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
# Contract Information

## Construction of Havelock Station for Thomson-East Coast Line

<table>
<thead>
<tr>
<th><strong>Client:</strong></th>
<th>Land Transport Authority</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main-Contractor:</strong></td>
<td>Gammon Construction Limited Singapore Branch</td>
</tr>
<tr>
<td><strong>Design Consultant:</strong></td>
<td>AECOM Singapore Pte Ltd</td>
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</table>

## Construction of Trenchless Underpass using the RTBM

<table>
<thead>
<tr>
<th><strong>Specialist Sub-Contractor:</strong></th>
<th>China Railway Tunnel Group Co., Ltd (Singapore Branch)</th>
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</thead>
<tbody>
<tr>
<td><strong>Design Consultant:</strong></td>
<td>Geoconsult Asia Singapore Pte Ltd</td>
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<tr>
<td><strong>Machine Supplier:</strong></td>
<td>China Railway Engineering Equipment Group</td>
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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
Singapore’s Rail Network

- North-South Line
- Jurong Region Line
- Bukit Panjang LRT
- Tuas West Extension
- Downtown Line
- Cross Island Line
- East-West Line
- Circle Line
- Punggol LRT
- Sengkang LRT
- North-East Line
- North-East Line Extension
- Circle Line Stage 6
- Thomson-East Coast Line
- Downtown Line Extension
- Canberra Station
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
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
Original Scheme for the Underpass

Conventional Cut & Cover Method

- Diversion / protection of utilities
- Installation of bored piles, retaining walls
- Ground treatment
- Installation of traffic decking
- Strutted excavation (bottom up)
- RC structure

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

Numerous utilities and cables running across the road such as sewer, telecom cables, HT cables, LV cables.
Pilot Project – Singapore’s First-Ever RTBM!

Assembled RTBM inside the Launch Shaft, taken prior to the launch
## The Journey of the RTBM

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
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<tr>
<td><strong>Feb 2014</strong></td>
<td>Award of the main civil contract to Gammon for the construction of Havelock Station</td>
</tr>
<tr>
<td><strong>Mar 2014</strong></td>
<td>Feasibility study trip to China</td>
</tr>
<tr>
<td><strong>Dec 2014</strong></td>
<td>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.</td>
</tr>
<tr>
<td><strong>Oct 2015</strong></td>
<td>Factory Acceptance Test (FAT) for the RTBM conducted in CREG’s factory in Zhengzhou, China.</td>
</tr>
<tr>
<td><strong>May – Nov 2016</strong></td>
<td>Successful launch and completion of the RTBM drive.</td>
</tr>
<tr>
<td><strong>Aug 2017 – Apr 2018</strong></td>
<td>Reuse of the RTBM in TEL Stevens Station to construct a 60m pedestrian underpass</td>
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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

Base of Kallang Formation

Rock Head from Borehole Logs

Mr Foo Yung Thye Henry
Key Public Stakeholders

- Geck Hong Tian Temple
- Blk 93
- Holiday Inn Atrium
- Zion Road
- Havelock Road
- Launch Shaft

Mr Foo Yung Thye Henry
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
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.
Monolithic Precast Box Segments

<table>
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<tr>
<th>Overall dimension:</th>
<th>7.6m (W) x 5.6m (H)</th>
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</thead>
<tbody>
<tr>
<td>Width:</td>
<td>1.5m</td>
</tr>
<tr>
<td>Thickness:</td>
<td>500mm</td>
</tr>
<tr>
<td>Weight:</td>
<td>50 ton</td>
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</table>

- **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.

**Plywood**

**Waterproofing Gasket**

**Lubrication Injection Hose**

**Overall dimension:** 7.6m (W) x 5.6m (H)

**Width:** 1.5m

**Thickness:** 500mm

**Weight:** 50 ton
Singapore’s First-Ever RTBM in Action!
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

Mr Foo Yung Thye Henry
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.
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
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.

![Graph showing settlement of SingTel Cable vs. Time]

**Settlement of SingTel Cable vs. Time**

- Start of RTBM Drive
- Start of Muck Injections
- Completion of RTBM Drive

**Muck injection from within the tunnel through the grout ports to control settlement of the 49W cables**

**Total Vol. of Muck Injected – 8m³**

Mr Foo Yung Thye Henry
Serviceability Challenges

4. Tunnel Water Tightness

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

![Diagram of Design Challenges](image-url)

- Entrance D KOP
- Future KOP
- Provision of 100mm PVC pipe to install 40mm tension bar
- Space for Future Services
- 3850mm height opening for future connection
- Installation & tensioning of the tension bar at the KOP locations after completion of the RTBM drive
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.
Benefits of Using the RTBM

1) Simpler and safer construction method
2) Achieved 30% improved productivity

Approximately 30% savings of manpower when using trenchless construction as opposed to cut and cover tunnels
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
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
Media Coverage on the TV and Newspapers

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

On The Red Dot 2016 - EP13
Fri 1 Jul 2016 - Science Of Things
23 min
By Channel 5 / Published: 01 Jul 2016 / Audio: English

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

Mr Foo Yung Thye Henry
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

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<th>Conference</th>
<th>Location</th>
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<tbody>
<tr>
<td>2 Dec 2015</td>
<td>New Civil Engineer (NCE) Tunnelling Summit</td>
<td>London, UK</td>
</tr>
<tr>
<td>2 Mar 2017</td>
<td>IES Seminar – Changing the Way We Build</td>
<td>Singapore</td>
</tr>
<tr>
<td>22 Mar 2017</td>
<td>Asia Pacific Rail 2017</td>
<td>Hong Kong</td>
</tr>
<tr>
<td>28 Mar 2017</td>
<td>Urban Underground Space &amp; Tunnelling Conference</td>
<td>Singapore</td>
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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)
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
Thank You