1) Project Outline

- Four times for tunnel break in and out
- Total 6.2Km (1.7+1.4+1.7+1.4Km) of tunnel was laid by TBM
- Four times for tunnel break in and out

2) Tunnel Building with the TBM

- TBM
- Backup Gentries
- Ground Surface
- Underground Surface
- Ring (Tunnel Concrete Lining)
2) Tunnel Building with the TBM

As the TBM thrusted forward, more tunnel concrete lining was put at the back of the machine.

There are 7 segments put together to form a complete RING

The lining of the tunnel was formed by a continuation built up of the rings.

The Final Product
To provide the dynamic geospatial information of the TBM in guiding the machine to travel in the predefined alignment
LEADING THE TUNNEL TO BE CONSTRUCTED IN THE CORRECT POSITION.

1) Survey Works prior to construction
   • Acceptance Criteria for field measurement
     1. The spread of a repeated angle measurement should be less than 3".
     2. The spread of a repeated distance measurement should be less than 2mm+2pm (7mm for the 2.5km as an example).
   • The coordinates of the stations were finalized and would be made use of for construction.

3a) Survey Methodology - Pre-construction Stage
   7.5KM
   • Transfer of control station at surface

3b) Survey Methodology - Construction Stage
   At the tunnel level of the TBM Launching Shaft
3b) Survey Methodology - Construction Stage

- The control station was moved ahead by traverse to reach the last gentry.

The traverse continued above the gentry to reach the Laser Station located behind the TBM.

Horizontal Control by Double Zigzag Traverse

RESECTION Station

Horizontal Control Station and Benchmark

The same horizontal control station and benchmark were used throughout the project.
- At first, the horizontal control station in form of a bracket was installed at the lower part of tunnel.
- The station was then plumbed up to the roof of tunnel.
- The benchmark was set above the walkway.
- The bracket was removed to make way for the construction work.
- The station was transferred onto the walkway from the roof station and it would last beyond the end of the project.

Horizontal Control by Double Zigzag Traverse leg consisted of two control stations at each end.
Redundant survey measurements to eliminate the gross error. Each traverse leg by itself became a quadrilateral.
More availability of line of sight from one station to the other for a quick set up of station fixing by method of RESECTION.

ADVANTAGES

Benchmarks were established at every 100th Ring and they were 180m apart.

- Determination of the POSITION OF THE TBM

The Laser Station shoots the prism target affixed to the bulkhead of TBM.

The TBM Position at this point was determined.

- More availability of line of sight from one station to the other for a quick set up of station fixing by method of RESECTION.
3b) Survey Methodology – Tunnel Guidance System

- **Determination of the ORIENTATION OF THE TBM**

1. **XY Plane**
   - The Laser Station shines onto the Video Target to measure the twist of the TBM.

2. **XZ Plane**
   - The built-in Inclinometer 1 measures the roll of the TBM.

3. **YZ Plane**
   - The built-in Inclinometer 2 measures the tilt of the TBM.

**Summary**

1. The Laser Station determined the 3D position of the TBM.
2. The Video Target determined the twist in XY plane.
3. The Inclinometer 1 determined the roll in XZ plane.
4. The Inclinometer 2 determined the tilt in YZ plane.
3b) Survey Methodology – Tunnel Guidance System

- The system was linked to the control cabin.
- The positional deviation of the TBM with the Design Tunnel Axis was displayed on the screen.
- The pilot made use of the information to steer the TBM.
3b) Survey Methodology – Tunnel Guidance System

The Articulation Jacks allow the TBM to twist and turn flexibly and advance forward in the direction of the design tunnel axis.

Engineering Survey System in TBM Tunnel Construction
The Articulation Jacks allow the TBM to twist and turn flexibly and advance forward in the direction of the design tunnel axis.

3b) Survey Methodology – Tunnel Guidance System

Articulation Jack
Elongation

3b) Survey Methodology – Tunnel Guidance System

Articulation Jack
Thrusting Jacks

3c) Survey Methodology – Post-construction Stage

An 8 points Wriggle Survey is carried out on the as built profile of the tunnel lining
1) For construction tolerance check
2) For dimension tolerance check of the diameter

Clearance between tunnel lining and Structure Gauge Envelope

3c) Survey Methodology – Post-construction Stage

Structure Gauge Envelope

4) Conclusion

<table>
<thead>
<tr>
<th>Breakthrough Date</th>
<th>Location</th>
<th>Change</th>
<th>Alignment</th>
<th>Accuracy</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>27-Feb-04</td>
<td>Down Track (1.7Km) Shung Shui to Kwu Tung</td>
<td>shortage</td>
<td>1 mm in shortage north</td>
<td>1 in 100,000</td>
<td>high</td>
</tr>
<tr>
<td>21-Jan-04</td>
<td>Down Track (1.4Km) Kwu Tung to Chau Tau</td>
<td>excess</td>
<td>7 mm in excess south</td>
<td>1 in 31,000</td>
<td>high</td>
</tr>
<tr>
<td>23-Dec-04</td>
<td>Up Track (1.8Km) Shung Shui to Kwu Tung</td>
<td>shortage</td>
<td>2 mm in shortage north</td>
<td>1 in 44,000</td>
<td>moderate</td>
</tr>
<tr>
<td>08-Apr-05</td>
<td>Up Track (1.4Km) Kwu Tung to Chau Tau</td>
<td>shortage</td>
<td>1 mm in shortage north</td>
<td>1 in 104,000</td>
<td>moderate</td>
</tr>
</tbody>
</table>

* The Survey Misclosure after the tunnel breakthrough for four TBM tunnel was satisfactory
4) Conclusion

<table>
<thead>
<tr>
<th>Location</th>
<th>Length of Tunnel Constructed (Outside Allowable Construction Tolerance (+/-75mm))</th>
<th>Factor A</th>
<th>Factor B</th>
<th>Factor C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Down Track (1.7Km) to Kwu Tung in Cheung Sha Wan Tunnel</td>
<td>1681m (97.5%)</td>
<td>16m</td>
<td>16m</td>
<td>11m</td>
</tr>
<tr>
<td>Down Track (1.4Km) to Kwu Tung in Cheung Sha Wan Tunnel</td>
<td>1472m (99.7%)</td>
<td>~</td>
<td>~</td>
<td>4m</td>
</tr>
<tr>
<td>Up Track (1.7Km) to Kwu Tung in Cheung Sha Wan Tunnel</td>
<td>1617m (93.8%)</td>
<td>57m</td>
<td>~</td>
<td>50m</td>
</tr>
<tr>
<td>Up Track (1.4Km) to Kwu Tung in Cheung Sha Wan Tunnel</td>
<td>1470m (99.9%)</td>
<td>~</td>
<td>~</td>
<td>2m</td>
</tr>
</tbody>
</table>

They did not infringe the Structure Gauge Envelope and had been given relaxation.

We considered that the entire tunnel was built in the right place and achieving the prime objective for the engineering survey in tunnelling.