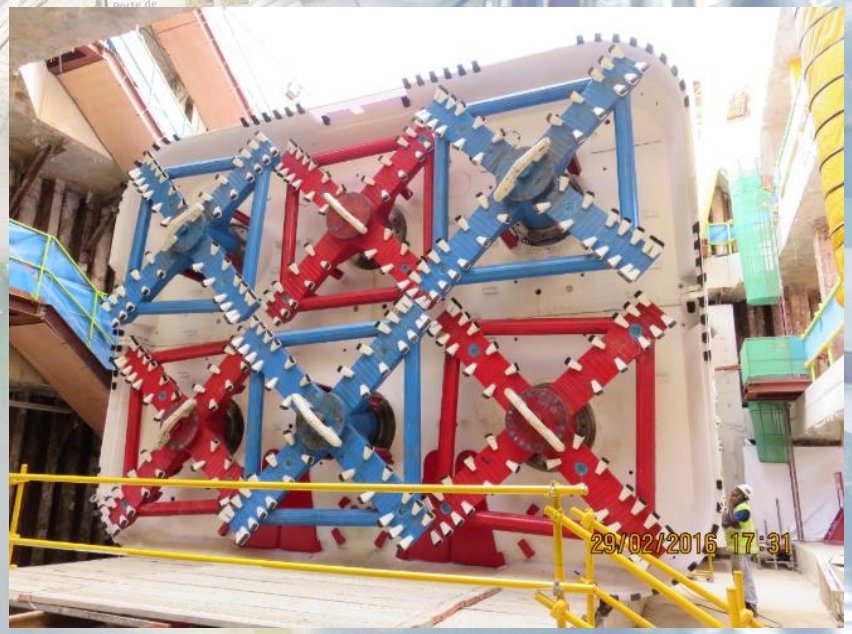
ITA TUNNELLING AWARDS 2017

TECHNICAL PROJECT INNOVATION - OF THE YEAR -

Trenchless Construction of Pedestrian Underpass Using a Rectangular Box Jack Tunnel Boring Machine (RTBM) at Thomson-East Coast Line Havelock Station



Mr Foo Yung Thye Henry
Land Transport Authority
Deputy Group Director, Thomson-East Coast and Cross Island Lines

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Contract Information

Construction of Havelock Station for Thomson-East Coast Line	
Client:	Land Transport Authority
Main-Contractor:	Gammon Construction Limited Singapore Branch
Design Consultant:	AECOM Singapore Pte Ltd

Construction of Trenchless Underpass using the RTBM	
Specialist Sub-Contractor:	China Railway Tunnel Group Co., Ltd (Singapore Branch)
Design Consultant:	Geoconsult Asia Singapore Pte Ltd
Machine Supplier:	China Railway Engineering Equipment Group

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About Land Transport Authority (LTA)

- Statutory board under the Ministry of Transport, which spearheads land transport developments in Singapore
- Over 20 groups supporting projects and regulation in public transportation systems
- Total staff strength of more than 6,000

Infrastructure and Development

- Infrastructure Design and Engineering
- Rail Asset, Operations & Maintenance
- Rail Infrastructure & Expansion
- **Thomson-East Coast & Cross Island Lines**
- Road & Commuter Infrastructure Development
- Rail / Road Systems Engineering
- North-South Corridor
- Traffic and Road Operations

Public Transport, Policy and Planning

- Policy and Planning
- Public Transport
- Vehicle Services

Corporate

- Corporate Planning and Development
- Corporate Communications
- Information Technology, CyberSecurity and Digital Service
- Finance

Quality Service Manager Office & Internal Audit

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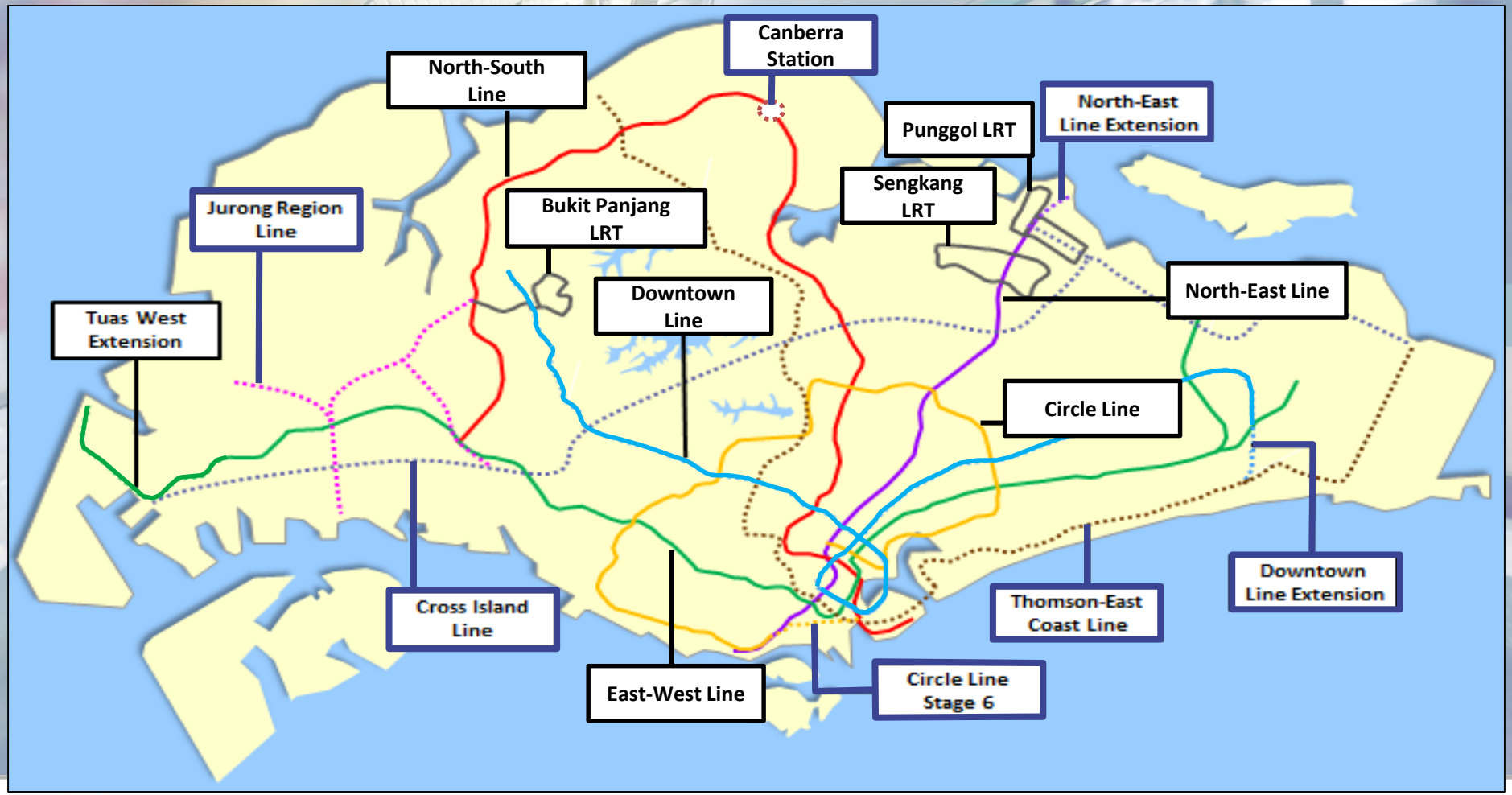
TECHNICAL PROJECT INNOVATION - OF THE YEAR -

Singapore's Rail Network



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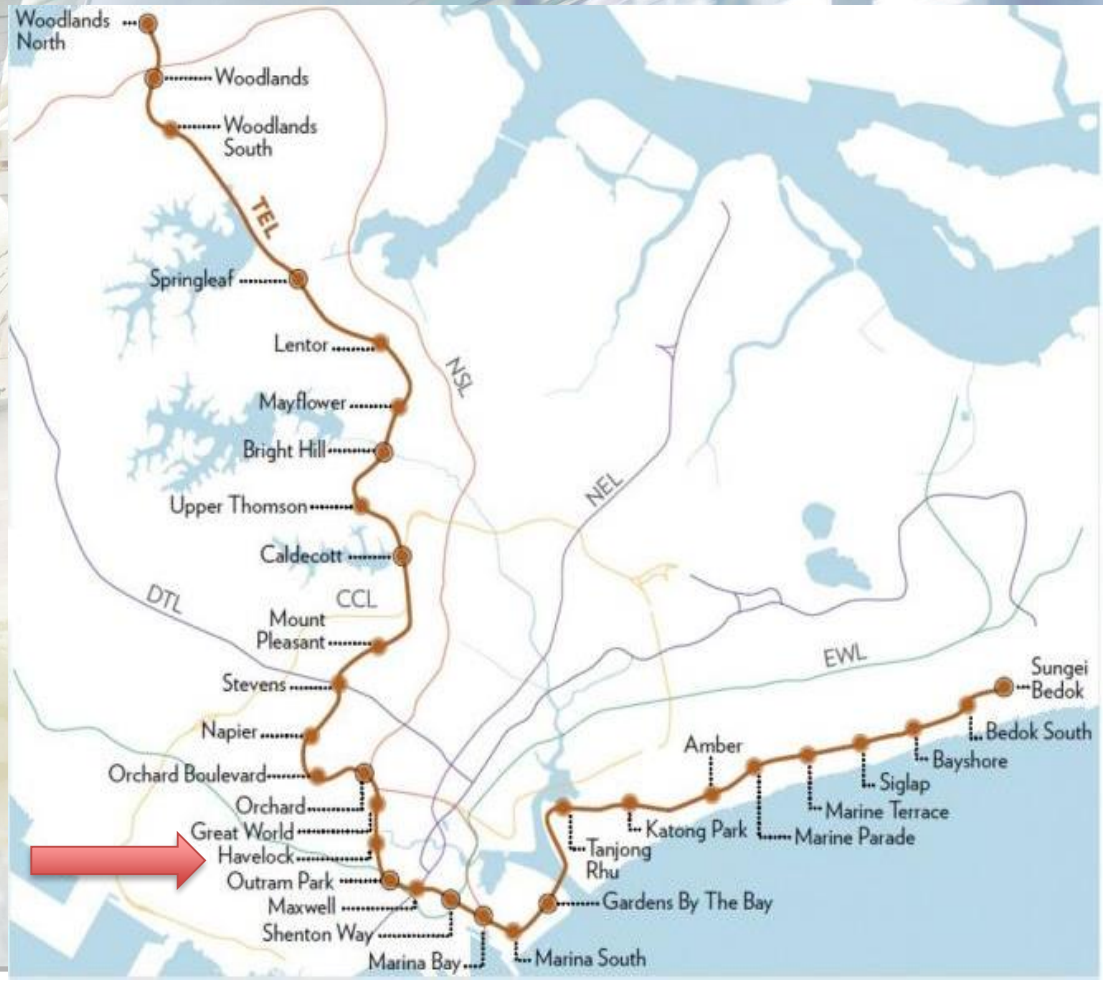
Thomson-East Coast Line (TEL)

- **Route length: 43km (fully underground)**
- **Number of stations: 31 (including 7 interchange stations)**
- **Opening in stages from 2019,**
  - **Woodlands North – Woodlands South: 2019**
  - **Springleaf – Caldecott: 2020**
  - **Mount Pleasant – Gardens by the Bay: 2021**
  - **Tanjong Rhu – Bayshore: 2023**
  - **Bedok South – Sungei Bedok: 2024**



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TECHNICAL PROJECT INNOVATION - OF THE YEAR -

TEL Havelock Station Overview

Information on the Station	
Dimensions	162m (l) * 37m (w) * 30m (d)
No. of Entrances	5
Date of Contract Award	21 February 2014
Contract Value	Approx. S$210 mil
Opening Date	2021

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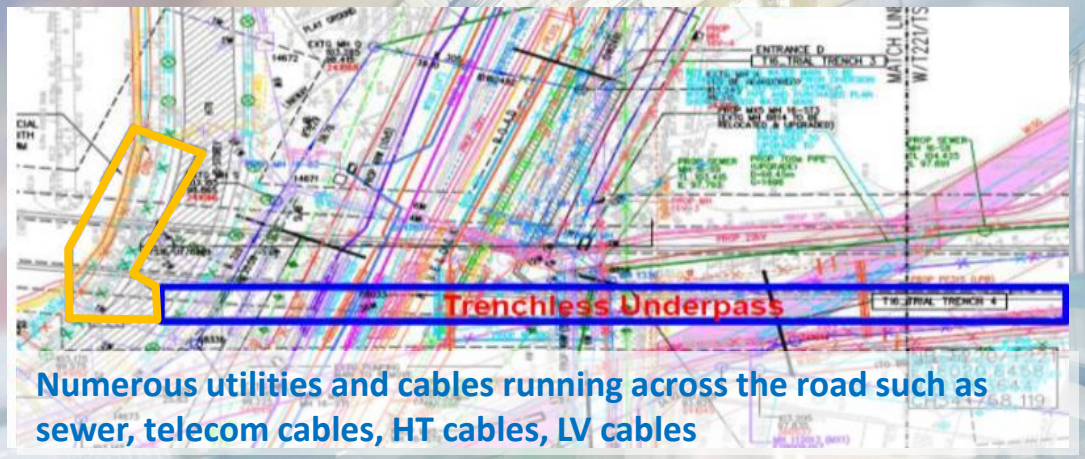
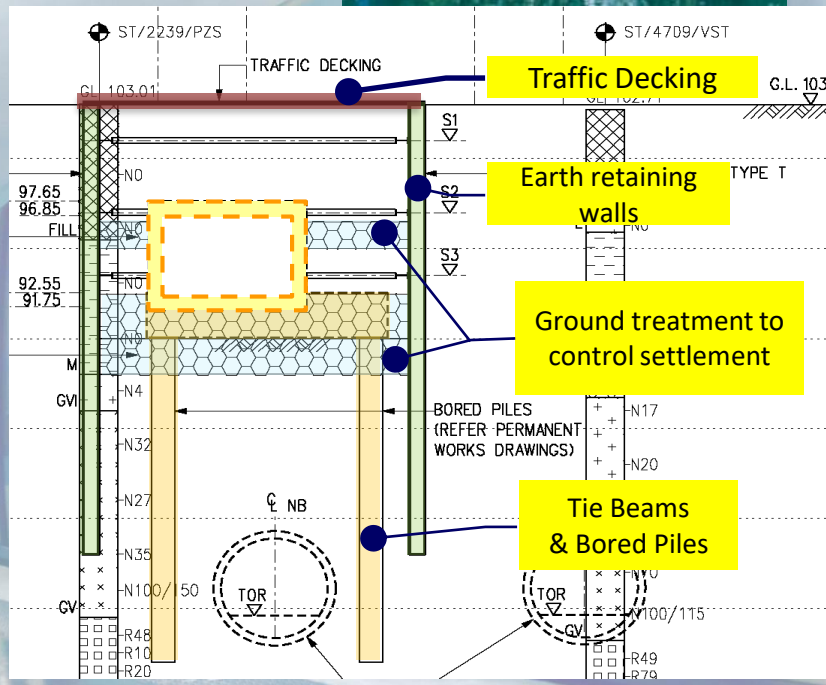
Original Scheme for the Underpass

Conventional Cut & Cover Method



Numerous utilities and cables running across the road such as sewer, telecom cables, HT cables, LV cables



Construction Sequence

1. Diversion / protection of utilities
2. Installation of bored piles, retaining walls
3. Ground treatment
4. Installation of traffic decking
5. Strutted excavation (bottom up)
6. RC structure

Results in:

- Multi-stage road diversions
- Utility diversions
- Heavy Protection to Utilities
- Noise & Dust
- Longer construction period

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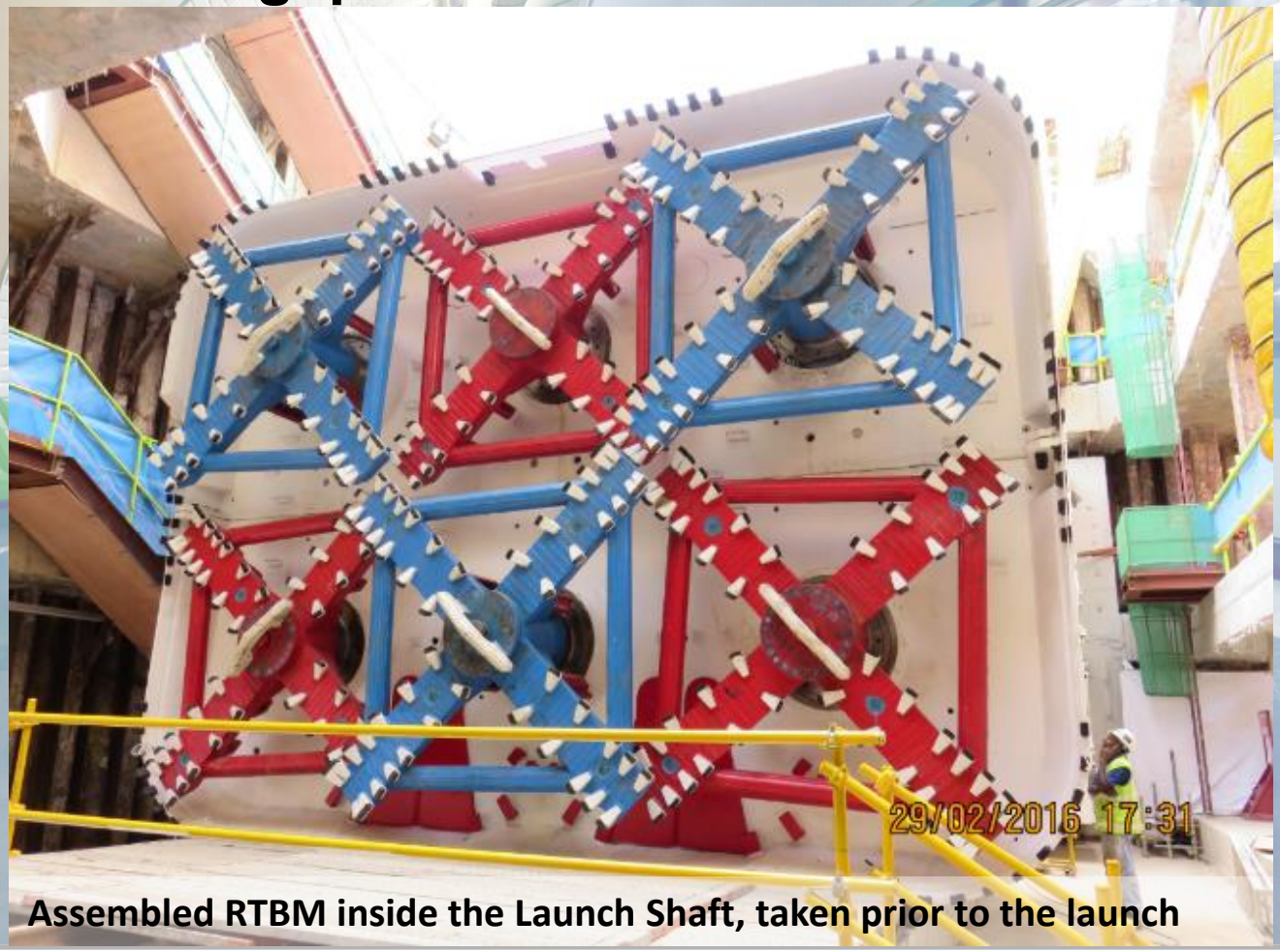
TECHNICAL PROJECT INNOVATION - OF THE YEAR -

Pilot Project – Singapore's First-Ever RTBM!



Assembled RTBM inside the Launch Shaft, taken prior to the launch

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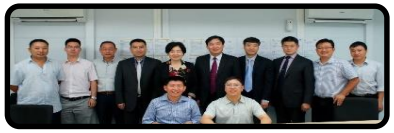
The Journey of the RTBM

Feb 2014

Award of the main civil contract to Gammon for the construction of Havelock Station

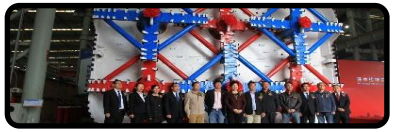
Mar 2014

Feasibility study trip to China



Dec 2014

In line with the national productivity drive, the original cut and cover construction was changed to trenchless construction using the RTBM. Sub-contract for the construction awarded to CRTG.



Oct 2015

Factory Acceptance Test (FAT) for the RTBM conducted in CREG's factory in Zhengzhou, China.

May – Nov 2016

Successful launch and completion of the RTBM drive.

Aug 2017 – Apr 2018

Reuse of the RTBM in TEL Stevens Station to construct a 60m pedestrian underpass

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TECHNICAL PROJECT INNOVATION - OF THE YEAR -

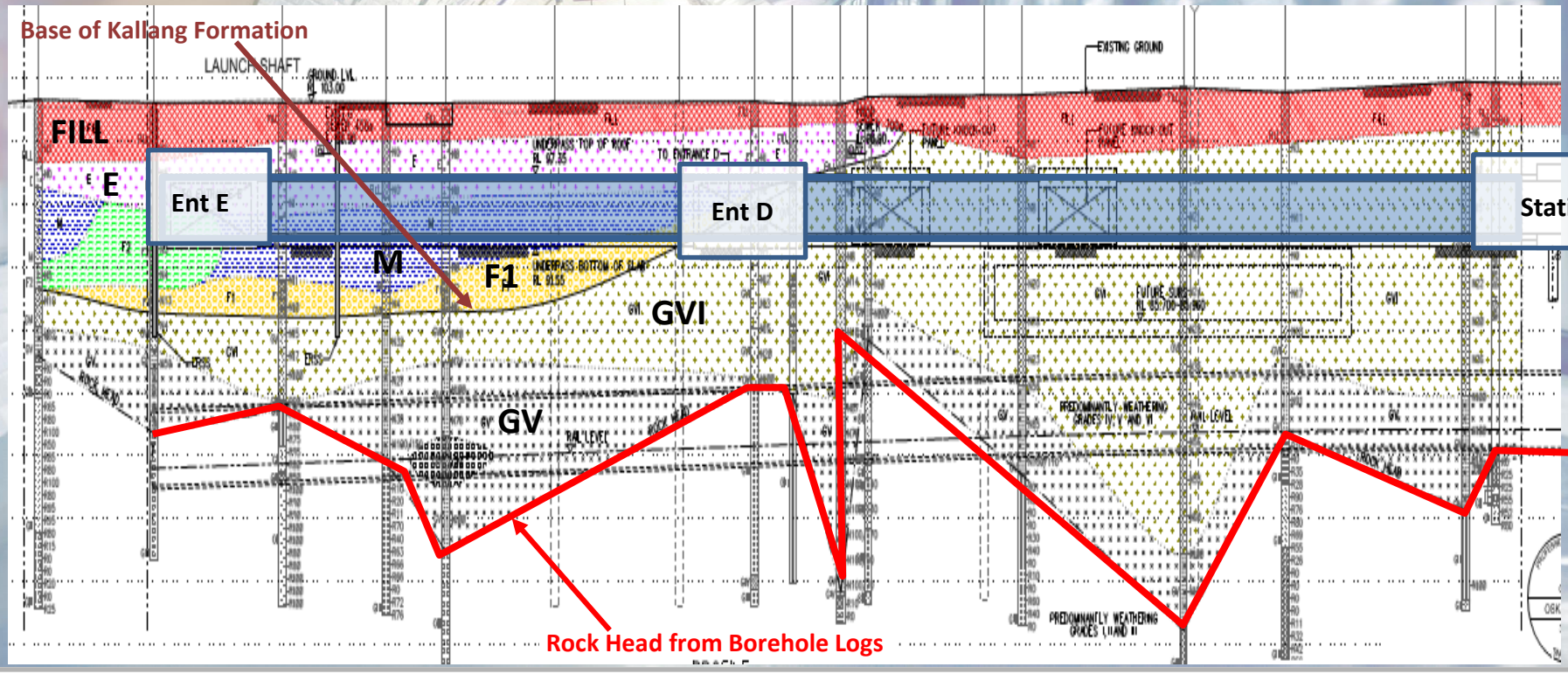
Underpass Geological Conditions

Kallang Formation (60m)

Peaty clay & Marine Clay
SPT N = 0 - 10

Bukit Timah Formation (90m)

Peaty Clay & Residual Soil GVI
SPT N = 6 - 24



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TECHNICAL PROJECT INNOVATION - OF THE YEAR -

Key Public Stakeholders

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TECHNICAL PROJECT INNOVATION - OF THE YEAR -

Key Components of the RTBM

Main Body

Capping bridge to maintain annulus for injection of anti-friction Bentonite

Thrust Ring

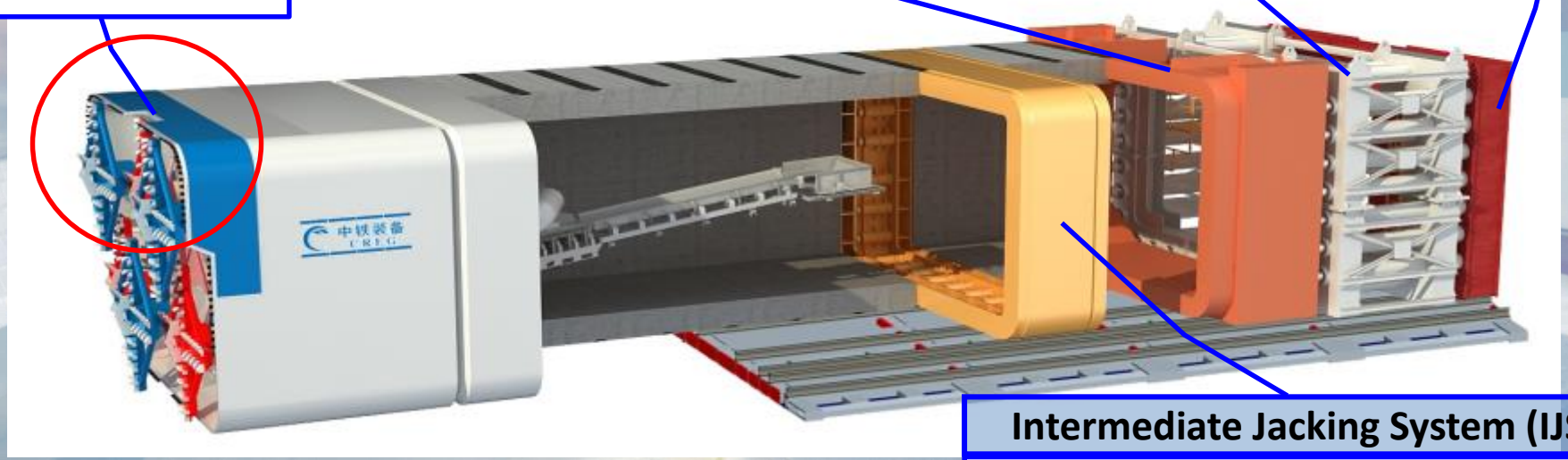
Cylinders push the thrust ring during excavation to create clearance for ring installation

Main Thrust System

24 nos of jacks with maximum jack stroke of 2200mm to propel the machine forward during excavation

Back Support

Acts as reaction frame for even load distribution onto the earth retaining stabilizing structures



Intermediate Jacking System (IJS)

Provided in conjunction with main jacks to supply additional thrust and to be incorporated as part of the permanent structure

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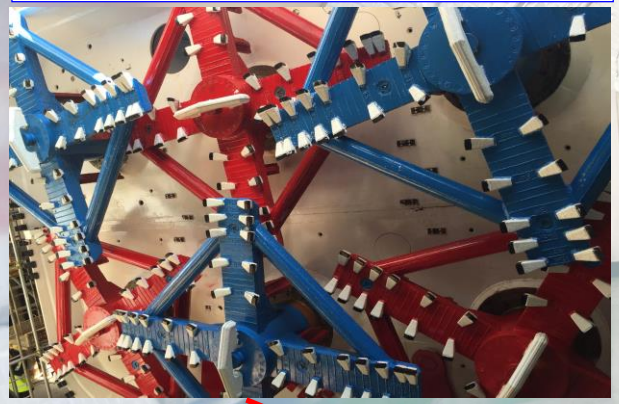
Special Features of the RTBM

Six Independent Cutterheads

Six Independently rotated cutterhead with low torque to minimize disturbances to the ground above at shallow depths

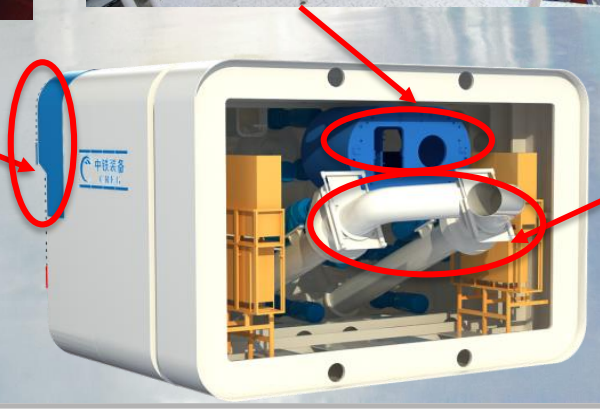


Manlock

Manlock retrofitted to facilitate cutterhead interventions for the first time ever in a RTBM

Double Screw Conveyor

Double conveyor for even muck discharge due to large cutting area



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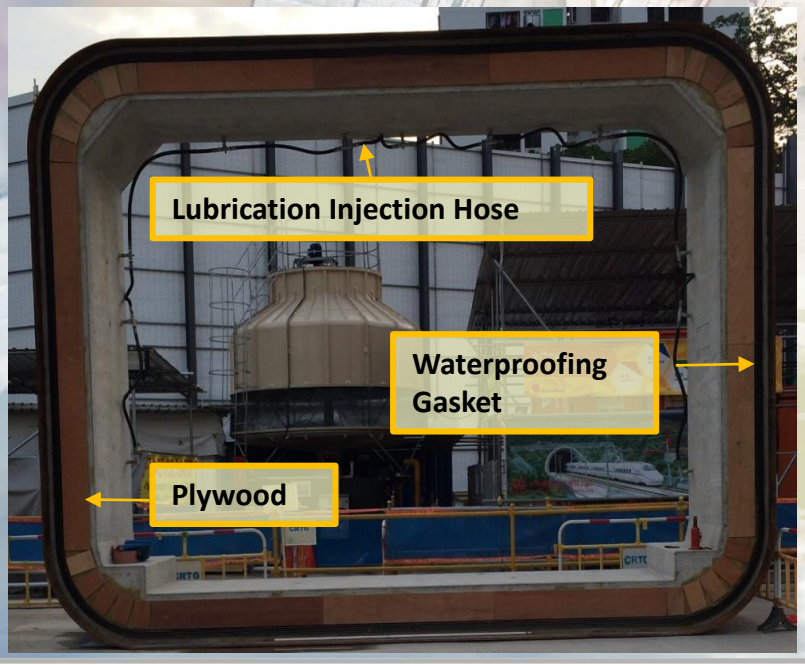
TECHNICAL PROJECT INNOVATION - OF THE YEAR -

Monolithic Precast Box Segments

Overall dimension:	7.6m (W) x 5.6m (H)
Width:	1.5m
Thickness:	500mm
Weight:	50 ton

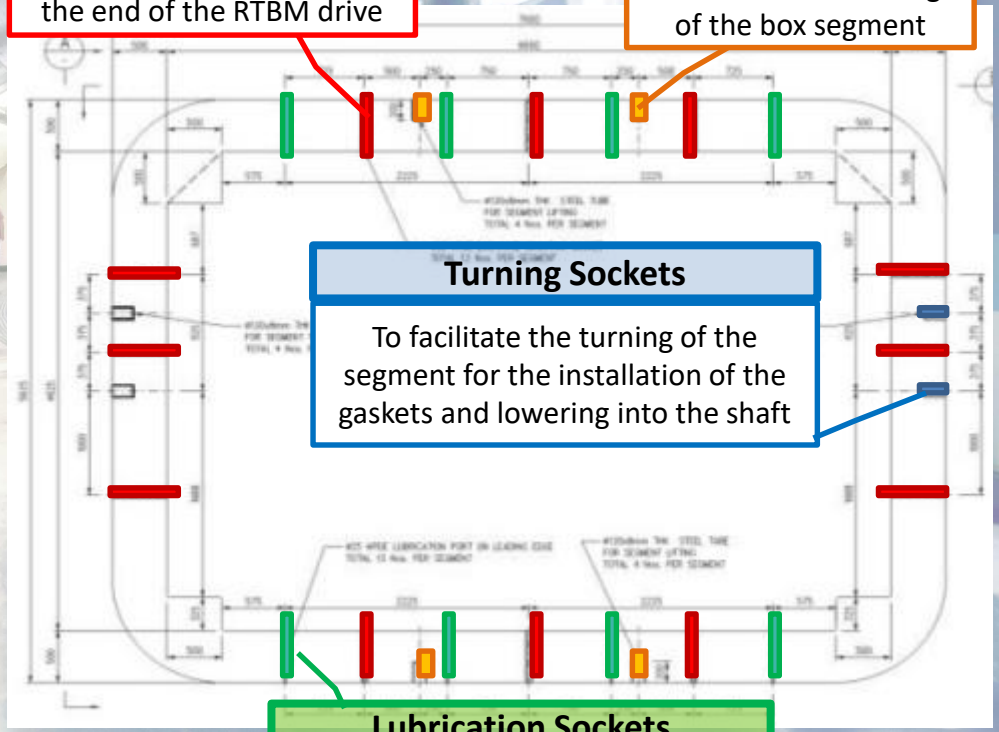


Grouting Sockets

Injection of backfill grout at the end of the RTBM drive

Lifting Sockets

To facilitate the lifting of the box segment



Turning Sockets

To facilitate the turning of the segment for the installation of the gaskets and lowering into the shaft

Lubrication Sockets

Injection of bentonite to minimize the frictional force between the segment and ground during jacking

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Singapore's First-Ever RTBM in Action!

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Project Challenges

- **Project Challenges**
  - **Construction Challenges**
    - Tunnelling in Soft Ground
    - Obstructions encountered during the tunnel drive
    - Settlement in localized areas during the tunnel drive
  - **Serviceability Challenges**
    - Tunnel Water Tightness
  - **Design Challenges**
    - Catering for Future Development
  - **High Capital Cost Challenge**
    - Re-Use of the RTBM

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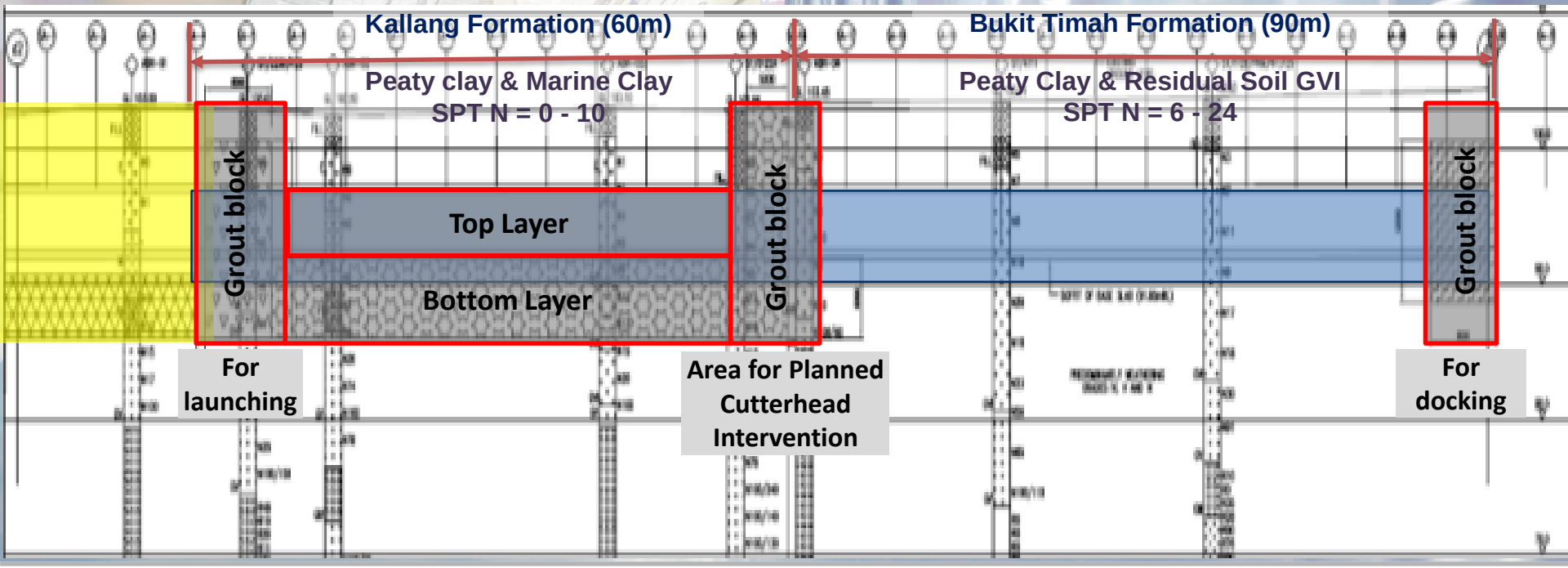
TECHNICAL PROJECT INNOVATION - OF THE YEAR -

Construction Challenges

1. Tunnelling in Soft Ground

- Ground treatment using Jet Grout Piles (JGP) & Deep Soil Mixing (DSM) carried out as a base support for the permanent structure at the first 60m Soft Kallang Formation.
- Additional grouting at top layer to create a homogenous cutting face.



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Construction Challenges

2. Obstructions Encountered During the Tunnel Drive

- Steel pipe debris, steel plates, granite boulder etc. encountered during the tunnel drive.
- Two Cutterhead Interventions (CHI) carried out to remove boulders obstructing the cutterhead & replace the worn out cutter bits.
- The first time a CHI has been carried out in this machine.

Boulder found in front of Cutterhead #6 measuring 1m X 0.5m X 0.4m

Replacement of cutter bits during CHI under free air

Steel bits and boulders encountered during the tunnel drive

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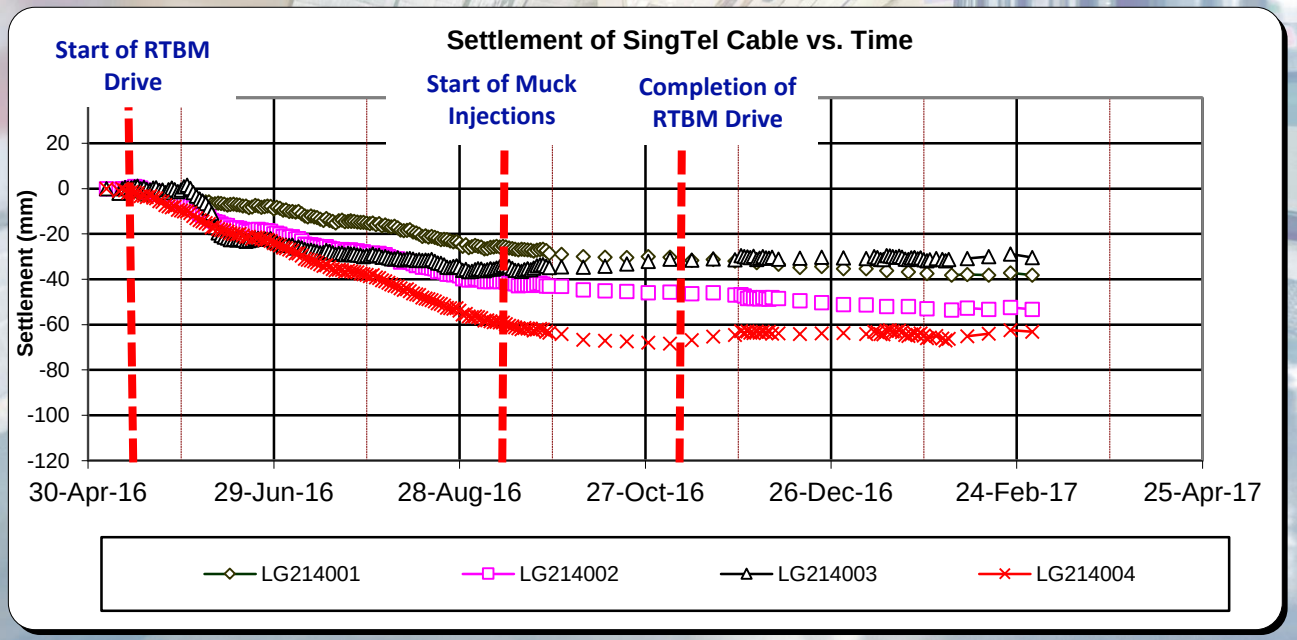
TECHNICAL PROJECT INNOVATION - OF THE YEAR -

Construction Challenges

3. Settlement in Localized Areas during the Tunnel Drive

- A 49-way SingTel telecommunication cable along Havelock Road which had previously heaved during the ground improvement, experienced settlement during the tunnel drive.
- A Muck Pump was used to inject high viscosity bentonite to stabilize the readings.



Muck injection from within the tunnel through the grout ports to control settlement of the 49W cables
Total Vol. of Muck Injected – 8m³

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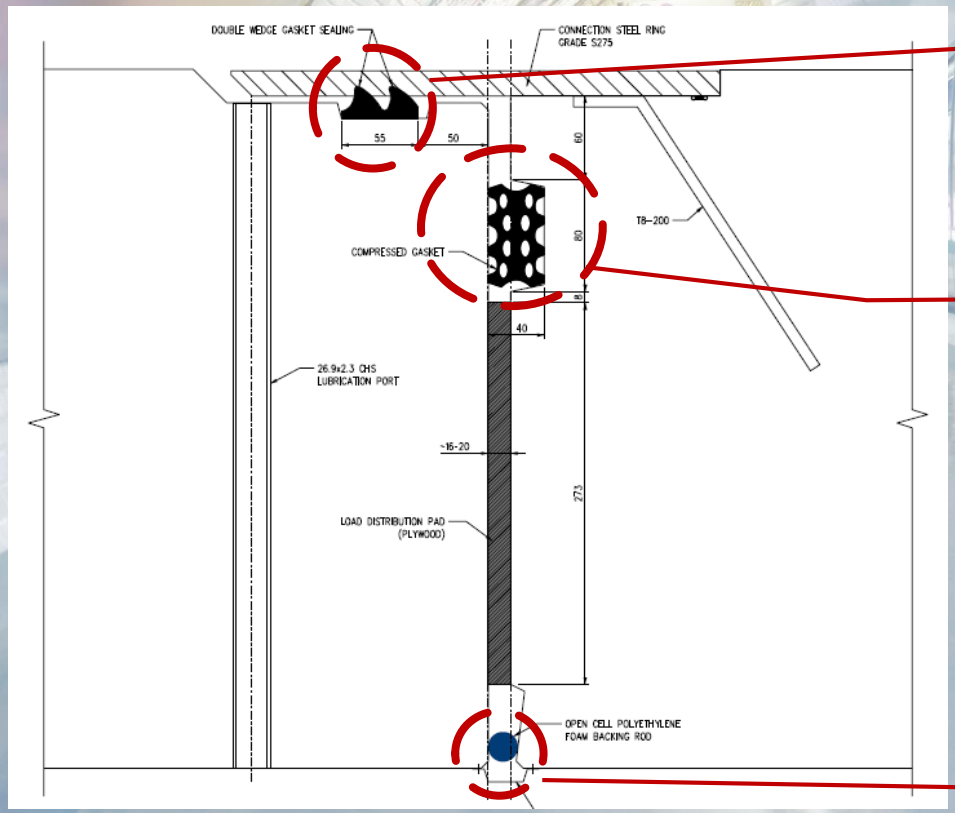
TECHNICAL PROJECT INNOVATION - OF THE YEAR -

Serviceability Challenges

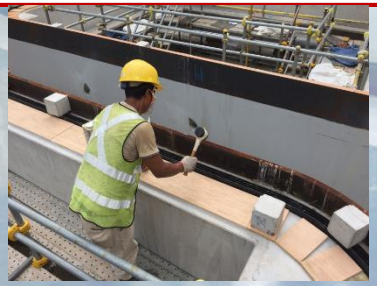
4. Tunnel Water Tightness

- Unique triple-layer waterproofing adopted to ensure the long term water tightness of the underpass



Double Wedge EPDM Seal

EPDM Gasket



Closed Cell Polyethylene Foam Backer Rod

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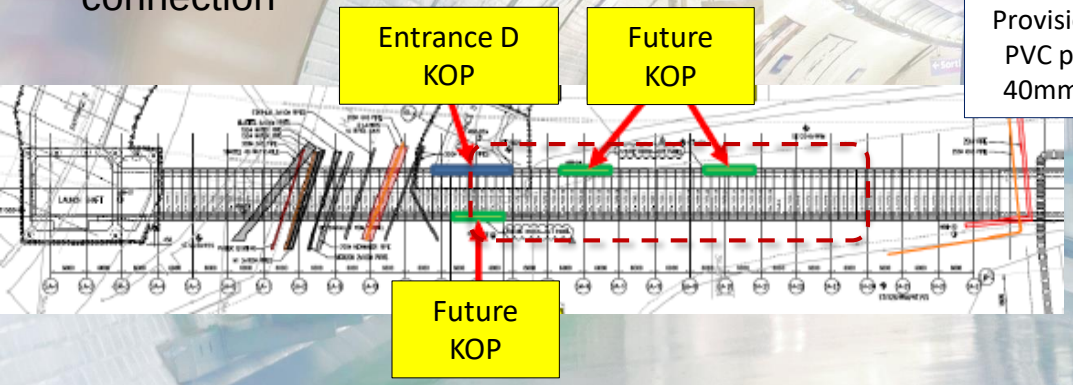
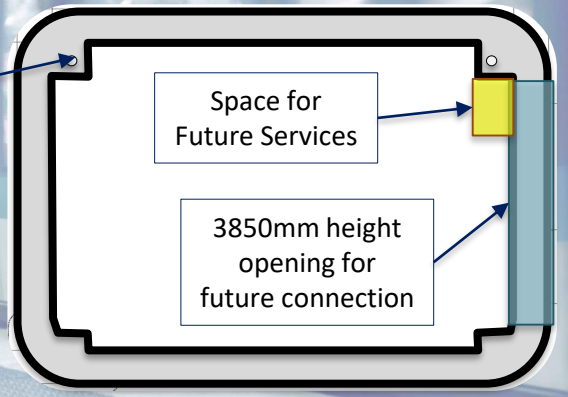
TECHNICAL PROJECT INNOVATION - OF THE YEAR -

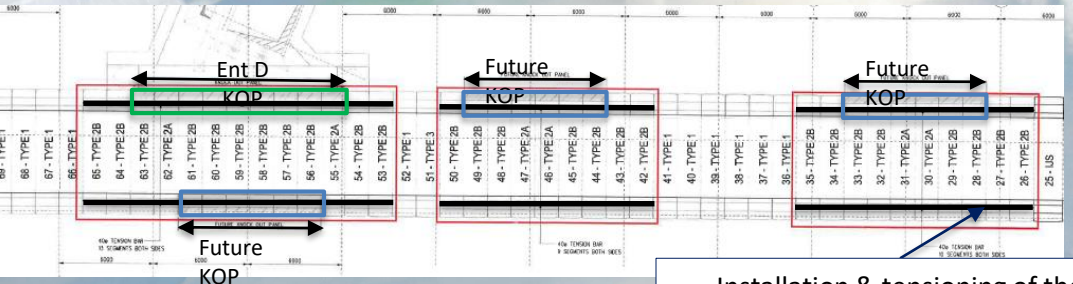
Design Challenges

5. Catering for Future Development

- Requirement to include Knock-Out Panels (KOP) at 3 locations to facilitate a direct underground connection from the underpass to future development in the vicinity
- Design of the monolithic precast box segments at the KOP locations modified to allow for future connection







Installation & tensioning of the tension bar at the KOP locations after completion of the RTBM drive

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TECHNICAL PROJECT INNOVATION - OF THE YEAR -

High Capital Cost Challenge

6. Re-Use of the RTBM

- To maximise the high upfront cost of the machine, the RTBM will be re-used to construct a 62m long pedestrian underpass at TEL Stevens Station.
- The underpass will undercross Dunearn Road, Wayang Satu flyover and the 27m-wide Bukit Timah Canal.

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Benefits of Using the RTBM

1) Simpler and safer construction method

2) Achieved 30% improved productivity

Table 1- Construction Manpower for Cut and Cover Method

No	Activities Description	Manhours
1	Backfill	4,000
2	Bored Piles	4,500
3	Rebar, Formwork and Concrete	26,000
4	Excavation	10,000
5	Ground Improvement	10,000
6	Road & Drain	3,000
7	Secant Bored Piles	3,000
8	Sheet Piles Installation	8,000
9	Sheet Piles Removal	8,000
10	Strut Removal and strut installation	28,000
11	Temporary Deck	14,000
12	Waterproofing	10,000
A	Total Manhours for Cut and Cover Construction	128,500

Table 2 - Construction Manpower for Rectangular Box Jack Tunnel Boring Machine Trenchless Method

No	Activities Description	Manhours
1	ERSS construction for jacking pit (~20m length)/Reaction Wall(including sheet piles, excavation, struts, concrete, rebar, formwork, bored piles, ground improvement etc.)	11,000
2	Preparation work for assembly	3,000
3	Rectangular Box Jack Tunnel Boring Machine assembly	9,000
4	Tunnelling by box jacking method	42,000
5	Preparation work for dismantling	3,000
6	Removal of jacking setup from Station	10,000
7	Construction & completion of ~20m length of underpass at jacking pit, backfilling and removal of ERSS (including sheet piles removal, struts removal, concrete, rebar, formwork, waterproofing, backfill etc.)	12,000
B	Total Manhours for Rectangular Box Jack Tunnel Boring Machine Trenchless Construction	90,000
	Total Saving (A-B)	**38,500**
	Savings (%)	**30.0%**

Approximately 30% savings of manpower when using trenchless construction as opposed to cut and cover tunnels

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Benefits of Using the RTBM

3) No compromise of surface activities

4) Eliminate the need for any utilities diversion and/or support

5) Minimal noise and dust generated

6) High quality on workmanship

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TECHNICAL PROJECT INNOVATION - OF THE YEAR -

Accolades won for the RTBM Initiative

- Singapore Concrete Institute (SCI) Excellence Awards 2015 (Innovators Category)

- Top prize at the Project Management Institute – Singapore Charter (SPMI) Project of the Year (PoY) Awards 2016 – Engineering & Construction Category

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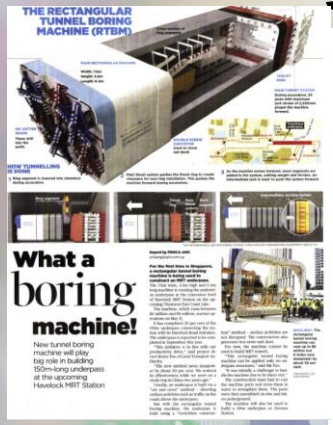
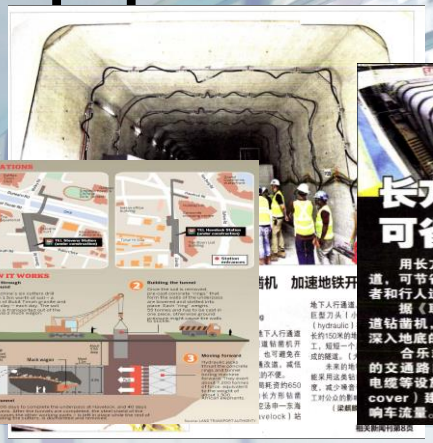
Media Coverage on the TV and Newspapers





Positive coverage by the local media on the use of the RTBM

The use of the RTBM featured on Channel 5's show, On the Red Dot

Interview by Channel News Asia on the use of the RTBM

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World Wide Recognition of the Initiative

- Visits from over 500 visitors from various local & international authority agencies and private companies to learn about the RTBM operations
- Invitation to LTA to present at 4 local and internal conferences

Date	Conference	Location
2 Dec 2015	New Civil Engineer (NCE) Tunnelling Summit	London, UK
2 Mar 2017	IES Seminar – Changing the Way We Build	Singapore
22 Mar 2017	Asia Pacific Rail 2017	Hong Kong
28 Mar 2017	Urban Underground Space & Tunnelling Conference	Singapore

Visit by the Ministry of National Development and Building Construction Authority

NCE Tunneling Summit, London

Asia Pacific Rail 2017, Hong Kong

Visit by Mass Rapid Transit Corporation (Malaysia)

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TECHNICAL PROJECT INNOVATION - OF THE YEAR -

Lessons Learnt from the Project

Following the successful completion of the RTBM drive at Havelock Station, the list of lessons learnt have been tabulated, with the aim of making improvements to the tunnelling operations at TEL Stevens Station.

The list of Lessons Learnt covers the following topics,

1. RTBM Design
2. Monolithic Box Segment Design and Production
3. Tunnelling Operations

Introduction of 7 additional grout ports in the RTBM tail shield at Stevens Station for injection of muck for settlement control

The design of the double wedge gasket has been modified with a smaller cross section area to improve its compressibility

The position of the turning sockets modified in Stevens Station to enable easy turning of segments instead of using a winch system (as pictured)

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Conclusion

- RTBM proves to be an interesting solution to engineering challenges
- Innovative alternative to the conventional Cut & Cover method at shallow depths
- Productivity savings of 30% in addition to other benefits
- Attractive construction method for densely built-up countries with rising labour costs
- Solutions derived from project challenges served as valuable lessons learnt for future projects

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Thank You