Deep Tunnel Sewerage System Phase 2
Public Utilities Board, Singapore

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Black & Veatch HK Ltd

Agenda

- Project Overview
- Tunnel Hydraulic
- Tunnel Alignment
- Air Flow Management
- Provision for Tunnel Isolation
- Fibre Optic Strain Sensing Systems
- Corrosion Protection for Tunnels and Shafts
- Tunnel Geology & TBM Selection
- Implementation Strategy
The Project – DTSS2

<table>
<thead>
<tr>
<th><strong>Client</strong></th>
<th>Public Utilities Board (PUB), Singapore Government</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Consultant</strong></td>
<td>Black &amp; Veatch – AECOM Joint Venture</td>
</tr>
<tr>
<td></td>
<td>To Provide Professional Engineering Services for the Feasibility Study, Preliminary Design and Programme Management</td>
</tr>
<tr>
<td><strong>Project Commencement/Commission Date</strong></td>
<td>21 April 2014 / Q3 2023</td>
</tr>
<tr>
<td><strong>Anticipated 1st Tunnel Contract Start Date</strong></td>
<td>July 2017 (D&amp;B contract)</td>
</tr>
<tr>
<td><strong>Main Components of DTSS2 Project</strong></td>
<td>(1) Tuas WRP and Outfall; (2) Deep Tunnels; and (3) Link Sewers</td>
</tr>
</tbody>
</table>
Used Water System Before DTSS (pre-2008)

- 6 Water Reclamation Plants (WRPs) and
- > 130 Sewage Pumping Station

DTSS Phase 1

- 48km tunnels (3.3m to 6m ID)
- 60km link sewers (0.3m to 3m ID)
- 178MGD plant at Changi
- 5km outfall (3m ID)
Completed DTSS scheme with 3 Water Reclamation Plants WRP)

Kranji WRP (existing)

Changi WRP (Ph 1)

Taus WRP (Ph 2)

Estimated Distribution of Used Water Flows at 2100

Kranji WRP
0.66 million CMD

Total Projected UW Flow in 2100
4.81 million CMD

Tuas WRP
1.86 million CMD

DTSS2

Changi WRP
2.29 million CMD
How DTSS Works

- **Link Sewers** convey used water from existing sewerage network to the **Deep Tunnels**
- Used water flows by gravity through the deep sewer tunnels to centralised **Water Reclamation Plants (WRPs)**
- Treated used water will be channelled to the NEWater plant for further purification or discharged through the **Outfall**
Existing Jurong and Ulu Pandan WRP Catchments and Pumping Installations within DTSS2

Layout of DTSS2 Conveyance System
Summary of Tunnel Lengths and Sizes
(TBM Works)

<table>
<thead>
<tr>
<th>Tunnel</th>
<th>Length (to nearest km)</th>
<th>Range in Tunnel Diameter (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Tunnel</td>
<td>27 km</td>
<td>3.0 m to 6.0 m</td>
</tr>
<tr>
<td>South Spur Tunnel</td>
<td>2 km</td>
<td>4.0 m</td>
</tr>
<tr>
<td>Industrial Tunnel</td>
<td>7 km</td>
<td>3.3 m to 4.0 m</td>
</tr>
<tr>
<td>Link Sewers (by TBM)</td>
<td>14 km</td>
<td>3.0 m to 4.0 m</td>
</tr>
<tr>
<td><strong>Total Length</strong></td>
<td><strong>50 km</strong></td>
<td></td>
</tr>
</tbody>
</table>

Summary of Link Sewer Lengths and Sizes
(Pipejacking Works)

<table>
<thead>
<tr>
<th>SEWER DIAMETER (mm)</th>
<th>LENGTH (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>496</td>
</tr>
<tr>
<td>400</td>
<td>638</td>
</tr>
<tr>
<td>500</td>
<td>780</td>
</tr>
<tr>
<td>600</td>
<td>1,062</td>
</tr>
<tr>
<td>700</td>
<td>46</td>
</tr>
<tr>
<td>800</td>
<td>2,192</td>
</tr>
<tr>
<td>900</td>
<td>2,355</td>
</tr>
<tr>
<td>1,000</td>
<td>2,610</td>
</tr>
<tr>
<td>1,200</td>
<td>6,669</td>
</tr>
<tr>
<td>1,500</td>
<td>744</td>
</tr>
<tr>
<td>1,650</td>
<td>871</td>
</tr>
<tr>
<td>1,800</td>
<td>1,992</td>
</tr>
<tr>
<td>2,000</td>
<td>8,447</td>
</tr>
<tr>
<td>2,100</td>
<td>5,741</td>
</tr>
<tr>
<td>2,200</td>
<td>1,307</td>
</tr>
<tr>
<td>2,500</td>
<td>7,292 (+ 1391: MCE)</td>
</tr>
<tr>
<td>2,700</td>
<td>853</td>
</tr>
<tr>
<td>3,000</td>
<td>3,148</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>47,243</strong></td>
</tr>
</tbody>
</table>
Benefits of DTSS

Benefits:
- More cost effective
- Free up valuable land
- Ensures sustainability of NEWater
- Robust, Reliable and Resilient

Existing WRPs & Pumping Stations – 300 ha

TUNNEL HYDRAULIC
Tunnel Hydraulics

A hydraulic study of these tunnels using modelling with MIKE URBAN was undertaken to determine the tunnel sizing and gradients, considering flow projections at various years from 2027 to 2100, and under different conditions of dry and wet weather up to 100-year return interval rainfall events.

The system is designed to be able to convey peak used water flows with adequate system containment while also transporting suspended materials efficiently to prevent solid deposition in the sewer (i.e. self-cleansing).

Scope of DTSS2 Conveyance System
Tunnels Sizing, Grading and Length of Each Tunnel Segment

<table>
<thead>
<tr>
<th>TUNNEL</th>
<th>SHAFTS</th>
<th>TUNNELdia (ID, m)</th>
<th>GRADIENT</th>
<th>LENGTH (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Tunnel</td>
<td>Ki To L</td>
<td>3.0</td>
<td>1 In 900</td>
<td>5,200</td>
</tr>
<tr>
<td>South Tunnel</td>
<td>L To M</td>
<td>3.3</td>
<td>1 In 1,500</td>
<td>810</td>
</tr>
<tr>
<td>South Tunnel</td>
<td>M To Z</td>
<td>6.0</td>
<td>1 In 2,000</td>
<td>17,310</td>
</tr>
<tr>
<td>Industrial Tunnel</td>
<td>P2 To V3</td>
<td>3.3</td>
<td>1 In 800</td>
<td>4,290</td>
</tr>
<tr>
<td>Industrial Tunnel</td>
<td>V3 To Zi</td>
<td>4.0</td>
<td>1 In 1,000</td>
<td>2,900</td>
</tr>
<tr>
<td>Holland LS</td>
<td>S To Ts</td>
<td>4.0</td>
<td>1 In 700</td>
<td>1,470</td>
</tr>
<tr>
<td>South Spur Tunnel</td>
<td>Ts To M</td>
<td>4.0</td>
<td>1 In 800</td>
<td>1,560</td>
</tr>
<tr>
<td>Southern Region LS</td>
<td>L-LS8 To L-LS5</td>
<td>3.0</td>
<td>1 In 450</td>
<td>1,520</td>
</tr>
<tr>
<td>Southern Region LS</td>
<td>L-LS5 To L-LS3</td>
<td>3.3</td>
<td>1 In 615</td>
<td>1,410</td>
</tr>
<tr>
<td>Southern Region LS</td>
<td>L-LS3 To L</td>
<td>3.3</td>
<td>1 In 615</td>
<td>2,650</td>
</tr>
<tr>
<td>Northwest LS</td>
<td>X1-LS1 To X1-LS3</td>
<td>3.5</td>
<td>1 In 1,000</td>
<td>2,740</td>
</tr>
<tr>
<td>Northwest LS</td>
<td>X1-LS3 To X1</td>
<td>3.5</td>
<td>1 In 1,000</td>
<td>2,630</td>
</tr>
<tr>
<td>Pasir Panjang LS</td>
<td>N-LS1 To N</td>
<td>3.5</td>
<td>1 In 400</td>
<td>1,490</td>
</tr>
</tbody>
</table>

Vertical Alignment of South Tunnel
Vertical Alignment of Industrial Tunnel

Vertical Alignment of Southern Region LS
TUNNEL ALIGNMENT

Scope of DTSS2 Conveyance System

> 90% of tunnel alignment within LTA’s road reserve zone
DTSS2 South Tunnel Alignment Animation

Constraints: along Keppel Road
Constraints at Keppel Road (with BIM Model)

Constraints at AYE / Tuas Road
Sharp Turning of Tunnel Alignment

Segments / TBM Features (for ID 6m TBM)

- Segment width:
  - Nominal (i.e. R > 150 m) 1.6m
  - Negotiate curves (i.e. R < 150) 1.0m
- TBM Cutters (for soil)
  - Utilize a copy-cutter (see next slide) for facilitating the turning operations and creating a sufficient over-excavation.
- TBM Cutters (for rock)
  - the gauge cutters (see next slide) will be shimmed before the TBM enters into any tight curve alignment area.
- TBM is equipped with an active articulation system, comprising of 12 no. jacks with max stroke of 400mm. The total thrust of the articulation jacks is equal to the total thrust of the main thrust jacks. (see next slide)
- The flexible shield joint at TBM, located between the front and the middle shield, is sealed, using a double lip seal system with inflatable function. (see next slide)
Schematic View of TBM Tight Turning

AIR FLOW MANAGEMENT OF SOUTH TUNNEL
Air Flow Management

- avoid odour nuisance;
- accommodate the air flow requirements associated with water level variations in the tunnels without excessive pressurisation or depressurisation of the air above the water, which could cause large localised air flows that could be dangerous; and
- provide sufficient ventilation to avoid the development of corrosive conditions in the tunnels and odour issues.

### Required Air Jumper and Odour Control Facilities Capacities

| Year | Dry / Wet Weather | Water level at IPS | SHAFTS | Component | K1 | K2 | L | M | N | N1 | N2 | N3 | O1 | P | X1 | Trans |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2017 | Dry | High | From Link Sewer | AI | AI | AI | AI | AI | AI | AI | AI | AI | AI | AI | AI | AI | AI |
| | | From Tunnel | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | Low | From Link Sewer | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | From Tunnel | 2.3 | 0.2 | 3.1 | 0.7 | 0.4 | 2.6 | 0.9 | 3.7 | 2.9 | - | - | - | - | - | - | - |
| | Wet | High | From Link Sewer | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | From Tunnel | 2.3 | 0.3 | 3.5 | 0.7 | 0.4 | 2.6 | 0.9 | 3.7 | 2.9 | - | - | - | - | - | - | - |
| 2020 | Dry | High | From Link Sewer | 2.7 | 0.3 | 3.8 | 0.7 | 2.2 | 0.6 | 2.3 | 1.2 | 4.4 | 4.0 | 4.0 | - | - | - | - |
| | | From Tunnel | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | Wet | High | From Link Sewer | 3.1 | 0.4 | 4.2 | 0.7 | 2.5 | 0.7 | 4.1 | 1.4 | 5.6 | 5.0 | - | - | - | - | - |
| | | From Tunnel | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |

Notes: Wet weather flows are for 2-year storm  
15) Air Jumper  
16) Odor Control Facility

Air Flows (m³/s)
**DTSS2 Conveyance System and Shafts Location**

**Drop Structure & Odour Control Facility**

- Withdraws Air from both Link Sewer and Tunnel, Treats & Releases
Drop Structure & Air Jumper

- Negative pressure in tunnel may not be sufficient to pull incoming link sewer air.
- Air Jumper force the air into tunnel

PROVISION FOR TUNNEL ISOLATION
Provision for Tunnel Isolation

For the purposes of maintenance and inspection, the isolation gates are lowered into position (at two shafts), a length of isolated tunnel is achieved thus enabling tunnel inspection, maintenance and any necessary repair works to be undertaken by the maintenance team.

Schematic Provision for Tunnel Isolation using Isolation Gates
## Roller Gate

<table>
<thead>
<tr>
<th>Type</th>
<th>Height of Opening (m)</th>
<th>Width of Opening (m)</th>
<th>Design Pressure (Bar)</th>
<th>Estimated Tonnage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>6</td>
<td>5</td>
<td>5</td>
<td>85 Ton</td>
</tr>
<tr>
<td>Type 2 (Isolation)</td>
<td>3.3</td>
<td>2.6</td>
<td>4</td>
<td>10 Ton</td>
</tr>
<tr>
<td>Type 2 (Diversion)</td>
<td>4</td>
<td>3.2</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>Type 3 (Diversion)</td>
<td>3</td>
<td>2.6</td>
<td>2</td>
<td>1 Ton</td>
</tr>
</tbody>
</table>

### Normal Flow Condition

![Normal Flow Condition Diagram](Diagram.png)
Flow Direction after Isolation

Procedure of Tunnel Isolation for Maintenance

1. Normal flow in link sewer and south tunnel
Procedure of Tunnel Isolation for Maintenance

2. Gate put in place first at upstream shaft
3. Water level rises to surcharge condition at upstream side
4. Water drains downstream side; & 2nd gate lowered at D/S shaft
5. U/S Link sewer flow diverted to upstream side compartment of the shaft
6. Use Blower (with down the shaft extension) and extractor to ventilate the tunnel
   (Extracted air could be analysed for any harmful gases before man entry is attempted)
Gate Assembly in Shaft

Procedure of Tunnel Isolation for Maintenance

7. Some water may collect in the isolated tunnel segment.
8. Lower pump, pass hose through the wall and pump gathered water across the gate.
   (workman needs to be hoist down to pass the pipe through wall)
**Procedure of Tunnel Isolation for Maintenance**

9. If happens, the rising downstream side water is retained by the gate at downstream shaft
10. Use ladder to climb down the shaft OR use man hoist to lower workmen
11. Carry out inspection or repair within tunnel

**Innovative Technology of Tunnel Inspection**
Innovative Technology of Tunnel Inspection

Use of Remotely Operated Vehicle (ROV) for Tunnel Inspections

Tunnel Inspection by Drone
Tunnel Structural Integrity Monitoring

*Fibre optic strain sensing system (FO)* installation is recommended for DTSS2 Tunnel with the main objective to monitor the structural integrity of the tunnel. The proposed FO installation will cover the entire length of South Tunnel and Industrial Tunnel.

The cables can be installed on two opposite sides and the crown of tunnel in the longitudinal direction to detect bending or lateral/vertical distortion of the tunnel due to proximity of excavation during other construction or geological fault movements.
Principle of Fibre Optic Strain Sensing Systems (FO)

- FO instrumentation has been used and installed in MRT (SG) and UK tunnel projects.

Resolution of FO Measurement

<table>
<thead>
<tr>
<th>Distance range (km)</th>
<th>Spatial resolution (m)</th>
<th>Sampling resolution (m)</th>
<th>Dynamic range (dB)</th>
<th>Estimated losses (dB)</th>
<th>Approximate Measurement time (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>0.5</td>
<td>0.05</td>
<td>3</td>
<td>2.25</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>0.1</td>
<td>5</td>
<td>3</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>0.1</td>
<td>5</td>
<td>4.5</td>
<td>&lt; 5</td>
</tr>
</tbody>
</table>
Measured Strain Resolution of FO

Example: Installation of Fibre Optic Cables to Tunnel
Fibre optic cables held in place temporarily prior to the installation of the secondary lining
CORROSION PROTECTION FOR TUNNELS AND SHAFTS
Process of Microbiological Influenced Corrosion in poor ventilation of sewer environment
Examples of Corroded Sewer Pipes & Manhole

Corrosion Protection Measures for DTSS2 Tunnels

- Use a system that must be able to withstand the corrosive sewer environment over its design life of 100 years;
- Use a proven system and materials;
- Minimise the risk of water ingress into the tunnels particularly under the sea where salt water inflows will be harmful to the membrane technology adopted at the Tuas Water Reclamation Plant;
- Use of technology that is widely available within the market;
- Allow for the provision of Fibre Optic Cables necessary for the instrumentation to monitor the performance of the tunnels during their operation.
One Pass Tunnel Lining Corrosion Protection System

- MIC Resistant or OPC Concrete Segment with preformed HDPE Liner
- Composite Segment

One Pass Tunnel Lining Corrosion Protection System

- HDPE Liner

DCPD frame
- Broad experiences at demanding environments: Chlor-Alkali Industry, sewage systems, truck bumpers
- DCPD used as segment embedded liner since 1995:
  - 13 projects by now,
  - > 6,500 rings equipped
One Pass Tunnel Lining Corrosion Protection System

Composite Segment

Polymer- / Geo-polymer- / CAC-concrete

Corrosion Protection System - Two Pass Tunnel Lining

Concrete Segmental Tunnel (Primary Lining)

Inner Secondary Lining

HDPE Lining (2.5 or 4 mm thk.)

Provision of Waterproof Membrane, 1 – 4 mm thk.
Installation of HDPE Liner for Cast-insitu Structure
Corrosion Protection System for Manhole Shafts

- **Manholes**

  Normal concrete with HDPE Liner; 150 mm thick concrete cover to reinforcement is recommended.

Corrosion Protection System for Tunnels and Shaft

- **Hydraulic Structures and Shaft with Gate**

  MIC resistant concrete lining with sufficient (100 mm) cover to reinforcement is recommended.
MIC Resistant Concrete Specification (Highlight)

- Resistance to designated microbiological/chemical exposures in the sewage or in the atmosphere above the sewage flow with pH value of less than 3.5 in order to achieve the design life of 100 years.
- A combination of approved methods of achieving the required resistance to corrosion shall be by one or more of the following:
  - The addition of a hydrophobic pore-blocker with a minimum active ingredient of 1.2% by weight of binder;
  - Replacing 80% or more of Ordinary Portland Cement (OPC) with Ground Granulated Blast furnace Slag (GGBS);
  - Replacing 15% or more of OPC with Silica Fume;
- Once the Contractor’s proposed MIC resistant concrete mix has been accepted by the S.O., the Contractor shall carry out tests in a Hamburg Simulation Chamber or similar approved to justify extent of sacrificial cover required. The proposed simulation chamber shall have the ability to:
  a) replicate the conditions likely to be experienced in the sewer tunnels;
  b) accelerate the corrosion process.
- The test in the Simulation Chamber shall be undertaken for a minimum period of one year. The acceleration factor to be applied to the test results shall be agreed and shall not be greater than 24. Taking the rate of corrosion observed during the test and the acceleration factor, the thickness of the sacrificial cover shall be determined to satisfy the design life of 100 years.
Singapore Geology

Typical Geological Profile along Tunnel Alignment

Tunnel is expected to go through rock
Typical Geological Profile along Tunnel Alignment

Tunnel is expected to go through soil

Typical Geological Profile along Tunnel Alignment

Tunnel is encounter mixed ground conditions
TBM Selection

**TUNNEL CONTRACT PACKAGES**
Proposed Tunnel Contract Packages

<table>
<thead>
<tr>
<th>Contract</th>
<th>Tunnel Length</th>
<th>Tunnel Internal Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>10km</td>
<td>6.0m</td>
</tr>
<tr>
<td>C2</td>
<td>12km</td>
<td>3.3 - 4.0m</td>
</tr>
<tr>
<td>C3</td>
<td>8km</td>
<td>6.0m</td>
</tr>
<tr>
<td>C4</td>
<td>8km</td>
<td>3.5 - 6.0m</td>
</tr>
<tr>
<td>C5</td>
<td>12km</td>
<td>3.0 - 3.3m</td>
</tr>
<tr>
<td>Total</td>
<td>50km</td>
<td></td>
</tr>
</tbody>
</table>

Total of 21 TBM will be deployed

Proposed Link Sewer (pipejacking) Contract Packaging

- Area 1: 12 No of PS, 9km Length
- Area 2: 9 No of PS, 11km Length
- Area 3: 5 No of PS, 13km Length
- Area 4: 5 No of PS, 9km Length
- Area 5: 3 No of PS, 6km Length

*Existing Pumping Installations*
THANK YOU