

Update on Implementation on OM in Singapore

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Geotechnical Society of Singapore



Overview

- 1) Background
- 2) Implementation on OM – excavation
- 3) Implementation on OM – tunnelling

1. Background

Framework on Observation Method

- Circular issued on 2nd Sep 2019 to construction industry in Singapore
- Framework consists of:
 - A) ERSS excavation; B) Groundwater control for deep shaft
- Conducted Seminar on Oct 2019 with 150 industry practitioners



Our Ref : APPBCA-2019-12

2 September 2019

See **Distribution List**

Dear Sir/Madam

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FRAMEWORK ON OBSERVATIONAL METHOD FOR THE DESIGN AND CONSTRUCTION OF ERSS WORK, AND GROUND WATER CONTROL FOR DEEP EXCAVATION

Objective

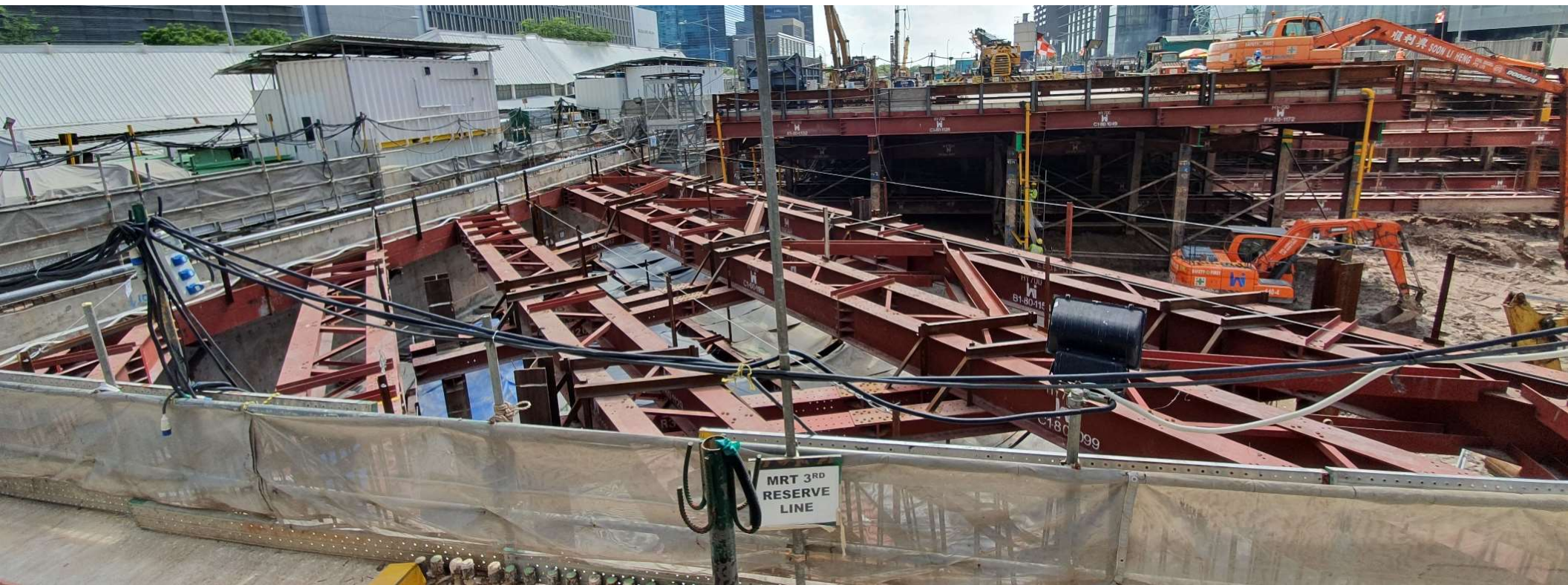
This circular is to inform the industry on the guidelines for the Observational Method (OM) for **A)** the Design and Construction of ERSS work, and **B)** Ground Water Control System for Deep Excavation

2. Implementation on OM – excavation projects

Adoption of OM in excavation projects

Project Title	Description of OM Implemented Groundwater control (GWC), Excavation (ERSS)	Cost Saving (\$, million)	Time Saving (month)
Case 1: 12m shaft, 55m deep	GWC: Reduction in base slab thickness for 4 shafts	0.38	1.5
Case 2: 40m shaft, 55m deep	GWC: Reduction of base slab thickness for deep shaft	0.50	2
Case 3 : 7.5 m exc.	ERSS: Reduce 1 layer strut	0.45	2
Case 4 : 16m shaft 65m deep	GWC: Reduction of base slab thickness for 2 shafts	0.31	1
Case 5: 14m shaft 44m deep	GWC: Reduction of base slab thickness for 4 shafts	0.20	1
Case 6 : 60m shaft 80m deep	GWC: Optimising grouting requirements for 2 shafts	3.2	2
Case 7 : 19m shaft 39m deep	GWC: Reduce thickness of temporary slab	1.6	3.5
Case 8 : 33m shaft 32m deep	GWC: Reduce thickness of temporary slab	2.7	1.5
Case 9 : 20 m exc.	ERSS: Reduce number of strut	pending	pending
	Total =	9.34 million	14.5

Case sharing of Basement Excavation with OM



➤ The Builder has successfully implemented OM for excavation work with 2 level of struts using most probable parameters, resulted in saving of one level of strut with cost saving of **\$450,000** and **2 month of project schedule!**

Contractual implication

Design for OM

➤ Contract type: Design and Build

➤ If OM implemented successfully :

Builder will enjoy the saving in term of money and time.

D&B Designer is entitled to claim on additional professional fee on extra effort for OM approach (based on agreed hourly rate)

➤ If OM failed:

Builder will implement design based on characteristic parameters and will not carry extra risk as it is the default solution

Builder will pay for additional I&M for OM and professional fee for the extra effort for OM approach.

Technical Paper

A Case History on Observational Method for Deep Excavation in Singapore

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Abstract

The Observational Method (OM) frameworks for deep excavation works in Singapore was launched in September 2019 by the Building and Construction Authority (BCA). The OM frameworks required both designs using normal and OM approach submitted to BCA for approval prior the construction works. The implementation of the OM will be decided based on the instrumentation monitoring results during construction. This paper outlines the OM frameworks and presents a case history for a deep excavation project that has been successfully carried out using the OM approach.

The case history involved a project with basement excavation of 8.5m depth generally and localized 11.5m depth at pit area in thick soft recent deposits of more than 30m in depth. The retaining system consists secant bored piles (SBP) wall supported with struts. The base design following the code requirements using the characteristic soil parameters required 3-level struts to support the excavation. In the OM design using the average (most probable) soil parameters, omission of 3rd level struts to 2-level struts was achieved. Extensive instrumentation for monitoring of the retaining wall, struts and surrounding structures had been carried out during the excavation. Based on the monitoring results, the 3rd level struts were judiciously omitted following the OM design. The implementation of the OM for the project resulted in substantial time and cost saving.

Keywords: Observation Method Framework, Excavation, Instrumentation and Monitoring, Time/Cost Saving

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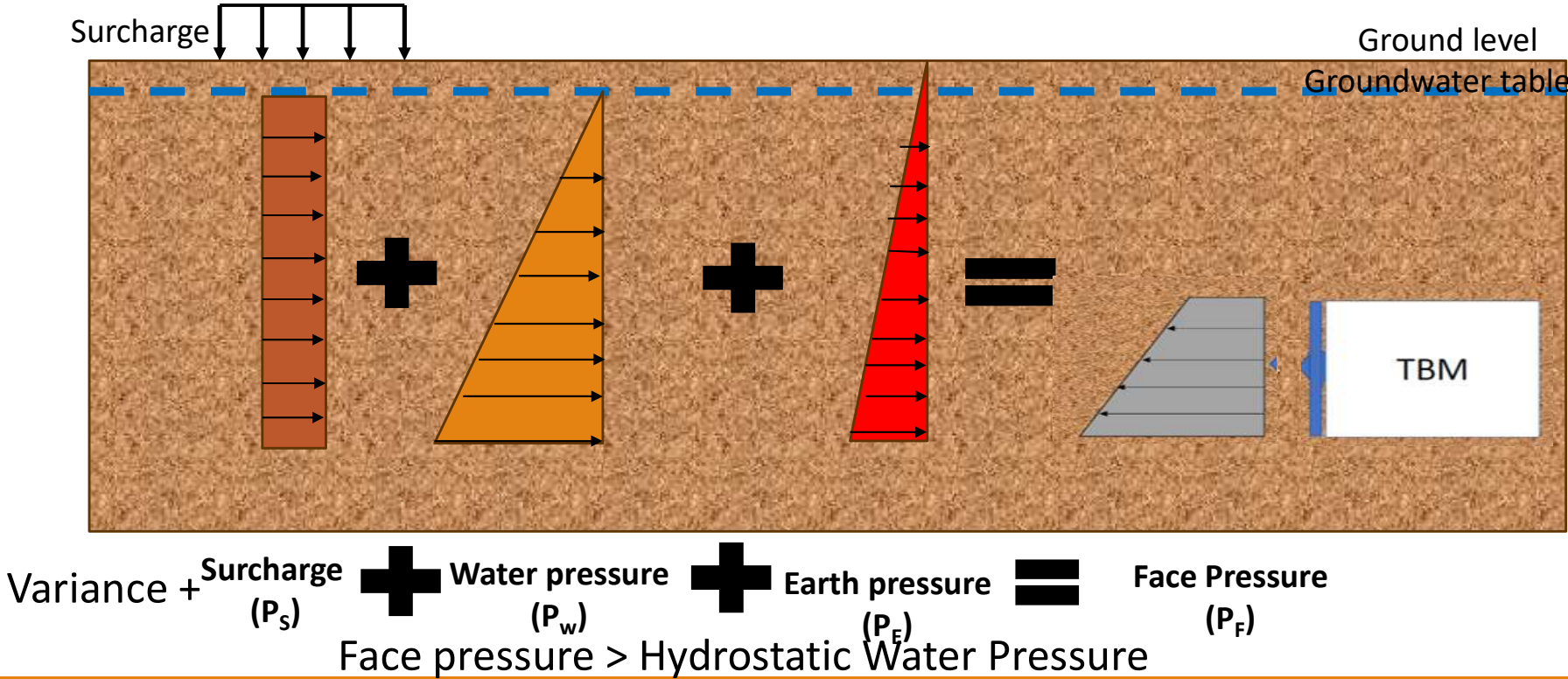
Builder will pay for additional I&M for OM and professional fee for the extra effort for OM approach.

3. Implementation on OM – tunnelling projects



Tunnel face pressure: Deemed-to-satisfy approach

- Onerous (Full) ground water pressure/ No seepage
- Limited ground movement



OM for face pressure for tunnelling works

- Pilot trial since Q4 2024
- Performance based approach based on OM
- Face pressure is allowed to be lower than water pressure. Suitable for cases with competent ground such as OA(A)/(B), intact rock and ground improvement block with low permeability.
- With lower face pressure, wearing of cutting tools is reduced and number of CHIs also reduced accordingly. Productivity of tunnelling work also increase.
- Lower face pressure - potential risks
 - **Over excavation due to seepage gradient**
 - **Dewatering**
 - **Unforeseen ground condition**
- Additional measures such as recharge well, piezometer are required to mitigate the risk
- **Contingency plan:** if the monitoring results cannot meet the expected performance, project parties are required to revert back to full face pressure with full hydrostatic water pressure

Steps-by-step guide

When seepage is allowed into the tunnel, 3D numerical analysis is required to assess the seepage effect accurately.

Note: German Tunnelling Committee (DAUB) recommends that 3D numerical modelling remains the only real way to predict the ground movement reliably in the drained condition, especially if seepage into the tunnel is present when the face pressure is applied below the hydrostatic pressure.

Steps	Details
1.	<p>3D Numerical Analysis of Tunnel Face Stability</p> <p>Carry out tunnelling analysis through fully coupled hydraulic-mechanical stress analysis using 3D geotechnical numerical model. The analysis shall include detailed steps covering the tunnelling activities such as ring by ring tunnel construction, CHI and TBM stoppage or unforeseen condition. The analysis shall also employ advanced soil models to capture realistic ground behaviour.</p> <p>Note:-</p> <ol style="list-style-type: none">1. “advanced soil models” refer to soil models which can model non-linear behaviour of soil and calibrated to local soil condition, for example the Hardening Soil model.2. The response of the ground to excavation under transient conditions is governed by the strong interaction between seepage flow and soil deformation. Hence, face collapse cannot be investigated by traditional limit equilibrium models, but only through fully coupled hydraulic-mechanical stress analysis [R. Schuerch, R. Poggiati, P. Maspoli, G. Anagnostou, 2016]3. 2-D analysis does not capture the 3-dimensional stress of the tunnel excavation. It is unclear whether the simplified approach is more or less conservative compared to the 3D model.4. As step-by-step 3D tunnelling analysis is time consuming, where appropriate, a simplified “Pseudo 3D” may be adopted, where the steps of TBM advance is not modelled.

Steps	Details
2.	<p data-bbox="218 305 655 337">Displacements vs. Time Graph</p> <p data-bbox="218 345 2053 548">a) The determination of stand-up time requires an evaluation of the time-development of the displacements at control points. The QP(D)(Geo) is required to plot the evolution of the displacements at point A (center of tunnel face), point C (tip of deep settlement marker monitoring level, ~1.5m below ground level) and point E (tip of rod extensometer monitoring level, ~3 to 6m above tunnel crown) over time from the 3D numerical analysis based on the proposed target and minimum face pressure.</p> <p data-bbox="218 557 2053 678">b) QP(D)(Geo) is to determine the allowable standup time from the displacements vs. time graph. The allowable standup time should be maximum time for the ground behaviour to be within the elastic range and with a sufficiently high factor of safety (minimum FOS = 2) against the onset of instability.</p> <p data-bbox="218 686 2053 760">c) For tunnelling undercrossing or in close proximity to the existing structures / buildings, in addition to point (b) above, the allowable standup time also subjected to impact assessment of adjacent existing structures/ buildings.</p> <p data-bbox="218 768 2053 841">d) The allowable standup time should consider the worst tunnelling rate (considering the time for tunnel ring building and worst TBM advancement rate considering maintenance of TBM and unforeseen condition).</p> <p data-bbox="218 849 2053 922">e) If the allowable standup time is shorter than worst tunnelling rate, the designer should increase the target face pressure and repeat the steps 1 to 2(d).</p> <div data-bbox="499 938 924 1312" data-label="Figure"> </div> <p data-bbox="336 1320 1045 1377">Figure 2.1: Example of contour of the plastic zone at different time increments and displacement vectors (not scaled)</p> <div data-bbox="1449 906 1806 1312" data-label="Figure"> </div> <p data-bbox="1239 1328 2032 1385">Figure 2.2: Example of evolution of the displacements at control points A, C, and D</p>

Steps	Details
3.	<p>Soil Permeability</p> <p>Determine the characteristic values of permeability for OA soils based on field permeability test data. For localized zone of high permeability in the ground which could lead to local failure of the tunnel face, the low value of 5% fractile (inferior parameters) is applicable. For details, please refer to “GEOSS Guide on Ground Investigation and Geotechnical Characteristic Values to EC7”.</p> <p>The designer shall carry out 3D numerical analysis considering both characteristic and 5% fractile permeability.</p>
4.	<p>Cutter Head Intervention (CHI)</p> <p>a) QP(D)(Geo) is to carry out face stability analysis for CHI following steps 1 to 2 by considering minimum face pressure determine by QP(D)(Geo) but not lower than 1.5bars or free air for CHI within ground improvement blocks or full-face rock. QP(D)(Geo) is to specify the allowable standup-time for each CHI on the “For approval” plans.</p> <p>b) QP(D)(Geo) is required to obtain the water ingress rate during CHI from the 3D numerical analysis and specify the allowable water ingress rate on the “For approval” plans.</p> <p>c) QP(D)(Geo) is required to specify the design strength of exposed tunnel face and QP(S)(Geo) or RE(Tunnel) to verify the strength with strength measurement such as pocket penetrometer on the “For approval” plans.</p>
5.	<p>Measures to mitigate additional risk associated with lower face pressure by allowing seepage into the tunnel.</p> <p>When seepage is allowed into tunnel, the following measures shall be implemented to mitigate additional risk associated with lower face pressure:</p> <p>a) Geophysical detection on potential void</p> <p>b) Adequate <u>recharge wells</u> that are pre-installed for existing buildings / structures located within the tunnelling influence zone. These recharge wells shall be activated when AL of piezometer has been breached.</p> <p>c) To provide <u>piezometers</u> at the border of the determined tunnel influence zone to verify there is no drawdown beyond this perimeter as assumed in the design.</p>

Why Geophysical Survey? → Minimise risk of tunnel incident

Slip road from Holland Road to Farrer Road closed to repair cave-in

Christopher Tan
Senior Transport
Correspondent

A slip road leading from Holland Road and Commonwealth Road into Farrer Road as well as an adjoining road have been closed to traffic since Tuesday as workers repair a cave-in caused by tunnelling works.

National water agency PUB said late on Wednesday night that “a sinkhole and some cracks were observed on the slip road”, where tunnelling work for a section of the Deep Tunnel Sewerage System (DTSS) Phase 2 is ongoing.

The agency said the damage was detected on Tuesday. It has stopped tunnelling work as a precaution while investigations are ongoing, and closed the slip road into Farrer Road as well as two lanes along a section of the Farrer Underpass for safety.

One lane along the underpass was reopened on Wednesday evening, and PUB said it hopes to reopen the slip road “in the next few days”.

“We apologise for the inconveniences caused,” said PUB, without elaborating on how exactly the tunnelling works caused the cave-in.



When The Straits Times went on-site on Wednesday afternoon, an entire stretch outside the Leedon Green condominium project was cordoned off with a canvas screen, and workers from Japanese construction giant Nishimatsu – a PUB contractor for the DTSS Phase 2 project – were present.

This is not the first time tunnelling works had caused such an incident in the area. In 2008, tunnelling for the MRT Circle Line caused a cave-in in the same vicinity. An 8m by 7m stretch of Cornwall Gardens in Holland Village – barely 200m from the damaged Farrer Road – had sunk into a 3m-deep crater.

In 2004, a section of Nicoll Highway collapsed because of a Circle

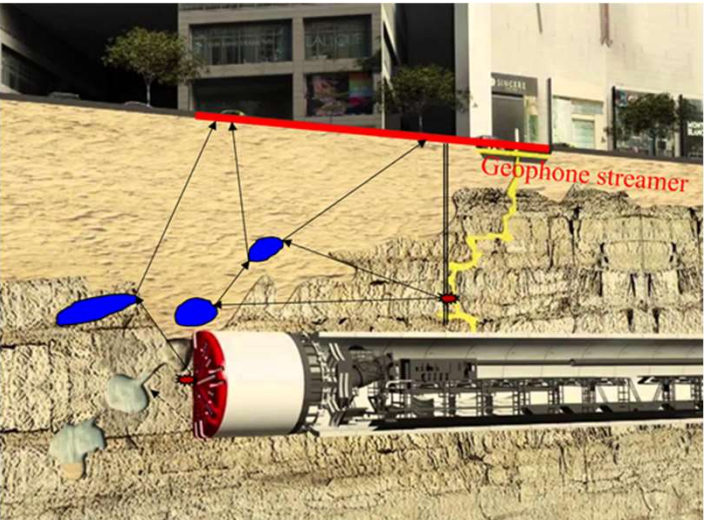


Heavy traffic in Queensway Road towards Farrer Road due to the road closure, as seen at close to 4pm on Wednesday.
ST PHOTO: LIM YAOHUI

STRAITS TIMES GRAPHICS

Continued on page A15

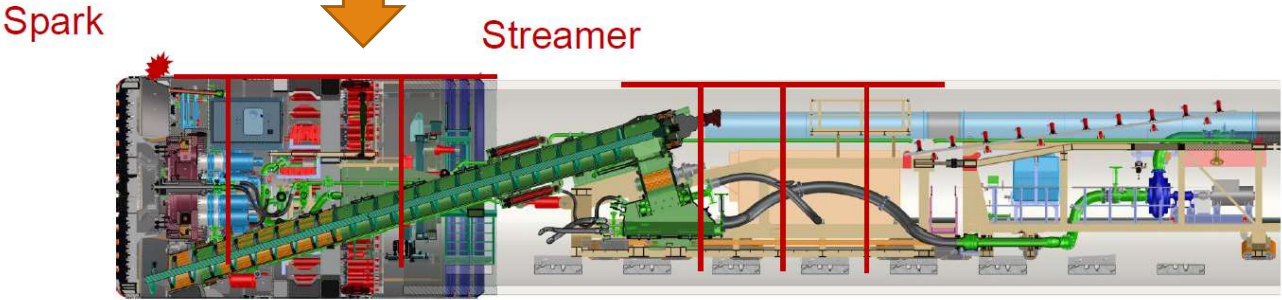
Use of Geophysical survey in detection of potential void during tunnelling works



Objective of this research is to derived a system that is reliable and cost effective in detecting underground voids during tunneling work, so that grouting up of such voids can be implemented timely

The system has been tested in to be in working condition, further field tests at actual tunnelling project has proven its reliability

Such system to be install in TBM for high-risk tunnelling works (close proximity to buildings), for early detection of underground voids and grouting up of such voids to minimised the risk of tunnelling works



Underground Eyes under development with Nanyang Technological University, Singapore

Geophysical method	Frequency (Hz)	Wavelength (m)	Resolution (m)	Depth (m)
Seismic reflection (SR)	50-100	10-20	5-10	>100
Ground penetration radar (GPR)	100M-400M	0.3-1.2	0.01-0.5	<10
Seismic scattering (SS)	500-5000	0.25-1	0.15-0.5	0-100

- Underground Eyes uses seismic scattering as a form of non-intrusive detection method
- Seismic scattering can achieve **higher resolution** than seismic reflection – able to detect smaller objects/cavities/voids than seismic scattering
- Seismic scattering able to detect objects/cavities/voids at deeper depth than GPR

	Seismic Scattering
Limitations	<p>Able to detect at deeper depth than GPR but shallower than SR</p> <p>Resolution higher than SR but lower than GPR – good enough to detect 500mm diameter size of void as per field test</p>
Cost	Estimated \$30k for setting up the system within TBM, can be used for multiple detections
Time	<p>Setting up will be done prior to tunneling works.</p> <p>Processing time takes about 5min for coarse detection</p>

Our solution: Underground Eyes (Ueyes) under development with NTU

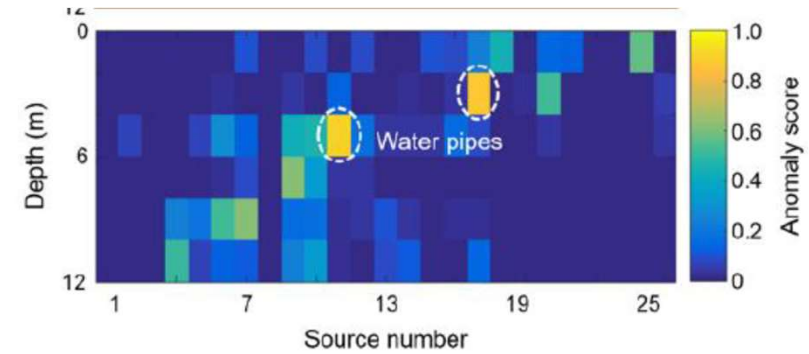
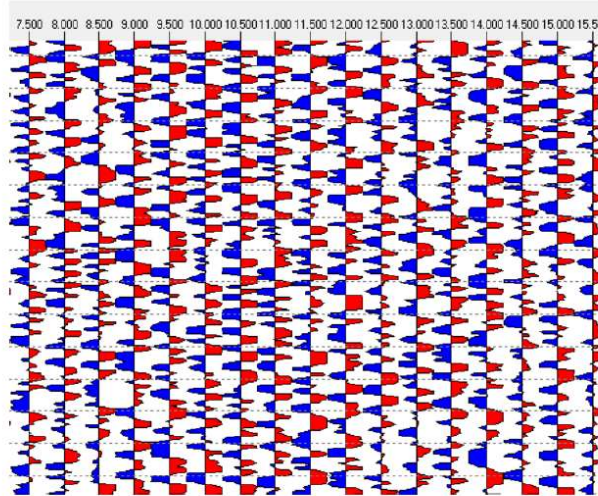
Signal collection



Data logger
(high-frequency band 10s kHz)

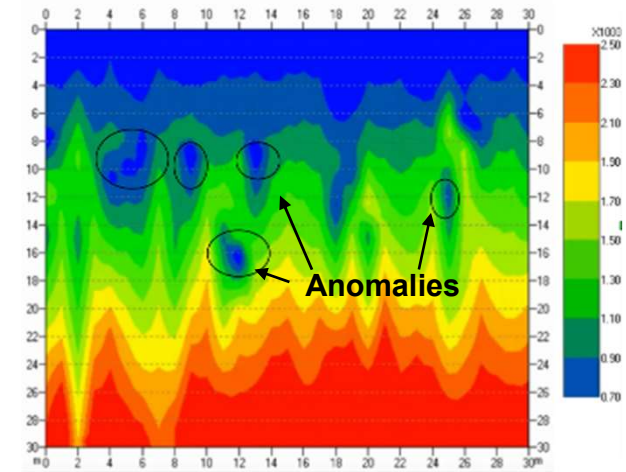


Raw data



Coarse Detection

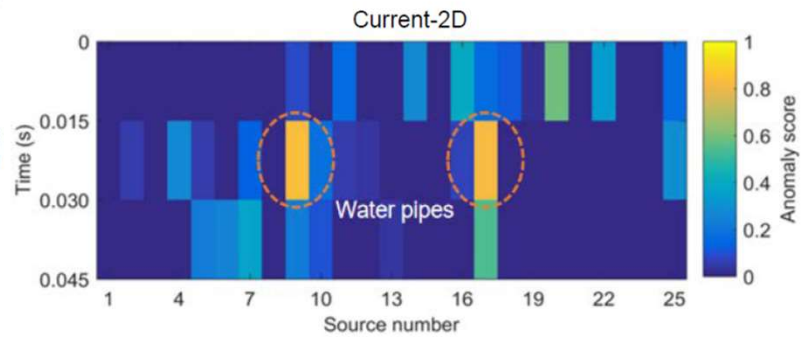
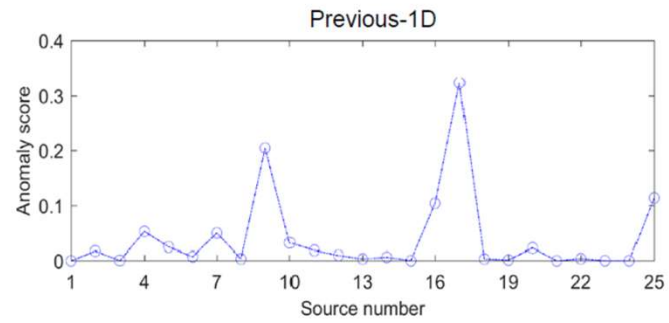
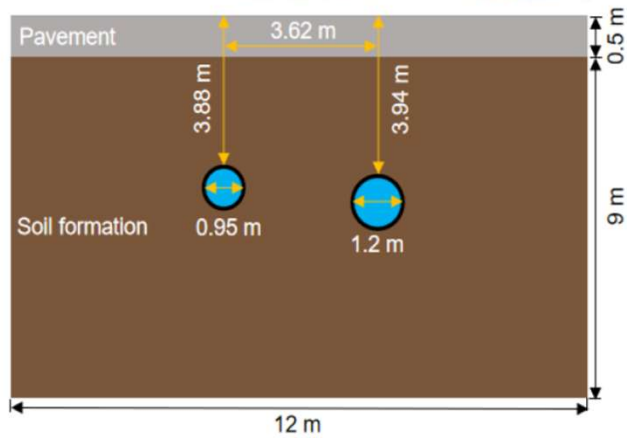
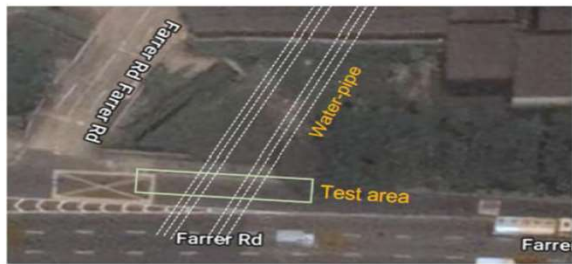
(able to detect anomalies fast ~5 mins)



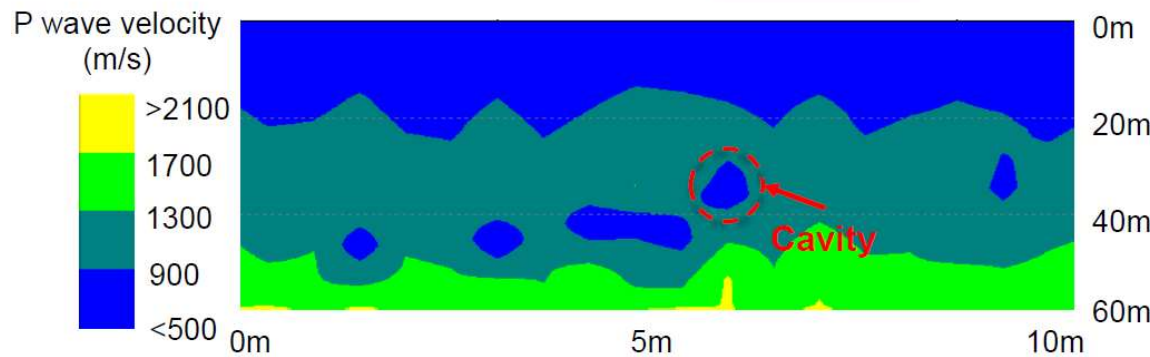
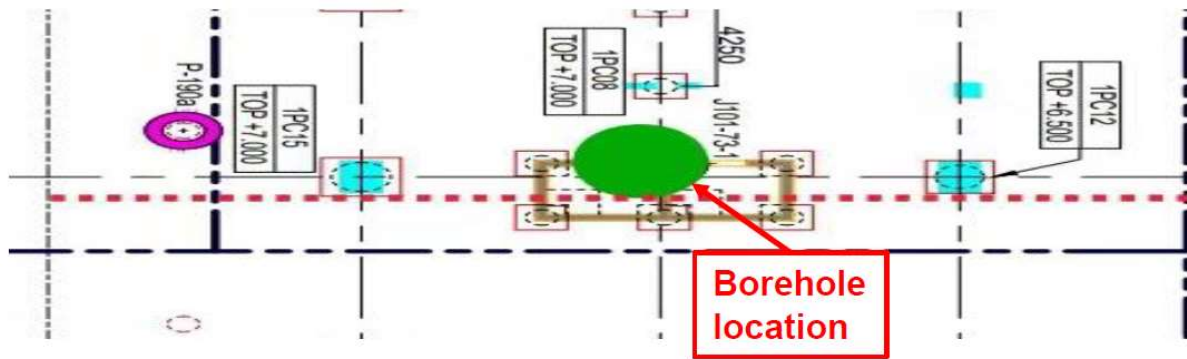
Fine Detection

(able to estimate sizes and location of anomalies, take longer time ~60 mins)

Coarse Detection of Water Pipe at Farrer Road



Fine Detection of Cavities at Tengah



Moderately strong to strong	Bl	100	74	65	g	27.00-28.00
Thick bedded	Bl	100	90	88	1	28.00-28.20
Fine-grained	Bl					
Light gray to medium gray	Bl					
LIMESTONE (S111)	Bl					
Slightly reaction with acid	Bl					
JURONG FORMATION	Bl					
Moderately weathered	Bl					
Highly fracture	Bl					
Very closed to closed space	Bl					
open aperture	Bl					
clean surface	Bl					

Summary of adoption of OM in Singapore

Summary of adoption of OM framework

1. OM Framework can be adopted in Singapore for excavation projects since 2 Sep 2019

2. Both normal design and OM design are approved by BCA prior to construction

3. Builder and Developer awareness on the potential benefits of OM will provide crucial support for the implementation of OM design

4. OM Framework can be adopted in Singapore for bored tunnelling works since Q4 2024

5. Case studies demonstrated that OM design can be successfully implemented and resulted in substantial cost and time savings.

6. Project parties should take advantage on this scheme to produce a safe and economic design

The End