




# Engineering Survey System in TBM Tunnel Construction

Presented at FIG2007


*Engineering Survey System in TBM Tunnel Construction*



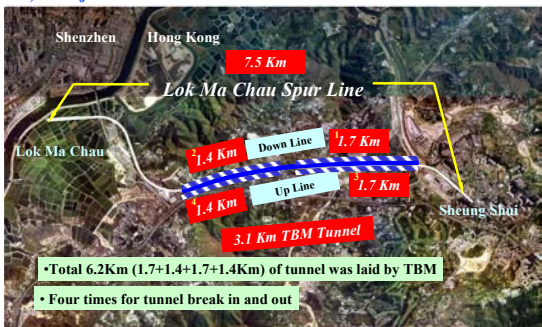
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- 3) Survey Methodology
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  - b: Construction Stage
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    - ~ Tunnel Guidance System
  - c: Post-construction Stage
- 4) Conclusion

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### 1) Project Outline



Shenzhen      Hong Kong

7.5 Km

Lok Ma Chau Spur Line

Lok Ma Chau      Sheung Shui


1.4 Km Down Line    1.7 Km

1.4 Km Up Line        1.7 Km


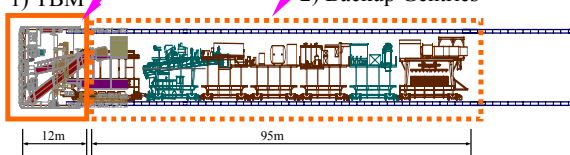
3.1 Km TBM Tunnel

- 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

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### 2) Tunnel Building with the TBM

1) TBM      2) Backup Gentries

12m      95m

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### 2) Tunnel Building with the TBM



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### 2) Tunnel Building with the TBM



Ground Surface  
Underground Surface

TBM      Ring (Tunnel Concrete Lining)

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## 2) Tunnel Building with the TBM

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

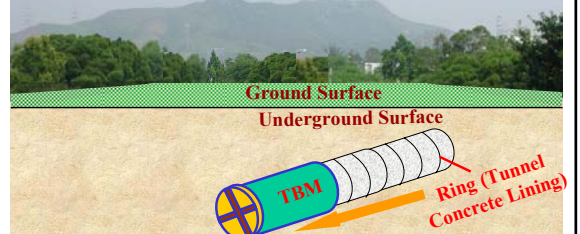


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## 2) Tunnel Building with the TBM

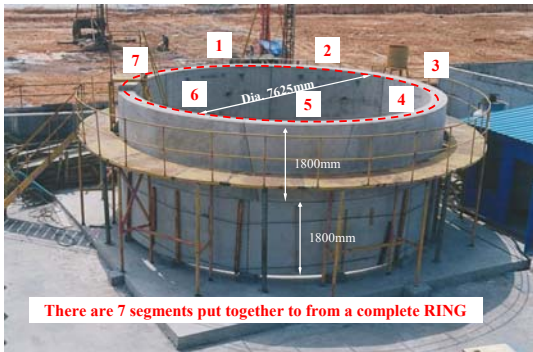
As the TBM thrust forward, more tunnel concrete lining was put at the back of the machine.



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## 2) Tunnel Building with the TBM



There are 7 segments put together to form a complete RING

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## 2) Tunnel Building with the TBM

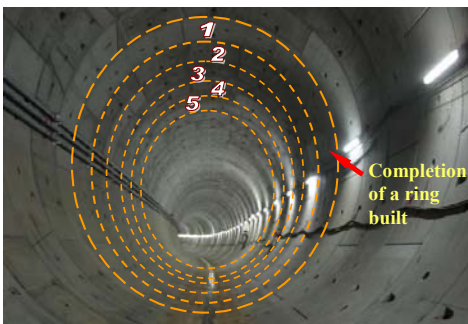
The storage of precast segment at the casting yard



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## 2) Tunnel Building with the TBM



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

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## 2) Tunnel Building with the TBM



The Final Product

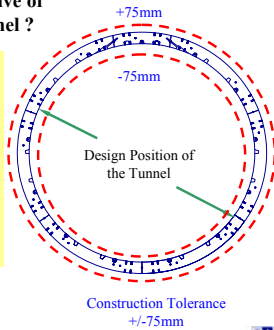
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### 2) Tunnel Building with the TBM

What is the Prime Objective of Surveying of a TBM Tunnel ?

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.



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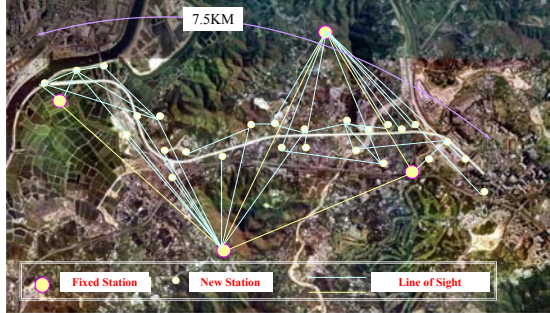
### 3a) Survey Methodology - Pre-construction Stage



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### 3a) Survey Methodology - Pre-construction Stage



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### 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+2ppm (7mm for the 2.5km as an example).

• The coordinates of the stations were finalized and would be made use of for construction.

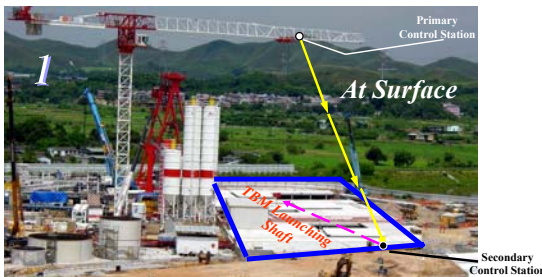


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### 3b) Survey Methodology - Construction Stage

• Transfer of control station at surface

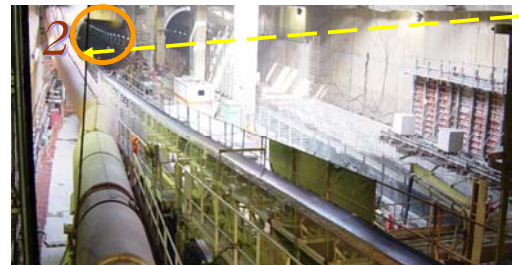


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### 3b) Survey Methodology - Construction Stage

At the tunnel level of the TBM Launching Shaft

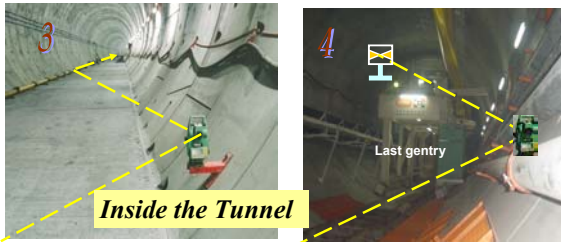


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### 3b) Survey Methodology - Construction Stage

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

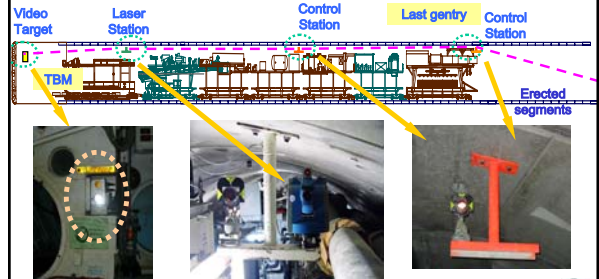


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### 3b) Survey Methodology - Construction Stage

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

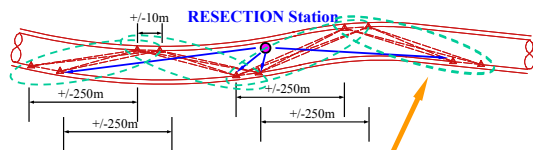


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### 3b) Survey Methodology - Construction Stage

#### Horizontal Control by Double Zigzag Traverse



**ADVANTAGES** 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 to form a rigid network.

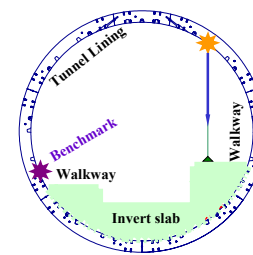
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### 3b) Survey Methodology - Construction Stage

#### Horizontal Control Station and Benchmark

The same horizontal control station and benchmark were used throughout the project.



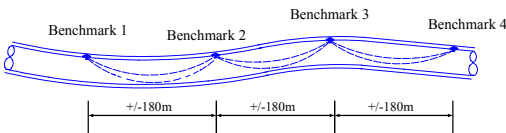
- At first, the horizontal control station in form of a bracket was installed at the lower part of tunnel.
- The station was then plumbed up to the roof of tunnel.
- The benchmark was set above the walkway.
- The bracket was removed to make way for the construction work.
- The station was transferred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

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### 3b) Survey Methodology - Construction Stage

#### Vertical Control by Precise Leveling



Benchmarks were established at every 100<sup>th</sup> Ring and they were 180m apart.

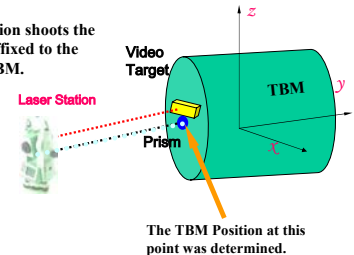
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### 3b) Survey Methodology – Tunnel Guidance System

- 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.

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### 3b) Survey Methodology – Tunnel Guidance System

#### • Determination of the ORIENTATION OF THE TBM

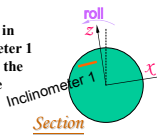
##### 1. XY Plane

The Laser Station shines onto the Video Target to measure the **twist** of the TBM.



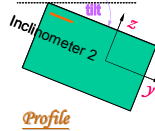
##### 2. XZ Plane

The built in Inclinator 1 measures the **roll** of the TBM.



##### 3. YZ Plane

The built in Inclinator 2 measures the **tilt** of the TBM.



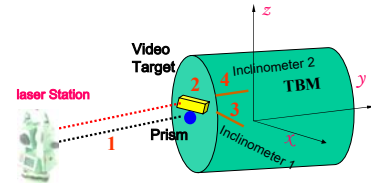
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### 3b) Survey Methodology – Tunnel Guidance System

#### • Summary

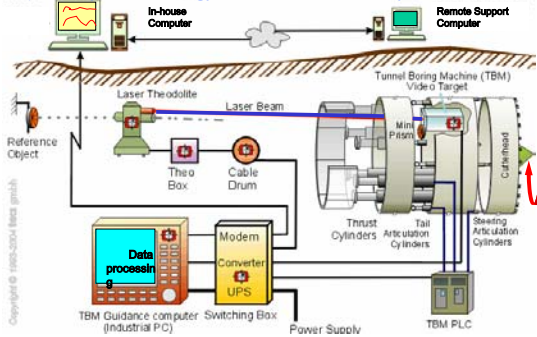
1. The Laser Station determined the **3D position** of the TBM
2. The Video Target determined the **twist** in XY plane.
3. The Inclinator 1 determined the **roll** in XZ plane.
4. The Inclinator 2 determined the **tilt** in YZ plane.



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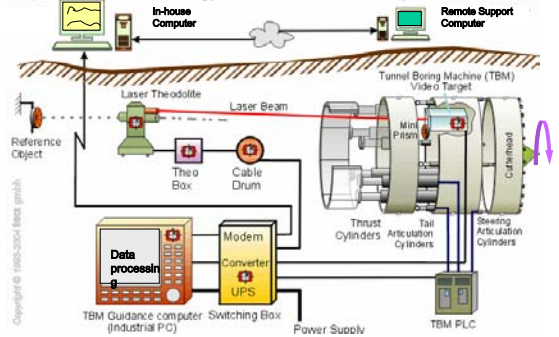
### 3b) Survey Methodology – Tunnel Guidance System



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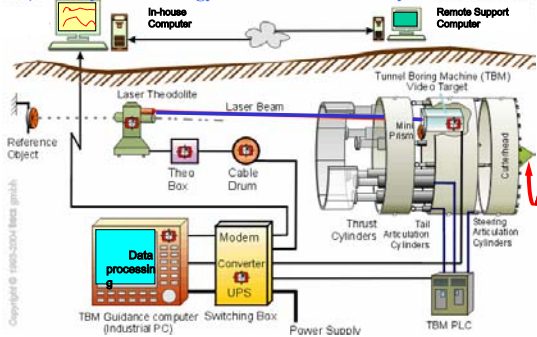
### 3b) Survey Methodology – Tunnel Guidance System



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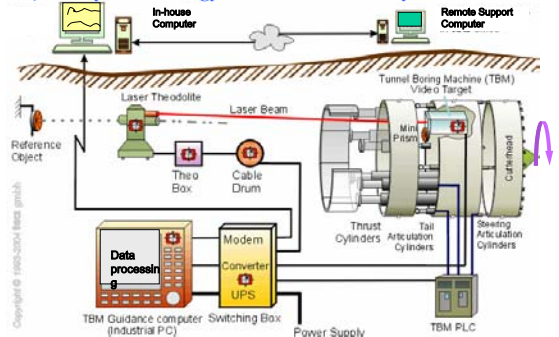
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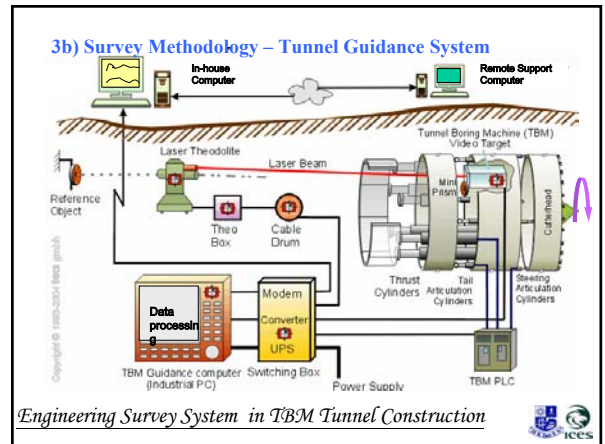
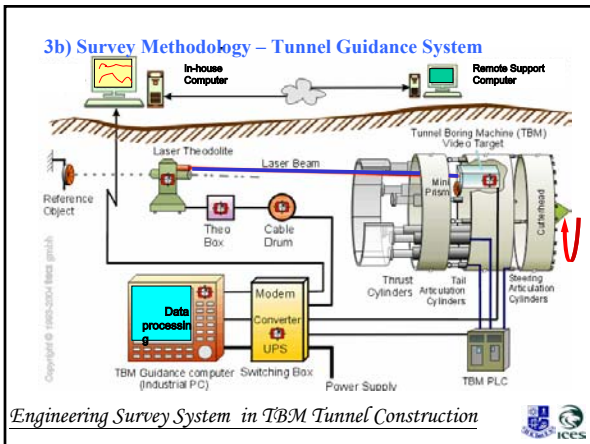
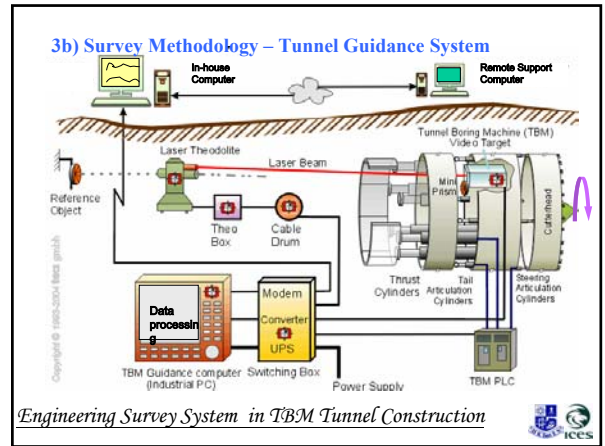
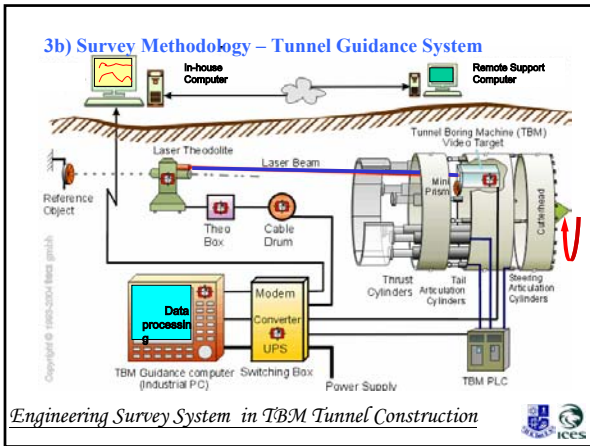


### 3b) Survey Methodology – Tunnel Guidance System



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### 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.

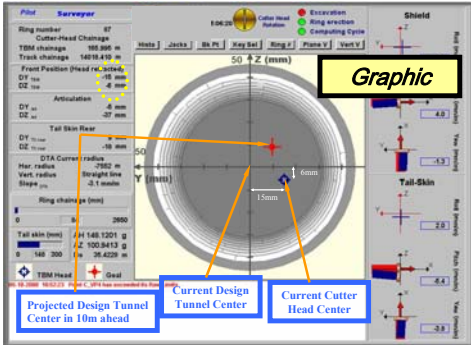
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### 3b) Survey Methodology – Tunnel Guidance System

Ring number	67
Cutter-Head Chainage	
TBM chainage	165.995 m
Track chainage	14018.410 m
Front Position (Head retracted)	
DY TBM	-16 mm
DZ TBM	-6 mm
Articulation	
DY A1	-5 mm
DZ A1	-37 mm
Tail Skin Rear	
DY T5 rear	9 mm
DZ T5 rear	-18 mm
DTA Current radius	
Hor. radius	-7662 m
Vert. radius	Straight line
Slope DTA	-3.1 mm/m

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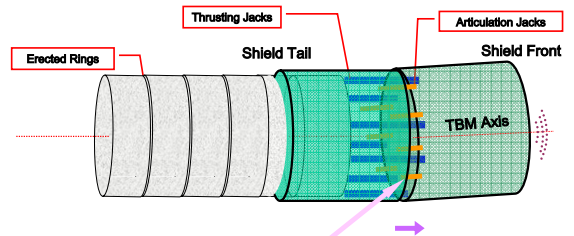
### 3b) Survey Methodology – Tunnel Guidance System



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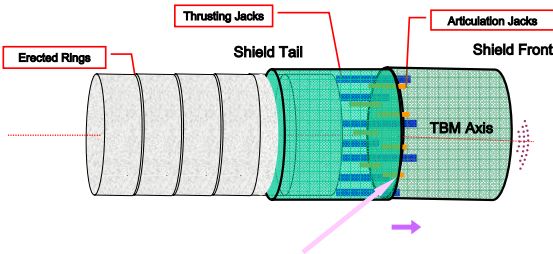


The Articulation Jacks allow the TBM to twist and turn flexibly and advance forward in the direction of the design tunnel axis.

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### 3b) Survey Methodology – Tunnel Guidance System

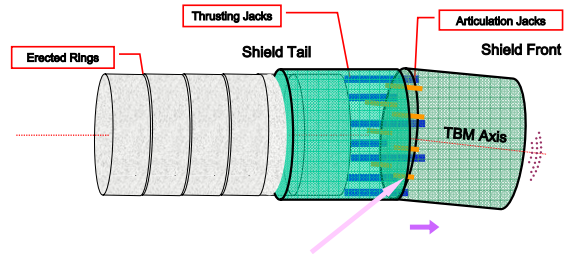


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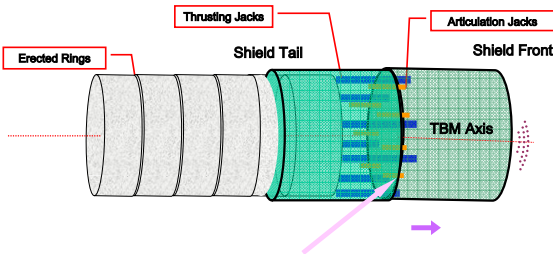


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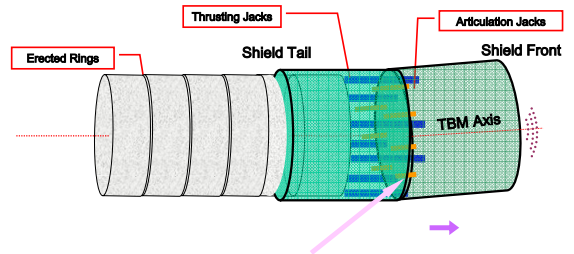


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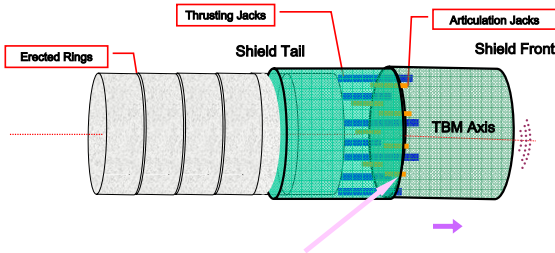


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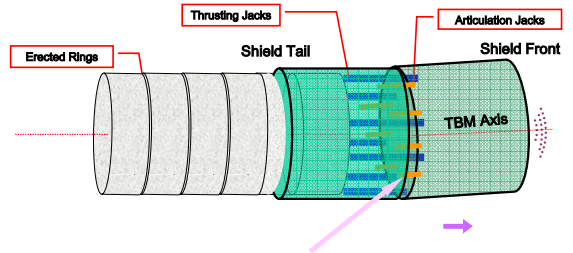


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### 3b) Survey Methodology – Tunnel Guidance System

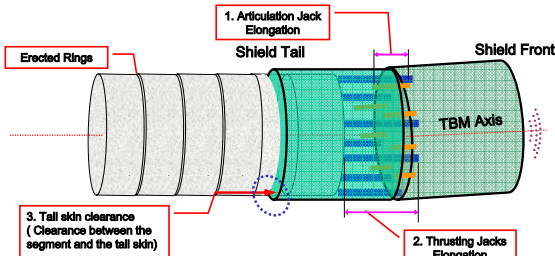


The Articulation Jacks allow the TBM to twist and turn flexibly and advance forward in the direction of the design tunnel axis.

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### 3b) Survey Methodology – Tunnel Guidance System



The elongation of all jacks and the shield tail clearance are measured by sensors and sent to the computer to derive the position of ring just erected.

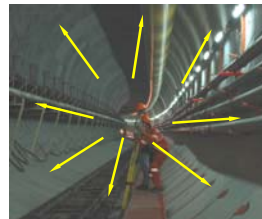
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### 3c) Survey Methodology – Post- construction Stage

An 8 points **Wriggle Survey** is carried out on the as built profile of the tunnel lining

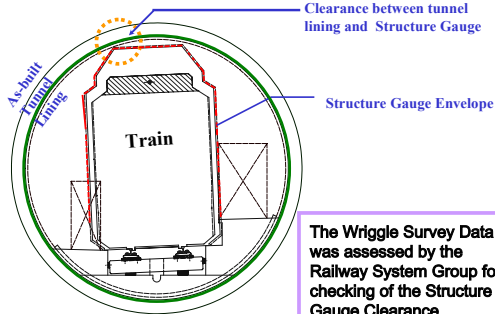
- 1) For construction tolerance check
- 2) For dimension tolerance check of the diameter



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### 3c) Survey Methodology – Post- construction Stage



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### 4) Conclusion

Breakthrough Date	Location	Survey Misclosure After Tunnel Breakthrough			
		Chainage	Alignment	Accuracy	Level
27-Feb-04	Down Track (1.7Km) Shung Shui to Kwu Tung	15mm in shortage	7mm in shortage north	1 in 103,000	10mm too high
21-Jun-04	Down Track (1.4Km) Kwu Tung to Chau Tau	5mm in excess	27mm in excess north	1 in 51,000	3mm too low
23-Dec-04	Up Track (1.7Km) Shung Shui to Kwu Tung	25mm in shortage	30mm in shortage north	1 in 44,000	5mm too low
08-Apr-05	Up Track (1.4Km) Kwu Tung to Chau Tau	9mm in shortage	10mm in shortage north	1 in 104,000	6mm too low

\* The Survey Misclosure after the tunnel breakthrough for four TBM tunnel was satisfactory

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**4) Conclusion**

**Ring Built Out of Tolerance (+/-75mm)**

Location	Length of tunnel constructed within the Allowable Construction Tolerance (+/-75mm)		Factor C
	To	From	
Down Track (1.7Km Shung Shui to Kwu Tung)	161	161	11m
Down Track (1.4Km Kwu Tung to Chai Kwoi)	161	161	4m

**MISSION ACCOMPLISHED**

to keep the TBM on course  
 ensure tunnel was built in the right place and  
 achieving the prime objective for the engineering survey in tunneling.

Factor B : Malfunction of the inclinometer.

Factor C : Poor workmanship in ring building.

