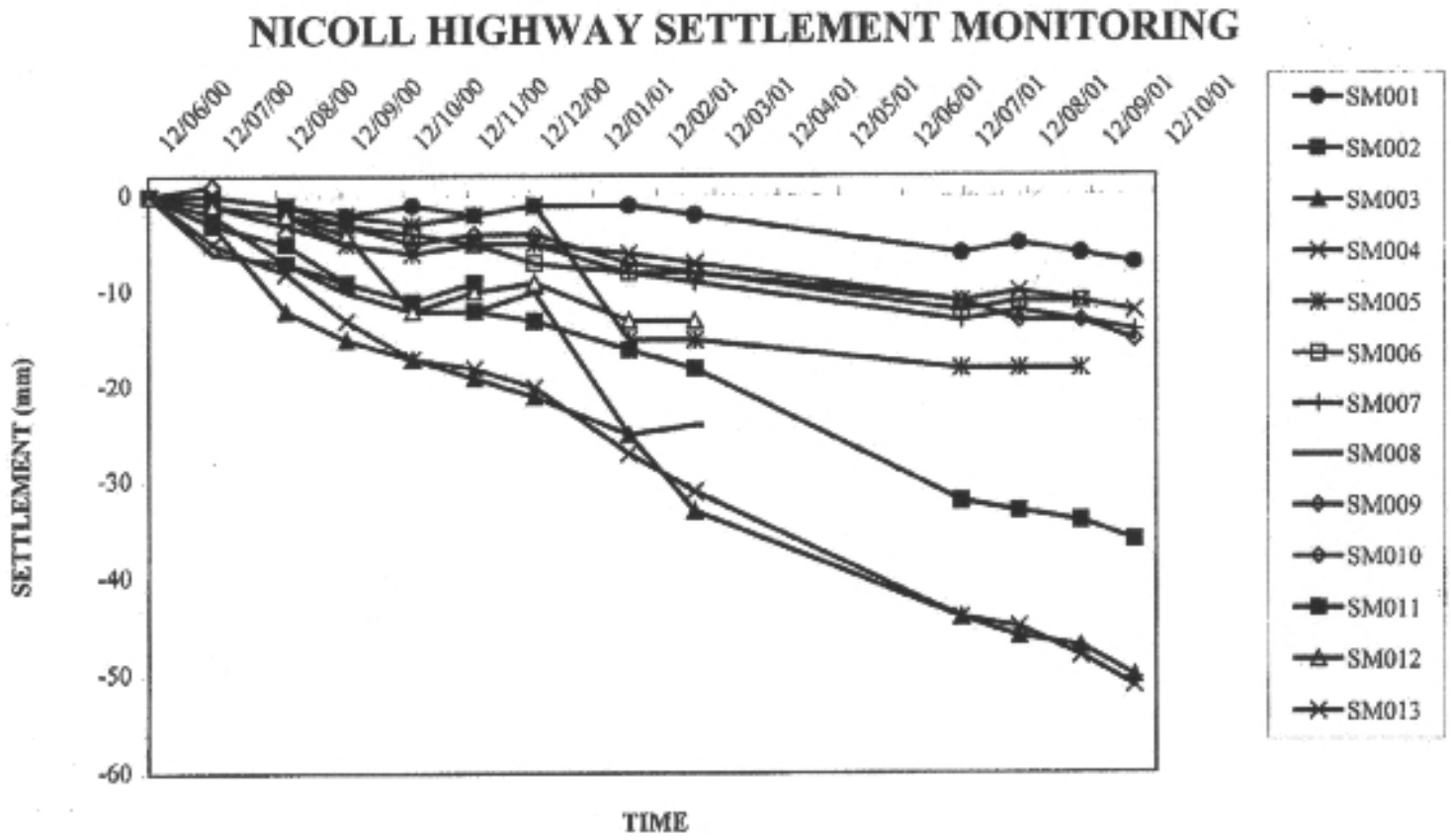


Note :

1.The spacing in the horizontal direction of struts is 4.00

Source : Fig 1.1.3 of NLC Expert Report

Figure 2.4	Cross Section 24 at the M3 area showing geology interpreted from the post-tender soil investigation.



Source : Fig 7.1 of LTA Expert Report

Figure 2.13	Settlement monitoring data in the C824 area from June 2000 to December 2001.

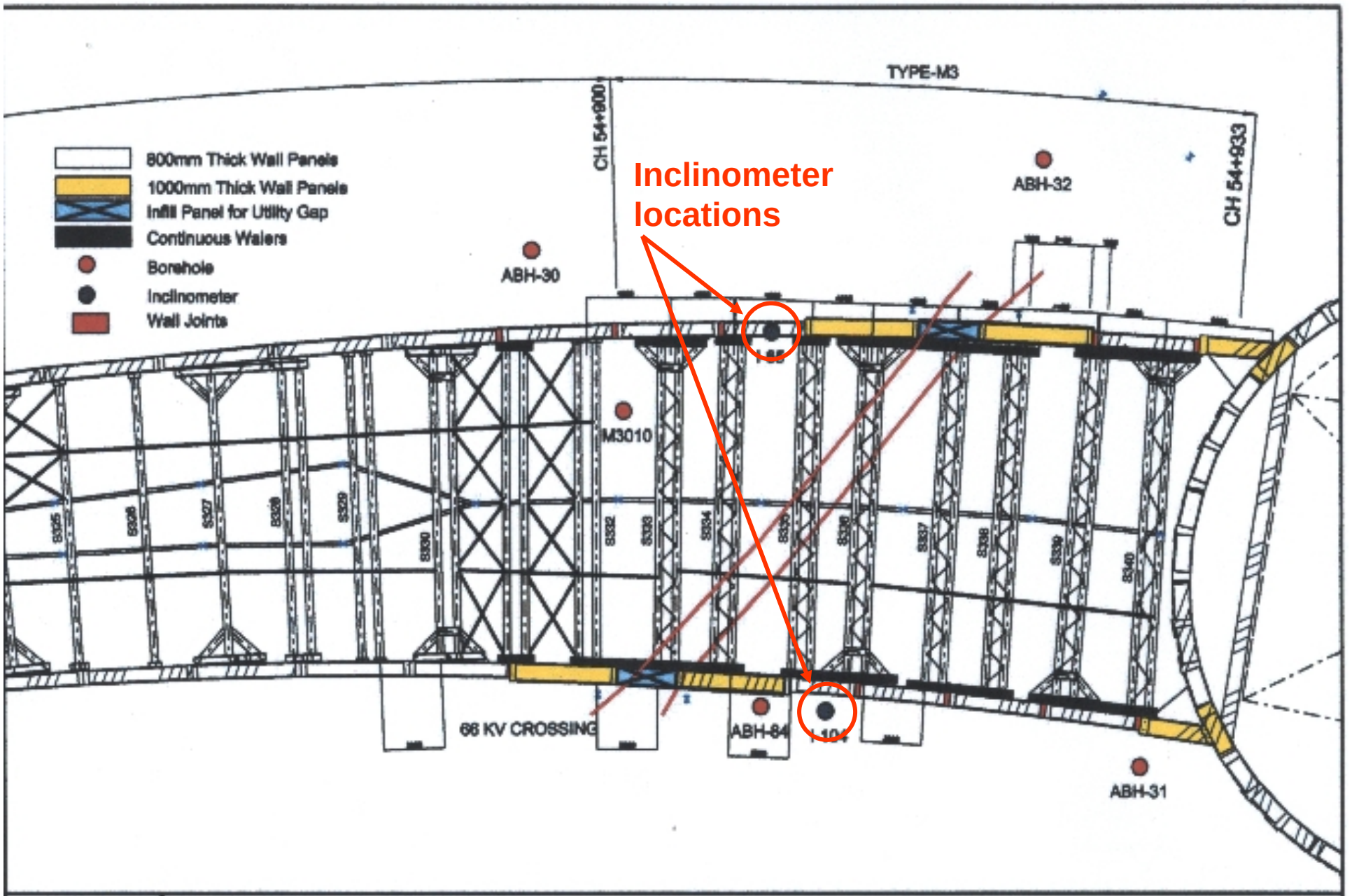
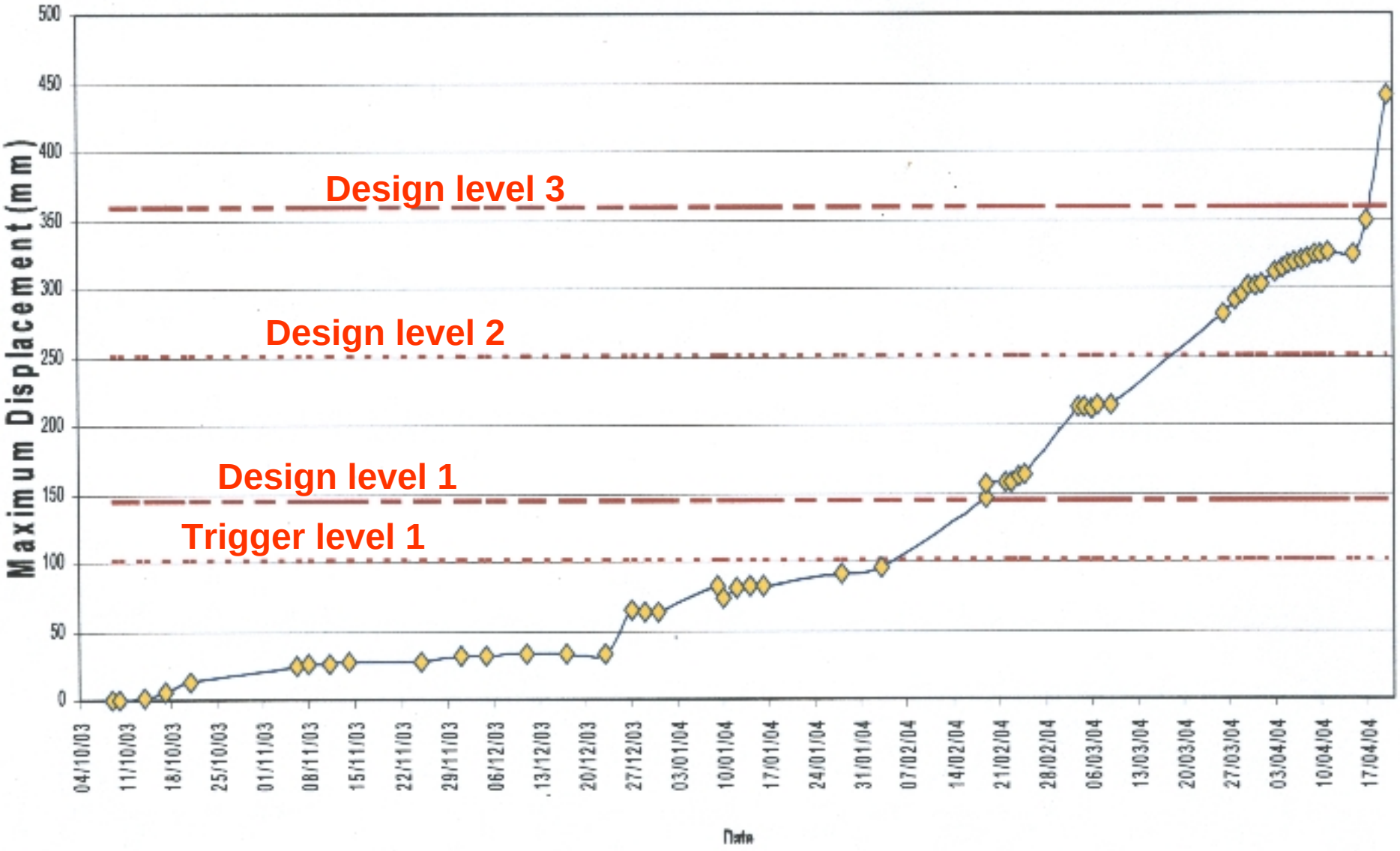


FIGURE 1.11 | OVERVIEW OF M3 AREA

Circle Line C824

Soil Inclinometer (IS-104)

(taken between the period between Oct 2003 to Apr 2004)



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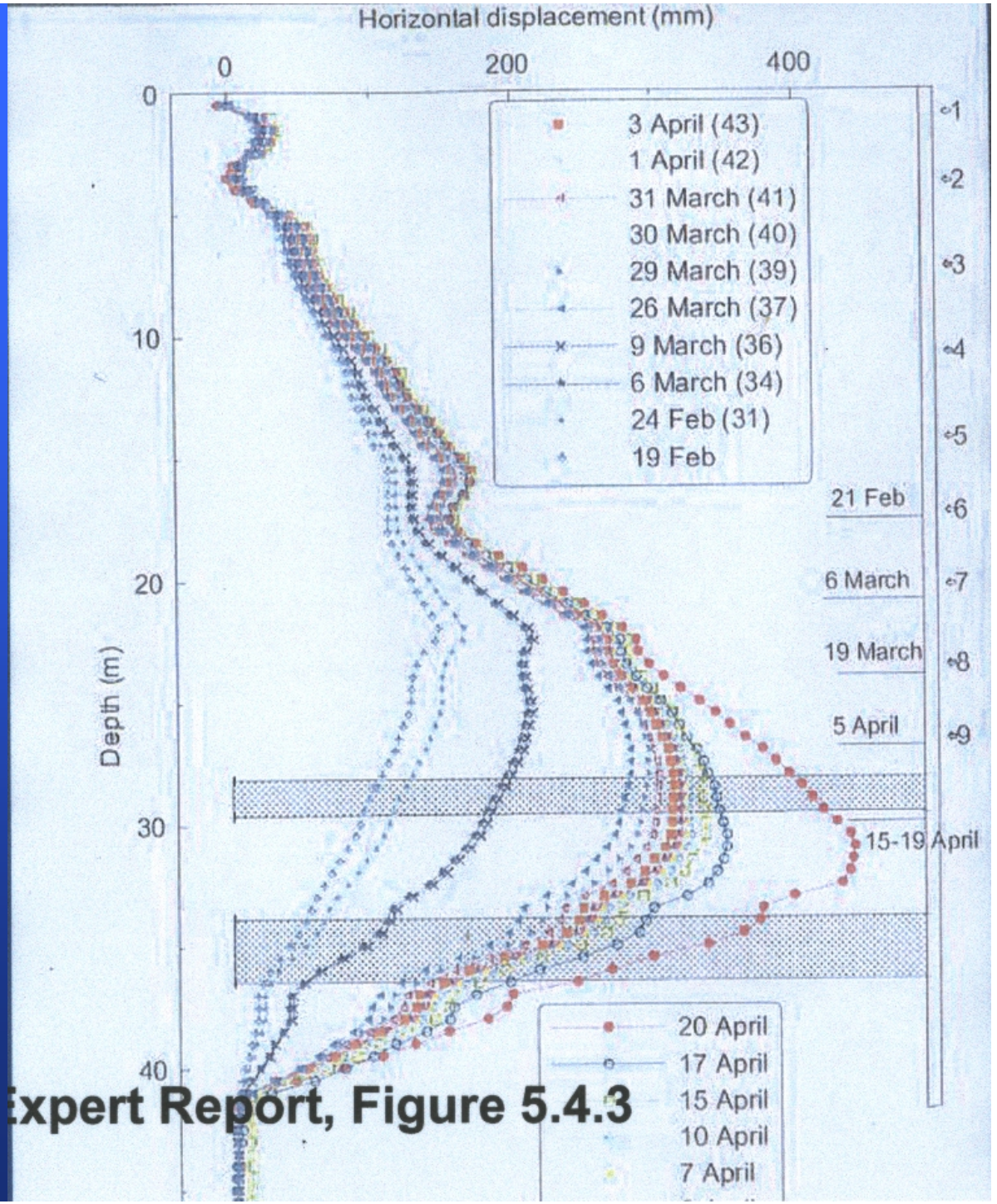

Expert Report, Figure 5.4.3

Deep excavations

The Commission of Inquiry found two "root" causes:

- **Under-design of the diaphragm wall**
  - Related to FE analysis using Plaxis and failure to understand soil model
- **Under-design of the strut/waler connections at the 9th level**

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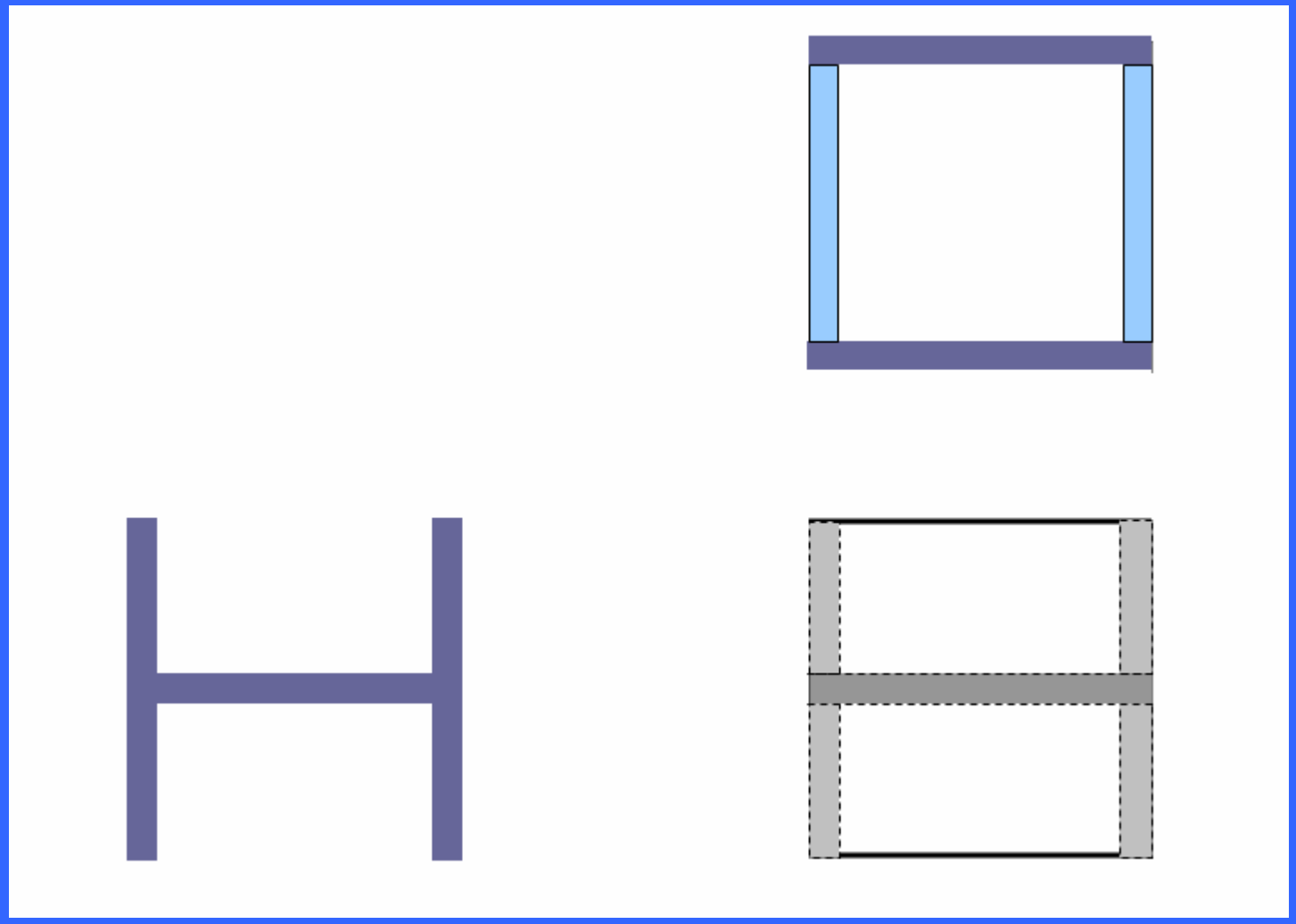

Source: NLC Expert Report, Figure 10.6.1


Source: Exhibit E93

Exhibit 15.3A: S338 (north) (9th level) on 20 April 2004 morning

Exhibit 15.3A: S335 (south) (9th level) on 20 April 2004 Between 10am to 10.30am


3:47 pm

- **"Wisarut and I wanted to run but we were unable to do so. I felt trapped and could only step aside to avoid the gas tanks, lorry and beam that moved towards us. I was frightened and thought of my family and my young child at that time. I thought that I might die at that point." – *Muenpatcha Wichian (Thai labourer)***
- **"Ng Joo Tong *(LTA Project Engineer)* .... Saw a LTA staff arriving and asked him to take over the traffic diversion (on Nicoll Highway). Ng, who was in shock, then sat along the roadside and cried."**
- **"according to Chikushi, Andy Wong *(NLCJV Project Engineer)* tried to tell him something but could not speak coherently."**

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www.mom.gov.sg

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