BCA BE Seminar 2022
Buildings: What Can Go Wrong

Case Studies of Excavation and Tunnelling Failure

Er. Ng Hee Yang

Principal Engineer/Geotechnical Engineering Department

Building and Construction Authority

Acknowledgement

- Excavation
  - Er. Dr. Poh Teoh Yaw
  - Er. Chai Kui Fhen
  - Er. Chow Wei Mun
  - Er. Ben Tan
  - Er. Lim Zhu Liang
  - Er. Woo Kwan Wye

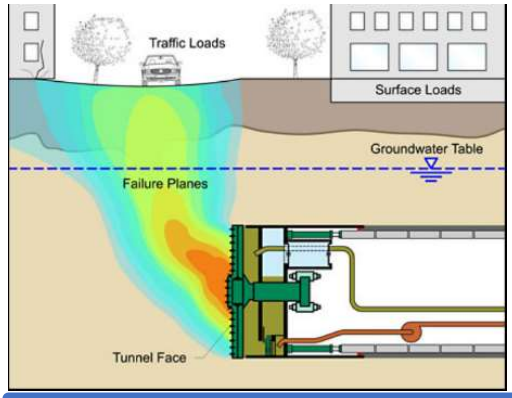
- Tunnelling
  - Er. Dr. Chin Kheng Ghee
  - Er. Kong Tze Foong

Contents

- **Excavation**
  - Common causes of failures

- Case 1 – CBP wall
- Case 2 – Sheet pile wall

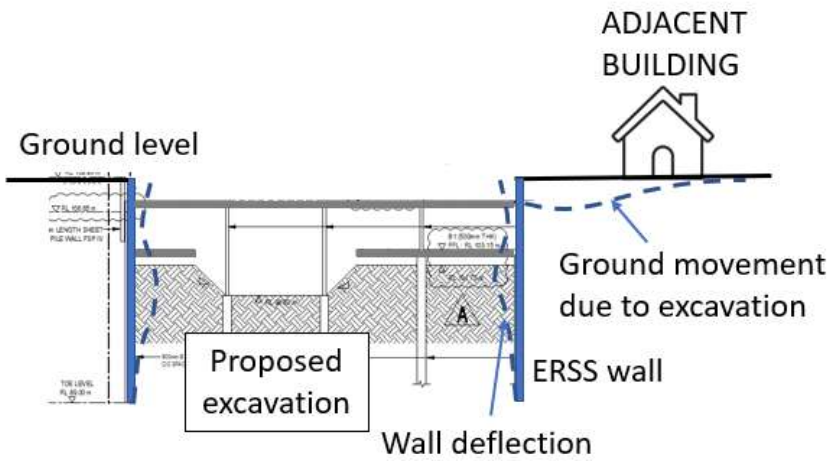
- **Tunnelling**
  - Hazards, settlement, damage and issues



- Case 3 – Chinese cemetery
- Case 4 – Bukit Timah Formation

1 Excavation – Risks

Risks of deep excavation works

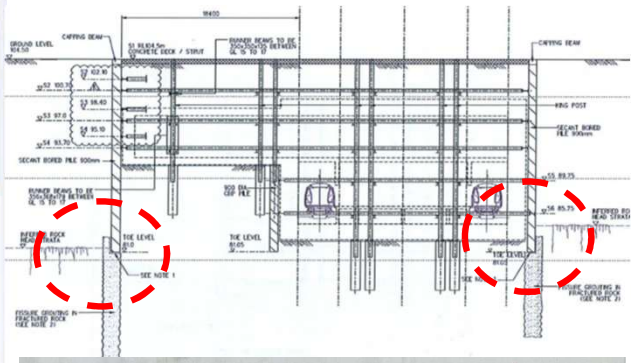


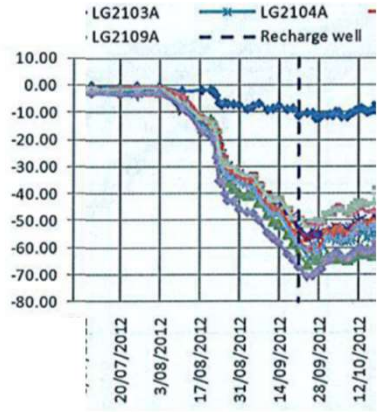
Safety of worksite and impact to adjacent buildings

Risks:

- Instability of retaining system
- Excessive wall deflection due to excavation
- Excessive ground settlement due to lowering of groundwater

1 Excavation – Causes of failures





Basal heave failure at strutted excavation for tunnel construction

Inadequate seepage cut-off at ERSS wall

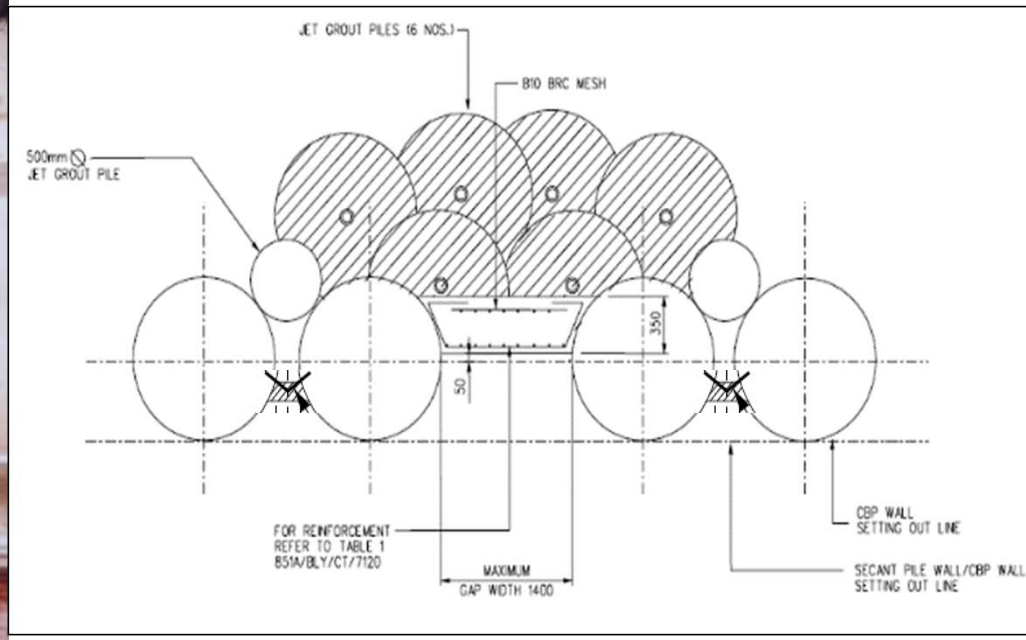
1 Excavation- Causes of failures

Excessive pile movement caused by unstable internal slope within excavation in soft clay

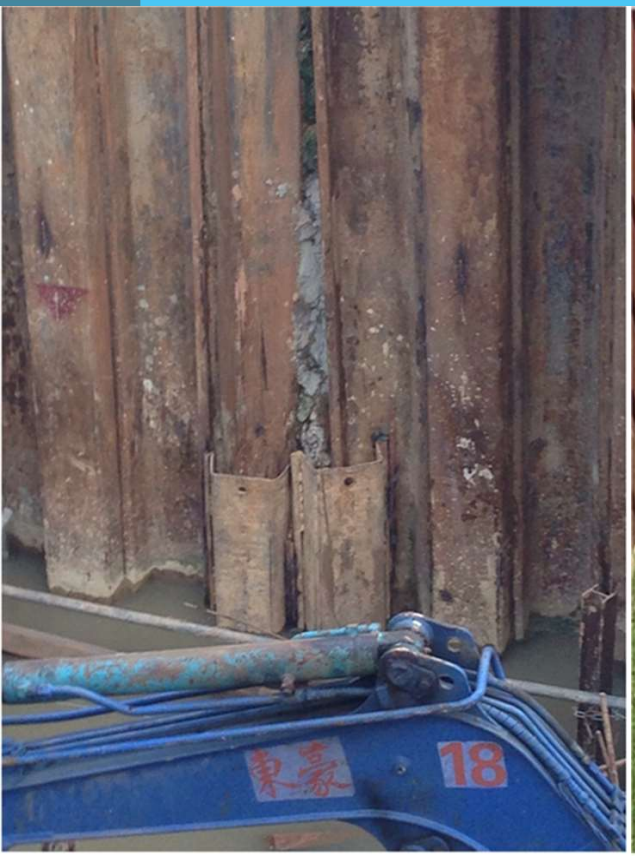
Damaged to RC piles, spun piles and bored piles were reported for these sites

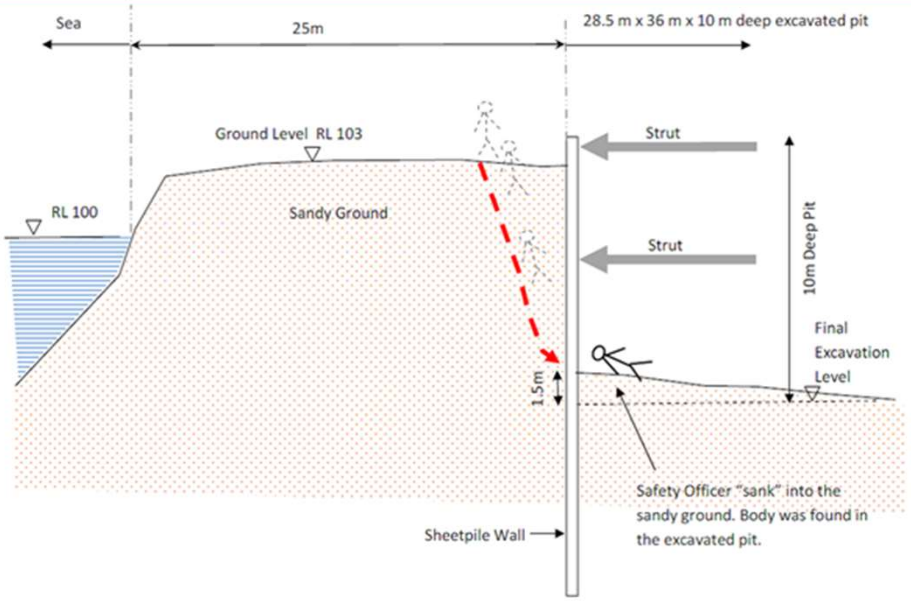
1 Excavation - Causes of failures

A sink hole behind a utility gap where the RC laggings were not constructed at each localised stage of excavation and left unsupported



1 Excavation - Causes of failures





Fatal incident involving a man fallen into sinkhole in sandy ground

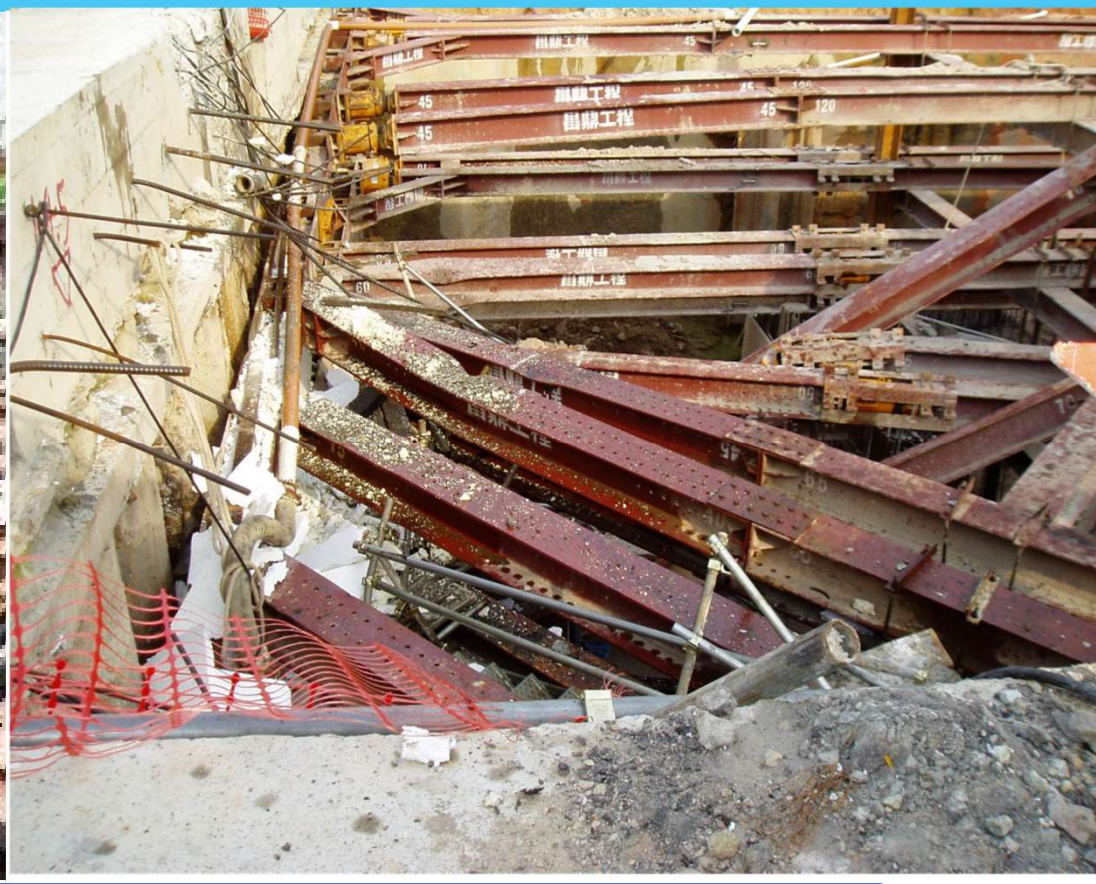
Sinkhole caused by sheet pile gaps

1 Excavation - Causes of failures

A localised collapse of diaphragm wall during trenching which trigger an incident of crane collapsed

Uncontrolled removal of pipe pile ERSS wall caused excessive ground settlement

1 Excavation - Causes of failures



Example of crane incident affecting ERSS support where the first layer strutting was dislodged due to accidental impact loads

1 Excavation – Damage to adjacent buildings

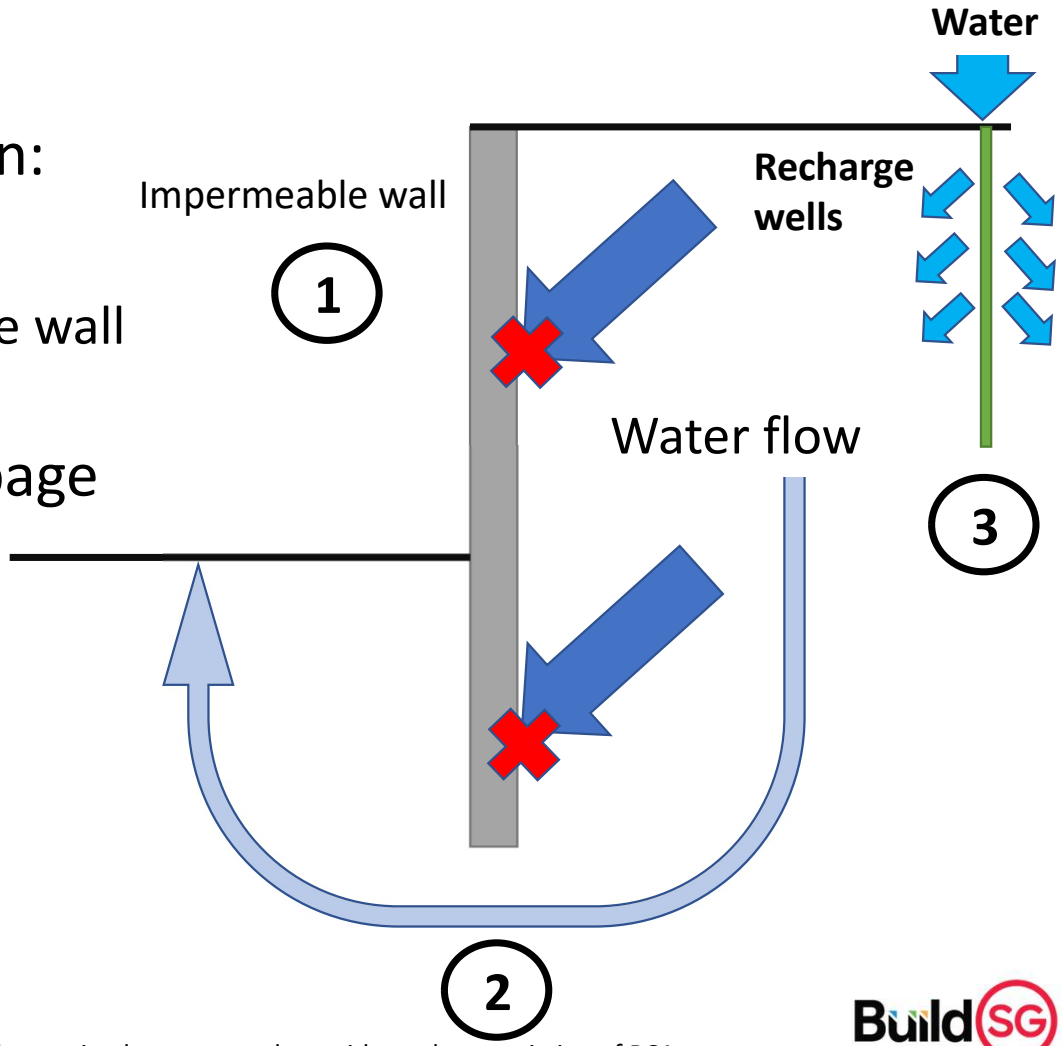
For site with difficult ground condition:

- Impermeable wall

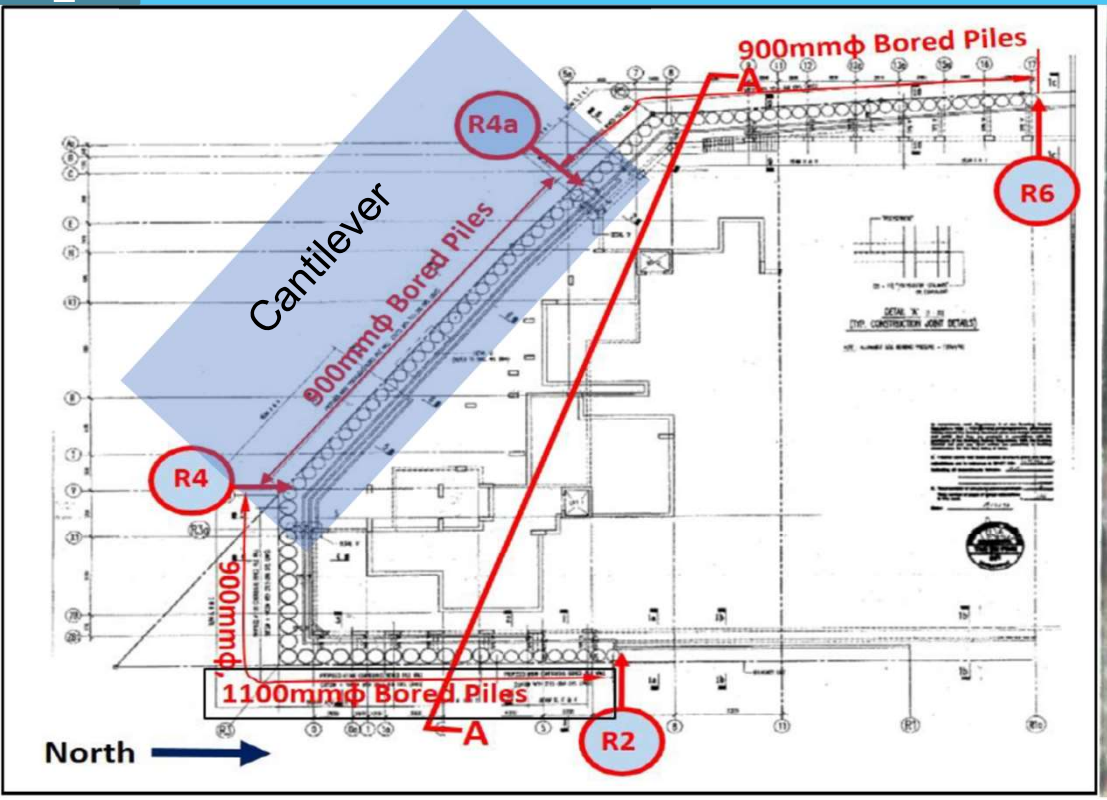
  (e.g. Diaphragm wall (D-wall), secant pile wall or sheetpile wall)

- Adequate wall embedment for seepage cut-off
- Recharge well

Lowering of groundwater level in **soft soil** cause **excessive ground settlement**



1 Excavation – Case 1 (CBP wall)

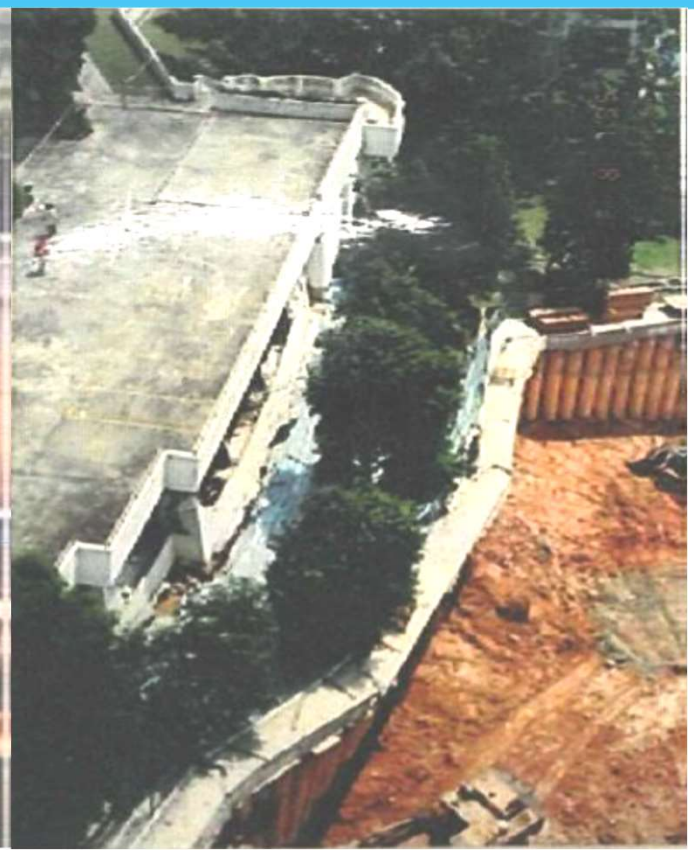


4-storey condominium with 2 levels of basement carpark

900/1100mm diameter CBP

1 Excavation – Case 1 (CBP wall)

The deflected CBP wall

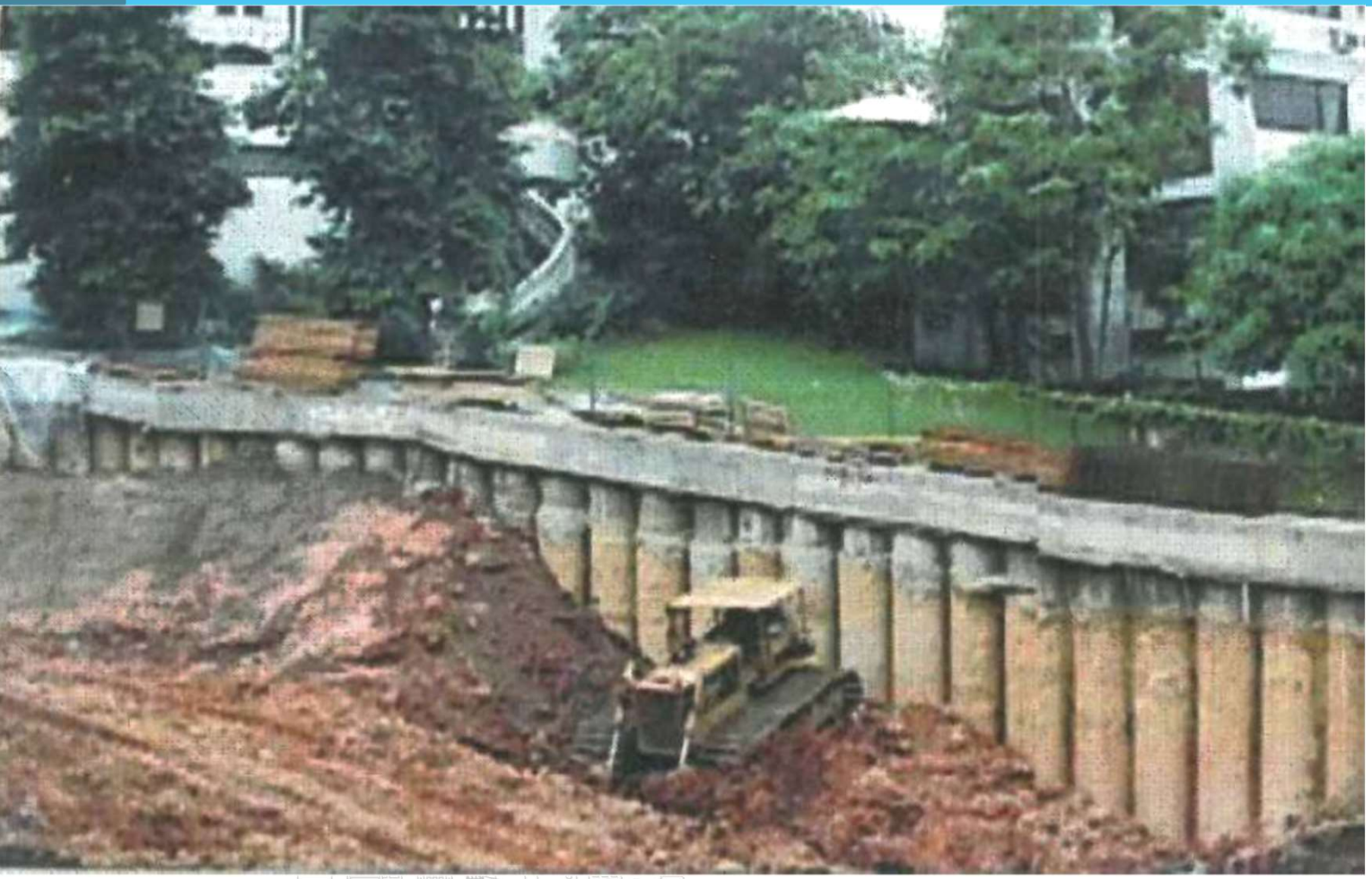


The CBP wall deflected away from single storey carpark.

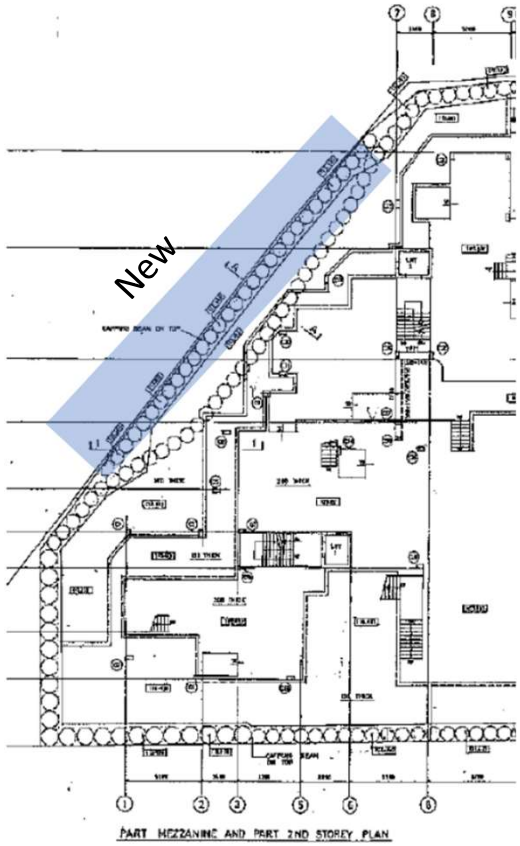
1 Excavation – Case 1 (CBP wall)

Views of carpark columns with large diagonal shear cracks

1 Excavation – Case 1 (CBP wall)

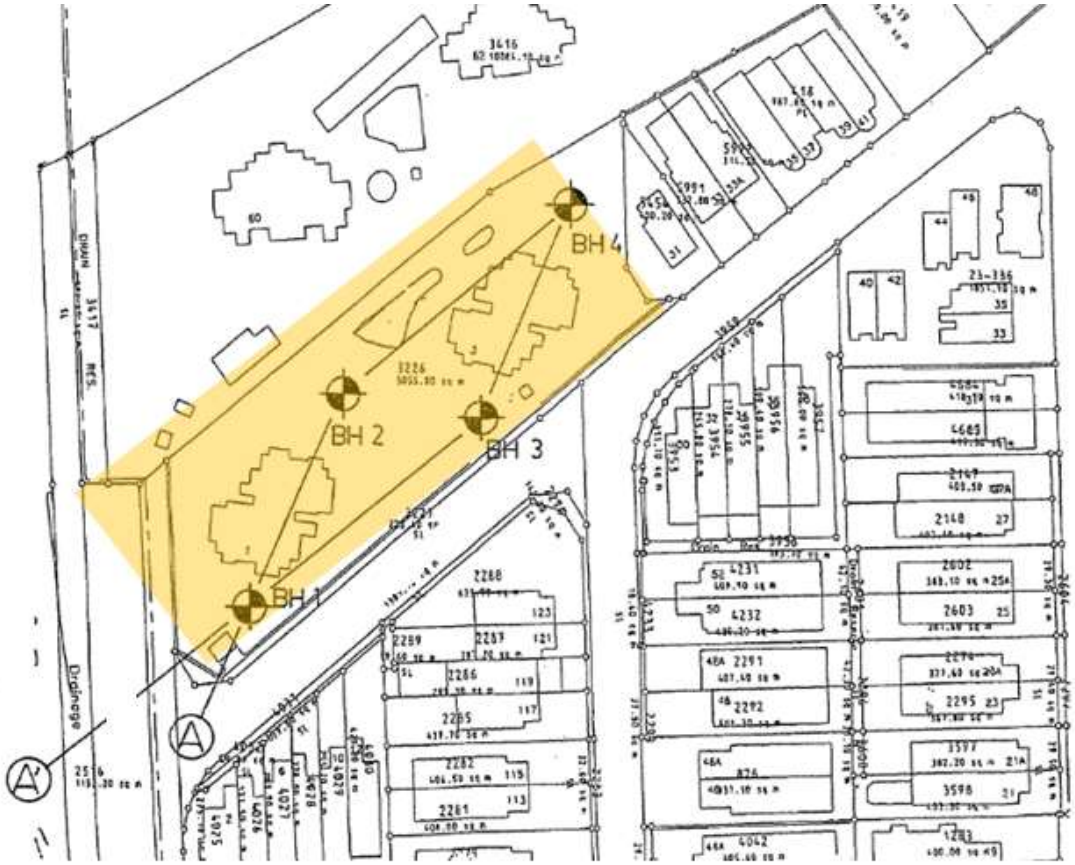


Backfilling operation in progress

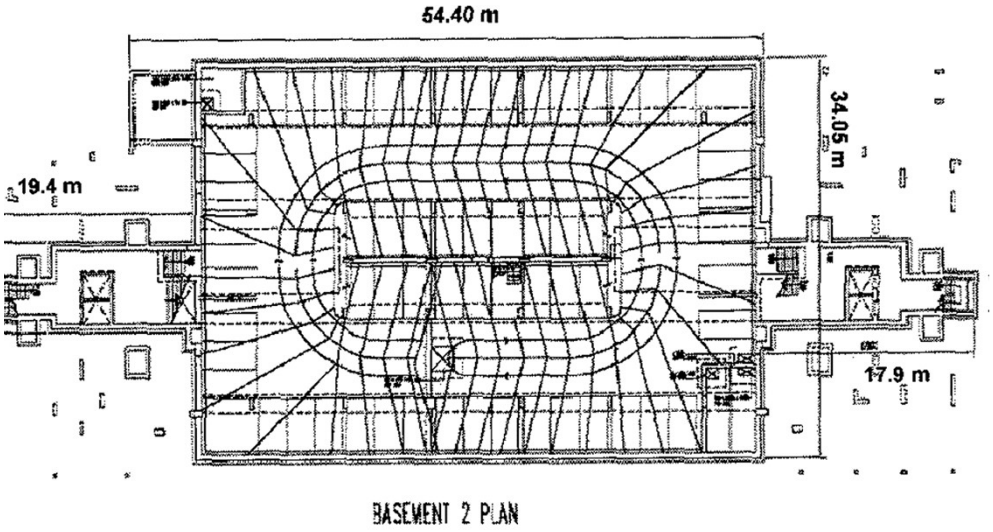


New CBP wall constructed

1 Excavation – Case 2 (Sheet pile wall)

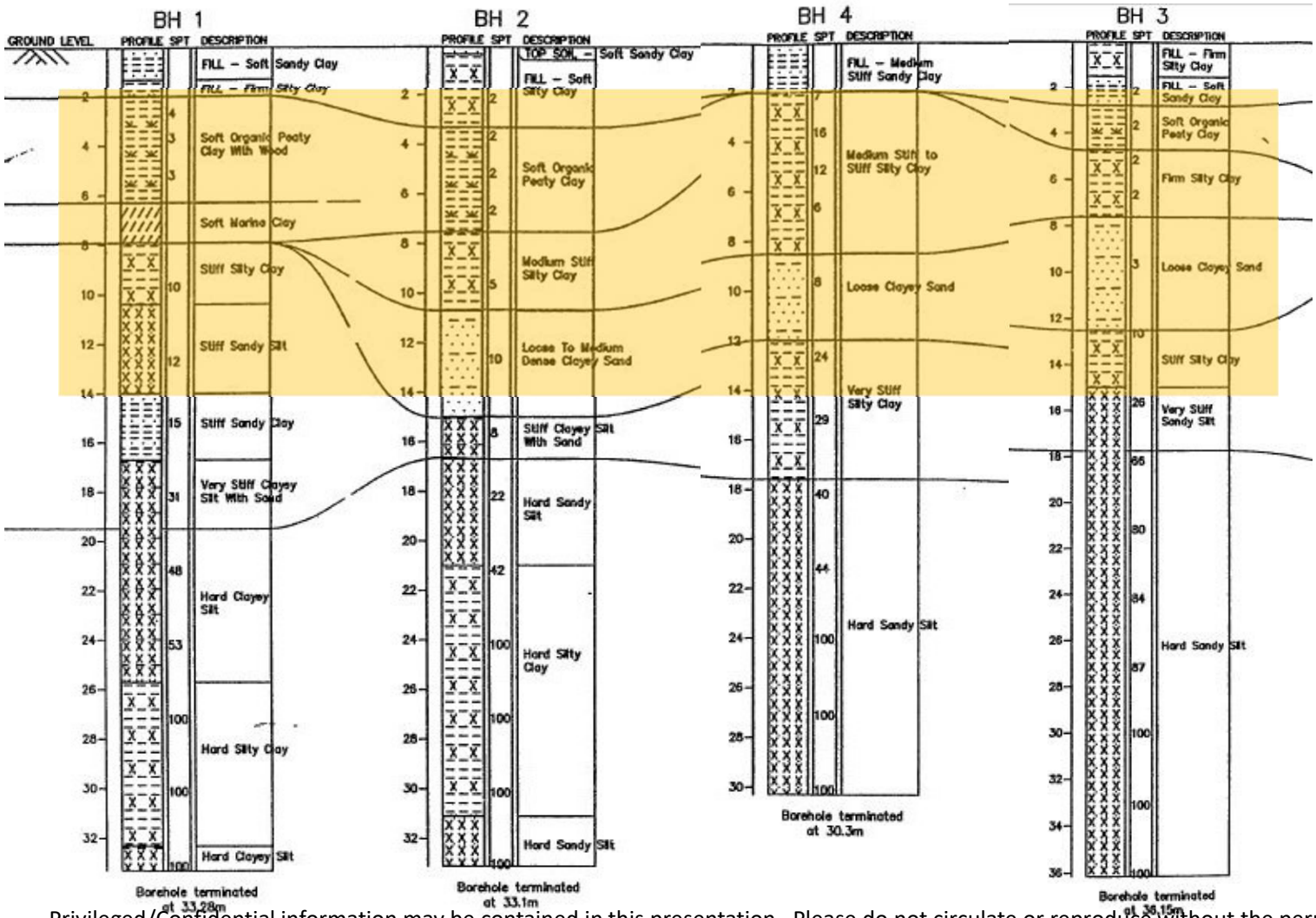


Soil borehole layout of the site



Basement 2 layout

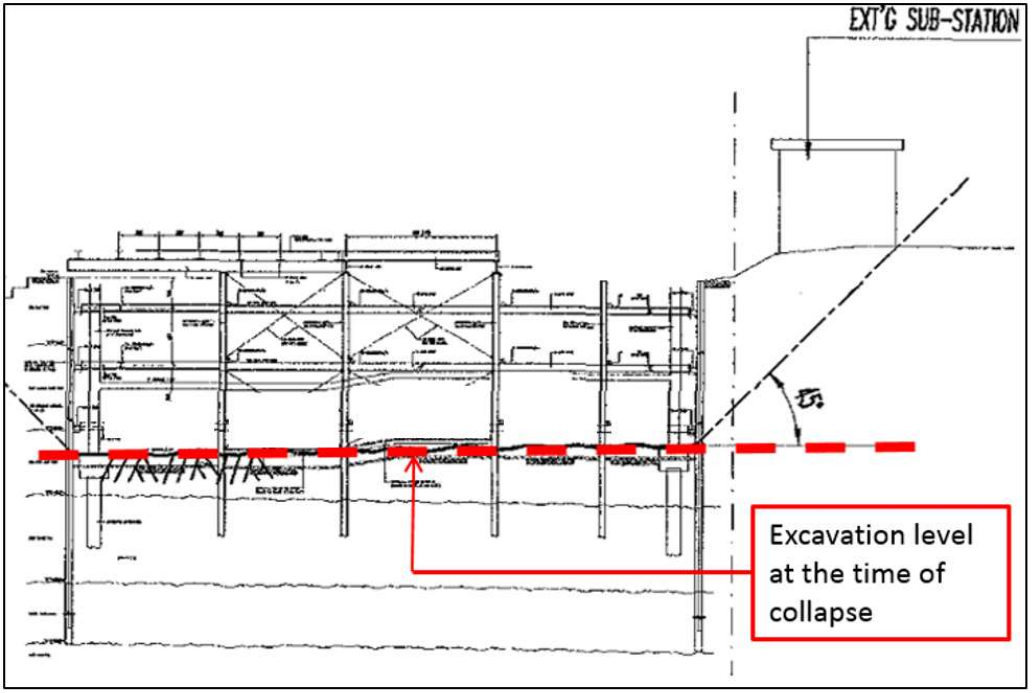
1 Excavation – Case 2 (Sheet pile wall)



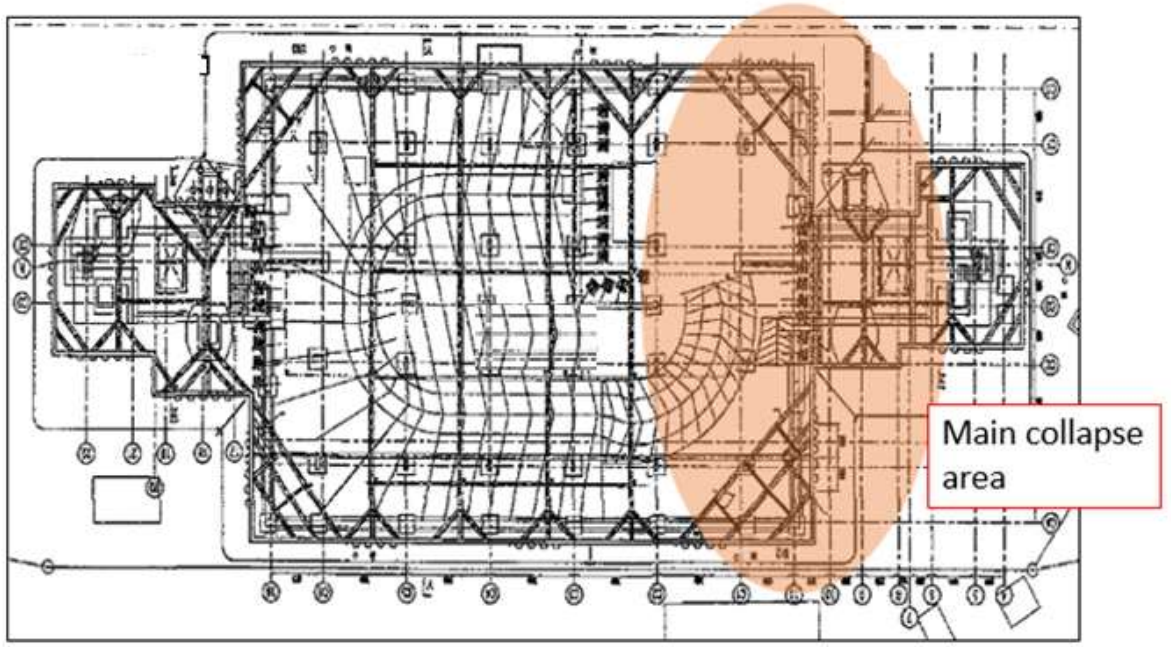
Thick soft clay layer

Boreholes soil profile at the site

1 Excavation – Case 2 (Sheet pile wall)



Excavation level at the time of collapse



Layout plan of the ERSS for the excavation site

1 Excavation – Case 2 (Sheet pile wall)

After the collapse, overall view of the site

1 Excavation – Case 2 (Sheet pile wall)

After the collapse, road in front of site and adjacent existing substation

1 Excavation – Case 2 (Sheet pile wall)

After the collapse, road in front of site and adjacent existing substation

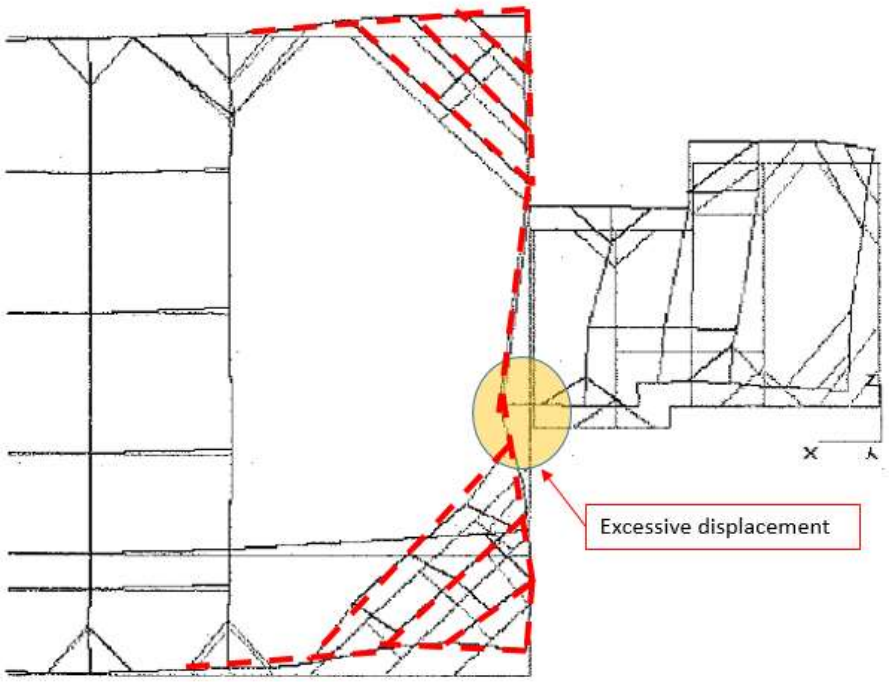
1 Excavation – Case 2 (Sheet pile wall)

Backfilling operation in progress

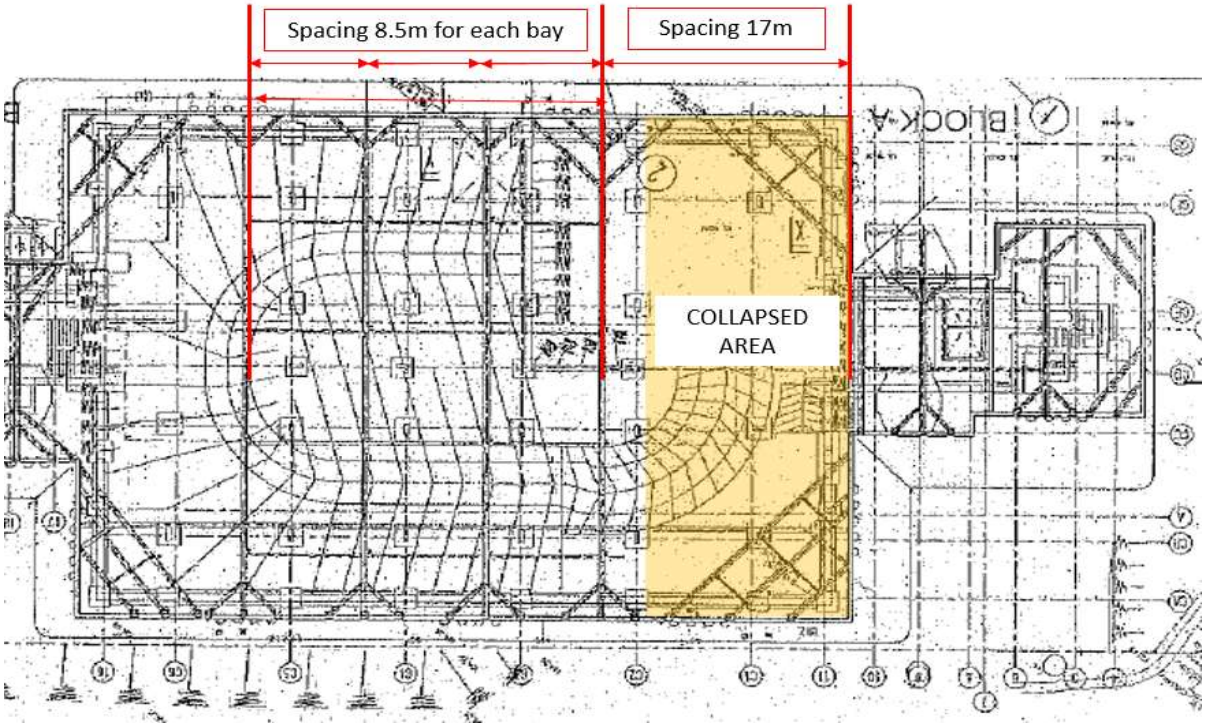
1 Excavation – Case 2 (Sheet pile wall)

Backfilling operation in progress

1 Excavation – Case 2 (Sheetpile wall)



Deformed shape of the temporary sheet pile wall system



Spacing of struts

2 Tunnelling - Hazards

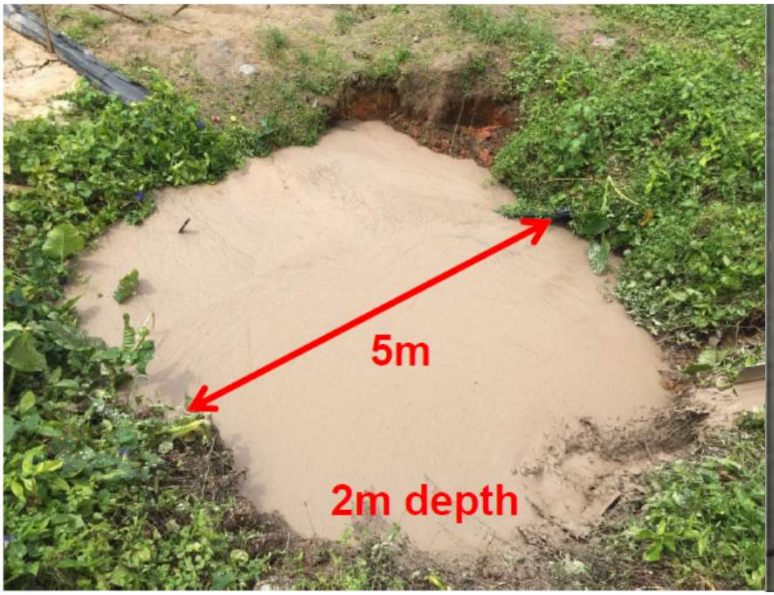
Potential Hazards – Tunnelling Projects

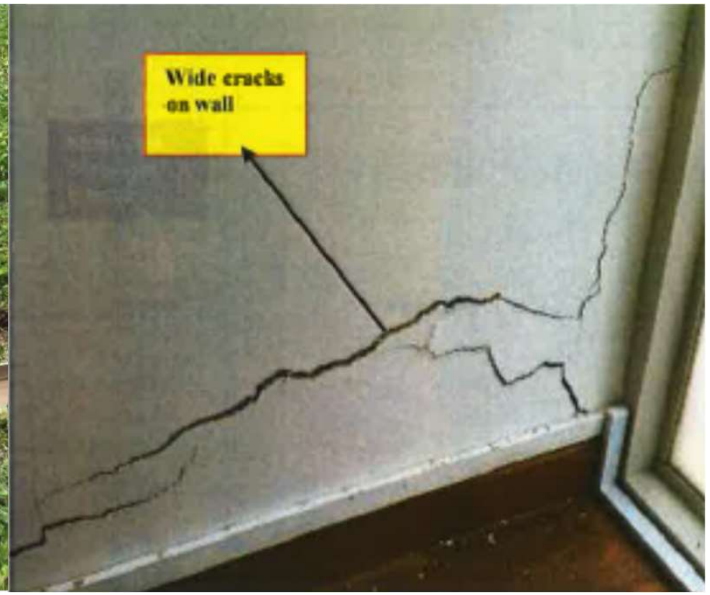
Graphics from external sources

In August 2010, a hole suddenly opened up in a road in Taiyuan, China, causing the collapse of part of the nearby building of the Shanxi Provincial People's Hospital an hour later. No casualties were reported in the accident.

2 Tunnelling – Damage to nearby building

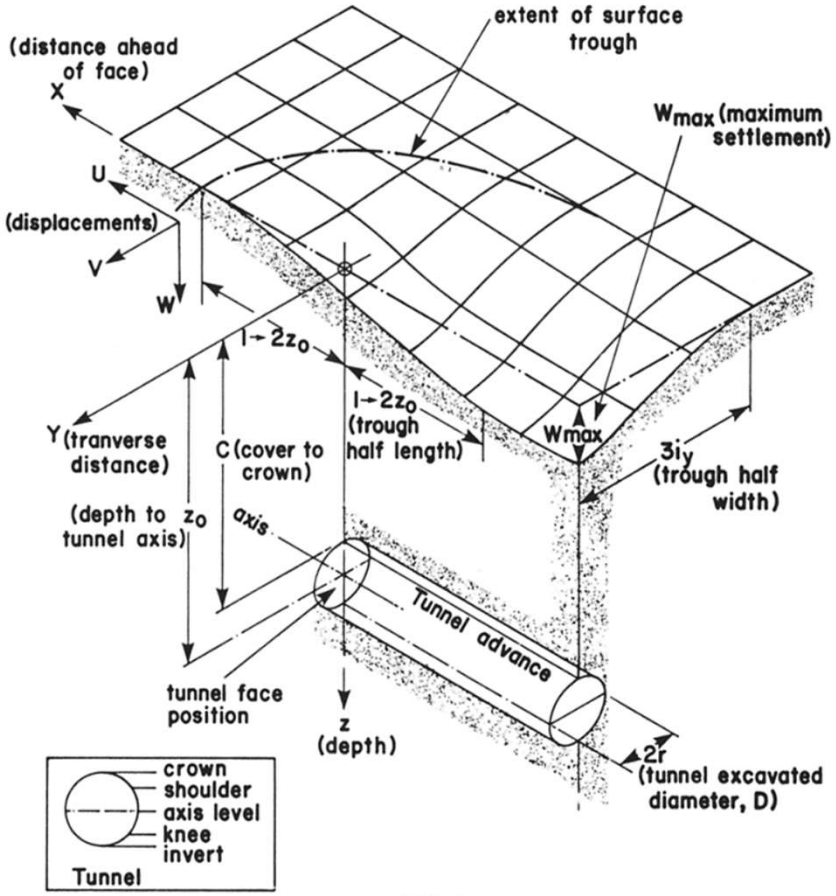
Building damage due to nearby tunnelling



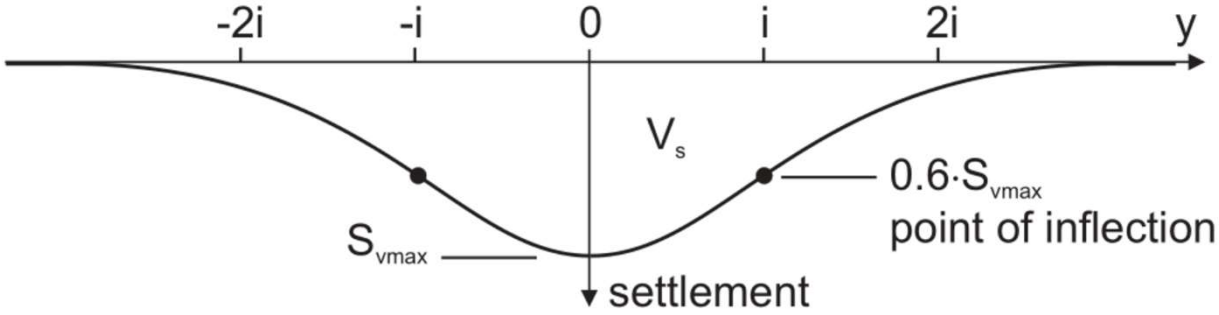


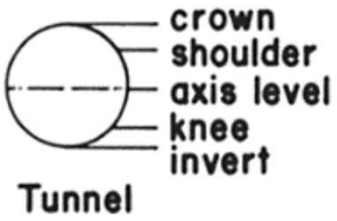
- Sinkhole at 4m away from the existing pile foundation of the house
- Building suddenly settled by 28mm
- Building damaged with large cracks
- Residents decanted immediately after the incident

2 Tunnelling - Settlement



Ground surface settlement

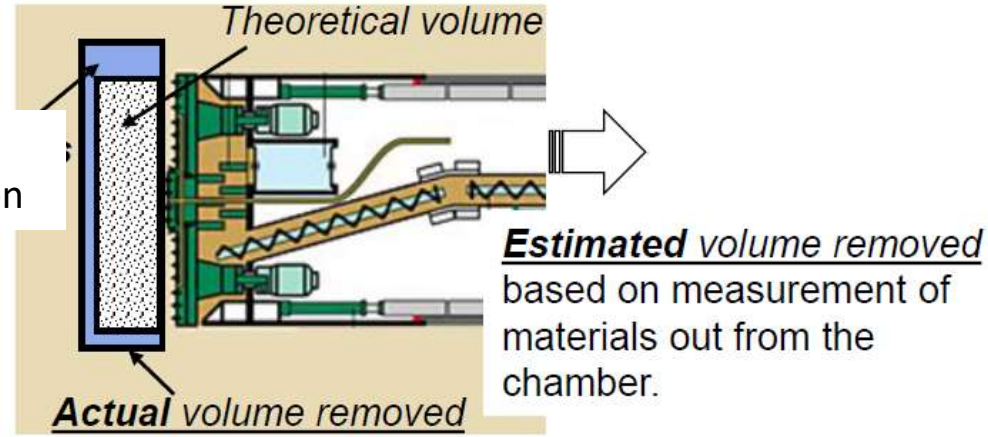




Graphics from external sources

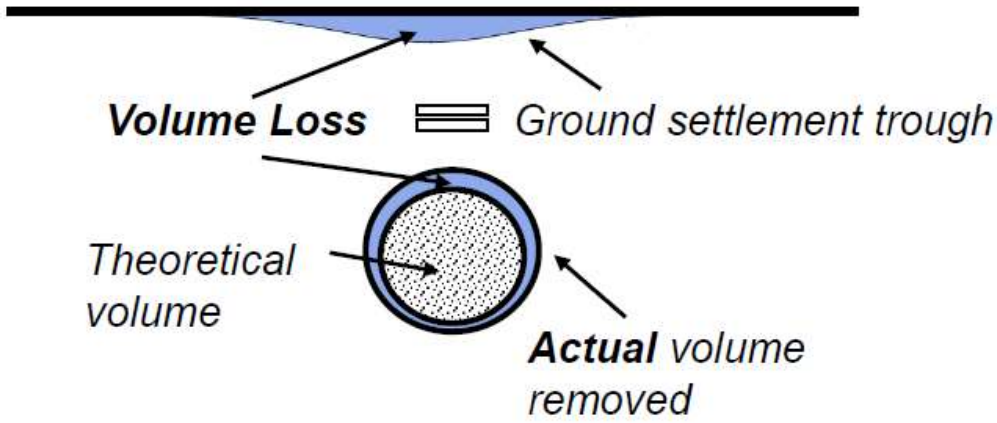
2 Tunnelling – Volume of excavation

Over-excavation



$$\text{'Over-excavation'} = \frac{\textbf{Estimated volume removed}}{\text{Theoretical volume}} - 1$$

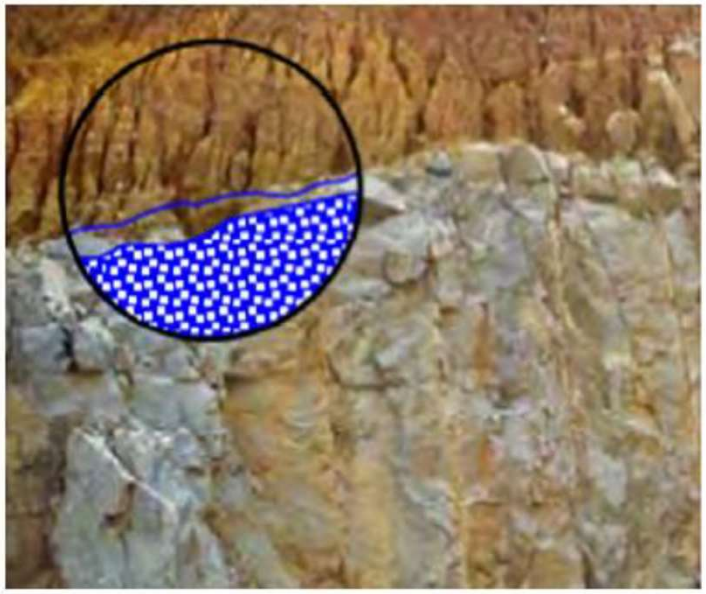
Excavation management system

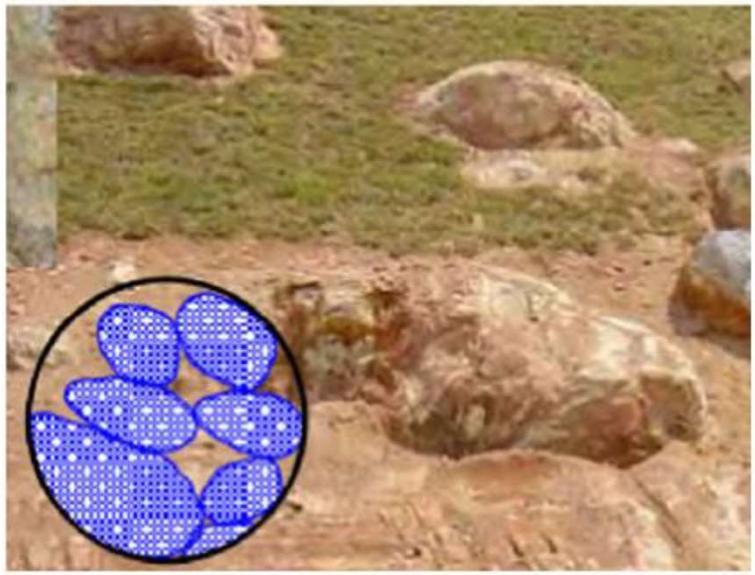


Ground settlement trough

Graphics from external sources

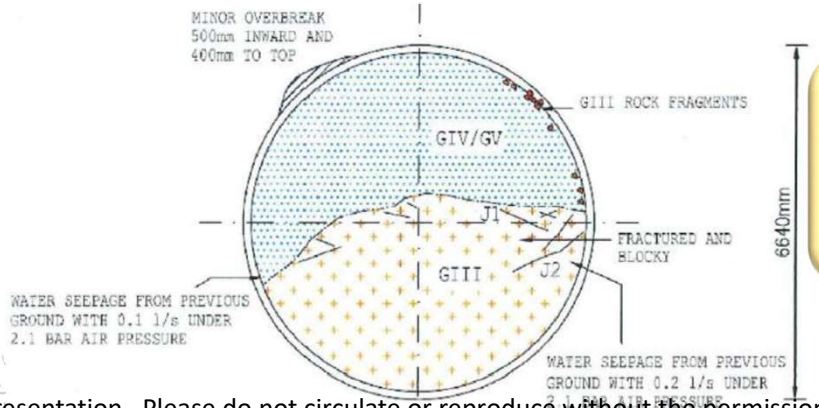
2 Tunnelling – Common issues





Graphics from external sources

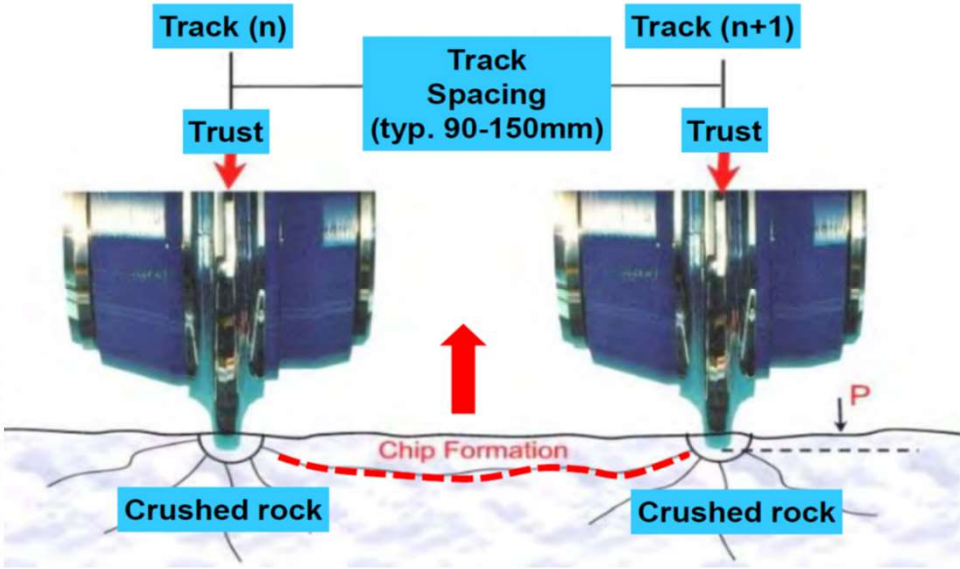
Mixed face conditions



Materials of very different strength and stiffness on same face

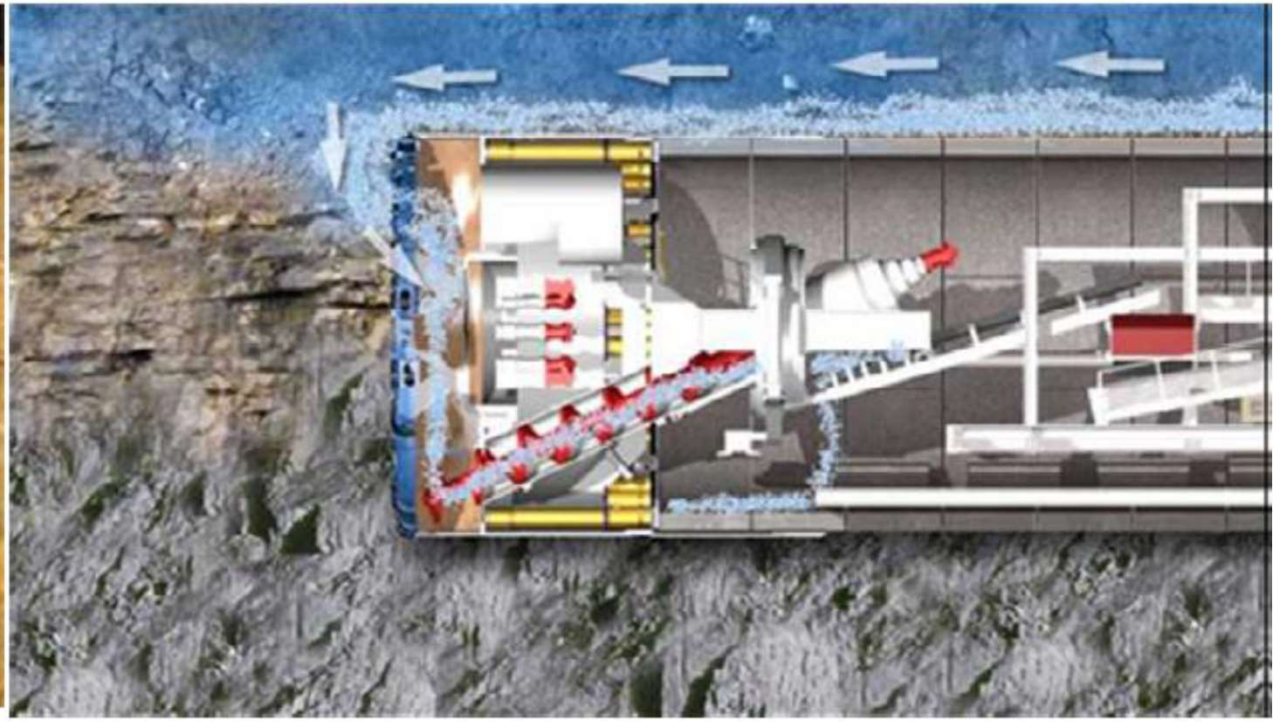
2 Tunnelling – Issues with mixed-face

High wear and damage to cutters due to impact



Graphics from external sources

2 Tunnelling – Issues with mixed face



Graphics from external sources

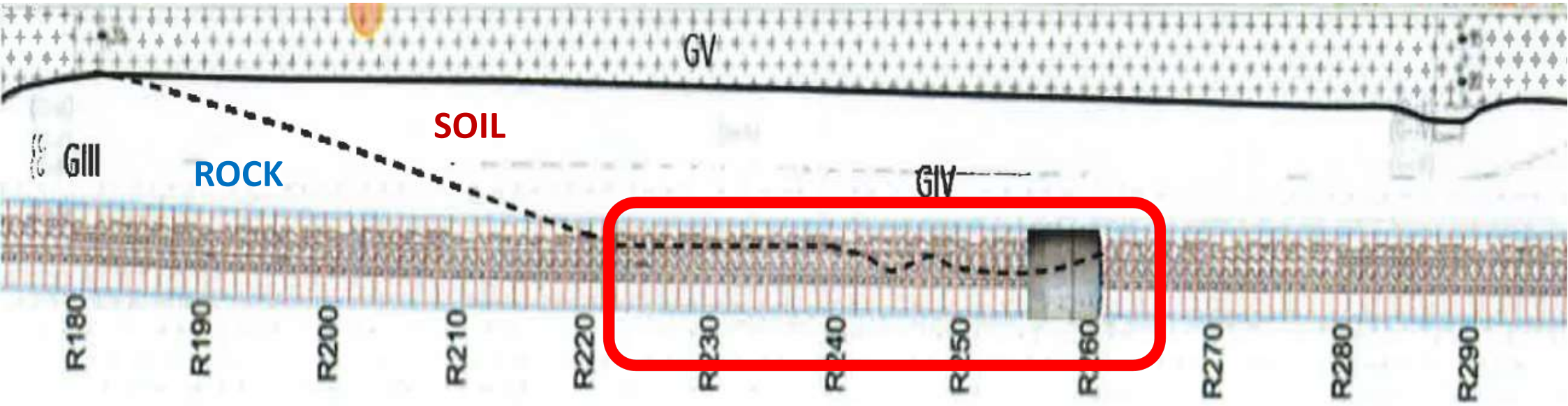
Face stability

Water ingress

2 Tunnelling – Case 3 – Chinese cemetery

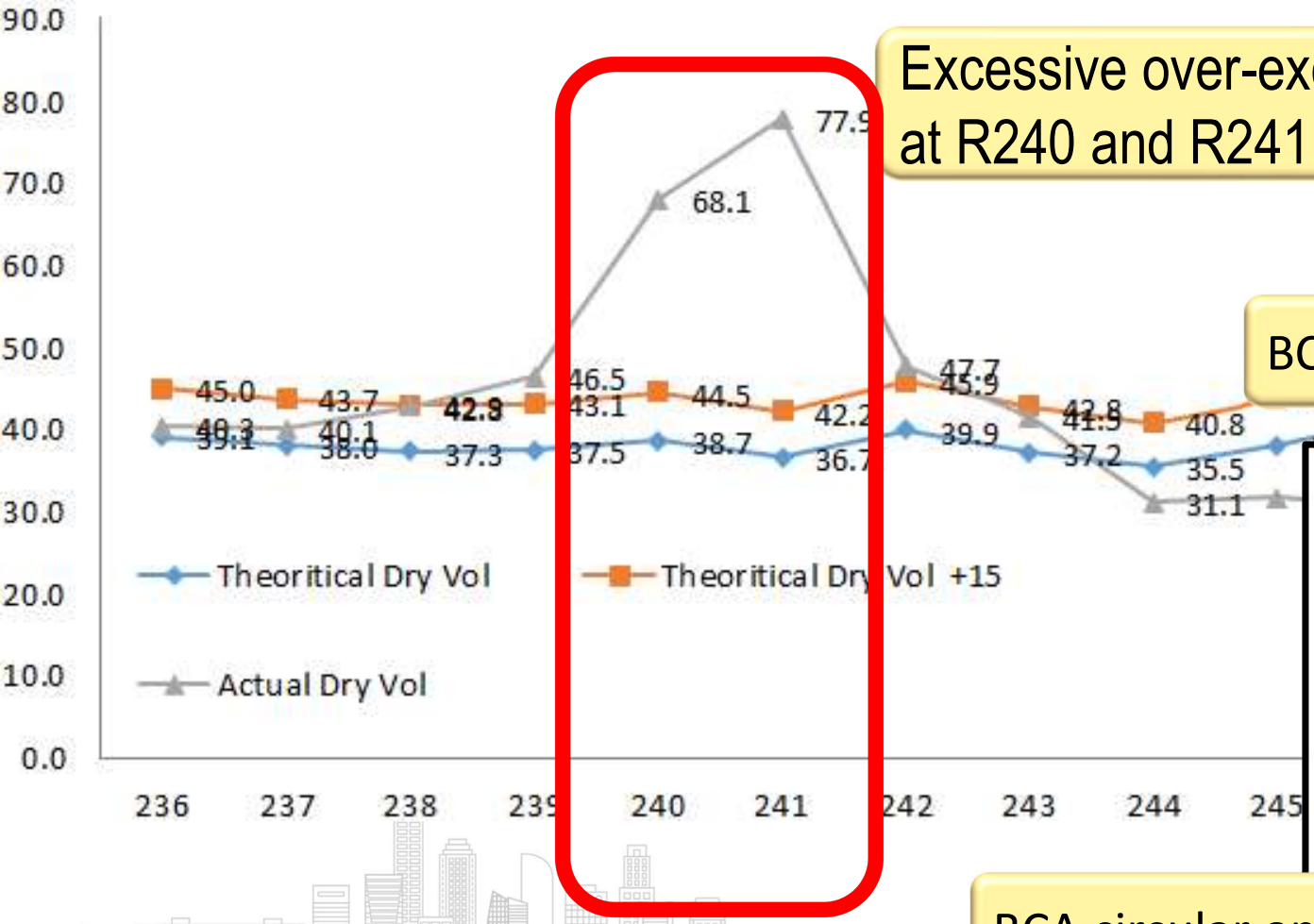
Location of sinkhole

2 Tunnelling – Case 3 – Chinese cemetery

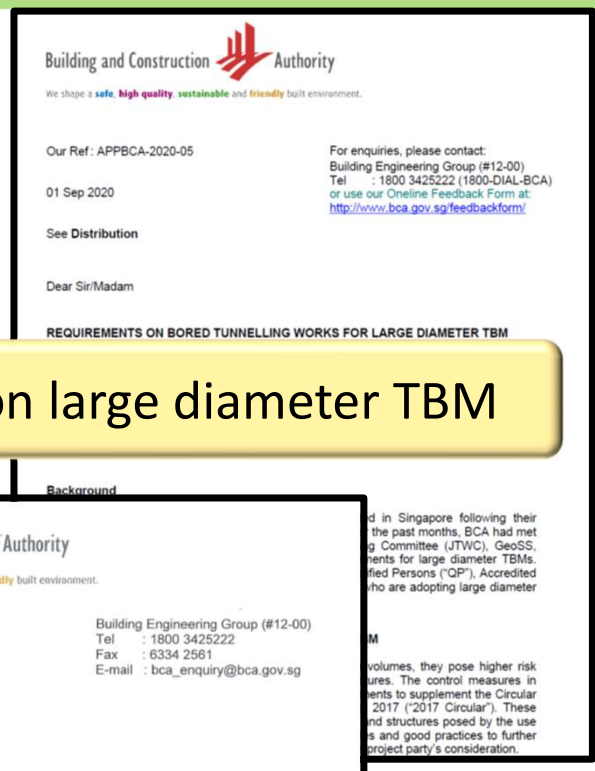


Mixed face zones (GIV/GIII) over 40 rings were encountered during actual tunnelling

2 Tunnelling – Case 3 – Chinese cemetery



Excessive over-excavation at R240 and R241.



Building and Construction Authority

We shape a safe, high quality, sustainable and friendly built environment.

Our Ref : APPBCA-2020-05

01 Sep 2020

For enquiries, please contact:
Building Engineering Group (#12-00)
Tel : 1800 3425222 (1800-DIAL-BCA)
or use our Oneline Feedback Form at:
http://www.bca.gov.sg/feedbackform/

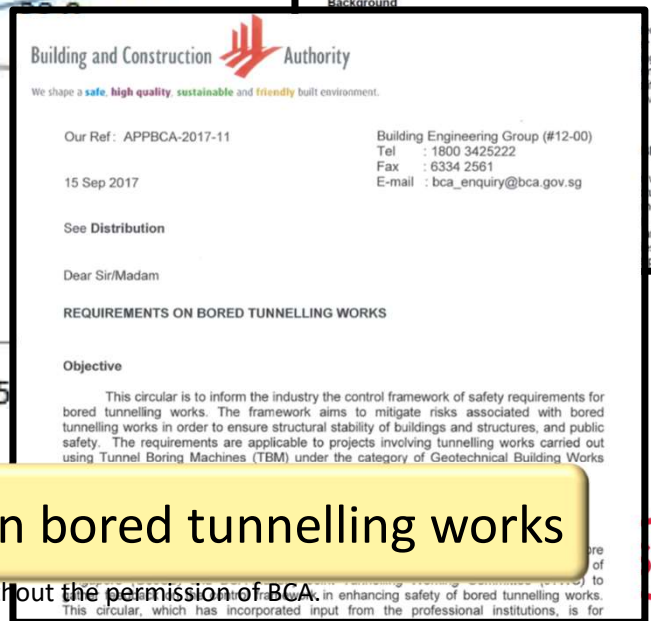
See **Distribution**

Dear Sir/Madam

REQUIREMENTS ON BORED TUNNELLING WORKS FOR LARGE DIAMETER TBM

Background

BCA circular on large diameter TBM



Building and Construction Authority

We shape a safe, high quality, sustainable and friendly built environment.

Our Ref : APPBCA-2017-11

15 Sep 2017

Building Engineering Group (#12-00)
Tel : 1800 3425222
Fax : 6334 2561
E-mail : bca_enquiry@bca.gov.sg

See **Distribution**

Dear Sir/Madam

REQUIREMENTS ON BORED TUNNELLING WORKS

Objective

This circular is to inform the industry the control framework of safety requirements for bored tunnelling works. The framework aims to mitigate risks associated with bored tunnelling works in order to ensure structural stability of buildings and structures, and public safety. The requirements are applicable to projects involving tunnelling works carried out using Tunnel Boring Machines (TBM) under the category of Geotechnical Building Works

BCA circular on bored tunnelling works

2 Tunnelling – Case 3 – Chinese cemetery

Graphics from external sources

Boulders/rock debris stuck at cutterhead

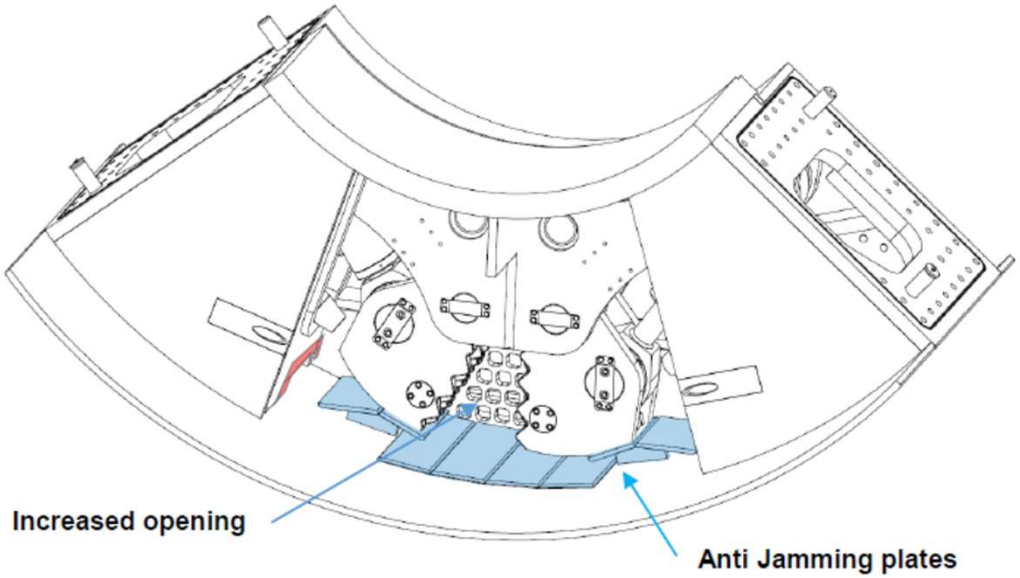
Install additional plates to minimize risks of jamming

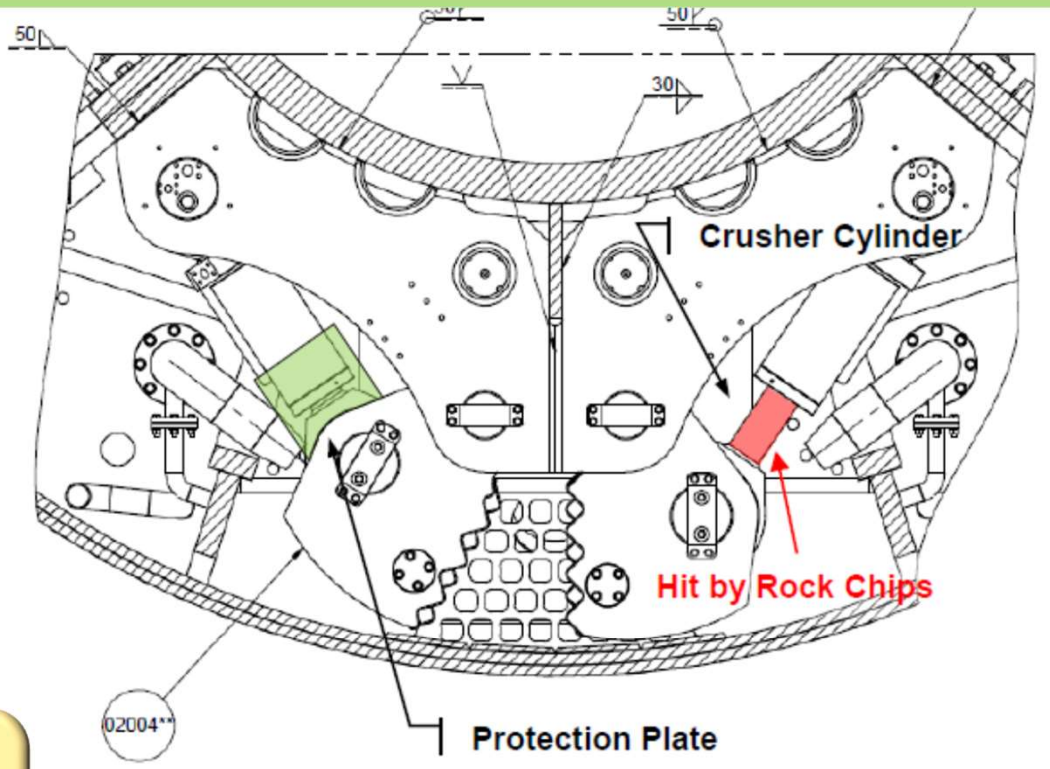
2 Tunnelling – Case 3 – Chinese cemetery

Graphics from external sources

Appropriate sizing of crusher grid

2 Tunnelling – Case 3 – Chinese cemetery





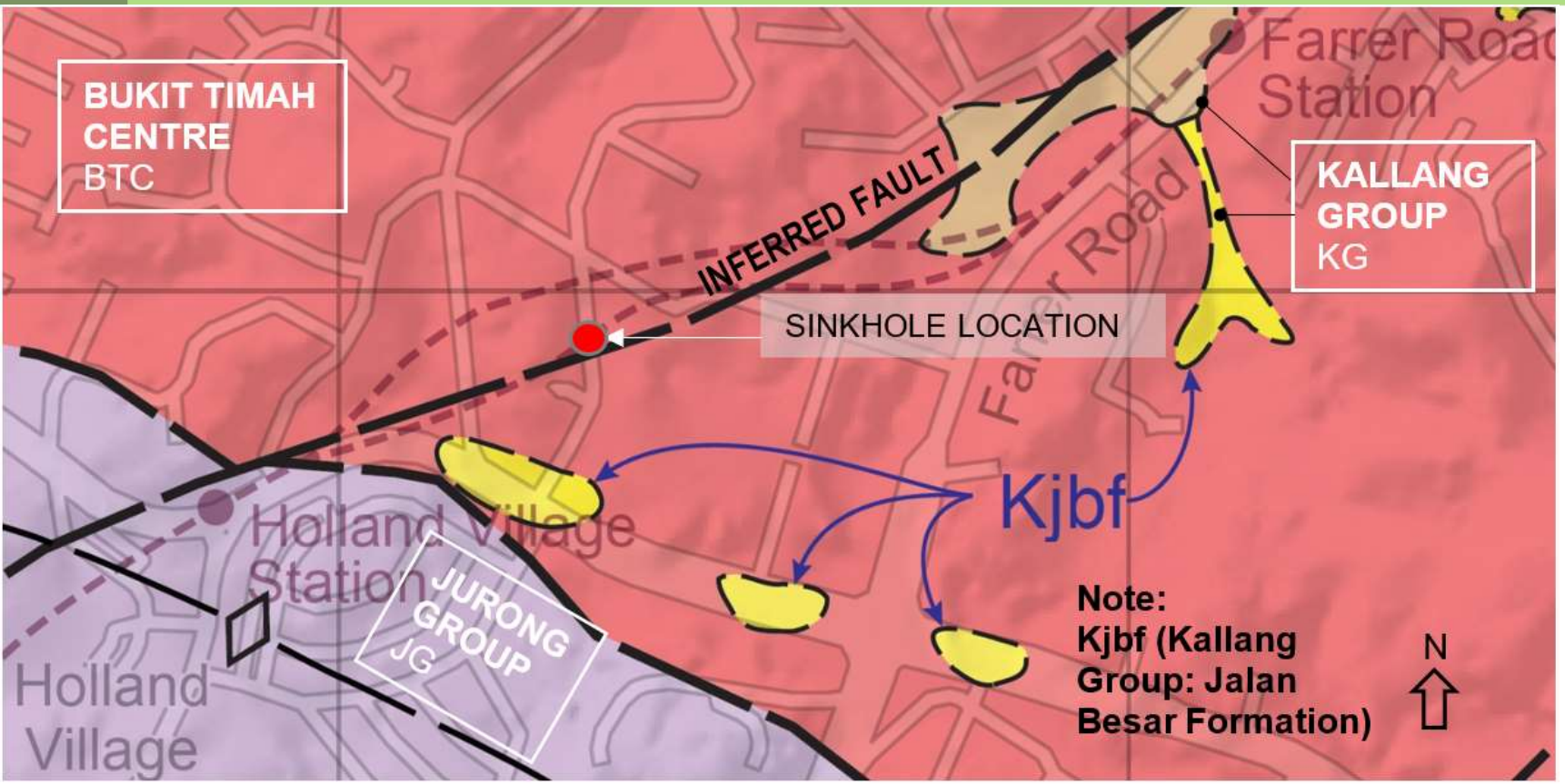
Rock crusher – protection plates and anti-jamming plates

Graphics from external sources

2 Tunnelling – Case 4 – Bukit Timah Formation

Sinkhole of:
12m (length)
5m (width)
3m (depth)
occurred on
May 2008

2 Tunnelling – Case 4 – Bukit Timah Formation



Location of sinkhole with geological formations

2 Tunnelling – Case 4 – Bukit Timah Formation

Faulty equipment	**The electronic muck control (EMC) system used to track the excavated soil/rock volume and compare it with the forward movement of the tunnel boring machine (TBM) for both inner and outer bound TBMs were not properly calibration.** **The EMC was hence unable to provide accurate estimation of the excavation and over excavation volumes. It was also observed that the bentonite density for the outflow pipe carrying the excavated material was typically lighter than that for the corresponding inflow pipe, indicating a faulty density meter.**

Equipment → Faulty density meter

Poor estimate of excavation volume

2 Tunnelling – Case 4 – Bukit Timah Formation

Inexperienced Personnel	**The professional engineer and key tunnel manager lacked experience in this form of tunnelling. Their decisions were highly dependent on third party advice from outside their firm. In addition, key tunnelling personnel of the tunnel team were not on duty during night shift tunnelling works.**

Human → Lack experience

Night shift – not on duty

2 Tunnelling – Case 4 – Bukit Timah Formation

Face pressure not in accordance with SOP	Tunnelling works carried out for rings 1512 to 1515 were not in accordance to the TBM Instruction Sheet. The affected rings were in transition of full-face rock (rings 1512 and 1513) to mixed face (rings 1514 and 1515). The input face pressures (ranged from 1.2 to 1.8 bar) were much lower than the specified pressures (ranged from 2.3 to 2.4 bar). Also, some of the KPI were not controlled within the allowable ranges. For example, at ring 1517 the stipulated face pressure was 2.3 bar while the actual face pressure varied from 1.9 to 3 bar, way beyond the acceptable variation of 0.1 bar from the stipulated value. Large variation of bentonite level was observed during tunnelling for rings 1519 to 1523 (rings located directly beneath the sinkhole) which the project parties attributed to a faulty bentonite level sensor.

Face pressure → Lower than required/large variations

2 Tunnelling – Case 4 – Bukit Timah Formation

Face instability	**Daily TBM Excavation Meeting minutes on May 2008 recorded that the TBM face appeared to be loosened and unstable despite using compressed air for ring 1516. Additional 6 cutter head interventions were carried out within a short period of one week under mixed face condition without implementation of additional precautionary/preventive measures.** **The cutter head intervention for ring 1515 was initially carried out under free air condition (instead of compressed air) and could have adversely affect the face stability. In addition, there were no records of temporary supports installed to support the unstable face. Frequent and prolong cutter head intervention under unstable mixed face could have resulted in the observed over excavation.**

Face stability → CHI carried out under free air (no compressed air)

2 Tunnelling – Case 4 – Bukit Timah Formation

Over-excavation	**Large volume of over excavation was observed (estimated from relative dry weight of the excavated material) for five of the tunnel rings - rings 1525, 1522, 1521, 1518, 1515 (with excavated material dry weight ranged from 1.5 to 3 times that of for a normal ring). Daily TBM Excavation Meeting minutes also recorded an estimated over excavation of 35m^3, 40m^3, 40m^3 for rings 1525, 1521, 1515, respectively.** **The design assumed a 1.5% volume loss (approximately 0.74m^3 per ring). The observed volume loss of completed tunnel was typically less than 1%. The estimated gross volume loss at the location of incident was estimated to range between 80% to 200% (based on relative dry weight).**

Over excavation → Large over-excavation volume

2 Tunnelling – Case 4 – Bukit Timah Formation

No surface grouting of over-excavated void

No grouting

Concerns on TBM being "grouted up"

Although over excavation was reported for ring 1515 and ring 1521 on May 2008, the project parties decided to carry on with TBM operation and to grout the voids later, after the TBM has passed through the over-excavated portion. They were concerned that the TBM might be "grouted up" when the grouting was targeted at voids near to TBM shield and cutterhead locations. However, as the TBM was operating in mixed face condition, the TBM could only be advanced slowly. The over-excavated voids eventually collapsed, causing sinkhole formed at the ground surface.

Tunnelling works were carried out not in accordance to the Method Statement for TBM Excavation Management in Mixed Face Ground. The method statement required that surface drilling and grouting to be carried out if more than 10%/15% of over-excavation was observed. However, despite observations of large volume of over-excavation for rings 1515, 1518, 1521, 1522, 1525, as early as 10 days prior to the sinkhole, tunnelling works continued without grouting.

3 Summary - Excavation

BCA circular Advisory Note 1/09

Building and Construction Authority

We shape a safe, high quality, sustainable and friendly built environment.

Our Ref : BCA BC 15.0.3 VOL 11

Building Engineering Division (#05-00)
Fax : 6325 7482
DID : 6325 7571

2 Apr 2009

See Distribution

Dear Sir/Madam

ADVISORY NOTE 1/09 ON EARTH RETAINING OR STABILISING S

BCA is embarking on a comprehensive review all build regulations on a 3-year cycle basis with priority given to those rule impact on construction costs and those that have attracted frequ industry. A review of BCA's requirements covering the design and co recently carried out.

2 This circular is to inform you of the Advisory Note 1/09 wh changes that primarily relate to more relaxed allowable wall deflec sites but subject to additional inspection, monitoring and checking changes include:

a) Allowable wall deflection limits (Para 9 and 10)
b) Ground improvement (Para 18, 19 and 20)
c) Control Strategies (Para 22 and 23)
d) Instrumentation and monitoring (Para 29)

3 This Advisory Note 1/09 will replace the Advisory Note 1/0 which was issued on 5 May 2005 with immediate effect.

4 The requirements of this Advisory Note are for compliant supervisors, builders and developers, where appropriate, in the des ERSS. I would appreciate it if you would disseminate the contents members' attention. The attached Advisory Note is also avail www.bca.gov.sg.

5 Please contact me or Dr Poh Teoh Yaw at 63255181 or M 63257492 if you need any clarification. Thank you.

Exc_erss_Annex A

DESIGN CONSIDERATIONS FOR EARTH RETAINING OR STABLISING STRUCTURES (ERSS)

Project Ref:_____ **Project Name:**_____
(note : this form is to be completed and attached to the design calculations)

SECTION I *(to be completed by the QP(D) for ERSS)*

1 **Key design considerations**

I have designed ERSS in
design is structurally safe

- Adequate and appropr
- Proper evaluation and
- Effects due to onerous
- Effects due to onerou soils, as well as the ef
- Effects of surcharge l slope, load from adjac
- Varying load condition
- Design robustness an loads etc;
- Adequacy of wall emb
- Adequate factor of saf
- Structural adequacy o
- Provision of proper adequate stiffeners an
- Provision of restraints
- Sensitivity analyses ar
- Effects due to ground
- Effects of ground deform

2 **Other specific controls o**

I have also allowed in my
- Construction tolerance
- Full water table level wall;
- Factor of safety for the
- Mobilization factors o respectively for limit e
- Unplanned excavation.

CERTIFICATIONS BY QPs and BUILDER Exc_erss_Annex B

Project Ref:_____ **Project Name:**_____

SECTION I *(to be completed by the QP(S) for ERSS)*

1 **Construction Sequence**

a I append below the construction plans and work sequence. I confirm that the builder's detailed excavation plan accordance to the ERSS design, and shall instruct the builder to seek my approval before proceeding with any exca every strut level.

2 **Inspection of erected works**

a I shall check that ERSS are constructed in accordance to my design and assess its performance at every strut lev giving approval to the builder for further excavation.

b I shall carry out site inspections, including but not limited to the following:-
- Check that the as-constructed embedded piled wall sizes and penetration depths are in accordance to my design
- Check that the structural sections, connections and bracings are structurally adequate and robust; and they a installed in accordance to my design
- Check that the structural supporting elements used on site are in accordance to the drawings, free from def damaged or deformed, and all are within the tolerances allowed for in my design.
- Check that the actual soil and water conditions, loads and pressures do not exceed design limits and assumptions

3 **Ground movement monitoring**

a I shall ensure that an adequate instrumentation and monitoring plan is executed and in place on site be commencement of ERSS. (The locations, number and types of instruments as well as the frequency of taking read other instrumentation measures are shown on the plans).

b I shall closely monitor the site to inspect and ensure that all deformations, loads and pressures do not exceed critica shall take necessary preventive, protective and remedial actions on site in consultation with appropriate QP and AC, th and the client/developer, in order to remove danger immediately and prevent damage to surrounding properties.

4 **Monitoring and Inspections**

a I shall ensure that the monitoring readings are properly and timely taken and assessed.

b I shall conduct regular site inspections and assess the actual performance of ERSS to ensure that the safe condition is maintained at all times as long as the excavations remain.

c I shall instruct the builder to take corrective action immediately and notify BCA if any of the critical limits is reached or damage to the neighbouring properties.

d I shall ensure that copies of "Site Inspection & Approval Records" and "Ground Movement Assessment Records" are site.

Table 1: Allowable maximum ERSS wall deflection limits

Wall deflection limits/Zones where x = distance from excavation face; H = excavation depth δ_w = wall deflection	Locations of buildings, structures and critical utilities			
	Zone 1 (x/H < 1)	Zone 2 (1 ≤ x/H ≤ 2)	Zone 3 (x/H > 2)	
			Ground Type A	Ground Type B
Allowable maximum ERSS wall deflection limits (δ_w/H)	0.5%	0.7%	0.7%	1.0%

BCA_INST_ANNEX_E_PAGE1

Building and Construction Authority

We shape a safe, high quality, sustainable and friendly built environment.

Page 1 of 4

Print this page

BCA_INST_ANNEX_E

MONTHLY INSTRUMENTATION & MONITORING RESULTS

(This form shall be completed by QP(S) and QP(S)(Geo) where applicable and submitted to CBC/BCA by 7th day of the following month after obtaining permit of GBW/ERSS works)

Date: 07/06/2022

To: Building and Construction Authority

Commissioner of Building Control
Building and Construction Authority
52 Jurong Gateway Road, #11-01
Singapore 608550
Website : http://www.bca.gov.sg

Instructions

1. This form is to be digitally signed by the appointed Qualified Person.

2. This form may take 10-15 mins to complete.

Particulars of Application

3 Summary - Tunnelling

Building and Construction Authority

We shape a **safe**, **high quality**, **sustainable** and **friendly** built environment.

Our Ref : APPBCA-2017-11

15 Sep 2017

Building Engineering Group (#12-00)
Tel : 1800 3425222
Fax : 6334 2561
E-mail : bca_enquiry@bca.gov.sg

See **Distribution**

Dear Sir/Madam

REQUIREMENTS ON BORED TUNNELLING WORKS

Objective

This circular is to inform the industry the control framework of safety requirements for bored tunnelling works. The framework aims to mitigate risks associated with bored tunnelling works in order to ensure structural stability of buildings and structures, and public

BCA circular on bored tunnelling works

Background

2 Over the past few months, BCA has met up with Institution of Engineers Singapore (IES), Association of Consulting Engineers Singapore (ACES), Geotechnical Society of Singapore (GeoSS) and BCA-Industry Joint Tunnelling Working Committee (JTWC) to gather feedback on the control framework in enhancing safety of bored tunnelling works. This circular, which has incorporated input from the professional institutions, is for

Building and Construction Authority

We shape a **safe**, **high quality**, **sustainable** and **friendly** built environment.

Our Ref : APPBCA-2020-05

01 Sep 2020

For enquiries, please contact:
Building Engineering Group (#12-00)
Tel : 1800 3425222 (1800-DIAL-BCA)
or use our Oneline Feedback Form at:
http://www.bca.gov.sg/feedbackform/

See **Distribution**

Dear Sir/Madam

REQUIREMENTS ON BORED TUNNELLING WORKS FOR LARGE DIAMETER TBM

Objective

This Circular is applicable for bored tunnelling works using large diameter Tunnel

BCA circular on large diameter TBM

2 Large diameter TBMs are expected to be adopted in Singapore following their successful adoption in overseas infrastructure projects. Over the past months, BCA had met up with IES, ACES, BCA-Industry Joint Tunnelling Working Committee (JTWC), GeoSS, TUCSS, CAG and LTA to gather feedback on the requirements for large diameter TBMs. The requirements in this circular are for compliance by Qualified Persons ("QP"), Accredited Checkers ("AC"), site supervisors, builders and developers who are adopting large diameter TBMs for tunnelling works.

Requirements / Control Measures with large diameter TBM

3 As large diameter TBMs involve bigger excavation volumes, they pose higher risk and greater impact to the surrounding building and structures. The control measures in Annex A of this Circular shall be additional/updated requirements to supplement the Circular "Requirements on Bored Tunnelling Works" dated 15 Sep 2017 ("2017 Circular"). These measures aim to mitigate the risk to surrounding buildings and structures posed by the use of large diameter TBMs. Annex B, which provides advisories and good practices to further help mitigate the risk caused by tunnelling works, are for the project party's consideration.

Thank you

@BCASingapore