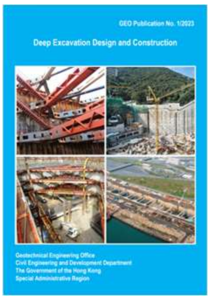
LAMBETH

Lessons learned in ELS design and construction: Implementation of GEO Publication No. 1/2023 Water tightness and Strut preloading



20 Dec 2024

Ir Dr Gavin Seng-Huat TOH

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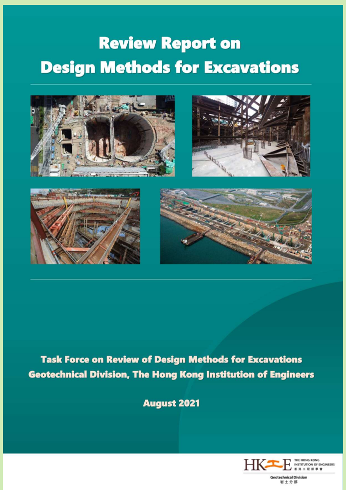
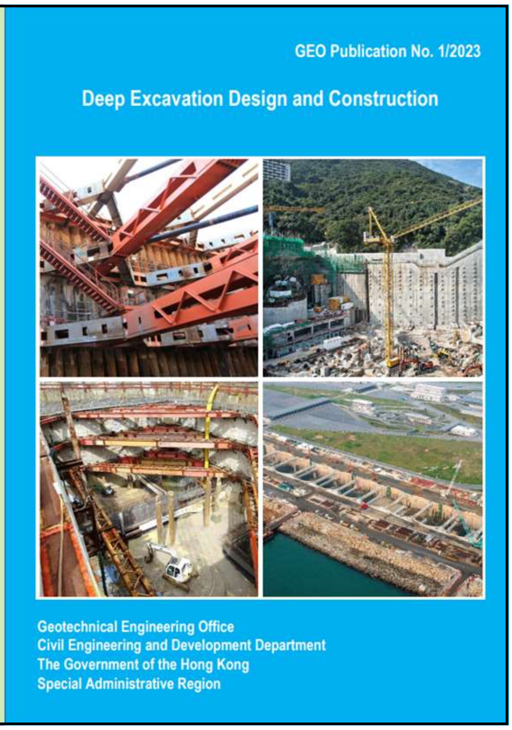
1

GEO Publication No. 1/2023

- First published: January 2024
- Updated version of GCO Publication No.1/90
- A standard of good practice for excavation and lateral support (ELS) design





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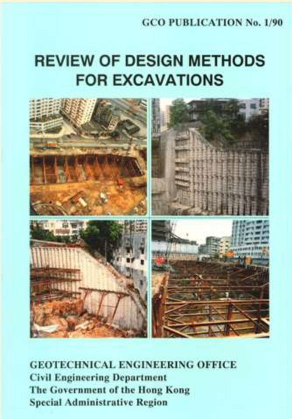
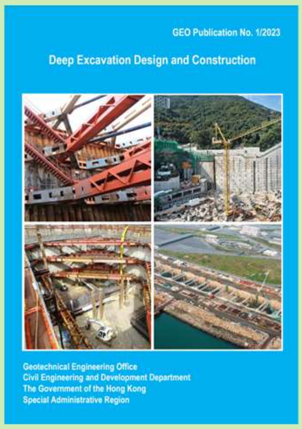
From GCO Pub No.1/90 to GEO Pub No. 1/2023



GCO Publication No.1/90

- Published in March 1990



GEO Publication No.1/2023

- Published in January 2024

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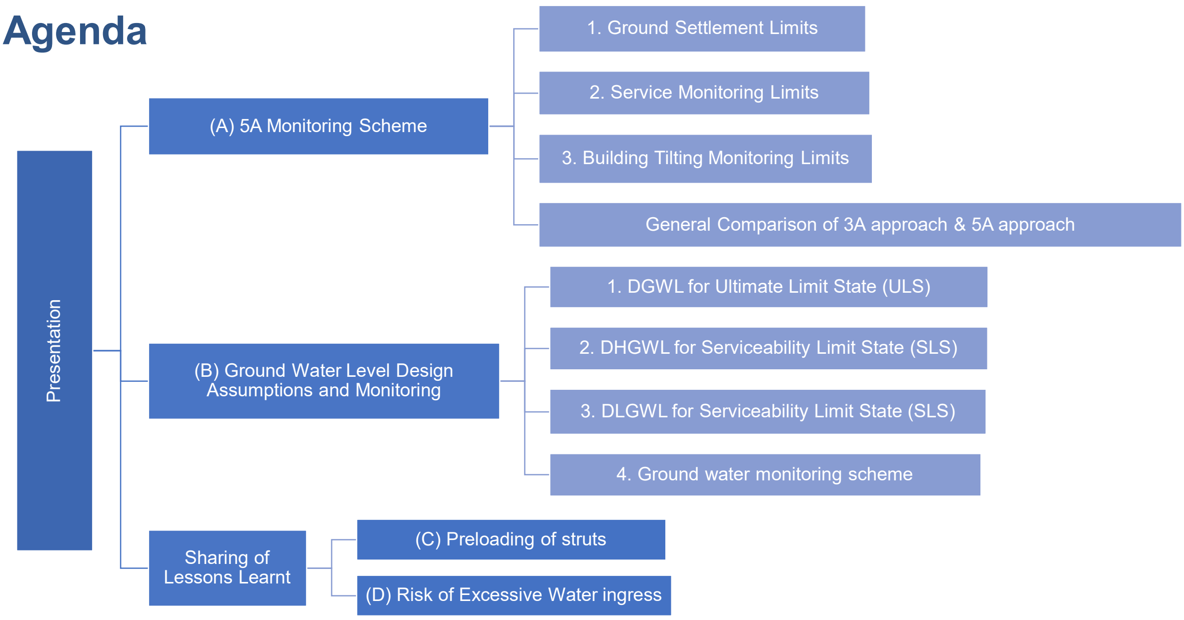
Agenda



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(A) 5A Monitoring Scheme

1. Ground settlement monitoring
2. Service monitoring
3. Building tilting monitoring

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1. Ground Settlement Limits

In PNAP APP-137

(Prior to 29-Nov-2024)

	Alert	Alarm	Action
Ground settlement	12mm	18mm	25mm
	(50% of action limit)	(75% of action limit)	

- 3A Approach
- Alert – Alarm – Action
- Action level usually 25mm
  → **for all types of works**
  → **not related to the depth of excavation**
- Typical value usually adopted in projects

In GEO Pub. No. 1/2023

Table 9.1 Recommended Empirical Limits for Setting Trigger Values (5A Approach)

Instrument	Criterion	Alert	Alarm	Action[4] Level 1	Action[4] Level 2	Action[4] Level 3
Ground monitoring marker[1]	Total settlement	10 mm	15 mm	20 mm	0.3%H_e[5] subject to a range of 25 mm to 60 mm	0.5%H_e[5] subject to a range of 30 mm to 100 mm
Services monitoring marker[2]	Angular distortion	1:600	1:500	1:400	1:350	1:300
Building monitoring marker[3]	Angular distortion	1:1000	1:750	1:600	1:550	1:500

GEO Pub. No. 1/2023
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- 5A Approach
- Alert – Alarm – Action level 1 – Action level 2 – Action level 3
- Each Action Level had a set of well-defined responses
- Action level depended on **maximum excavation depth (He)**

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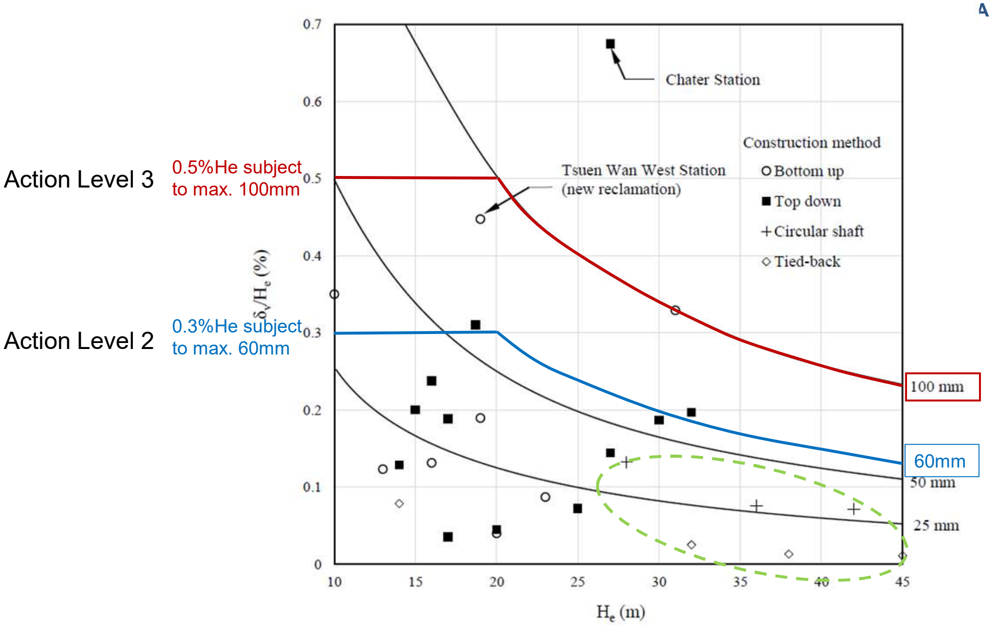

Figure 8.6 Total Ground Settlement against Maximum Excavation Depth from Case Study Data for Projects in Hong Kong

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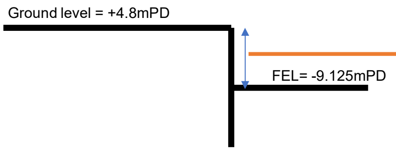
1. Ground Settlement Limits in Project 1

Ground settlement	Suggested in PNAP APP-137	Suggested in GEO pub. No.1/2023
Alert Level	12mm (50% of action limit)	10mm
Alarm Level	18mm (75% of action limit)	15mm
Action Level 1	25mm	20mm
Action Level 2		0.3% He* = 0.3% x 13.925 = 41mm
Action Level 3		0.5% He* = 0.5% x 13.925 = 69mm

Response sooner

More reasonable values

Action level depended on **maximum excavation depth (He)**



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2. Service Monitoring Limits

In PNAP APP-137

(Prior to 29-Nov-2024)

	Alert	Alarm	Action
Services settlement	12mm	18mm	25mm
	(50% of action limit)	(75% of action limit)	
Services angular distortion	1:600	1:450	1:300

- 3A Approach
- Alert – Alarm – Action
- Typical value usually adopted in projects

In GEO Pub. No. 1/2023

Table 9.1 Recommended Empirical Limits for Setting Trigger Values (5A Approach)

Instrument	Criterion	Alert	Alarm	Action[(4)] Level 1	Action[(4)] Level 2	Action[(4)] Level 3
Ground monitoring marker[(1)]	Total settlement	10 mm	15 mm	20 mm	0.3%H_e[(5)] subject to a range of 25 mm to 60 mm	0.5%H_e[(5)] subject to a range of 30 mm to 100 mm
Services monitoring marker[(2)]	Angular distortion	1:600	1:500	1:400	1:350	1:300
Building monitoring marker[(3)]	Angular distortion	1:1000	1:750	1:600	1:550	1:500

GEO Pub. No. 1/2023
P. 117

- 5A Approach
- Alert – Alarm – Action level 1 – Action level 2 – Action level 3
- serviceability of underground services
  - e.g. water mains / cooling mains / gas mains / sewage pipes / cable ducts
- No recommended limits for utility settlement

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2. Service Monitoring Limits

Service angular distortion	Suggested in PNAP APP-137	Suggested in GEO pub. No.1/2023
Alert Level	1:600	1:600
Alarm Level	1:450	1:500
Action Level 1	1:300	1:400
Action Level 2		1:350
Action Level 3		1:300

Same Value

Reference from WSD:
"…differential settlement affecting water mains made of different materials should be controlled within a range of 1:400 to 1:200……"

Response sooner

Increase review frequency

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3. Building Tilting Monitoring Limits

In PNAP APP-137
(Prior to 29-Nov-2024)

	Alert	Alarm	Action
Building tilting	1:1000	1:750	1:500

- 3A Approach
- Alert – Alarm – Action
- Typical value usually adopted in projects

In GEO Pub. No. 1/2023

Table 9.1 Recommended Empirical Limits for Setting Trigger Values (5A Approach)

Instrument	Criterion	Alert	Alarm	Action[4] Level 1	Action[4] Level 2	Action[4] Level 3
Ground monitoring marker[1]	Total settlement	10 mm	15 mm	20 mm	$0.3\%H_e$[5] subject to a range of 25 mm to 60 mm	$0.5\%H_e$[5] subject to a range of 30 mm to 100 mm
Services monitoring marker[2]	Angular distortion	1:600	1:500	1:400	1:350	1:300
Building monitoring marker[3]	Angular distortion	1:1000	1:750	1:600	1:550	1:500

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- 5A Approach
- Alert – Alarm – Action level 1 – Action level 2 – Action level 3
- relevant stakeholders should be consulted at an early stage

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3. Building tilting monitoring limits in Project 1

Service angular distortion	Suggested in PNAP APP-137 (Prior 29-Nov-24)	Suggested in GEO pub. No.1/2023
Alert Level	1:1000	1:1000
Alarm Level	1:750	1:750
Action Level 1	1:500	1:600
Action Level 2		1:550
Action Level 3		1:500

Same Value

Increase review frequency

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3A approach and 5A approach in ground settlement

In PNAP APP-137

(Prior to 29-Nov-2024)

1. Registered Contractor (RC)
   - submit written report to RSE/RGE
   - prepare action plan
     → additional checkpoints
     → monitoring frequency ↑
2. RSE/RGE
   - assess effect of ground movement
   - agree with the action plan proposed by RC

12mm Alert 10mm

Alarm

Action level 1

Action level 2

Action level 3

In GEO Pub. No. 1/2023

1. Registered Contractor (RC)
   - notify the RSE/RGE
   - inspect and record the conditions of affected sensitive receivers
   - prepare action plan
   - implement necessary measures
2. RSE/RGE
   - agree with the action plan proposed by RC

Response sooner!

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(A) 5A Monitoring Scheme

3A approach and 5A approach in ground settlement

In PNAP APP-137

(Prior to 29-Nov-2024)

1. Registered Contractor (RC)
   - submit report → RSE/ RGE/ BD
   - prepare emergency plan
   - implement remedial measure
   - suspend necessary works
2. RSE/RGE
   - agree with the emergency plan by RC
   - review method statement
3. RC/RSE/RGE
   - attend joint site inspection if needed
   - review response action

12mm Alert 10mm

18mm Alarm 15mm

Action level 1

Action level 2

Action level 3

In GEO Pub. No. 1/2023

1. Registered Contractor (RC)
   - notify AP/ RSE/ RGE
   - inspect and record the conditions
   - propose remedial measures
   - implement remedial measures
   - carry out preparation works for reaching Action level 1
2. RSE/RGE
   - agree with the emergency plan by RC
   - agree with the remedial measures by RC

Response sooner!

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(A) 5A Monitoring Scheme

3A approach and 5A approach in ground settlement

In PNAP APP-137

(Prior to 29-Nov-2024)

1. Registered Contractor (RC)
   - all works that cause ground movements are ceased
   - notify BD and relevant parties immediately
   - implement the agreed emergency plan
   - submit incident report to RSE/ RGE
2. RSE/RGE
   -review the incident
   - agree the further remedial measures
3. RC/RSE/RGE
   - attend joint site inspection immediately

Construction activities suspended

Until remedial works completed

12mm Alert 10mm

18mm Alarm 15mm

25mm Action level 1 20mm

Action level 2

Action level 3

In GEO Pub. No. 1/2023

1. Registered Contractor (RC)
   - notify AP/ RSE/ RGE and stakeholders
   - inspect and record the conditions
   - proposed remedial measure
   - implement remedial measures
   - carry out preparation works for reaching Action level 2 includes:
   → actions by RC before trigger action lv.2
   → detailed investigation works implemented for action lv.2
   → remedial works implemented for action lv.2
   → works to be suspended for action lv.2
2. RSE/RGE
   - agree with the emergency plan by RC
   - agree with the remedial measures by RC
3. RC/RSE/RGE and other relevant stakeholders
   - attend joint site inspection immediately

Response sooner!

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(A) 5A Monitoring Scheme

3A approach and 5A approach in ground settlement

In PNAP APP-137

(Prior to 29-Nov-2024)

12mm Alert 10mm

18mm Alarm 15mm

25mm Action level 1 20mm

0.3%He subject to max. of 60mm Action level 2

Action level 3

In GEO Pub. No. 1/2023

1. Registered Contractor (RC)
   - notify the AP/ RSE/ RGE/ BD/ GEO/ relevant stakeholder
   - conduct detailed investigation
   - submit investigation report to AP/ RSE/ RGE/ BD/ GEO
   - implement remedial measures with agreement of AP/RSE/ RGE / BD/ GEO and other stakeholders

   - prepare the emergency plan include:
   → actions by RC before trigger action lv.3
   → full-scale investigation works implemented for action lv.3
   → remedial works/ strengthening works implemented for action lv.3
   → works to be suspended for action lv.3
2. RSE/RGE
   - designer review and revise the design and method statement
   - designer submit the amendment to BD/ GEO for approval

PM/ AP/ RSE/ RGE:
- suspend the relevant works
if
- required responses actions are ineffective
- not implemented by RC within reasonable time frame

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(A) 5A Monitoring Scheme

3A approach and 5A approach in ground settlement

In PNAP APP-137 (Prior to 29-Nov-2024) | **In GEO Pub. No. 1/2023**

In PNAP APP-137	Level	In GEO Pub. No. 1/2023
12mm	Alert	10mm
18mm	Alarm	15mm
25mm	Action level 1	20mm
0.3%He subject to max. of 60mm	Action level 2	
0.5%He subject to max. of 100mm	Action level 3	

1. Registered Contractor (RC)
   - suspend relevant works
   - notify AP/ RSE/ RGE/ BD/ GEO
   - conduct full scale investigation
   - prepare investigation report
   - submit investigation report
   - propose/ implement remedial/ strengthening works with agreement of AP/RSE/RGE/BD/GEO
   - prepare works resumption plan include:
     → conduct survey after remedial/ strengthening works
     → revised design and method statement approved by BD/GEO
     → trigger values for further response
     → detailed of further response actions
2. RSE/RGE
   - re-examine and revise the design and method statement
3. BD/ GEO/ RC
   - attend joint site inspection

Construction activities suspended Until remedial works completed

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(A) 5A Monitoring Scheme

5A Table for the Monitoring Works in Approved Submission

TABLE 1 – THE PROPOSED ALERT LEVEL, ALARM LEVEL AND ACTION LEVEL 1 TO 3 FOR GROUND/SERVICES/BUILDING MONITORING ARE:

INSTRUMENT TYPE	CRITERION	ALERT	ALARM	ACTION LEVEL 1	ACTION LEVEL 2	ACTION LEVEL 3	MONITORING FREQUENCY
GROUND SETTLEMENT MARKER (GS1–GS35)	TOTAL SETTLEMENT/ HEAVING	10mm	15mm	20mm	41mm	69mm	DAILY
UTILITIES MONITORING MARKER (UTM1–UTM28; UTM37–UTM44)	TOTAL SETTLEMENT	10mm	15mm	20mm	41mm	69mm	DAILY
	ANGULAR DISTORTION	1:600	1:500	1:400	1:350	1:300	
UTILITIES MONITORING MARKER (UTM1–UTM5)	RESULTANT MOVEMENT	10mm	15mm	20mm	41mm	69mm	DAILY
	RESULTANT ANGULAR DISTORTION	1:600	1:500	1:400	1:350	1:300	
BUILDING TILTING MARKER (TM1–TM2)	ANGULAR DISTORTION	1:1000	1:750	1:600	1:550	1:500	DAILY
VIBRATION MONITORING POINT (VP1–VP21, VP26)	PEAK PARTICLE VELOCITY	5mm/s	7.5mm/s	15mm/s			DAILY

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(B) Ground Water Level Design Assumptions and Monitoring

1. DGWL for ULS
2. DHGWL for SLS
3. DLGWL for SLS
4. GWL monitoring

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Design Ground Water Level assumption in ULS/ SLS

Common practice

- Design Ground Water Level
  - DGWL for ULS
  - DGWL for SLS

In GEO Pub. No. 1/2023

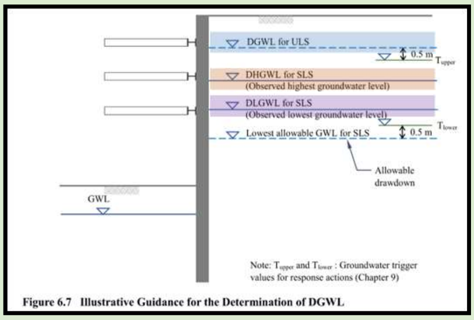

Figure 6.7 Illustrative Guidance for the Determination of DGWL

GEO Pub. No. 1/2023
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- DGWL for Ultimate Limit State (ULS)
- DHGWL for Serviceability Limit State (SLS)
- DLGWL for Serviceability Limit State (SLS)

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1. DGWL for Ultimate Limit State (ULS)

DGWL for ULS | DHGWL for SLS | DLGWL for SLS

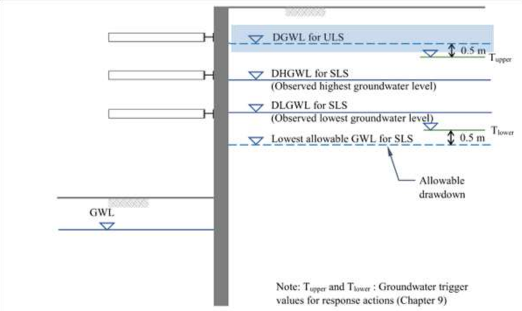

Figure 6.7 Illustrative Guidance for the Determination of DGWL

GEO Pub. No. 1/2023
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Why?	For all structural checking (include wall capacity. Strut size and capacity)
What?	• **Highest GWL anticipate** during ELS works
How?	• Based on **site-specific** field measurement of GWL • Consider **topography/ hydrogeological** conditions (e.g., perched water table)
Suggestion in GEO no.1/2023	• For GWL **higher** than FEL ULS Level = Measured highest GWL + 1 to 2m

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1. DGWL for Ultimate Limit State (ULS) in Project 1

DGWL for ULS | DHGWL for SLS | DLGWL for SLS

DGWL in ULS design	level	notes
Highest measured groundwater level (HMGWL)	+1.87mPD	
Extreme sea level from Port Work Design Manual For Return Period = 50 years	+3.66mPD	- Adopted in 1st amendment in Aug 2023 (3A scheme)
GEO Publication No.1/2023	ULS Level = HMGWL + (1 to 2m) = +2.87mPD to +3.87mPD (Thus, +3.66mPD is adopted)	- Adopted in 6th amendment in Oct 2024 (5A scheme)

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2. DHGWL for Serviceability Limit State (SLS)

DGWL for ULS

DHGWL for SLS

DLGWL for SLS

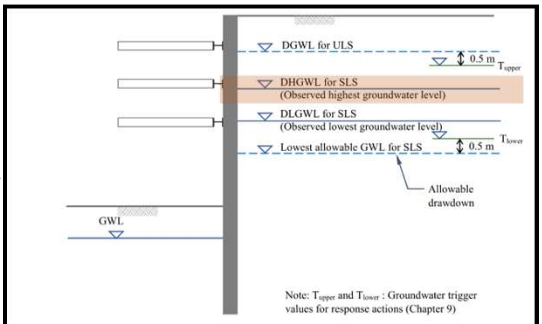

Figure 6.7 Illustrative Guidance for the Determination of DGWL

GEO Pub. No. 1/2023
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Why? For **ground settlement** and **pile wall deflection** due to excavation works assessment at **high** water level

What? **Realistic estimation** of highest GWL under **normal** scenarios during ELS works

How?
- Based on **site-specific** field measurement of GWL

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2. DHGWL for Serviceability Limit State (SLS) in Project 1

DGWL for ULS

DHGWL for SLS

DLGWL for SLS

DGWL in SLS design	GWL	Notes
Highest measured groundwater level	+1.87mPD	
Extreme sea level from Port Work Design Manual For Return Period = 5 years	+3.03mPD	- Adopted in 1st amendment in Aug 2023
GEO Publication No.1/2023	+1.90mPD	- Adopted in 6th amendment in Oct 2024 - Supported by over 1 year ground water monitoring record

<u>In adopting the DHGWL for SLS models</u>

Not be overly conservative
- Especially for the excavations with preloading works
- The reaction of preload = combined action of soil and water of retained side of excavation
- If designed preloading force larger than required
  - Overstress the retained side
  - Unfavorable to the pile wall (deflection and capacity)

[from GEO Pub. No. 1/2023]

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3. DLGWL for Serviceability Limit State (SLS)

DGWL for ULS

DHGWL for SLS

DLGWL for SLS

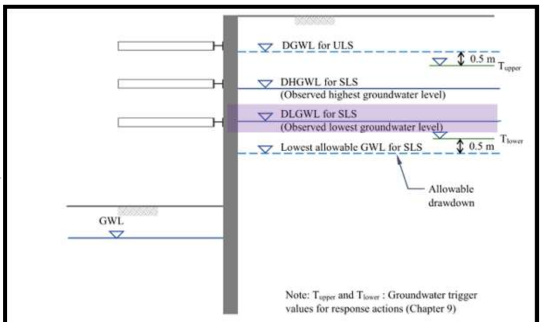

Figure 6.7 Illustrative Guidance for the Determination of DGWL

GEO Pub. No. 1/2023
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Why?	For acceptable **ground settlement** caused by **GWL drawdown** outside the excavation assessment
What?	• **Lowest recorded** GWL
How?	• Based on **site-specific** field measurement of GWL

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3. DLGWL for Serviceability Limit State (SLS) in Project 1

DGWL for ULS

DHGWL for SLS

DLGWL for SLS

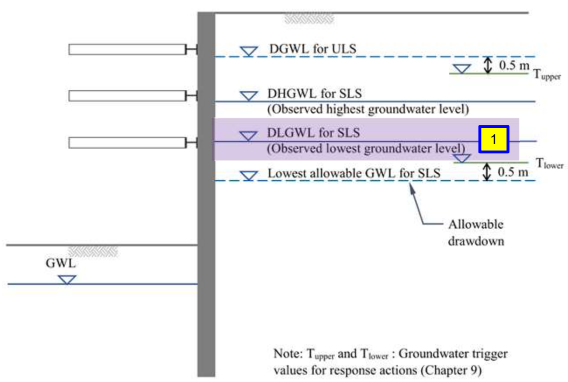

Figure 6.7 Illustrative Guidance for the Determination of DGWL

Example of adopting DLGWL for SLS

Lowest measured groundwater level on-site
= +0.94mPD

Design low groundwater level for SLS
[DLGWL for SLS]
= +0.94mPD — — — — — — — — — — 1

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4. Ground water monitoring scheme

Common Practice

3A limit	Standpipe water drawdown
Alert level	0.3m
Alarm level	0.5m
Action level	1m

In GEO Pub. No. 1/2023

T_{upper} Trigger level for ULS
→ 0.5m below the DGWL for ULS

T_{lower} Trigger level for SLS
→ 0.5m above the lowest allowable GWL for SLS

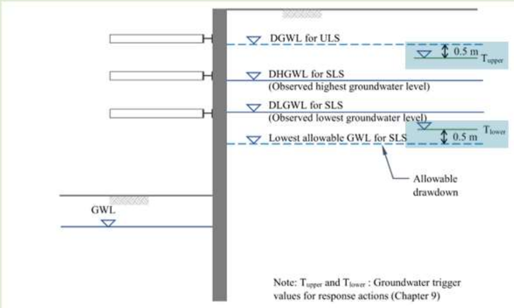

Figure 6.7 Illustrative Guidance for the Determination of DGWL

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4. Ground water monitoring scheme

Common Practice

In GEO Pub. No. 1/2023

Reaching
Action Level / Trigger Level

Common Practice:

- GWL exceeding Action Level → Suspend the work

In GEO Pub. No. 1/2023:

- GWL exceeding Trigger Levels
  - Sudden ingress of excessive groundwater → Suspend the work; Implement agreed response actions
  - Change in GWL caused ground settlement → Implement agreed response actions
  - No other impacts → Implement agreed response actions

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4. Ground water monitoring scheme in Project 1

Example adopting upper trigger level, lower trigger level and the lowest allowable GWL for SLS

T_{upper}

Design ground water level for ULS = +3.66mPD

T_{upper}
= DGWL for ULS – 0.5m
= +3.66 – 0.5
= +3.16mPD

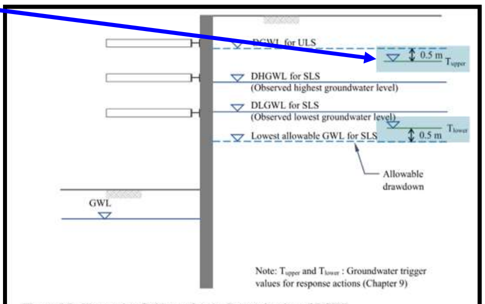

Figure 6.7 Illustrative Guidance for the Determination of DGWL

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(B) Ground Water Level Design Assumptions and Monitoring

4. Ground water monitoring scheme in Project 1

Example adopting upper trigger level, lower trigger level and the lowest allowable GWL for SLS

T_{upper}

Design ground water level for ULS = +3.66mPD

T_{upper}
= DGWL for ULS – 0.5m
= +3.66 – 0.5
= +3.16mPD

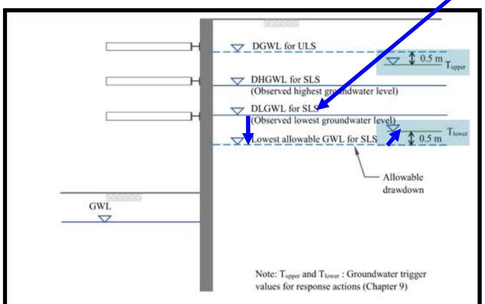

Figure 6.7 Illustrative Guidance for the Determination of DGWL

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T_{lower}

Lowest measured ground water level = +0.94mPD

Design low ground water level for SLS = +0.94mPD

Allowable water drawdown that superimposed in our design = 1.5m

Lowest allowable GWL for SLS = +0.94 – 1.5= -0.56mPD

T_{lower}
= lowest allowable GWL for SLS + 0.5
= -0.56 + 0.5 = -0.06mPD

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4. Ground water monitoring scheme in Project 1

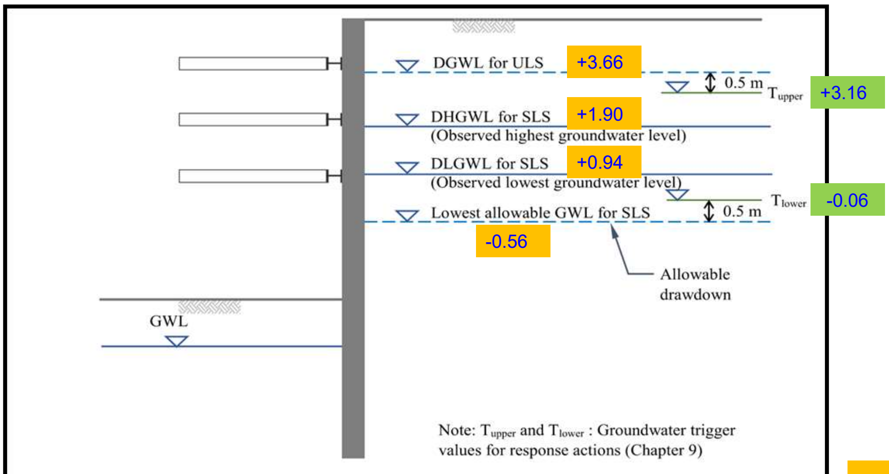

Figure 6.7 Illustrative Guidance for the Determination of DGWL

For design

For monitoring

GEO Pub. No. 1/2023
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Trigger Levels for Standpipe Ground Water Monitoring in Approved Submission

TABLE 2A – THE PROPOSED TRIGGER LEVELS FOR GROUND WATER MONITORING BY STANDPIPE ARE:

	STANDPIPE	CRITERION	TRIGGER LEVEL (mPD)	MONITORING FREQUENCY	LOWEREST MEASURED GROUND WATER LEVEL /DESIGN LOW GROUNDWATER LEVEL (mPD)	ALLOWABLE GROUND WATER LEVEL (mPD)
T_{UPPER}	SP1–SP13	WATER RISE UP (*Tupper)	+3.16	DAILY	N/A	+3.66 (HIGHEST)
T_{LOWER}	SP1	WATER DRAWDOWN (**Tlower)	+0.29	DAILY	+1.29	–0.21 (LOWEST)
	SP2		+0.20		+1.20	–0.30 (LOWEST)
	SP3		–0.06		+0.94	–0.56 (LOWEST)
	SP4		+0.21		+1.21	–0.29 (LOWEST)
	SP5		+0.21		+1.21	–0.29 (LOWEST)
	SP6		+0.15		+1.15	–0.35 (LOWEST)
	SP7		+0.29		+1.29	–0.21 (LOWEST)
	SP8		+0.29		+1.29	–0.21 (LOWEST)
	SP9		+0.21		+1.21	–0.29 (LOWEST)
	SP10		+0.21		+1.21	–0.29 (LOWEST)
	SP11		–0.06		+0.94	–0.56 (LOWEST)
	SP12		+0.21		+1.21	–0.29 (LOWEST)
	SP13		–0.05		+0.95	–0.55 (LOWEST)

DESIGN HIGH GROUNDWATER LEVEL (DHGWL) IS +1.9mPD.
DESIGN LOW GROUNDWATER LEVEL (DLGWL) IS AS AS SHOWN IN TABLE 2A AND 2B.
DESIGN GROUNDWATER LEVEL FOR ULS IS +3.66mPD.
*Tupper = 0.5m BELOW DESIGN GROUND WATER LEVEL FOR ULS DESIGN
**Tlower = 0.5m ABOVE LOWEST ALLOWABLE GROUND WATER LEVEL FOR SLS DESIGN

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Trigger Levels for Piezometer Monitoring Works in Approved Submission

TABLE 2B – THE PROPOSED TRIGGER LEVELS FOR GROUND WATER MONITORING BY PIEZOMETER ARE:

T_{LOWER}

PIEZOMETER	CRITERION	TRIGGER LEVEL (m)	MONITORING FREQUENCY	LOWEREST MEASURED GROUND WATER LEVEL /DESIGN LOW GROUNDWATER LEVEL (mPD)	LOWEST ALLOWABLE PIEZOMETRIC HEAD (m)	PIEZOMETER TIP LEVEL (mPD)	SOIL TYPE AT TIP LEVEL
SP1	PIEZOMETRIC HEAD DROP (*Tlower2)	5.89	DAILY	+1.29	6.39	−31.10	CDG
SP2		5.40		+1.20	5.90	−35.73	
SP3		0.87		+0.94	1.37	−51.90	
SP4		3.67		+1.21	4.17	−46.94	
SP5		2.71		+1.21	3.21	−54.27	
SP6		4.74		+1.15	5.24	−47.28	
SP7		4.64		+1.29	5.14	−38.61	
SP8		4.64		+1.29	5.14	−46.52	
SP9		3.95		+1.21	4.45	−54.27	
SP10		2.71		+1.21	3.21	−54.27	
SP11		2.31		+0.94	2.81	−54.65	
SP12		3.40		+1.21	3.90	−41.10	
SP13		3.68		+0.95	4.18	−29.00	

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Current situation in Project 1

In our latest submission using GEO Publication No.1/2023,

屋宇署 BUILDINGS DEPARTMENT

土木工程拓展署 土力工程處 CEDD Geotechnical Engineering Office Civil Engineering and Development Department

渠務署 Drainage Services Department

水務署 Water Supplies Department

路政署 HIGHWAYS DEPARTMENT

No further comments!

煤氣 Towngas

PCCW 電訊盈科

CLP 中電

Private UU Companies

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(C) Preloading of Struts

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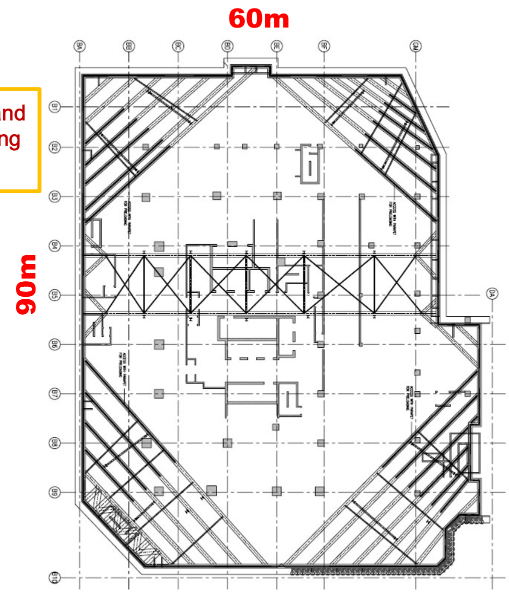
Safe preloading sequence

Some key considerations:
- Struts are often designed to be preloaded to control deformation.
- Strut arrangement could be – cross horizontal, corner, or raking struts.
- Preloading of different strut arrangement of strut is critical to ensure safe transfer of load.
- In area of unbalanced load, preloading magnitude need to be considered in the ELS design.
- To remove the strut, the loading in the strut must be released in a safely manner.

What would be a practical and safe sequence of pre-loading one layer of the shoring?



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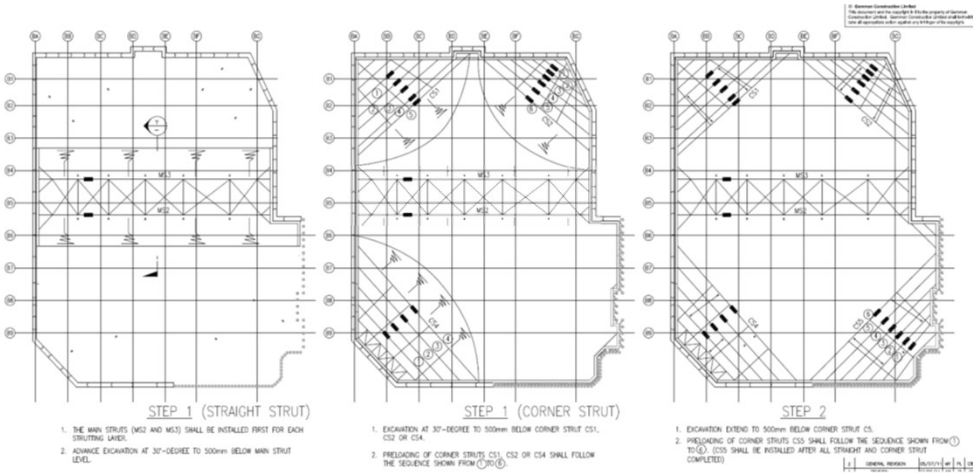
Safe preloading sequence

Safe preloading sequence at each layer



⚠ Pre-loading Sequence – watch out when pre-loading corners struts

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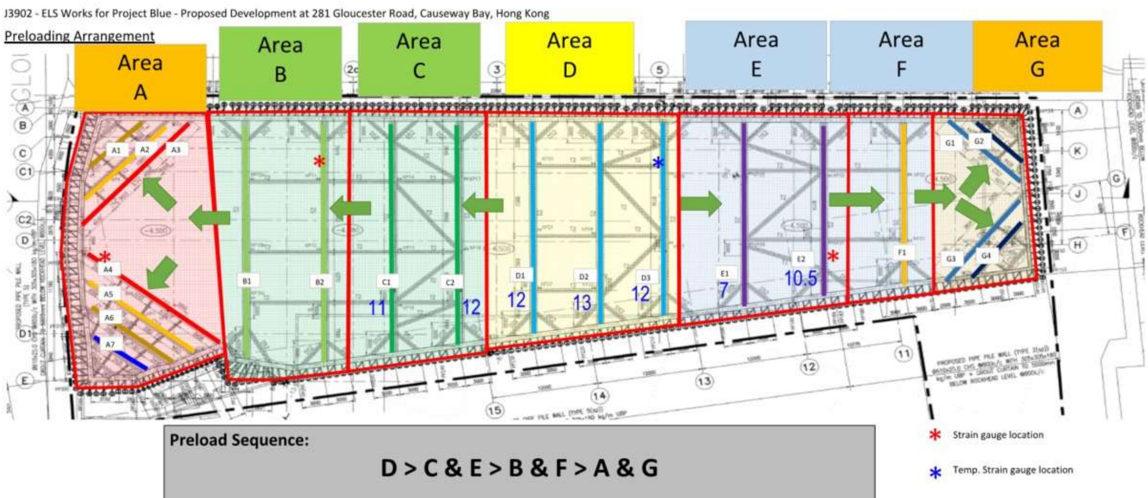
Safe preloading sequence

Preloading sequence at each layer



Preload Sequence:

D > C & E > B & F > A & G

Preloading in pairs of strut

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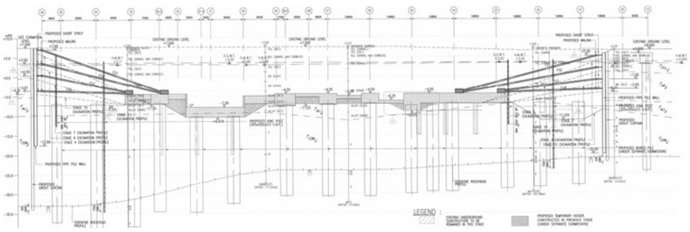
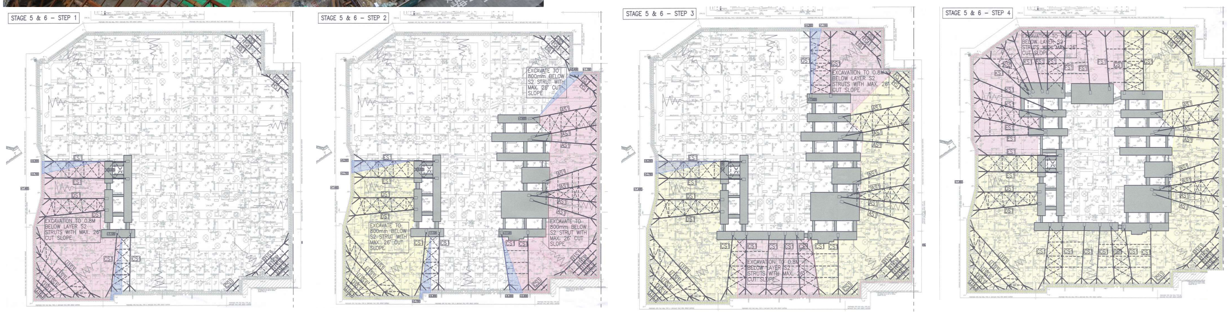
Safe preloading sequence

Preloading sequence for raking struts





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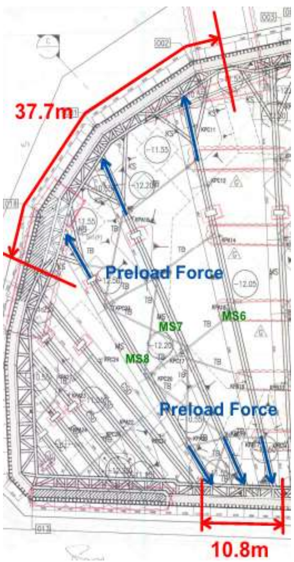
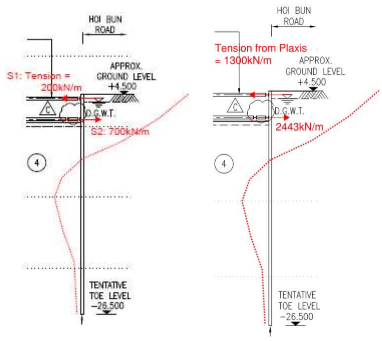
Safe preloading sequence

Unbalanced loading





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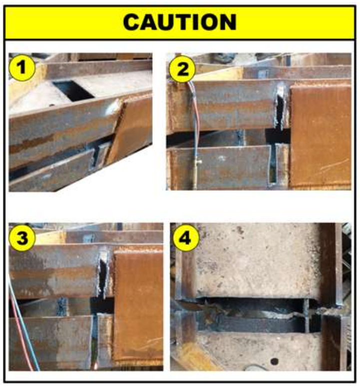
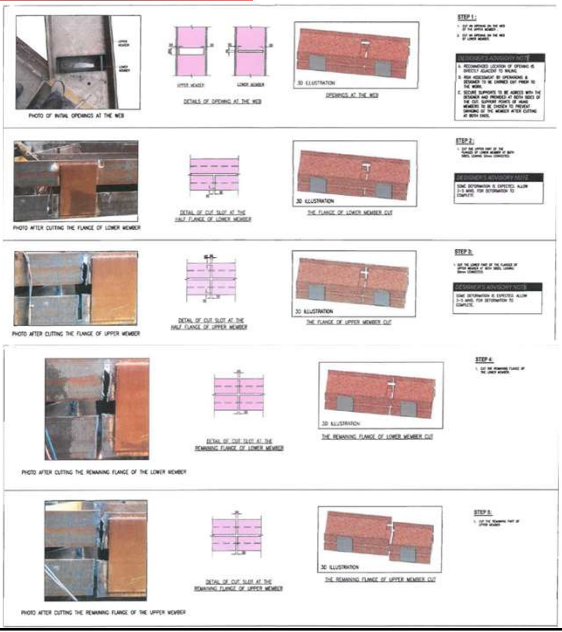
Safe preloading sequence

Safe release of forces in strut





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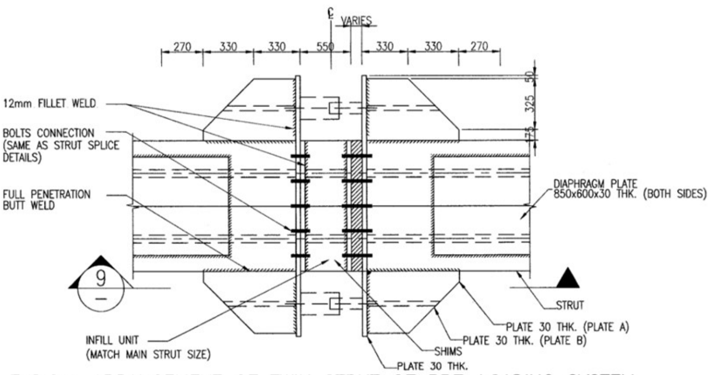
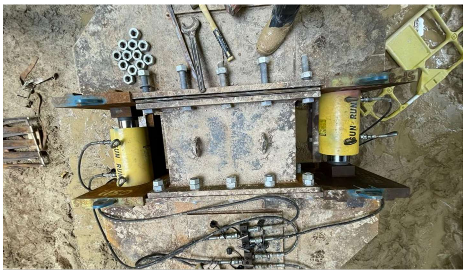
(C) Sharing of Lessons Learnt

Safe preloading sequence

Preloading detailing – Use of shims plates



TYPICAL ARRANGEMENT OF TWIN STRUT OF PRE-LOADING SYSTEM



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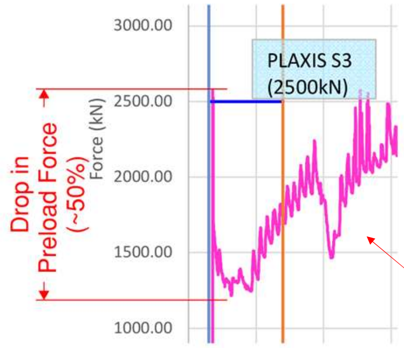
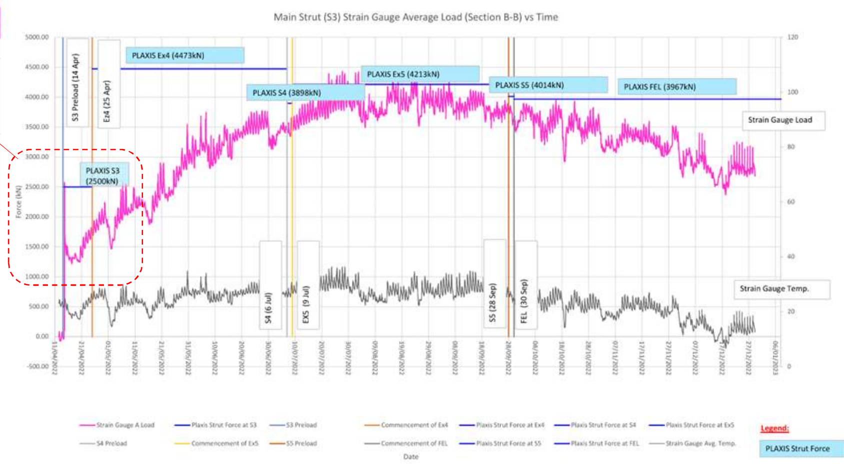
(C) Sharing of Lessons Learnt

Safe preloading sequence

Preloading detailing – Use of shims plates



Graph of Strut Force (S3) against Time



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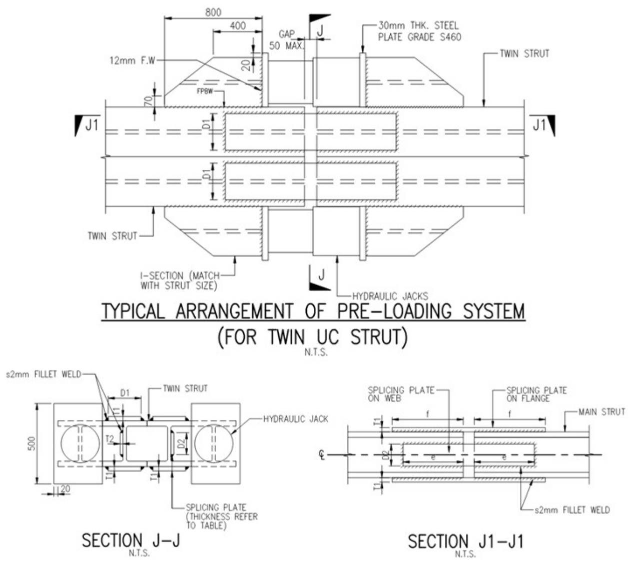
(C) Sharing of Lessons Learnt

Safe preloading sequence

Preloading detailing – Use of splicing plates



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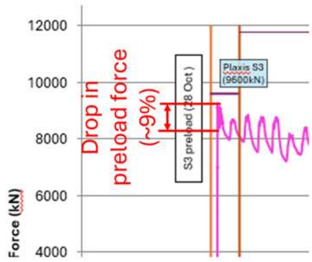
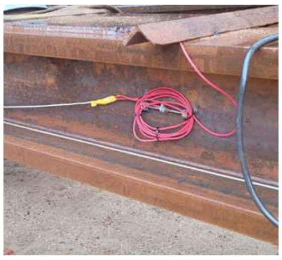
(C) Sharing of Lessons Learnt

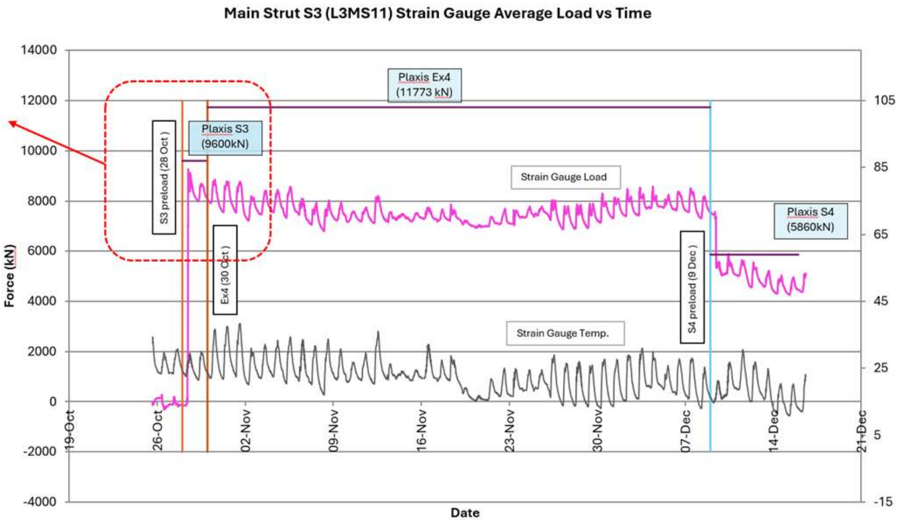
Safe preloading sequence

Preloading detailing – Use of splicing plates





Graph of Strut Force (S3) against Time



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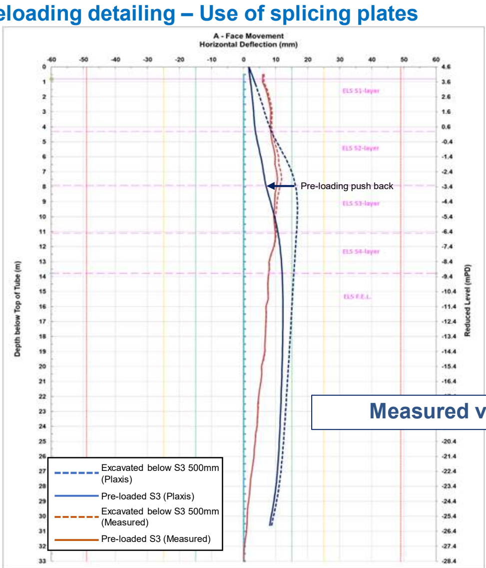
(C) Sharing of Lessons Learnt

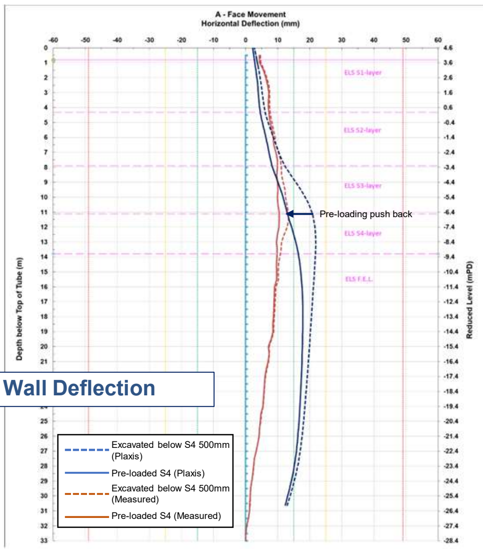
Safe preloading sequence

Preloading detailing – Use of splicing plates



Inclinometer for ELS – S3

Measured vs Predicted Wall Deflection



Inclinometer for ELS – S4

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(D) Risk Excessive Water Ingress

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Risk of excessive water ingress

Some key considerations:

- Water cut-off wall type such as sheet pile, clutched pipe pile, or diaphragm wall.
- Conventional pipe pile wall is unclutched with grout curtain and lagging plate.
- Grout curtain design mix and control pressure – carry out trial on site. Review any abnormality in grout intake volume.
- Frequent inspection for any unforeseen excavated material that may damage the grout curtain.
- Install lagging plate early – don't leave the grouted soil exposed overnight.
- Utilities "windows" – prone to water ingress with conventional TAM grouting.

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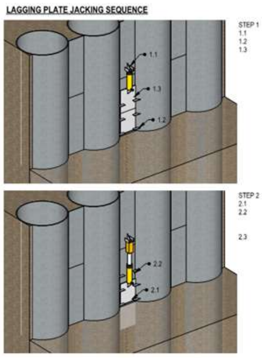
Risk of excessive water ingress

Water ingress remedial work: sand bagging, needle grouting, pressing steel plate in advance

Needle grouting

Sand bagging



Pressing Steel Plate in advance

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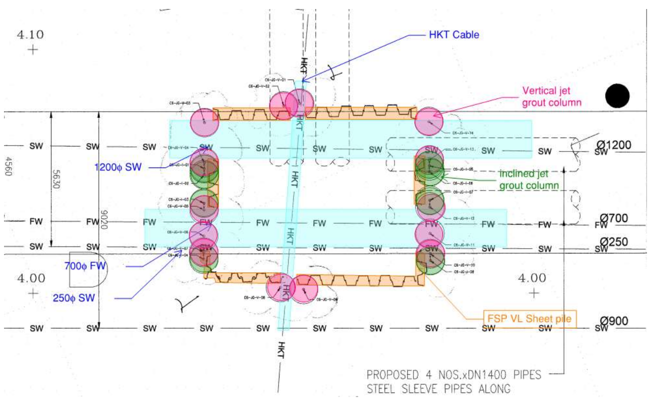
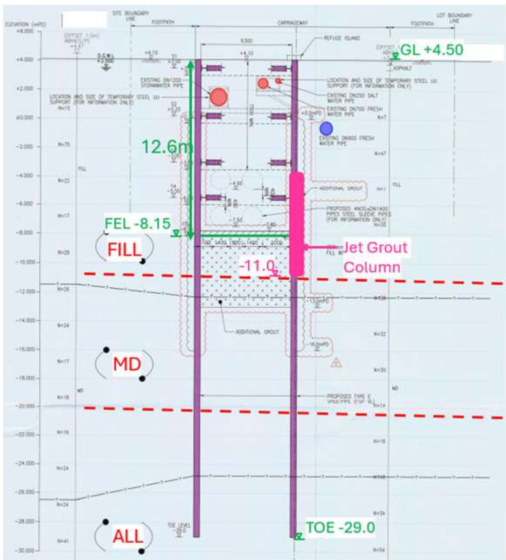
Risk of excessive water ingress

Large utility windows, use jet-grout columns





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D) Sharing of Lessons Learnt

Risk of excessive water ingress

Localised lenses of soft marine clay

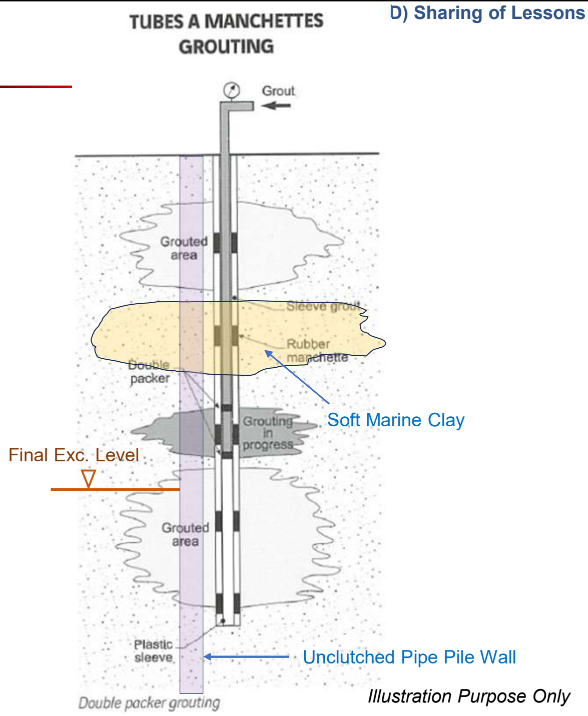

Illustration Purpose Only

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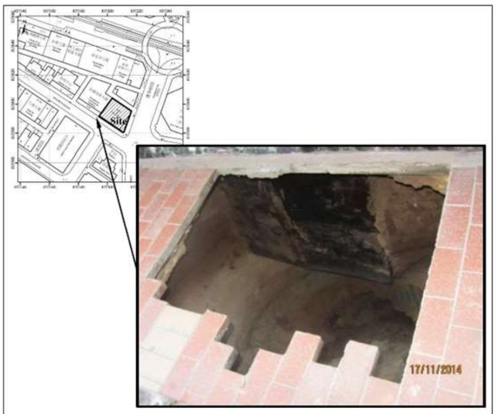
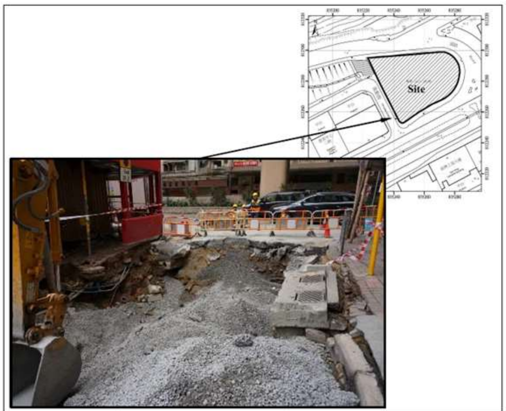
GEO Technical Guidance Note No. 49 (TGN 49)
Supplementary Guidelines on Precautionary Measures for Mitigating the Risks of Excessive Ground Loss and Sinkhole Formation Associated with Deep Excavations

Case No. 5: 60-66 Jardine's Bazaar



Date of incident	17 November 2014	Ground Conditions	
Size of sinkhole	3.5m x 2.5m x 3.7m deep	Top soil layers	25m FILL/ALL
Consequences	A passer-by fell into the sinkhole and suffered injuries		
Major preceding construction activities	Bulk excavation within pipe pile & grout curtain cofferdam in progress	Depth of rockhead	40m
Drilling method/ flushing medium	Concentric drilling/air for pipe piles	Depth of groundwater table	1 to 2.5m

Case No. 8: Yip Kan Street, Aberdeen



Date of incident	23 February 2019	Ground Conditions	
Size of sinkhole	4m x 4m x 6m deep	Top soil layers	9m FILL/MD
Consequences	Yip Kan Street entirely closed temporarily		
Major preceding construction activities	Bulk excavation within pipe pile & grout curtain cofferdam in progress	Depth of rockhead	20m
Drilling method/ flushing medium	Concentric drilling/air for pipe piles	Depth of groundwater table	2 to 3m

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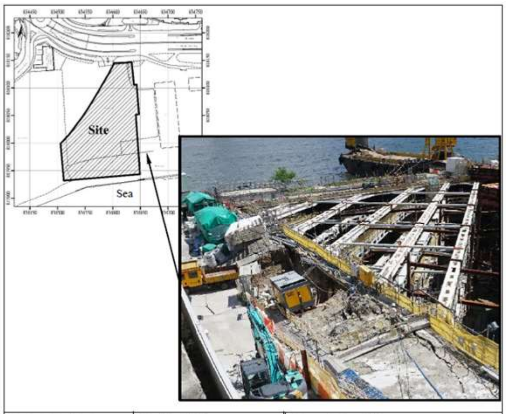
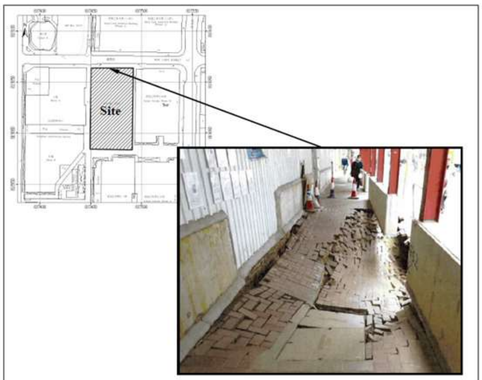
GEO Technical Guidance Note No. 49 (TGN 49)
Supplementary Guidelines on Precautionary Measures for Mitigating the Risks of Excessive Ground Loss and Sinkhole Formation Associated with Deep Excavations

Case No. 9: Lyric Theatre, West Kowloon Cultural District



Date of incident	*25 July 2019*	***Ground Conditions***	
Size of sinkhole	*10m x 5m x 2m deep*	**Top soil layers**	*27m FILL*
Consequences	*Adjacent site area/site office affected*		
Major preceding construction activities	*Bulk excavation within pipe pile & grout curtain cofferdam in progress*	**Depth of rockhead**	*45m*
Drilling method/ flushing medium	*Concentric drilling/air for pipe piles*	**Depth of groundwater table**	*2m*

Case No. 11: Hok Yuen Street, Hung Hom



Date of incident	*3 April 2023*	***Ground Conditions***	
Size of sinkhole	*6m x 3.8m x 1.8m deep*	**Top soil layers**	*6-12m FILL*
Consequences	*Adjacent footpath temporarily closed, carriageway undermined and underground utilities damaged*		
Major preceding construction activities	*Bulk excavation within pipe pile & grout curtain cofferdam in progress*	**Depth of rockhead**	*32m*
Drilling method/ flushing medium	*Concentric drilling/air for pipe piles*	**Depth of groundwater table**	*2 to 2.5m*

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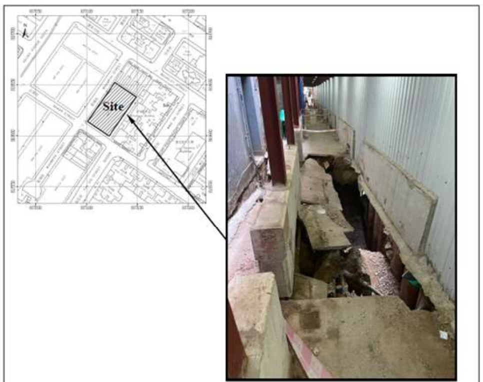
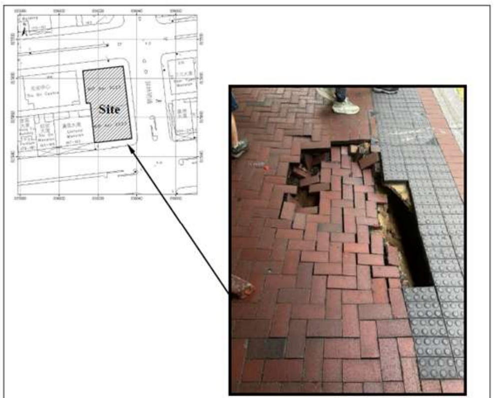
GEO Technical Guidance Note No. 49 (TGN 49)
Supplementary Guidelines on Precautionary Measures for Mitigating the Risks of Excessive Ground Loss and Sinkhole Formation Associated with Deep Excavations

Case No. 13: Whampoa Street, Hung Hom



Date of incident	*20 May 2023*	***Ground Conditions***	
Size of sinkhole	*5m x 1m x 5m deep*	**Top soil layers**	*4-5m FILL* *3-4m MD* *4m ALL*
Consequences	*Adjacent service lane temporarily closed and underground utilities damaged*		
Major preceding construction activities	*Bulk excavation within pipe pile & grout curtain cofferdam in progress*	**Depth of rockhead**	*18 to 20m*
Drilling method/ flushing medium	*Concentric drilling/air for pipe piles*	**Depth of groundwater table**	*1.6m*

Case No. 15: Hennessey Road, Wan Chai



Date of incident	*5 June 2023*	***Ground Conditions***	
Size of sinkhole	*1.5m x 1m x 0.7m deep*	**Top soil layers**	*6m FILL* *3m MD* *5m ALL*
Consequences	*Adjacent walkway was temporarily closed*		
Major preceding construction activities	*Bulk excavation within pipe pile & grout curtain cofferdam in progress*	**Depth of rockhead**	*30m*
Drilling method/ flushing medium	*Concentric drilling/air for pipe piles*	**Depth of groundwater table**	*0.3m*

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The Government of the Hong Kong Special Administrative Region

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4.2 A review was carried out by GEO on incidents occurred between 2007 and 2019 with relevant records available. Lee (2019) documented the finding of the review. The objective of the review was to look for any common attributes in terms of site conditions and construction methods which may contribute to excessive ground loss or formation of sinkholes. Some of the key contributory factors identified are summarised below:

- Difficult site conditions particularly vulnerable to ground loss
- Disturbance to adjacent soil during piling operations
- Ingress of soil through gaps between non-interlocking piles
- Excessive groundwater ingress and improperly constructed or damaged grout curtains
- Inadequate site supervision and lack of contingency plan.

5.2 Disturbance to Adjacent Soil during Piling Operations

5.2.1 Compressed air is commonly used in piling operations for flushing and extracting cuttings from drillholes/boreholes. High air flushing pressure could cause excessive disturbance to the adjacent ground and loss of soil around/beneath the drill bit, resulting in a well-known "overbreak" phenomenon (see Annex TGN 49 A1). When boulders or a mixed soil/rock stratum are encountered, a higher air pressure and a longer time are often needed to advance the drill bit. This process may significantly increase the risk of ground loss.

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Thank You

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