

Overcoming Challenges in the Bored Tunnel Construction under Beiheng Expressway Package II



By Dr. Xiao Xiaochun



The Hong Kong Institution of Engineers

Date : 21-08-2019



1. Project Overview

2. TBM Specifications

3. Overcoming Challenges

4. Conclusions



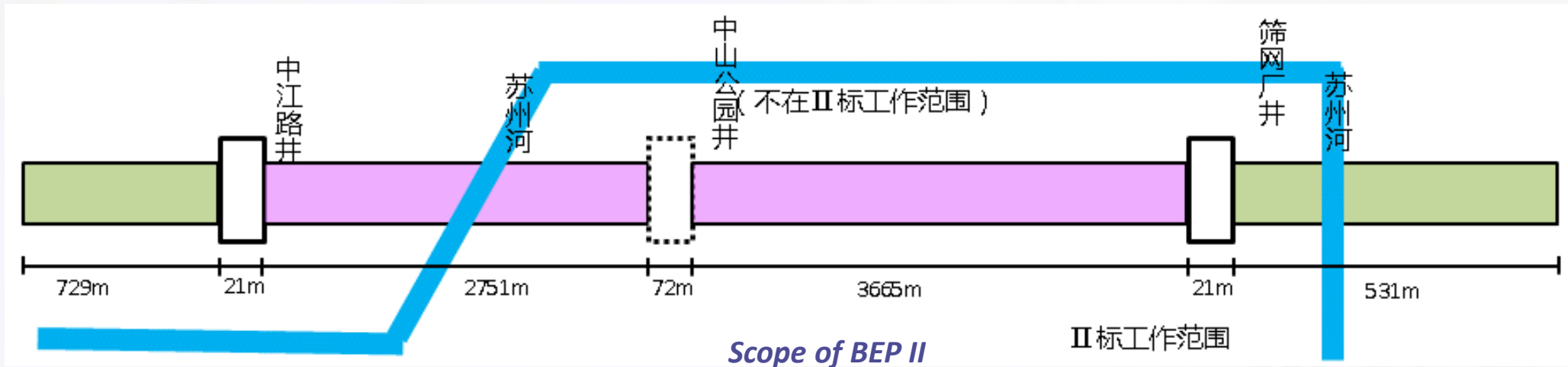
Overview of Shanghai Expressway System



BEP starts from the west of Middle Ring Beihong flyover and ends at Neijiang Road (East). It is 19.1km long and runs through the north area of Shanghai Urban Center.



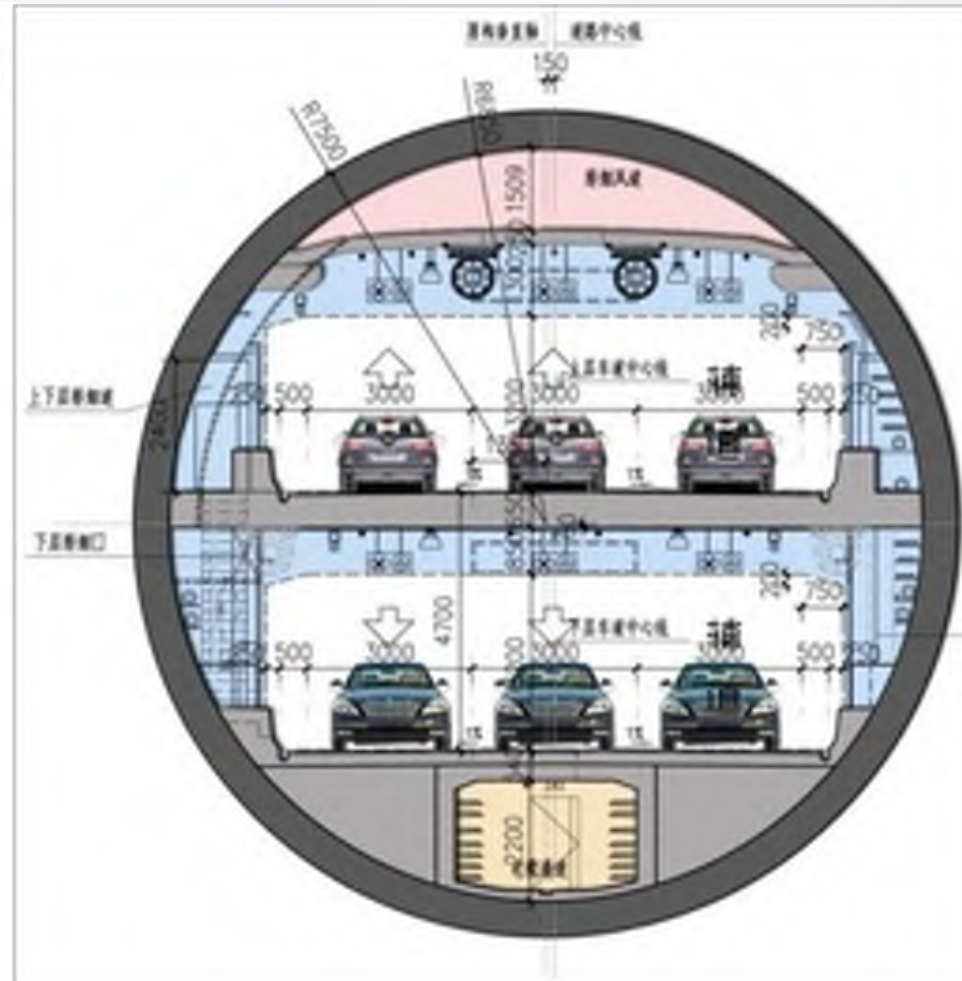
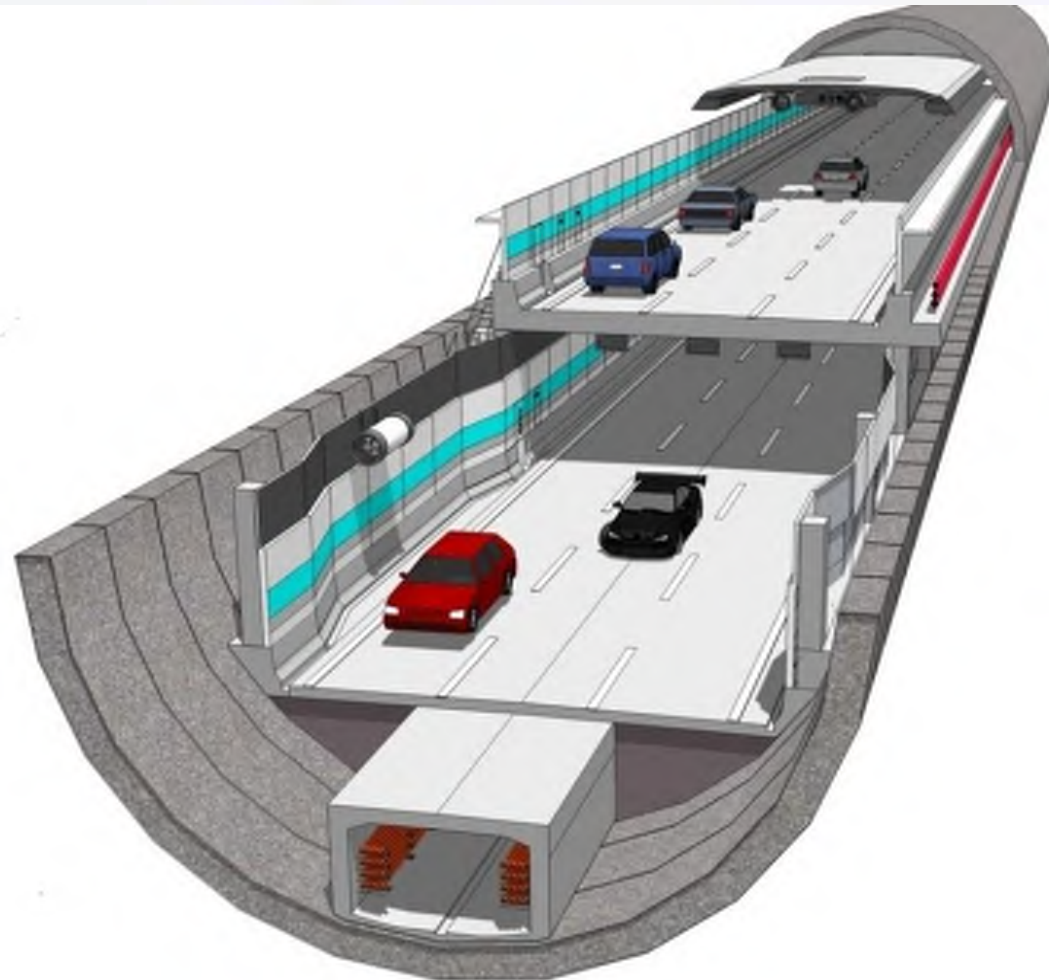
Revised Design of Eastern Section



Construction Section	Length (m)	Construction Method	Remarks
C&C in the west of Launching Shaft	729	C&C	
Launching Shaft	21	C&C	
TBM 1 st drive	2761	TBM	Main work
Intermediate shaft	72	C&C	By others
TBM 2 nd drive	3665	TBM	Main work
Receiving shaft	21	C&C	
C&C in the East of Receiving shaft	531	C&C	
Total	7788		

Segment Lining Design

OD: 15000mm	ID: 13700mm	Width: 2000mm	Grade: C60 with waterproofing Grade P12
Segment Configuration:		9 + 1 (7 standard p (B1 – B7), 2 adjoining (L1, L2), & 1 Key (F))	

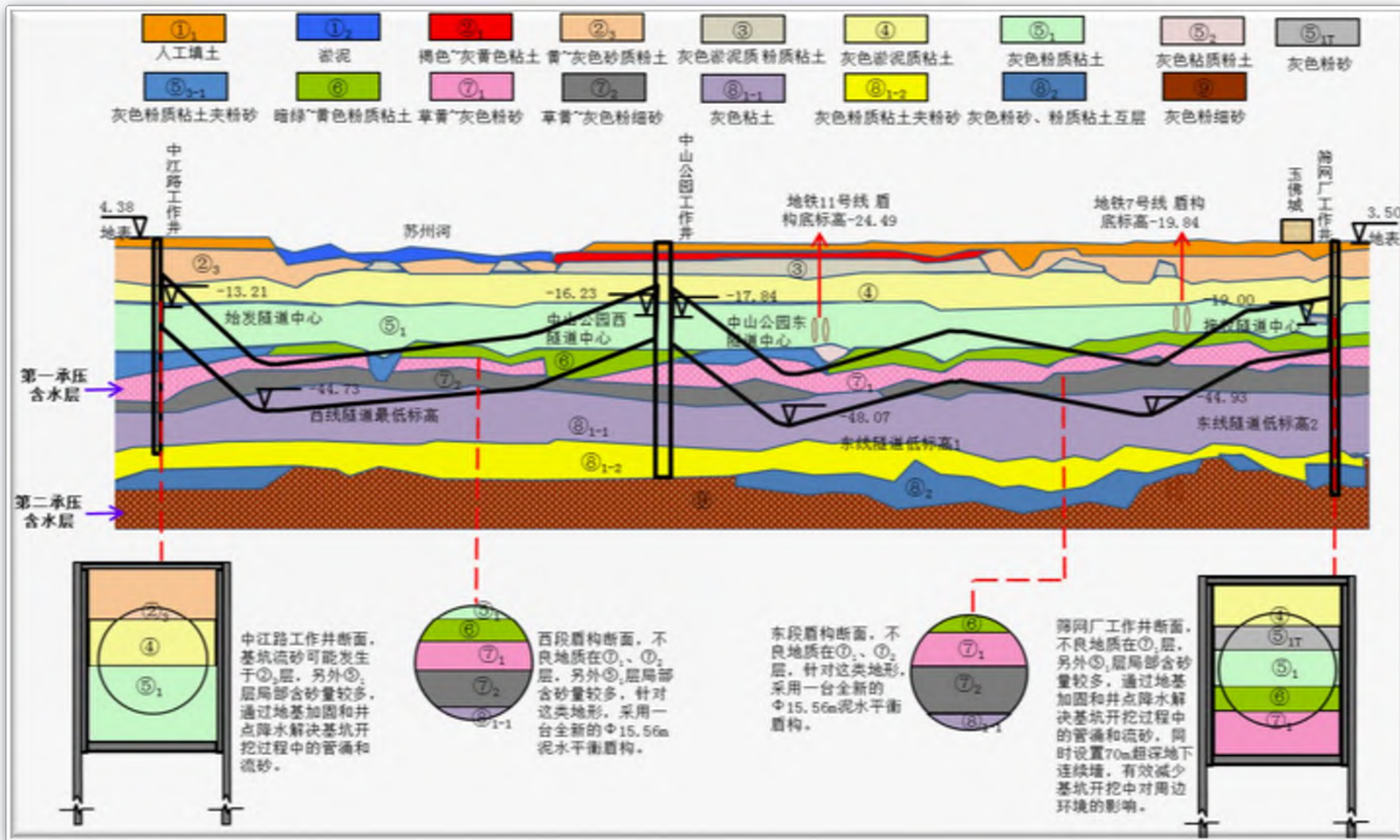


Road Element

4000 × 2500 × 2000
(L*W*H); C40

Ventilation Slab

8900 × 1200 × 250
(L*W*H); C40;
mixed with
polypropylene fiber.



In general speaking, Shanghai is homogeneous soft ground, but there are still adverse soil strata in the proposed alignment, such as ⑦₁, ⑦₂ silty sand soil layers .



Major Challenge 1:

Super-large diameter TBM tunnelling through continuous tight curves (TBM: Φ 15.56m, minimum horizontal curve radius of 500m)

Major Challenge 2:

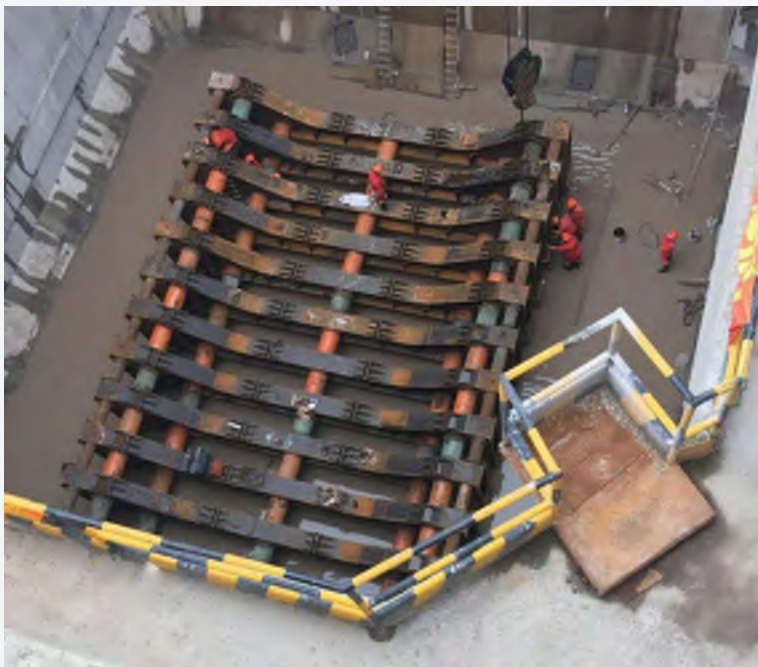
Tunnelling through sensitive structures in densely urban area (including buildings, flyovers, flood walls, utilities etc.)

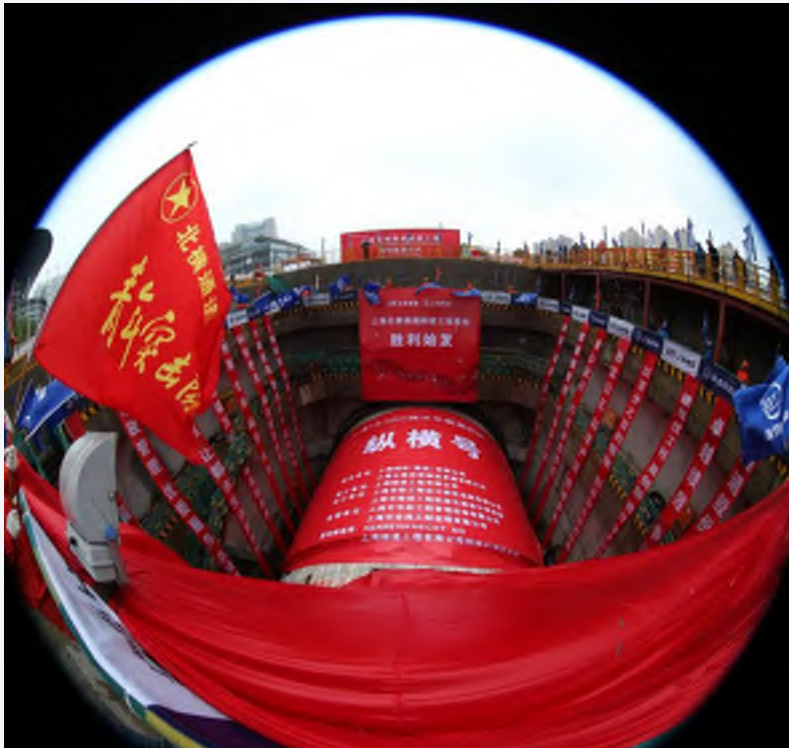
Major Challenge 3:

Crossing under 3 'Live' Metro Lines (Line 3(4), 11 & 7)



- **Project commencement** : **24th Dec 2014**
- **TBM started assembly** : **1st July 2016**
- **TBM Launched 1st drive** : **26th Dec 2016**
- **TBM Breakout (middle shaft)** : **28th Dec 2017**
- **TBM launched 2nd drive** : **10th June 2018**
- **Expected TBM Breakthrough** : **20th Sep 2019**





TBM Launch Ceremony



First Drive Completed

TBM was launched on 26th Dec 2016. Break-out into the middle shaft on end-2017, signaling the completion of the 1st drive.



TBM Received in Middle Shaft



TBM Transit in Middle Shaft



TBM Initial Drive in Middle Shaft



TBM Drive in Progress



1. Project Overview

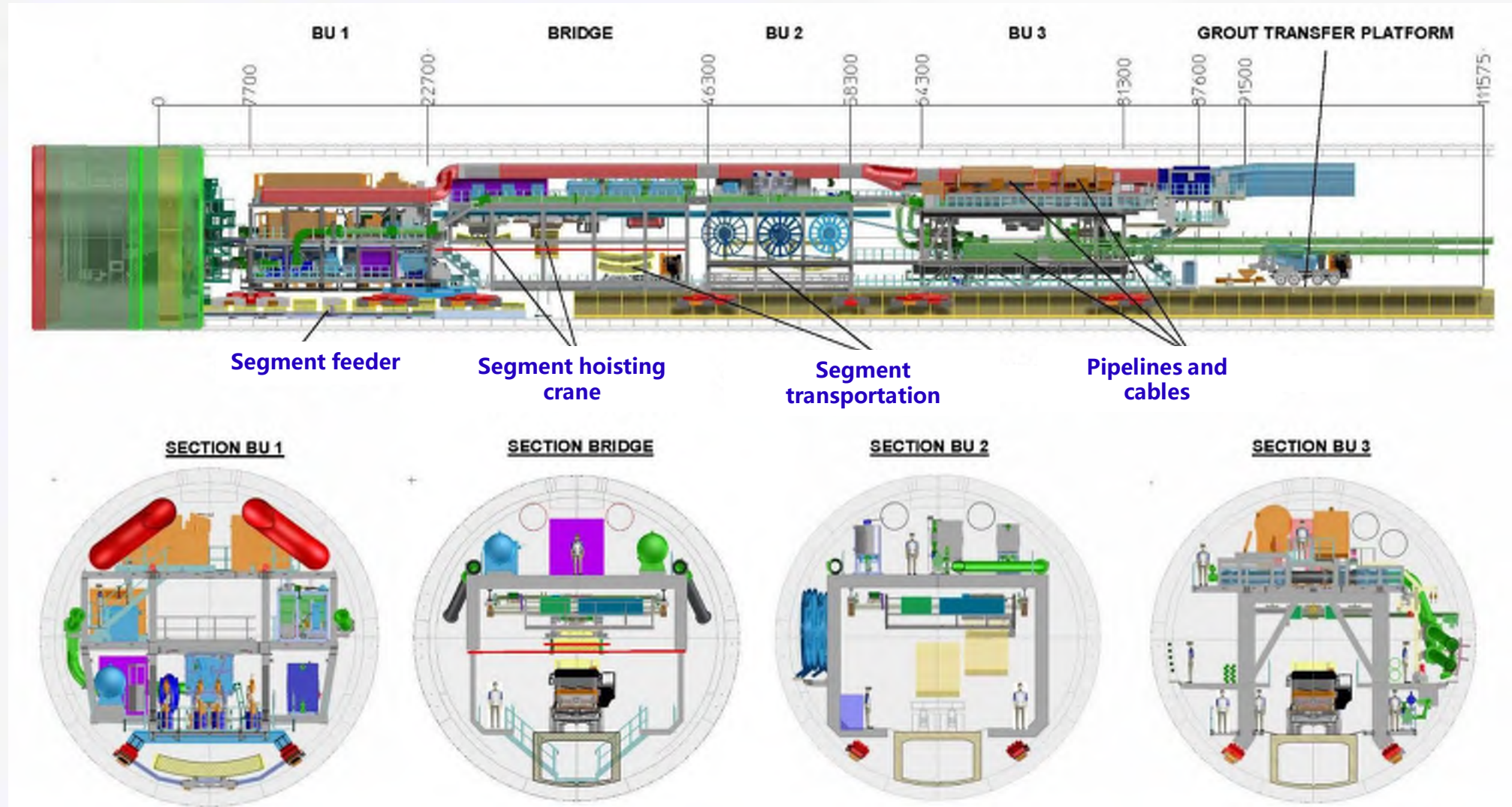
2. TBM Specifications

3. Overcoming Challenges

4. Conclusions



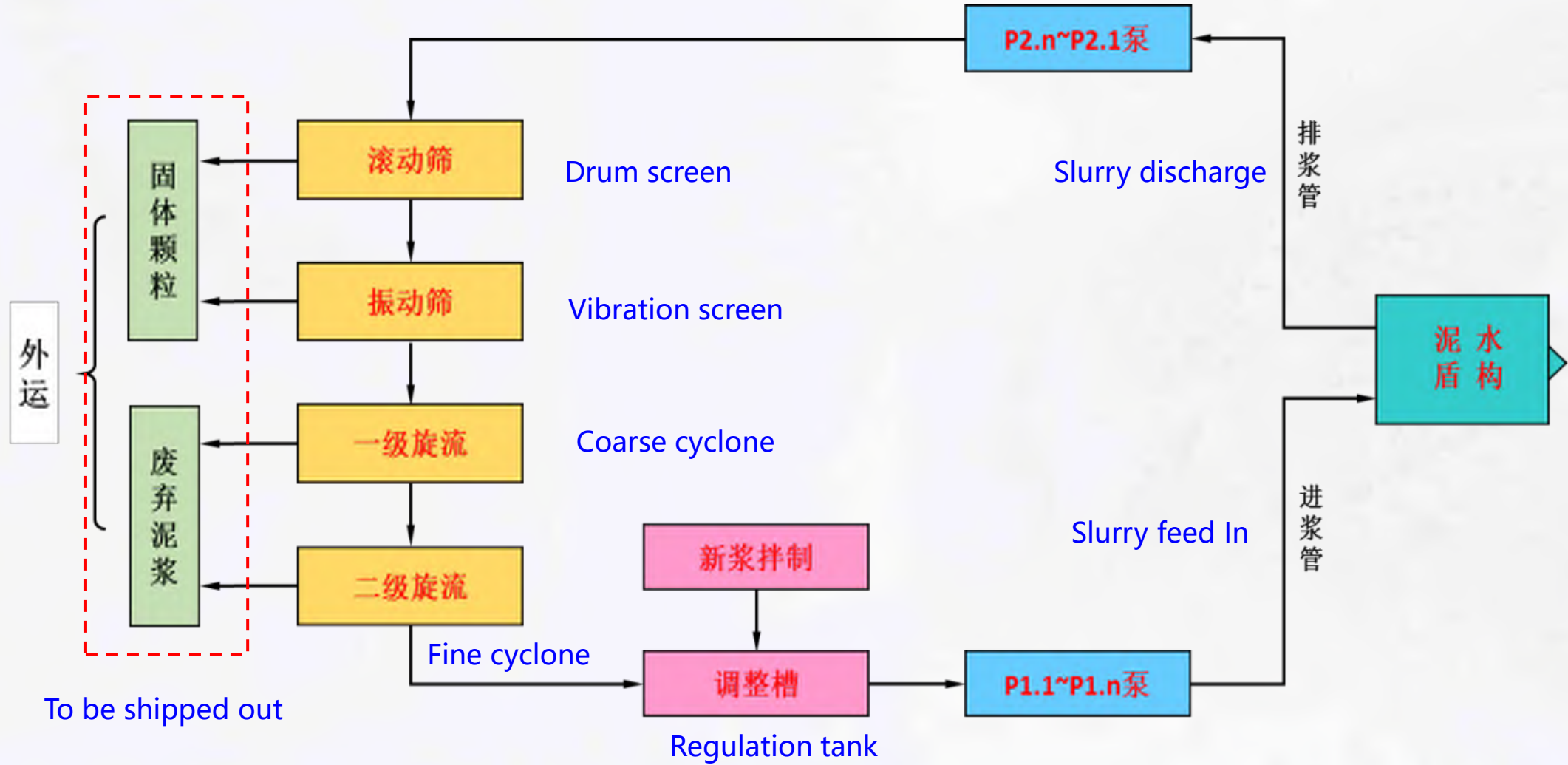
New 15.56m dia. Mixed Shield from Herrenknecht

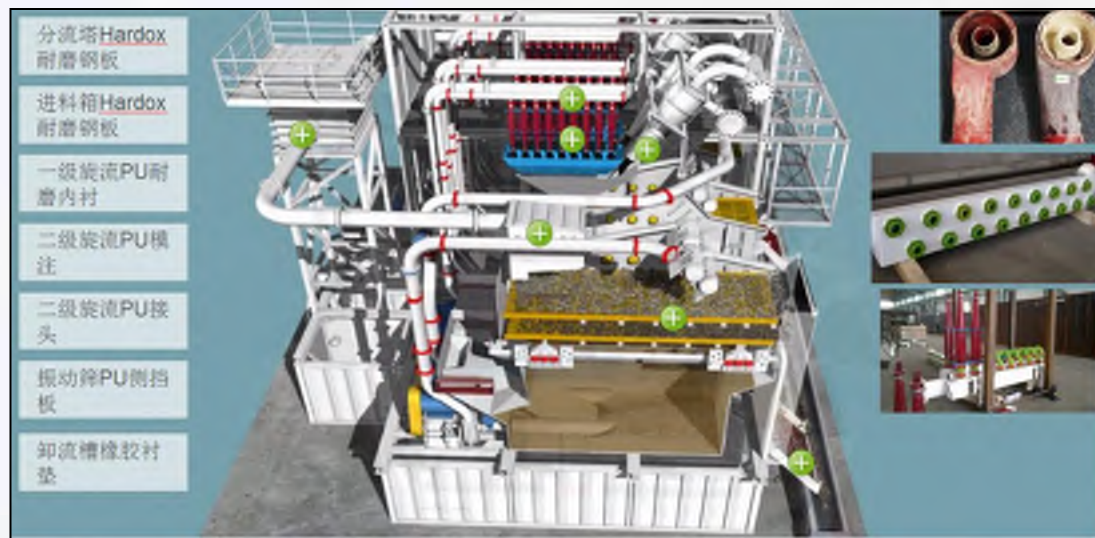
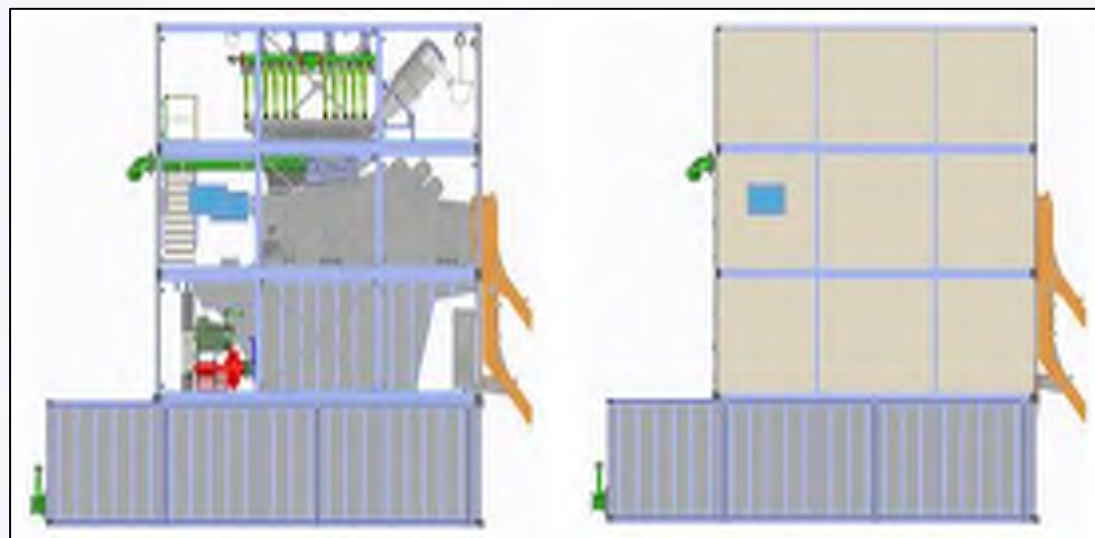


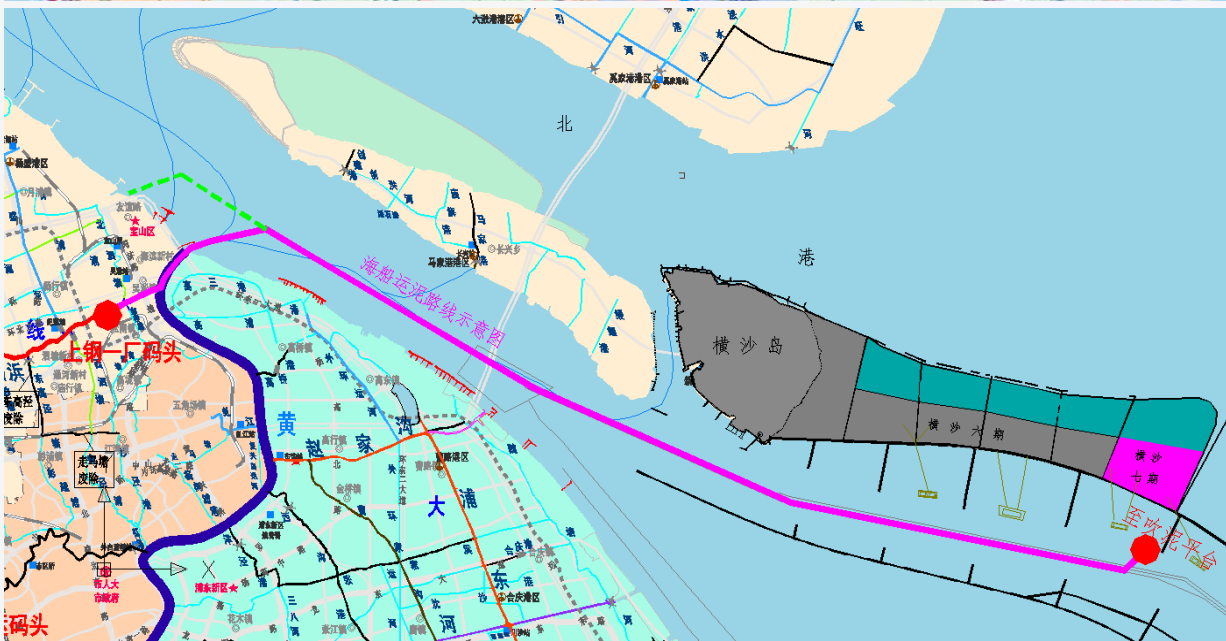


Item	Description
TBM Type	Slurry Pressure Balance TBM with air cushion chamber
Cutter Head Diameter	15560mm
TBM Shield Structure	Central Body + 10-piece blocks
Total Thrust Force	200,000 kN
Working Pressure	8 bar
Thrust Cylinders	19 groups (3 cylinders per group) (360 / 280 – stroke 3m)
Main Drive	DN7600, 13 nos. variable frequency electrical motors

Item	Description
Segment Erector	Middle support type, vacuum gripper
Backfill Grouting	8 x 2 points (DN65, 1 duty, one spare)
Tail Seal Grease	3 x 19, DN25
Tail Seal Brush	3 rows of steel wire brushes + 1 row spring plate
Man Lock	Ø2000mm, 6 persons + 2 persons
Material Lock	1 no.







River Boat Transit Route :

Slurry shipment pier \leftrightarrow Suzhou Canal \leftrightarrow Yunzao Canal (Yunxi Gate and Yundong Gate) \leftrightarrow **Transfer port**. Distance is around 60km.

Ship Transit Route :

Transfer port \leftrightarrow Yunzao river \leftrightarrow Huangpu River \leftrightarrow Wusong Security Guard \leftrightarrow South Port \leftrightarrow Yuansha Security Guard \leftrightarrow North Channel \leftrightarrow hydraulic fill reclamation Area。 Distance is around 73km.



1. Project Overview

2. TBM Specifications

3. Overcoming Challenges

4. Conclusions



- **Sharp Horizontal Turning Radius**
- **Tunnelling Within Close Proximity to Buildings**
- **Crossing Under Live Metro Lines**



TBM First Drive (Total: 2761m, Tight curve sections: 1016m)



Radius of curves (m)	500	550	600	700	1000	2000	Transition	Straight
Percentage (%)	12.4	18.0	6.4	4.7	9.5	12.7	15.9	20.4

36.8%



TBM Second Drive (Total: 3664m, Tight curve sections: 1872m)

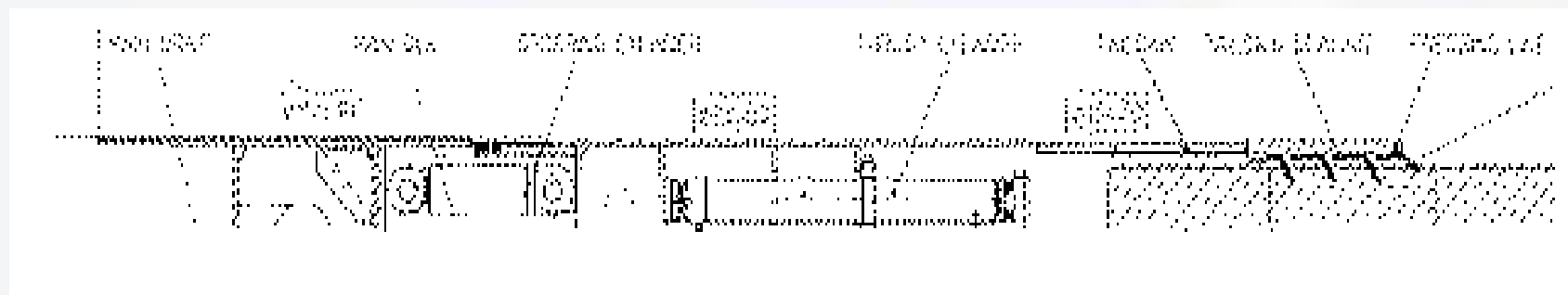
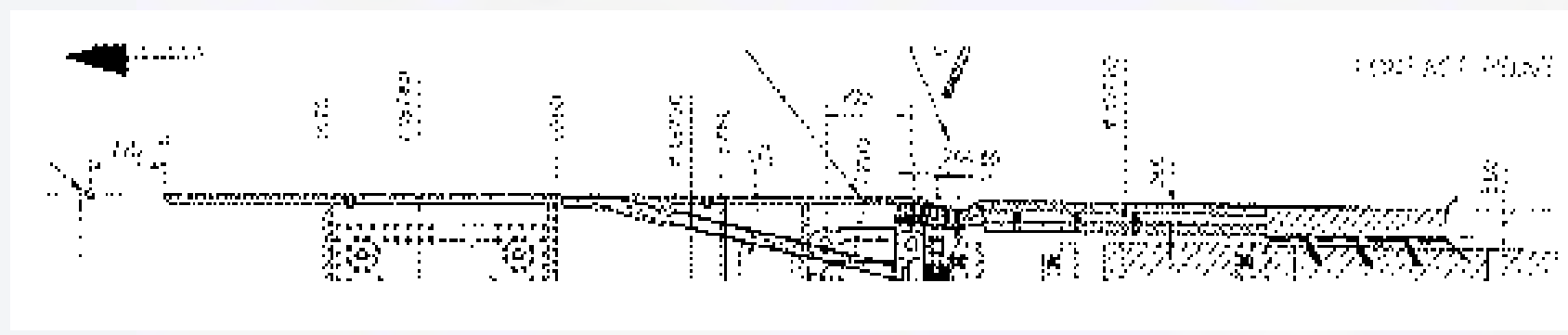
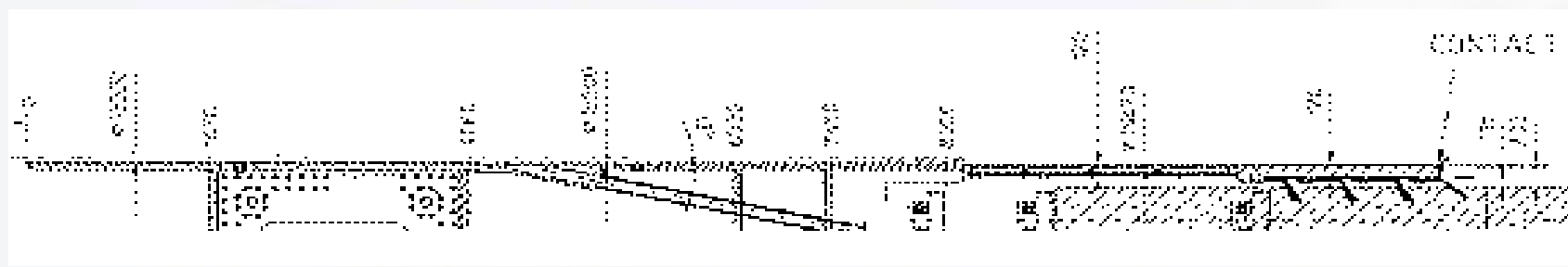


Radius of curves (m)	500	550	600	700	1000	2000	Transition	Straight
Percentage (%)	34.3	7.7	9.1	0.5	8.4	10.7	13.7	15.5

51.1%



Solutions – Special TBM Design (Shield Design)



In terms of shield design, to negotiate the tight curves, 3 options were proposed and studied.

1. passive articulated
2. active articulated and
3. fixed tail skin

Eventually the fixed tail skin was chosen for the TBM shield design.

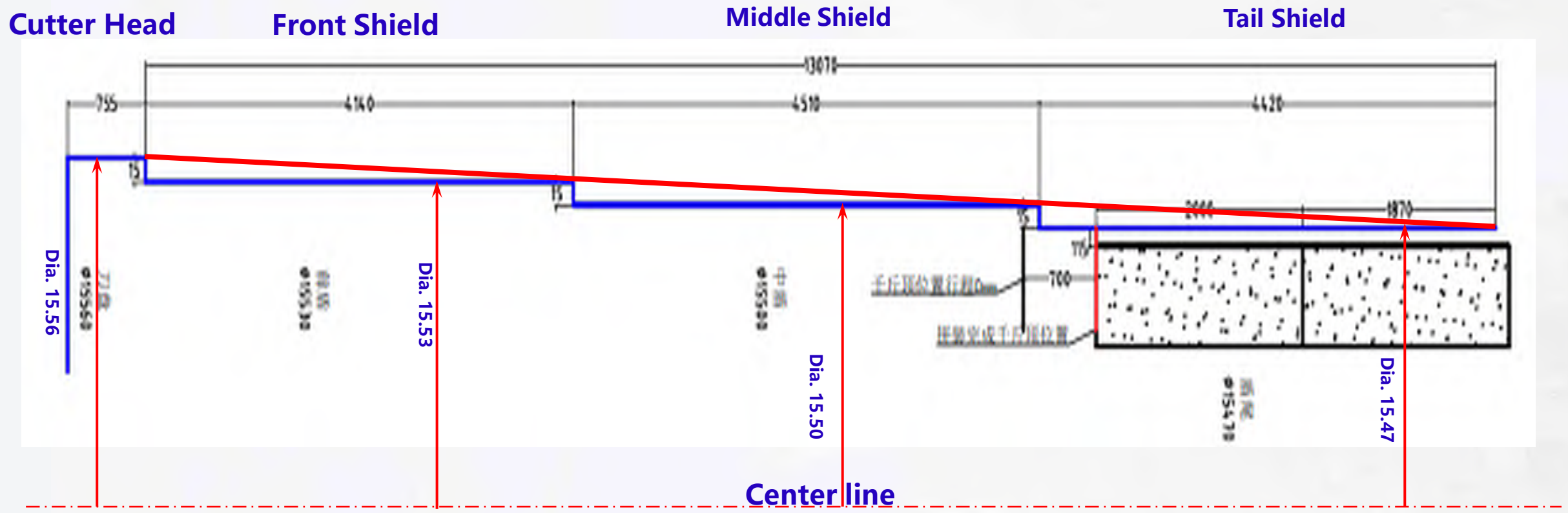


Solutions – Special TBM Design(Shield Design)

TBM No.	Name of Project	TBM Type	TBM Dia. (m)	Min. Curve Radius (m)
S-317/S-318	Shanghai Yangtze River Tunnel	Mix Shield	15.43	750
S-349/S-350	Nanjing Yangtze River Tunnel	Mix Shield	14.96	750
S-574	Galleria Sparvo (Italy)	EPB	15.55	500
S-666	Shanghai Hongmei South Road Tunnel	Mix Shield	14.9	700
S-764	Auckland Waterview Connection	EPB	14.41	500
S-880	Hongkong Tuen Mun-Chek Lap Kok Link Tunnel	Mix Shield	17.56	580
S-908/S-909	Wuhan Sanyang Road Tunnel	Mix Shield	15.73	600



Solutions – Special TBM Design (Tapered Shield)

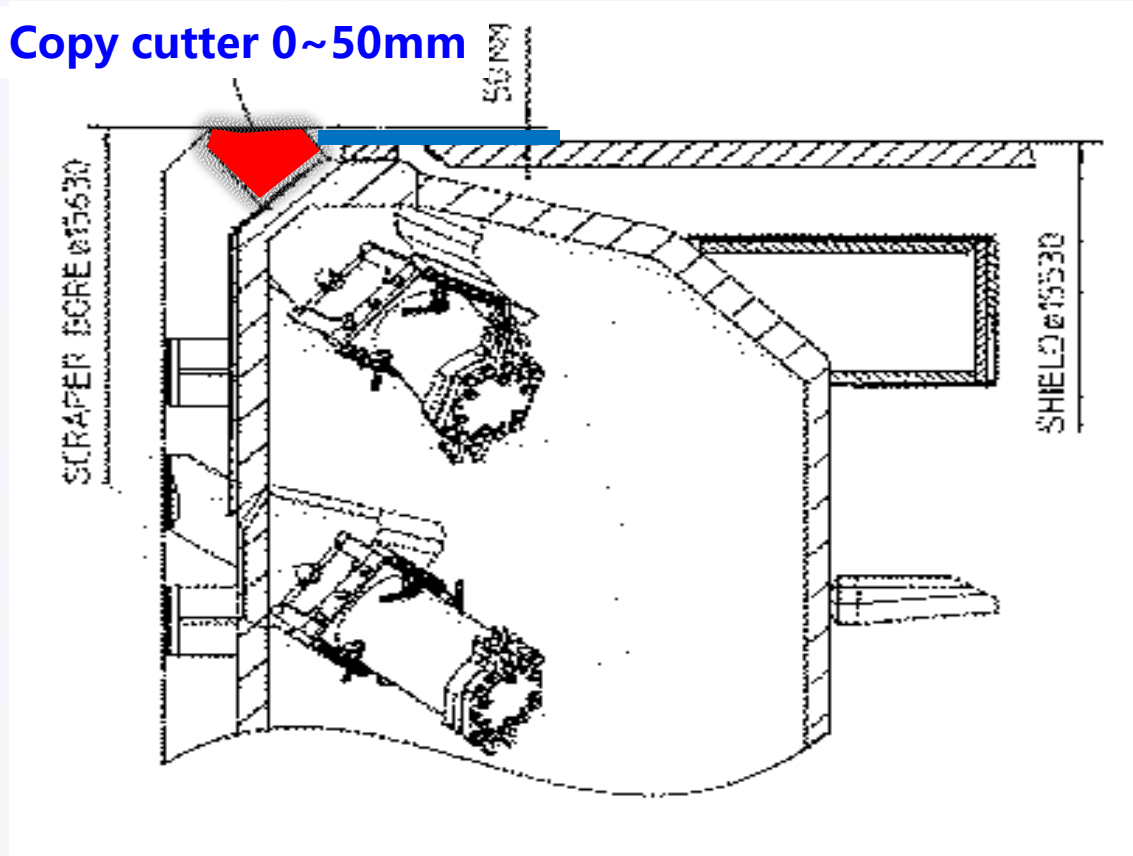


Tapered Shield Design



Solutions – Special TBM Design (Copy Cutters)

Copy cutter 0~50mm

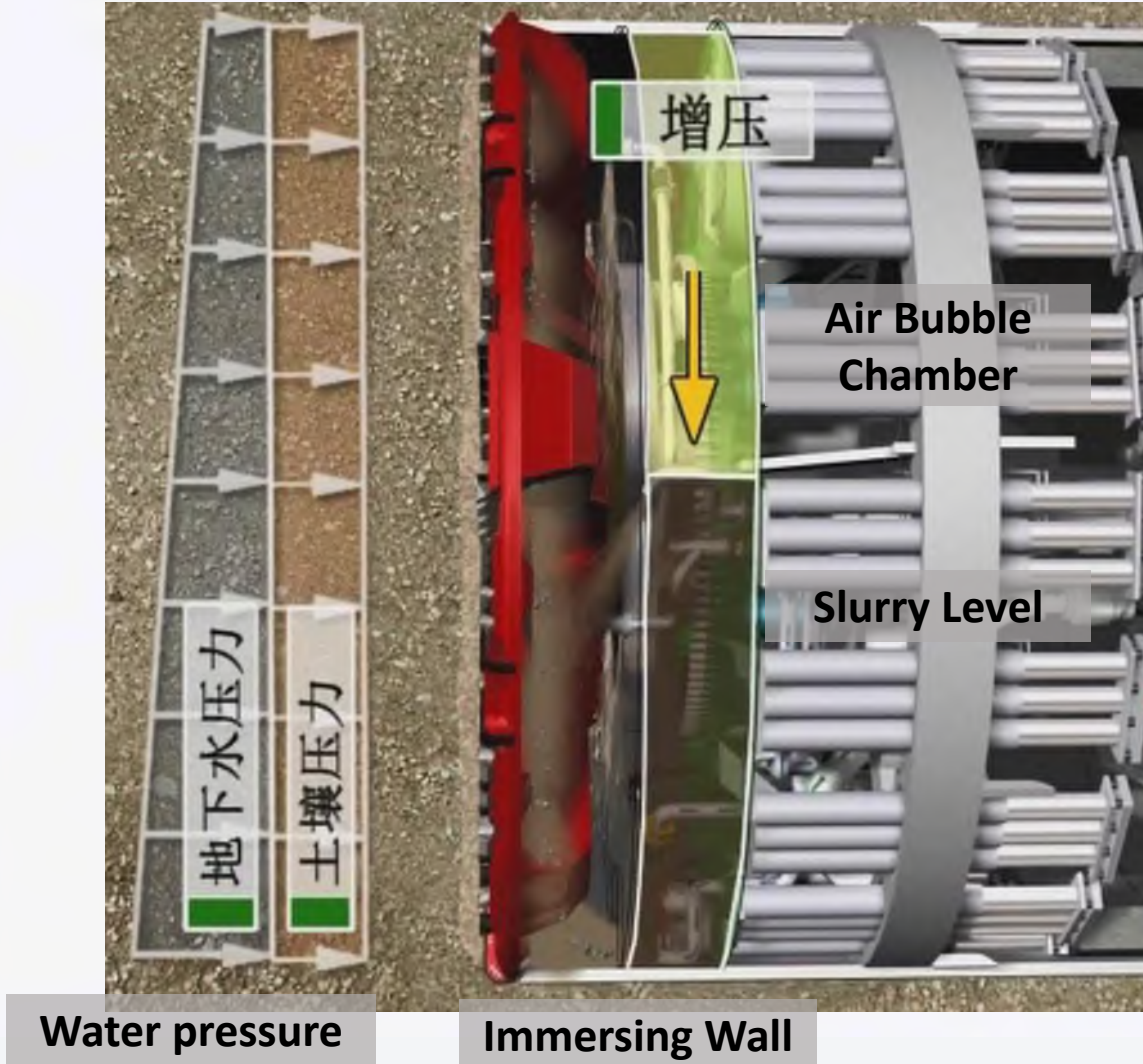


Radius of curve (m)	Extension (mm)
300	50
500	30
800	15
1000	0

4 nos. of copy cutters are equipped for overcut in tight curves. The amount of copy cutter extension was calculated based on curvature of the alignment.



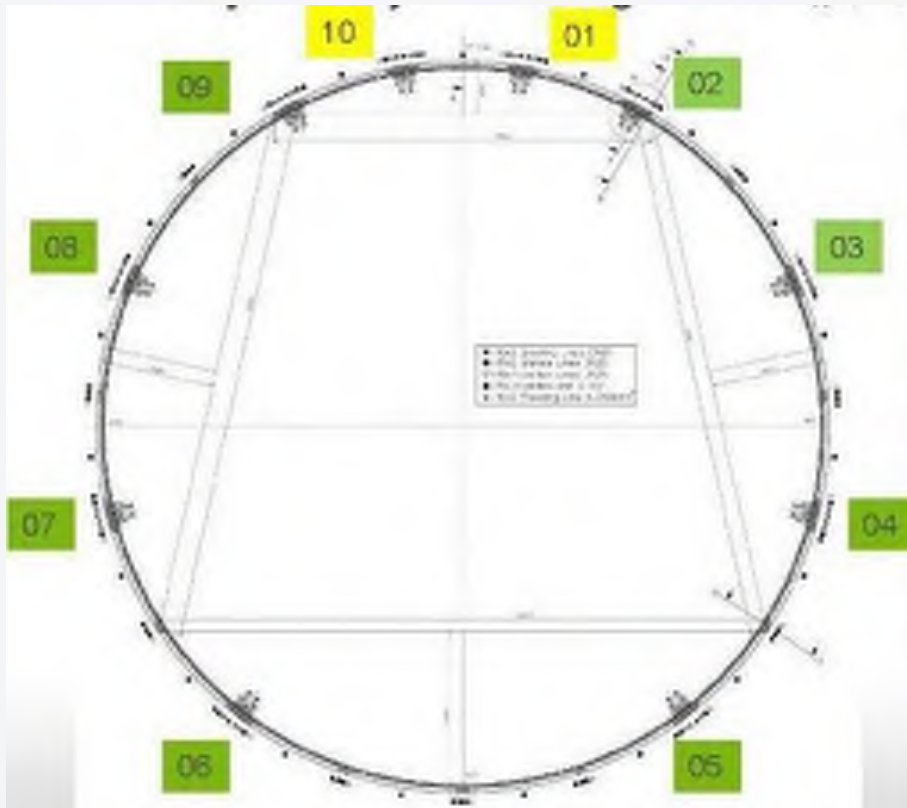
Solutions – Special TBM Design(Copy Cutters)



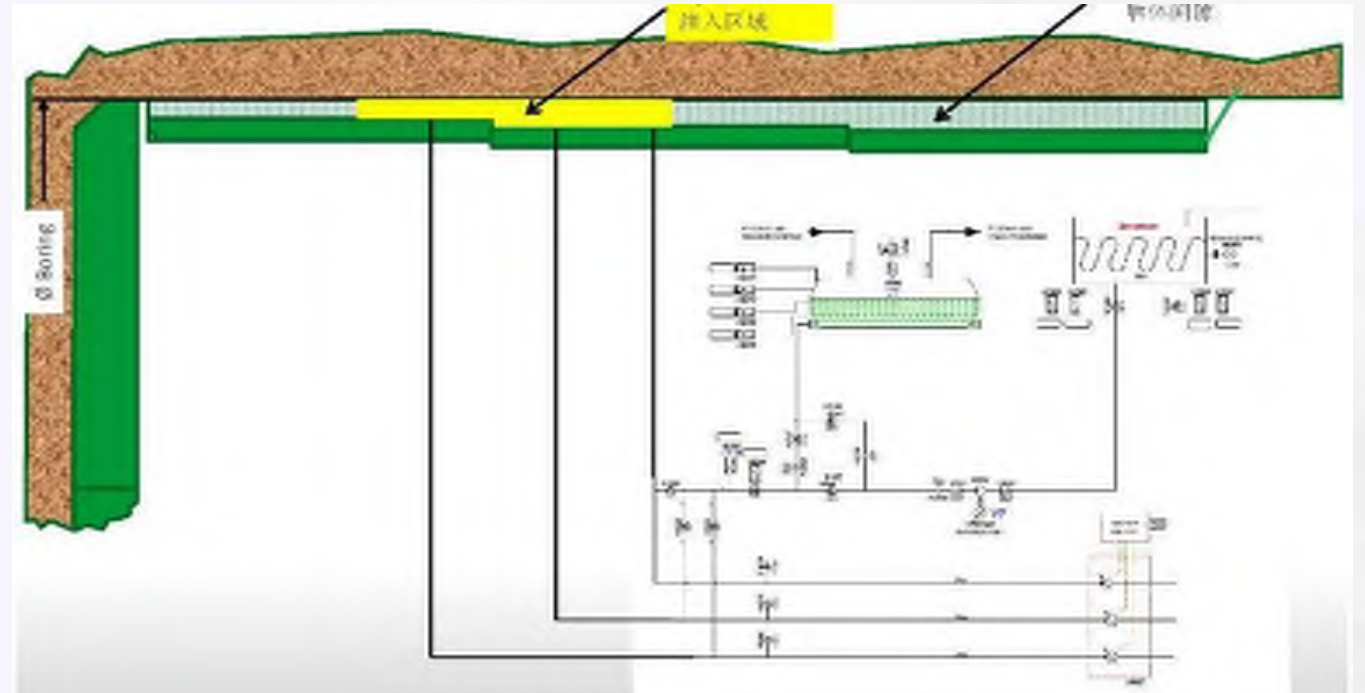
- Slurry-air balance TBM
- Maximum 8 bar working pressure allowed
- Fluctuation of air pressure is controlled within 0.5 bar
- Maintain stability of excavation surface with high precision
- Greatly avoid the disturbance caused by pressure fluctuation



Solutions – Special TBM Design (Grouting System)



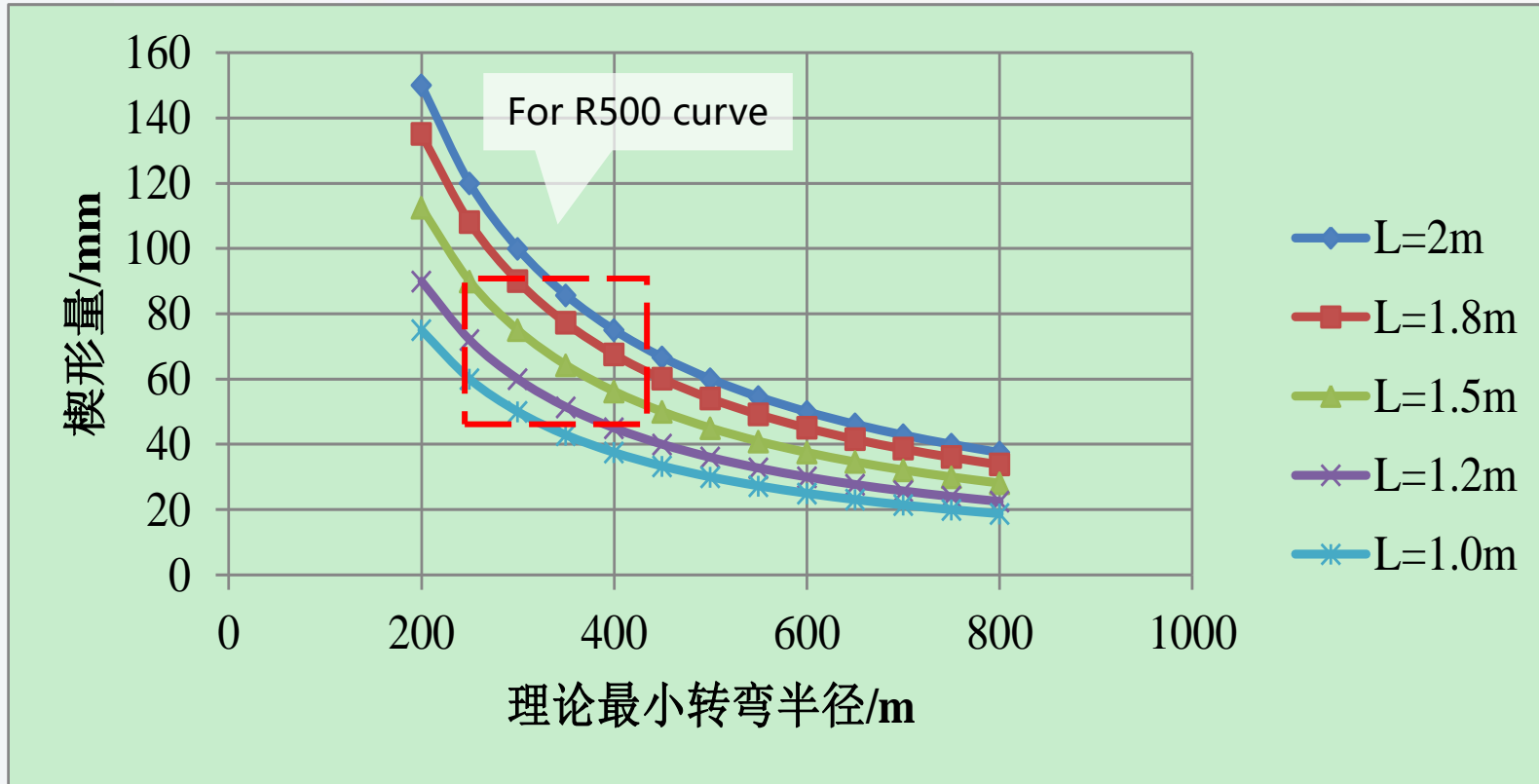
Synchronous Grouting (10 Points)



Shield Injection



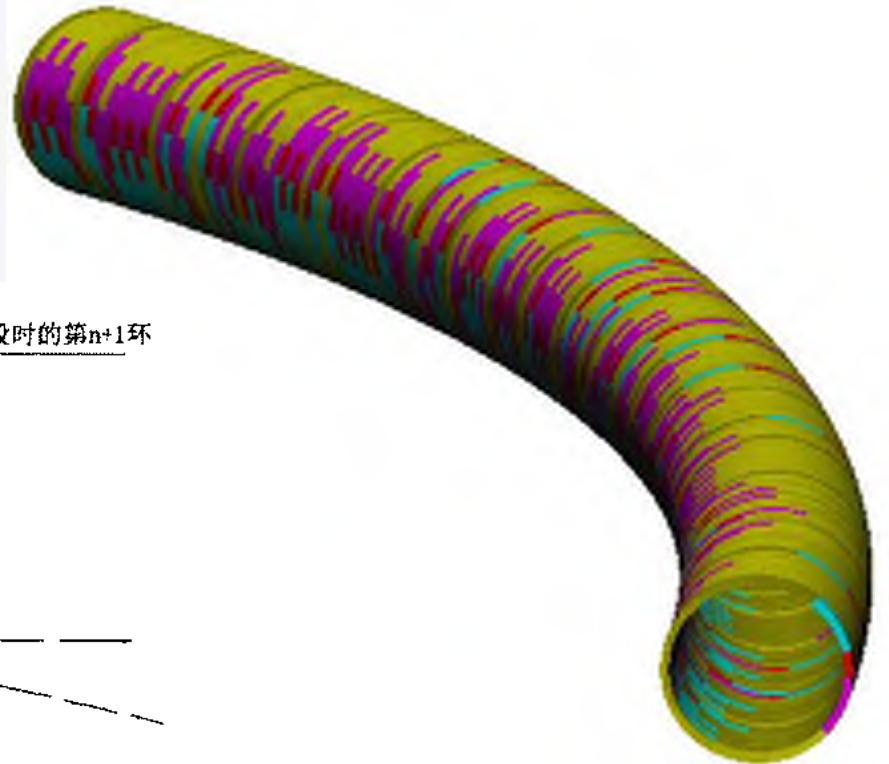
Solutions – Lining Design (Geometry)



- Previous projects in Shanghai of 15m Dia. tunnels, segment taper was designed as 40mm, and corresponding horizontal curve was 750m.
- To fit tight curve with radius of 500m, either *increase the taper or reduce the width of the segment.*

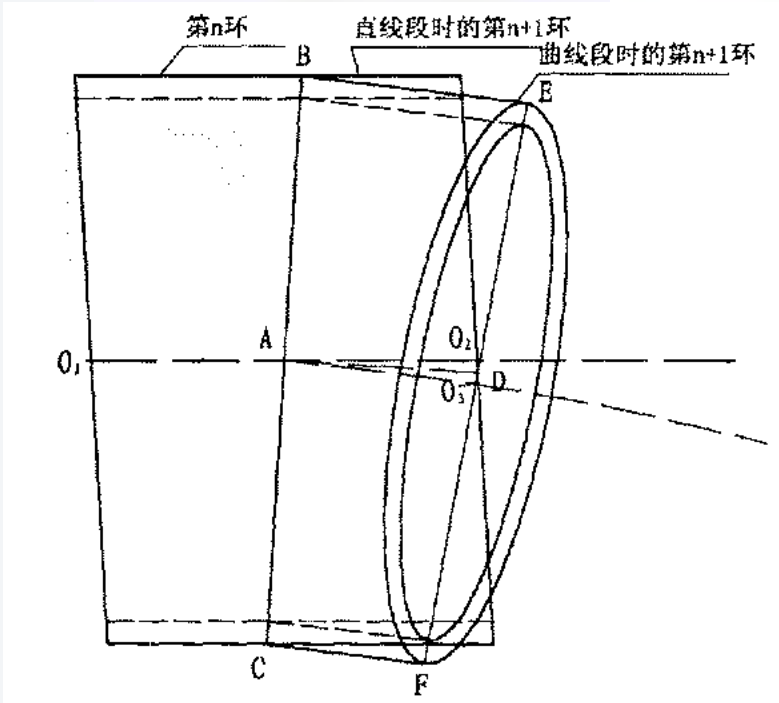


Solutions – Lining Design (Geometry)



- 3-D simulation (taper=80mm width=2.0m)
- Consider worst case condition from both horizontal and vertical curve. (Horizontal curve radius=500m Vertical curve radius=2000m)
- Deviation is less than 20mm for both plane curve and vertical curve

3-D Simulation



Analysis Model



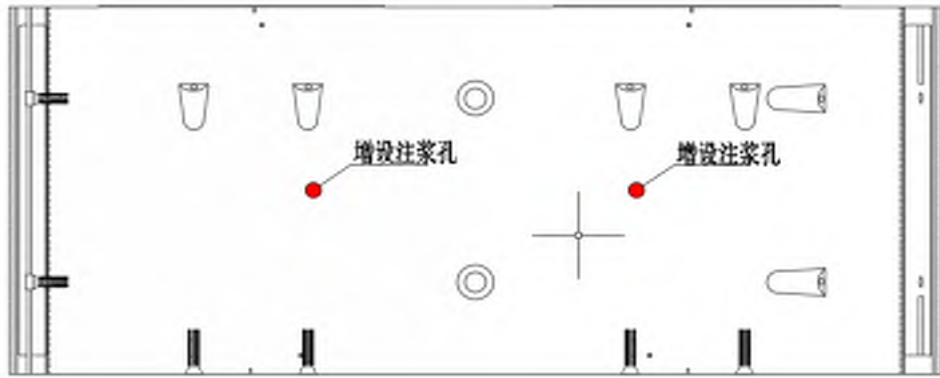
Solutions – Lining Design (Geometry)

Plane curve radius (m)	Segment width (m)	Minimum Radius (m)	Taper (mm)
< 1000m	2.0	375	80
≥ 1000m	2.0	750	40



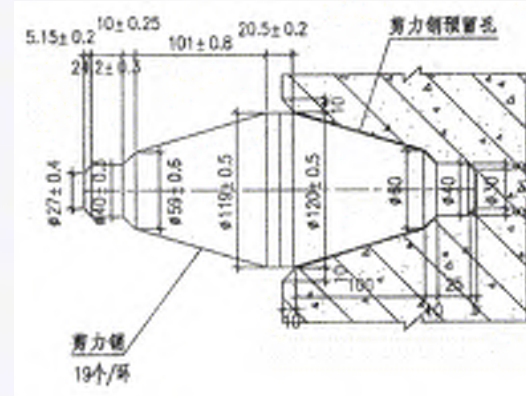
Solutions – Lining Design (Shear Key & Grouting holes)

Additional Grouting Ports



For curve sections, additional grouting holes are installed; Secondary grouting can be injected through these holes as necessary when TBM passed.

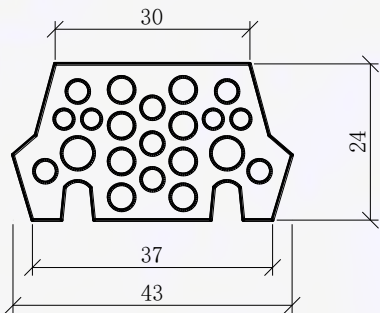
Shear Keys



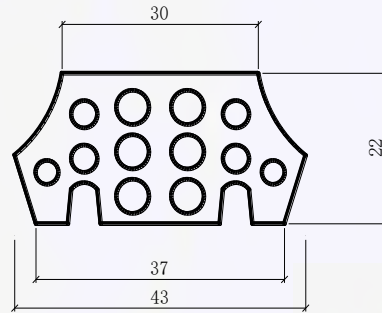
For the curve section, shear keys are introduced at ring connection to increase built rings stability and integrity .



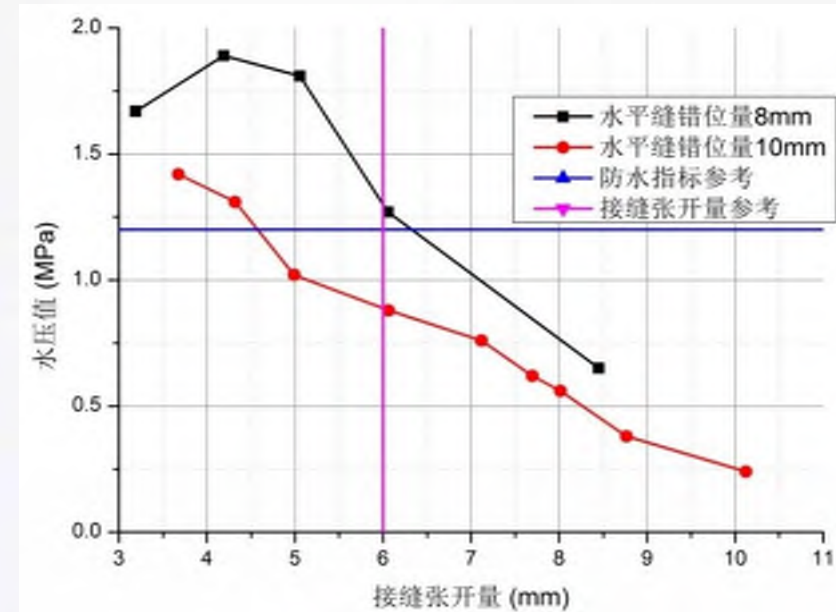
Solutions – Lining Design (Gasket)



Type A



Type B

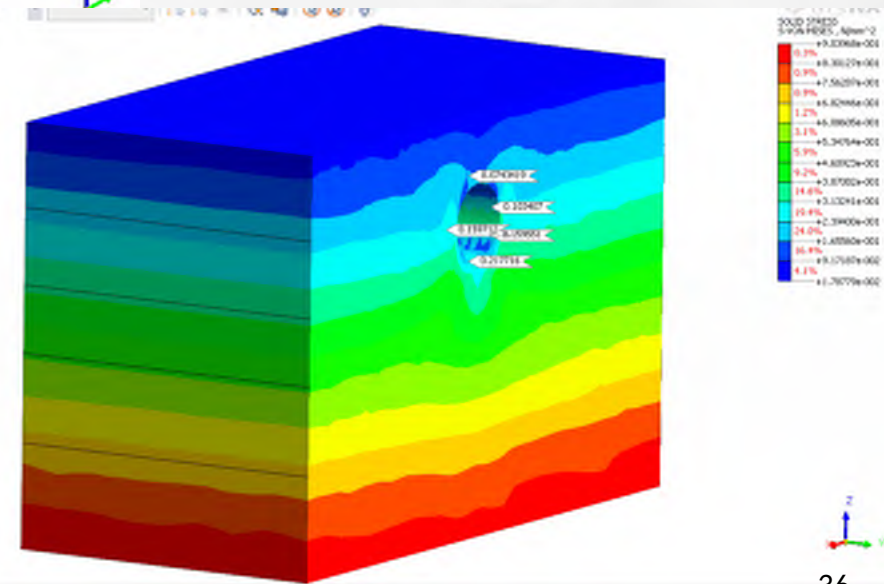
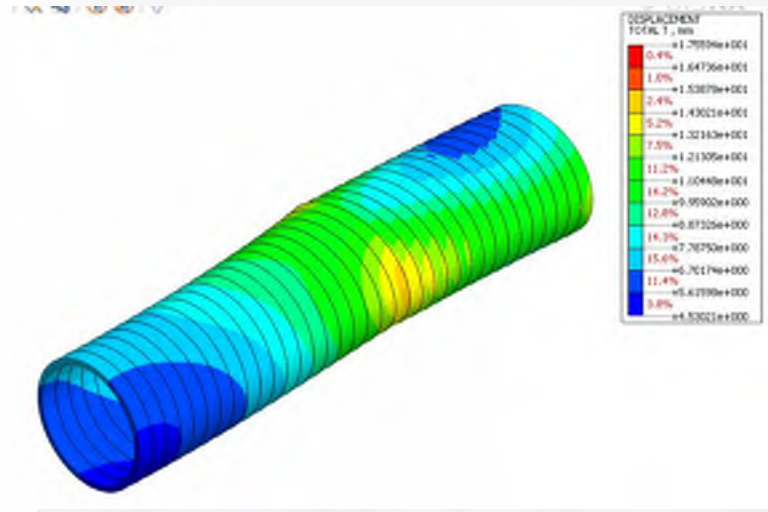
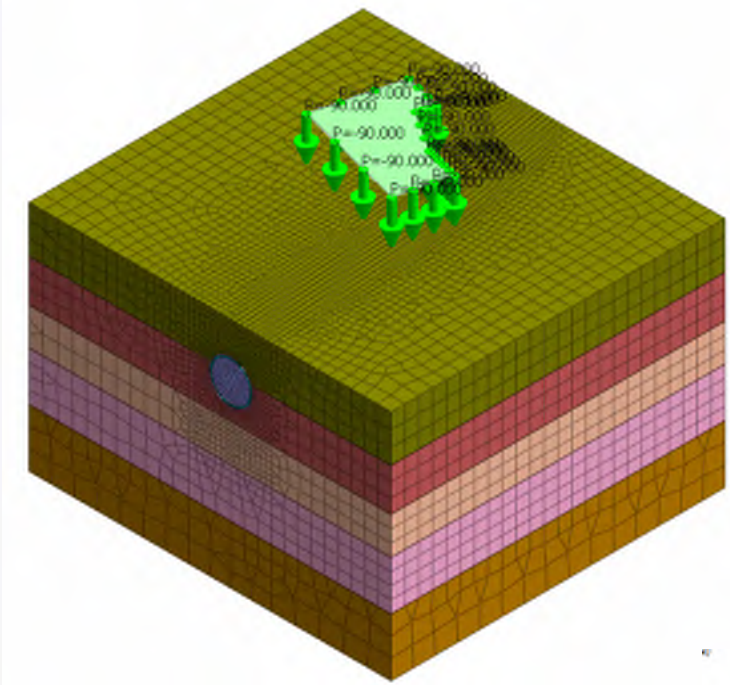
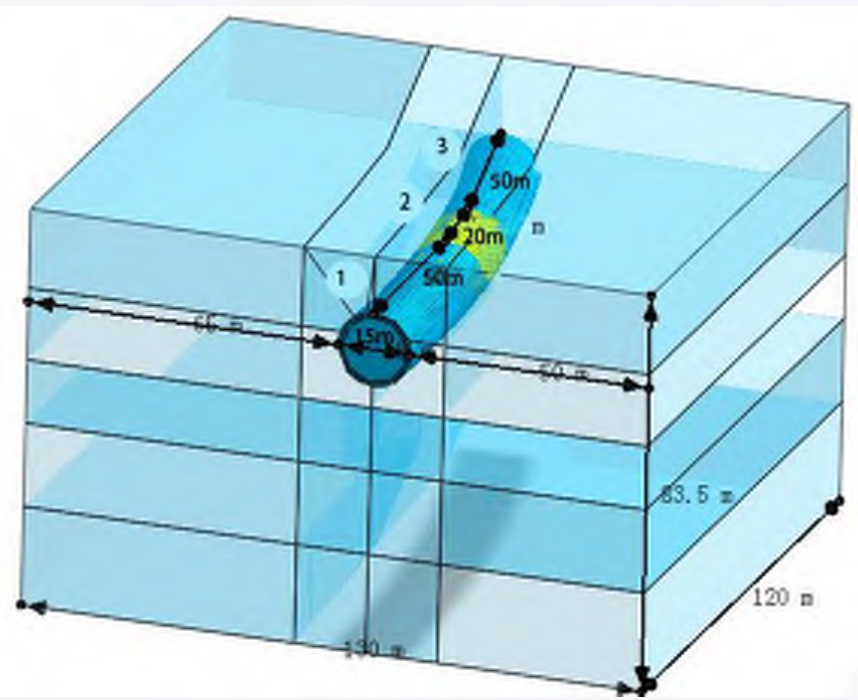


The Gasket waterproof test results:

- Segment Gap : 6 mm
- Gasket Offset : 8mm
- Water Resisting Pressure : 1.27 MPa



Solutions – Construction Control



To verify the overall stability and soil stress condition during curve tunnelling, a R500 curve section beneath a 5-floor office building was selected and simulated with 3D FEM. Results revealed that the max. tunnel axis deviation is 6.4mm, no sheared failure occurred in the soil around.



Solutions – Construction Control

- **Face Pressure Control**
- **TBM Advance Speed:** 20~30mm/min
- **Ring Build:** 80mm taper, Key segment location
- **Primary Grouting:** Slump 12-14cm, volume 110-130%
- **Tail Seal Grease Injection:** 180kg/ring, 50 : 60 : 70
- **Over Excavation:** Copy cutters are not used



Solutions – Construction Control

To date, all tight curved sections have been completed within specification and rings were erected with high built quality:

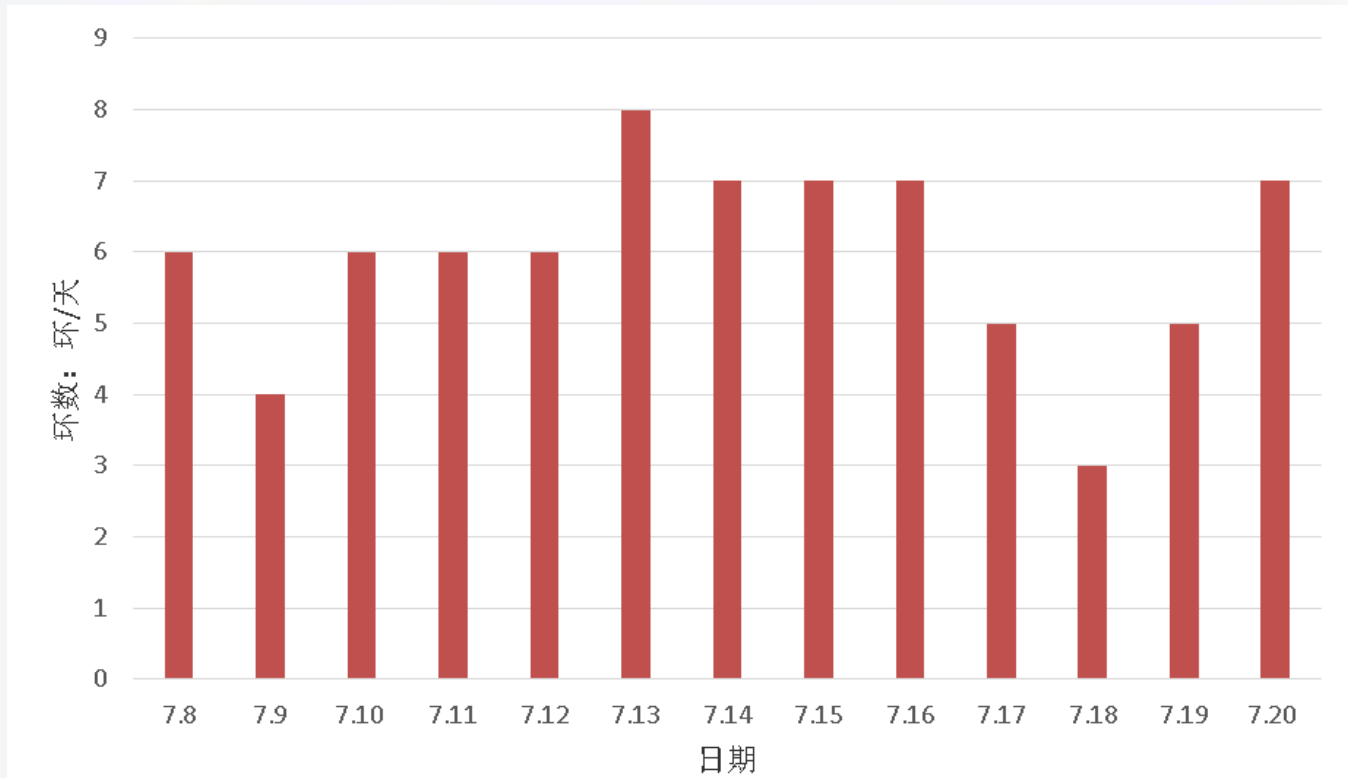
- **Water tightness, cracks and construction tolerances in segments meet specified requirements;**
- **TBM alignment is controlled within $\pm 50\text{mm}$;**
- **The building and ground settlement are within tolerance.**

Solutions – Construction Control

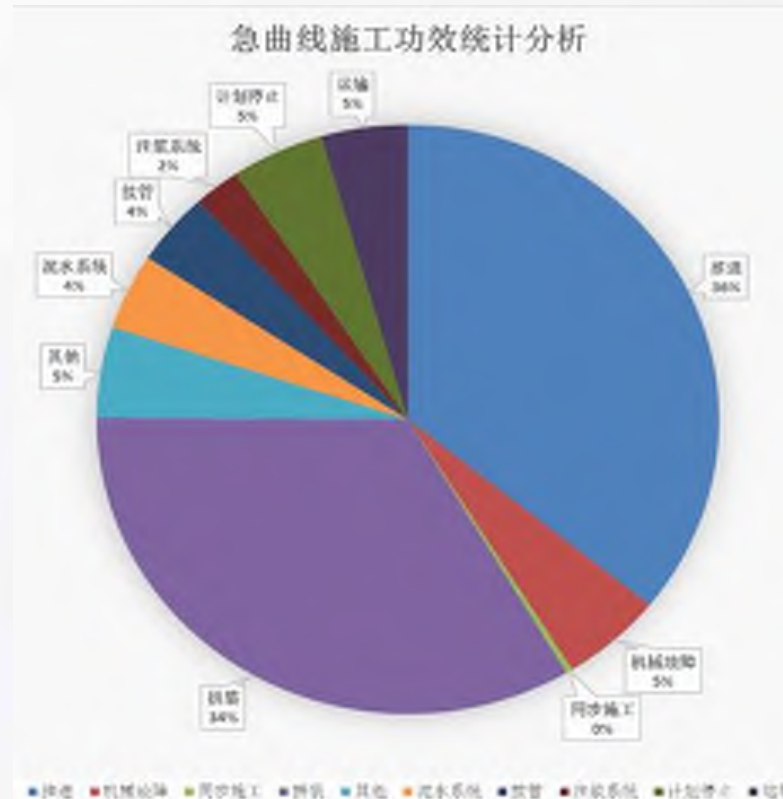




Solutions – Construction Control



Production Rate



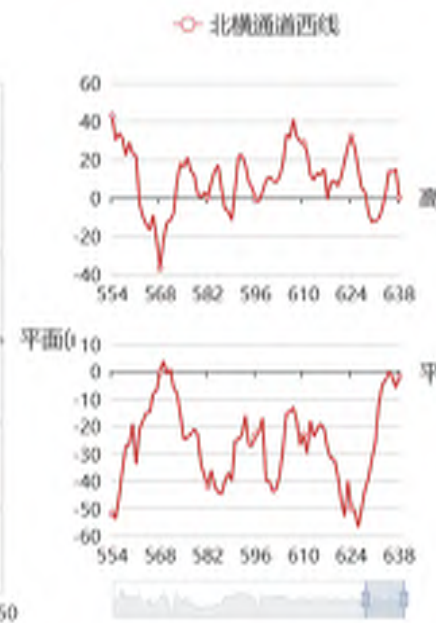
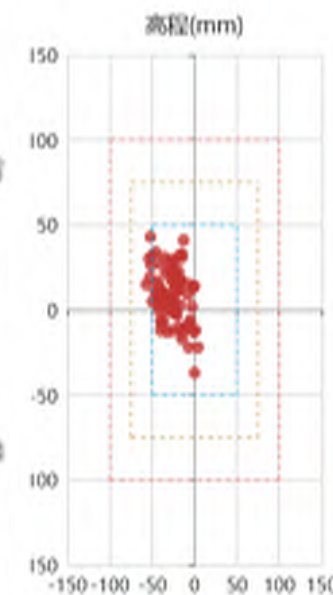
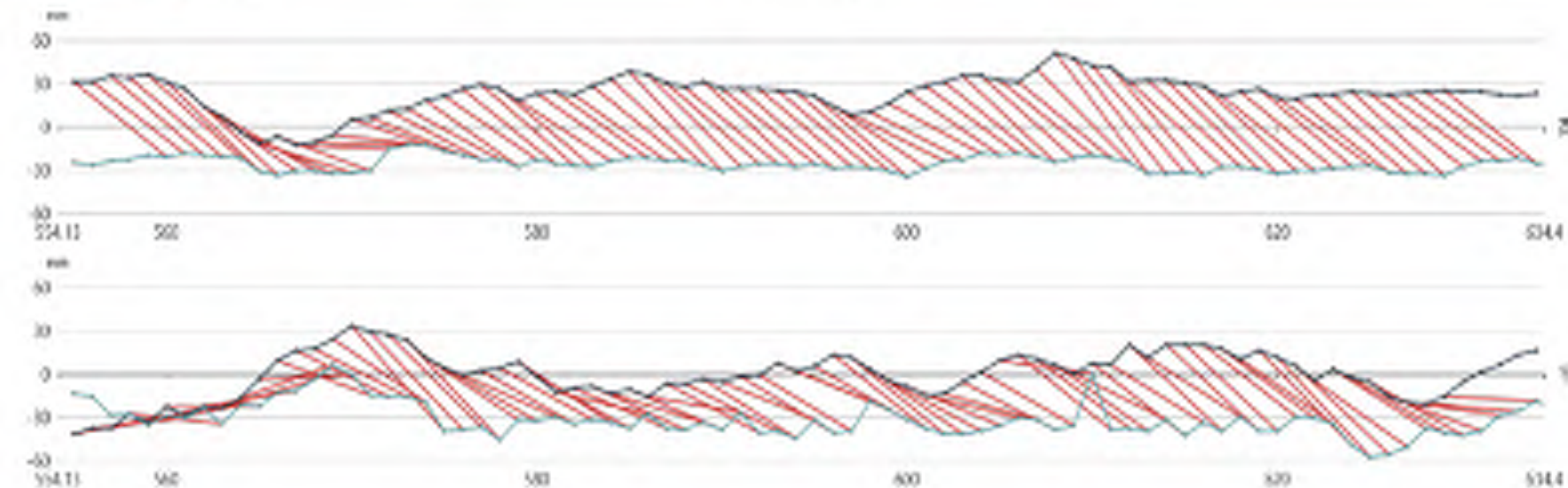
Efficiency Analysis



Solutions – Construction Control

◆ 切口 ◆ 偏压 ◆ 结构姿态

北横通道西线





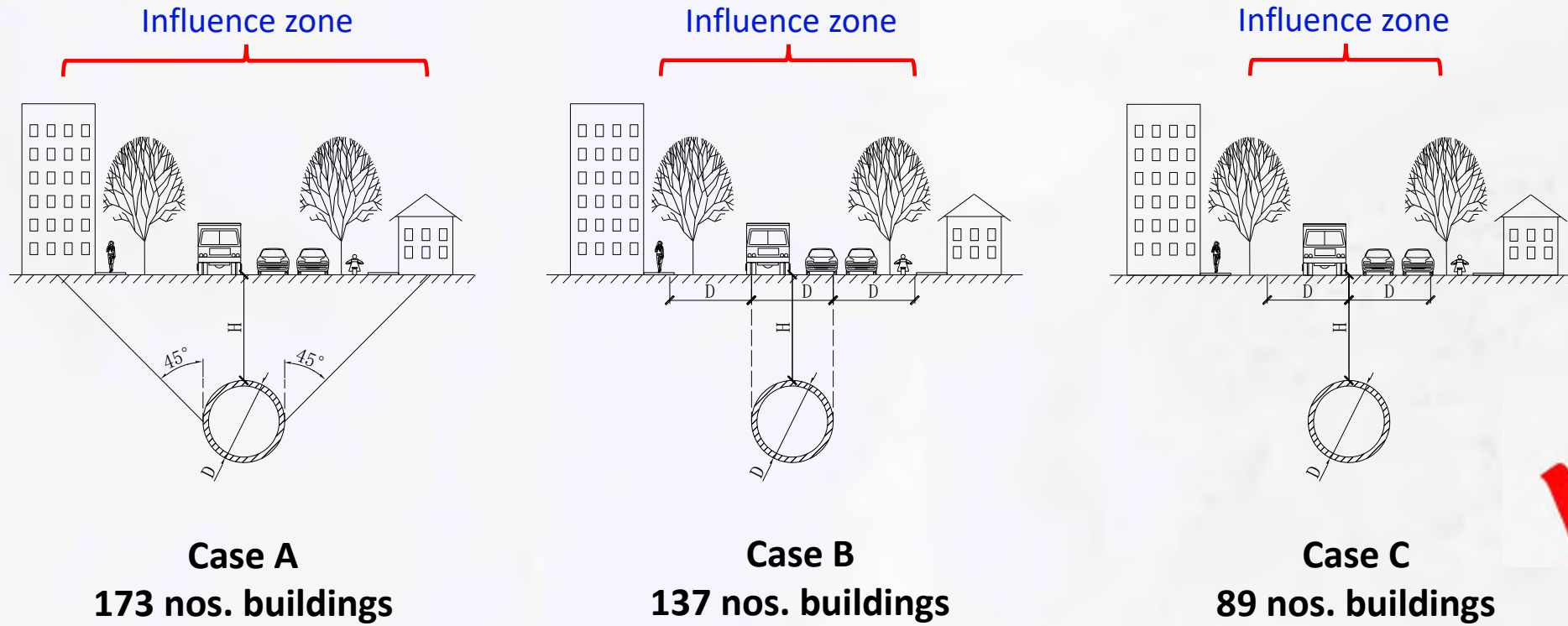
Solutions – Construction Control

急曲线段水平位移曲线



Vertical Displacement of Built Tunnel

Influence Zone



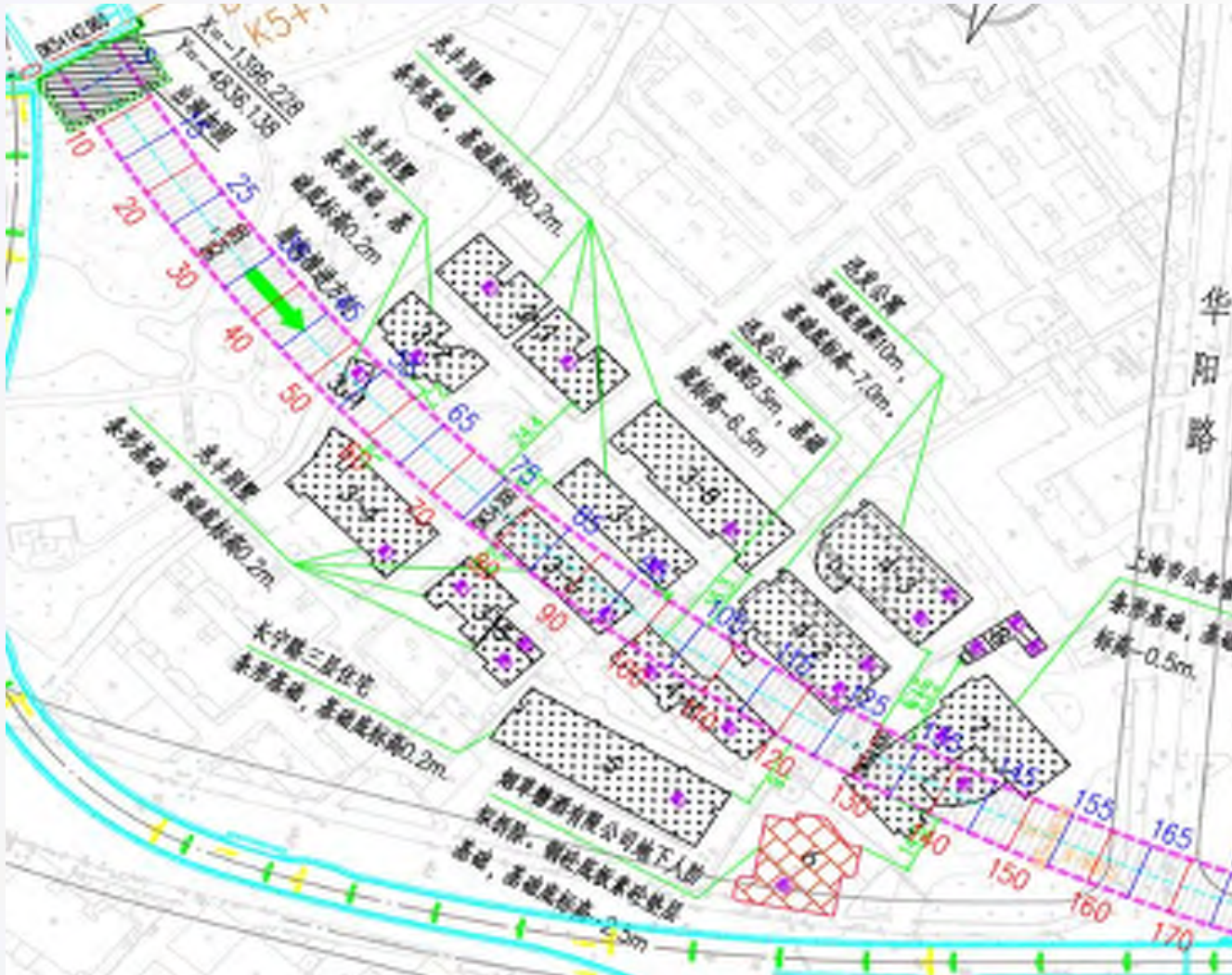
For the influence zone, no regulations for the 15m diam. TBM was specified, the 3 cases were studied and reviewed and previous experiences were referred as well, and Case C was selected as the influence zone this project.

Influence Zone – General Information

Description	Buildings			Total
	Without pile	With piles	High-rise (>27m)	
Within Influence	18	21	20	59
TBM Under-cross	21	9	0	30
Total	39	30	20	89

The 2nd drive of BEP II affects 89 buildings, which the TBM under-crosses 30 nos. buildings and 59 buildings were within the tunneling influence zone.

Influence Zone – General Information



Section 1: Between ring numbers 50 to 150, the TBM under-cross the Zhaofeng Villa(7), Xunfa Apartment(2) and office building at No. 330 Huayang Road(1).

Influence Zone – General Information



Zhaofeng Villa (Shallow Foundation)

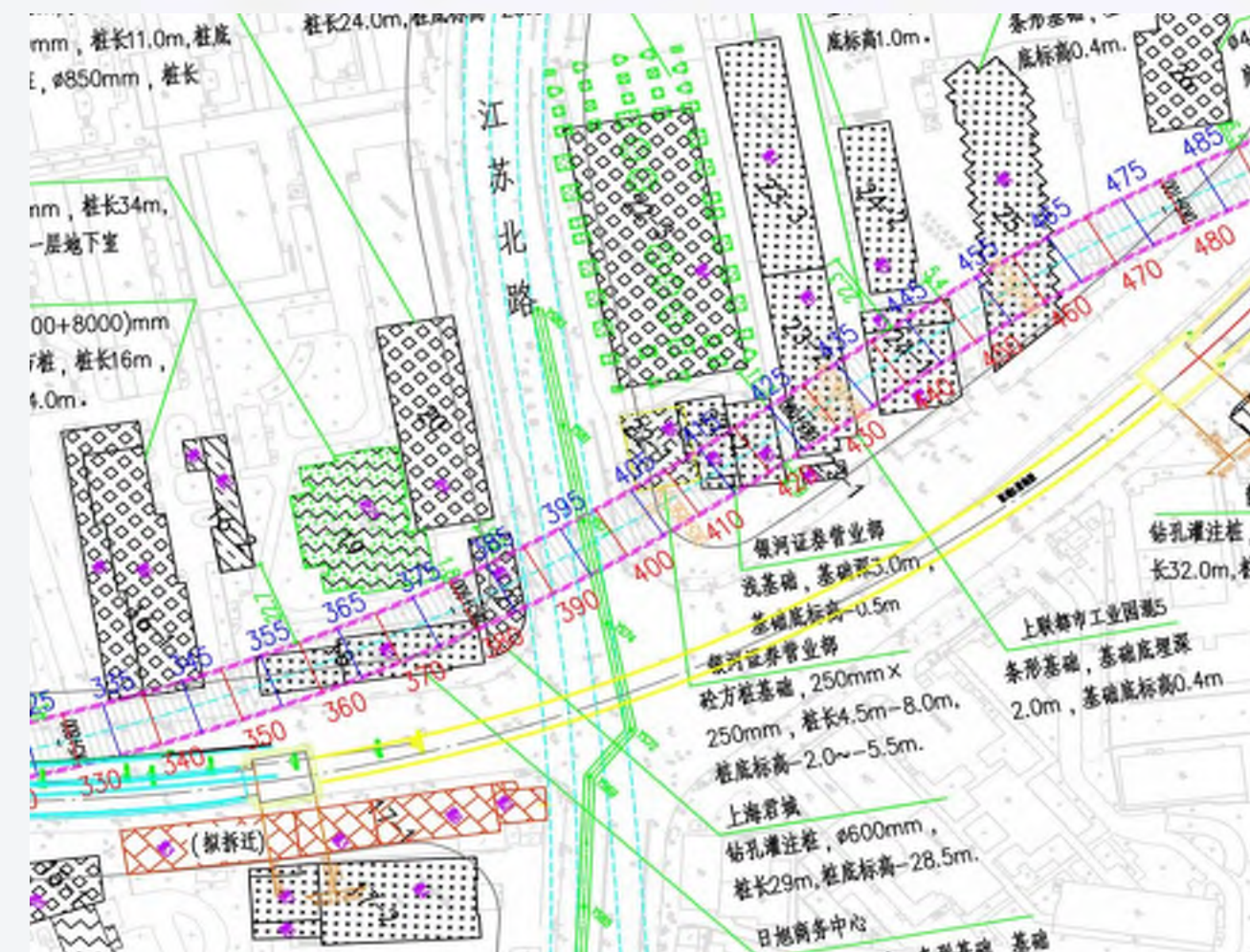


Xunfa Apartment (Shallow Foundation)



Office Buildings (Shallow Foundation)

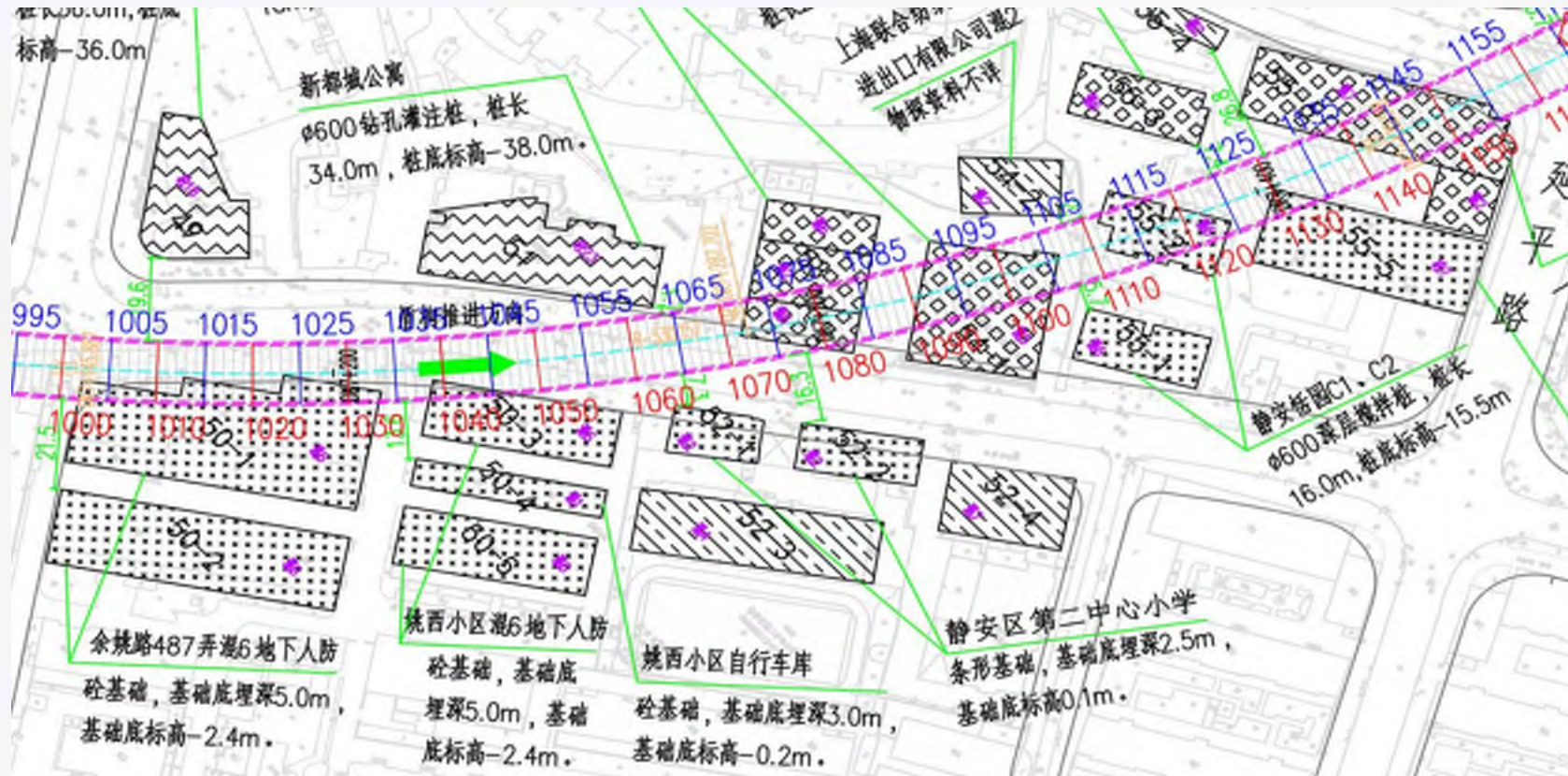
Influence Zone – General Information



Building No.	Name
16-1	Daming Community (6 floors)
18	Sunrising Business Center (5 floors)
21	Shanghai Juncheng (7 floors)
22-1	Galaxy Securities Sales Department
22-2	Galaxy Securities Sales Department (2-3 floors)
23-2	Shanglian Industrial Park(5 floors)
24-1	Holiday Inn hotel (5 floors)
25	No. 234, Changning Road
32	Yuyao 110kV Substation

Section 2: At the crossing of Jiangsu Road-Changning Road, TBM tunnelled through 10 buildings between Ring 330 to Ring 470

Influence Zone – General Information



Section 3: 8 buildings in the range of Rings 1000 to 1160: United Textile Import and Export Corporation, Yaoxi Communities etc.

Risk Assessment

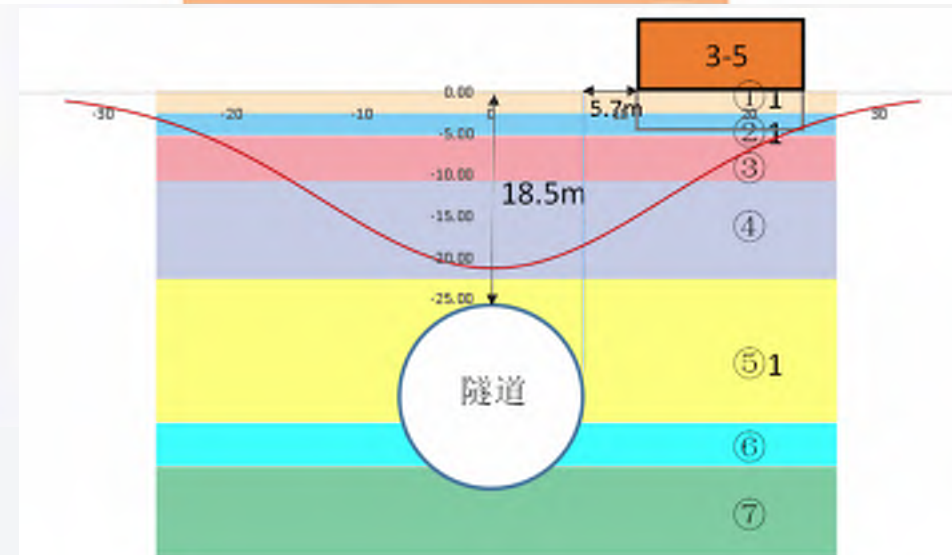
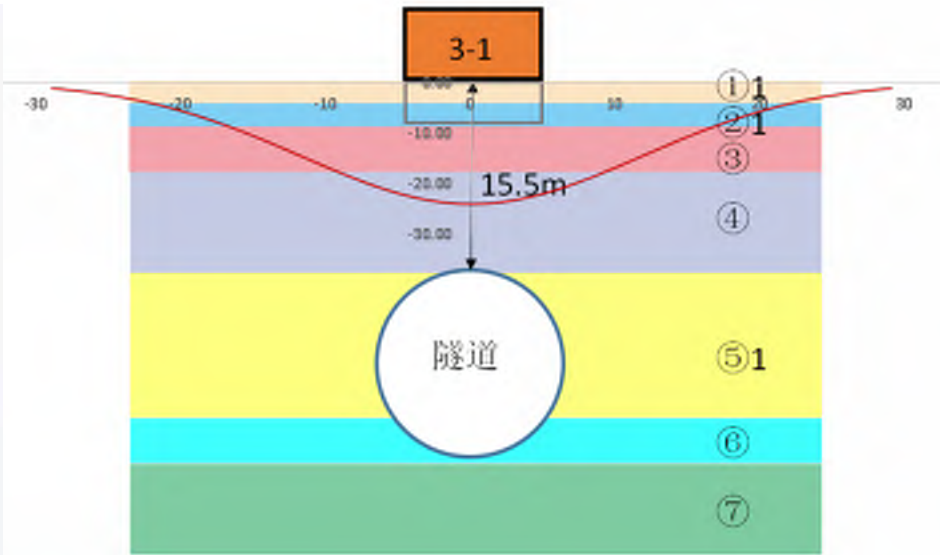
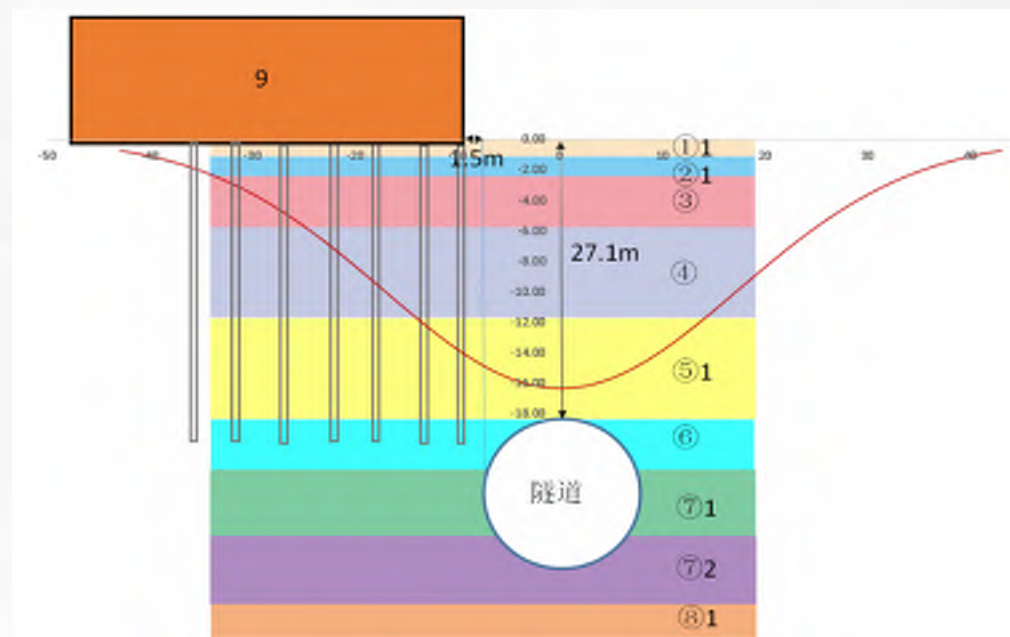
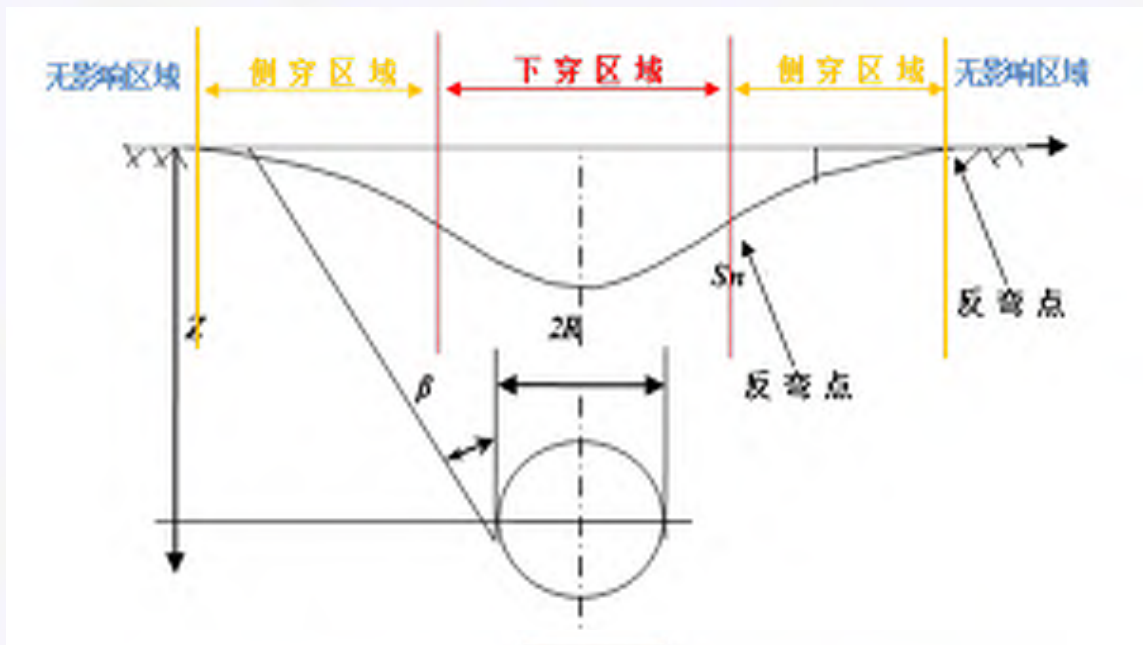
$$F = \sum_{i=1}^7 \alpha_i * F_i$$

Factor	Overburden	Foundation	Structure Type	Under-cross Pattern	Structural status	Tunnel Axis	Geological condition
Weight	0.2500	0.2144	0.1784	0.1428	0.1072	0.0715	0.0357

Risk Assessment

Factor	Rate	Criteria	Risk Value
Overburden	Shallow	$H < 1.5m$	10
	Normal	$15m < H < 25m$	5
	Deep	$H > 25m$	1
Foundation Type	No foundation	Including independent column foundation	10
	Shallow foundation	Most shallow foundations such as strips and cymbals (including the case of a basement)	5
	Deep foundation	Piles	1
Structural Type	Brick-concrete, masonry structure	Most Multi-layer structures	10
	Concrete frame structure	Most high-rise structures	5
	Core tube (shear wall) structure	Some high-rise structure and sky scrapes	1
Under-crossing Pattern	Under-crossing	Distance $< i$	10
	By-pass	$i < \text{distance} < 2i$	5
	Beyond the range of influence	Distance $> 2i$	1
Structural Status	High risk	Age $> 30\text{ys}$, Large inclination more than 10‰, cracks	10
	Moderate risk	$30\text{ys} > \text{age} > 10\text{ys}$, inclination 5~10‰, moderate cracks	5
	Low risk	Age $< 10\text{ys}$, small inclination less than 5‰	1
Tunnel Axis	Tight curve	$R < 600m$	10
	Transition curve	$600m < R < 1000m$	5
	Straight	$R > 1000m$	1

Risk Assessment



Risk Assessment

序号	编号	建筑物名称	里程	环号	隧道埋深		基础形式		结构形式		穿越方式			结构现状		隧道线型		地质条件		风险估值	风险等级
					覆土厚度	风险估值	形式	风险估值	形式	风险估值	净距离	沉降槽宽度	风险估值	隐患程度	风险估值	转弯半径	风险估值	地质情况	风险估值		
1	3-1	兆丰别墅区 A	K5+248	53	15.5	5	浅基础	5	多层	10	0	7.75	10	风险高	10	急曲线	10		10	7.68	I
2	3-2	兆丰别墅区 B	K5+256	57	15.5	5	浅基础	5	多层	10	2.7	7.75	10	风险高	10	急曲线	10		10	7.68	I
3	3-4	兆丰别墅区 D	K5+268	63	15.8	5	浅基础	5	多层	10	3.1	7.9	10		1	急曲线	10		10	6.71	I
4	3-5	兆丰别墅区 E	K5+316	87	18.5	5	浅基础	5	多层	10	5.7	9.25	10	风险高	10	急曲线	10		10	7.68	I
5	3-6	兆丰别墅区 F	K5+318	88	18.5	5	浅基础	5	多层	10	0	9.25	10	风险高	10	急曲线	10		10	7.68	I
6	3-7	兆丰别墅区 G	K5+320	89	18.5	5	浅基础	5	多层	10	1	9.25	10	风险高	10	急曲线	10		10	7.68	I
7	4-1	迅发公寓 5 层楼 A	K5+362	110	23.5	5	浅基础	5	多层	10	0	10.6	10	风险高	10	急曲线	10		10	7.68	I
8	4-2	迅发公寓 5 层楼 B	K5+374	116	23.5	5	浅基础	5	多层	10	0	10.6	10	风险中等	5	急曲线	10		10	7.14	I
9	7	上海市政务管理中心	K5+422	140	23.2	5	浅基础	5	多层	10	0	11.6	10	风险中等	5	急曲线	10		10	7.14	I
10	9	长宁会馆	K5+504	181	27.1	1	深基础	1	多层	10	1.5	13.55	10	风险中等	5	急曲线	10		10	5.28	II
11	10-1	锦江之星 (拟拆迁)	K5+525	201	17.9	1	浅基础	5	多层	10	4.3	12.95	10		1	急曲线	10		10	5.71	II
12	12-1	兴联大厦裙楼	K5+615	237	29.1	1	深基础	1	多层	10	1.6	14.55	10		1	急曲线	10		10	4.86	II
13	12-2	兴联大厦	K5+596	227	29.1	1	深基础	1	高层	5	1.6	14.55	10		1	急曲线	10		10	3.96	III
14	12-3	兴联大厦	K5+636	247	29.1	1	深基础	1	高层	5	1.6	14.55	10		1	急曲线	10		10	3.96	III
15	13-4	长新小区 (拟拆除)	K5+718	288	32.8	1	资料不详	10	多层	10	2.3	16.4	10		1	急曲线	10		10	6.79	I
16	14-4	兆丰大厦裙房	K5+774	316	35.1	1	深基础	1	单层	10	6	17.55	10	风险中等	5	急曲线	10		10	5.28	II
17	14-5	兆丰大厦	K5+774	316	35.1	1	深基础	1	高层	5	6	17.55	10	风险中等	5	急曲线	10		10	4.39	III
18	16-1	大明小区混 6	K5+826	342	35.2	1	深基础	1	多层	10	0	17.6	10	风险中等	5	急曲线	10		10	5.28	II
19	18	日旭商务中心	K5+882	370	35.1	1	浅基础	5	多层	10	0	17.55	10	风险高	10	急曲线	10		10	6.68	I
20	19	长宁大厦	K5+886	372	35.6	1	深基础	1	高层	5	1.8	17.8	10		1	急曲线	10		10	3.96	III
21	21	上海君城	K5+910	384	35.1	1	深基础	1	多层	10	0	17.55	10	风险中等	5	急曲线	10		10	5.28	II
22	22-1	银河证券营业部	K5+960	409	33.7	1		10	多层	10	0	16.85	10	风险高	10	缓和曲线	5		10	7.39	I
23	22-2	银河证券营业部	K5+980	419	33.1	1		10	多层	10	0	16.55	10	风险高	10	缓和曲线	5		10	7.39	I
24	23-1	上联都市工业园混 2	K5+996	428	33.6	1		10	多层	10	2.9	16.8	10		1	缓和曲线	5		10	6.43	II
25	23-2	上联都市工业园	K5+2	430	33.6	1	浅基础	5	多层	10	0	16.8	10	风险中等	5	缓和曲线	5		10	5.78	II

Table of Risk Assessment

Risk Assessment

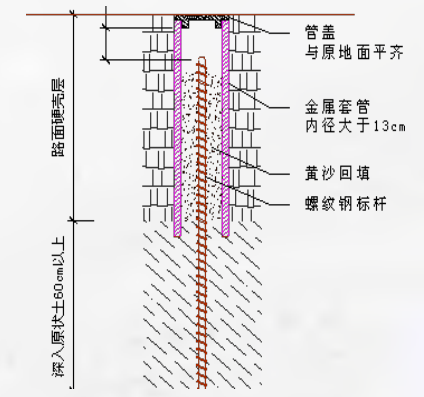
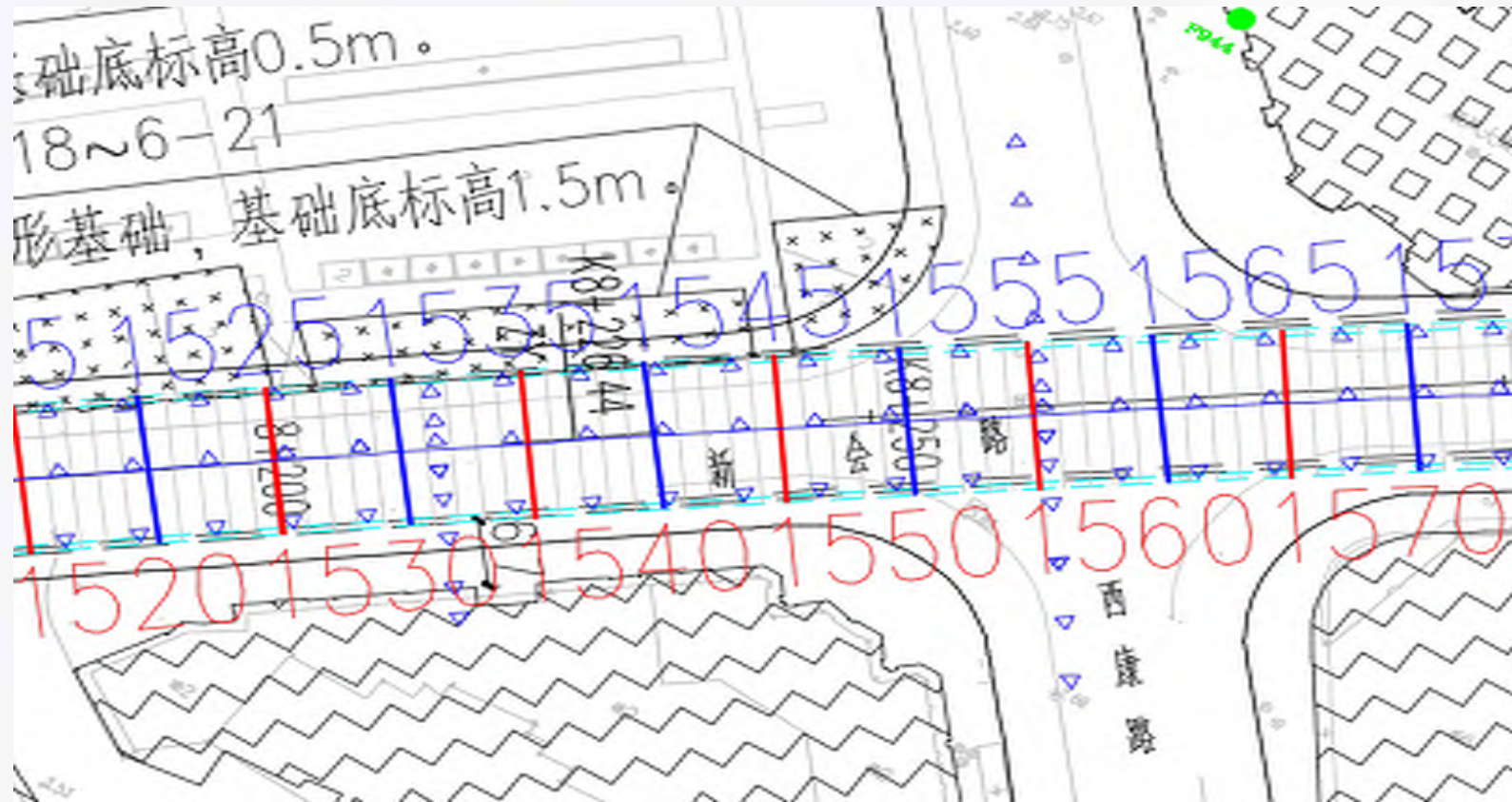
Risk value Range	Risk Grade	Number of Buildings	Risk Management Strategy
6.5~10.0	I (High)	26 (29.21%)	General Measures + Specific Measures
4.0~6.5	II (Moderate)	42 (47.19%)	General Measures
1.0~4.0	III (Low)	21 (23.60%)	Treat as Conventional Risks

Pre-Condition Survey

No.	Purpose	Objective	Conduct time
Round 1	To verify and record the building's condition before tunnelling	According to the risk assessment	1 month before under-crossing
Round 2	To check condition of the buildings and the influence of the TBM to the buildings during TBM tunnelling	All buildings within the influence zone	During TBM tunnelling through
Round 3	To evaluate the structural health of the affected buildings after under-crossing	Largely impacted buildings or the ones whose owners have controversial conflicts	3 months after tunnelling through, or after the building is stable

An independent third party is nominated to conduct the 3 - round building site investigation and provide official reports.

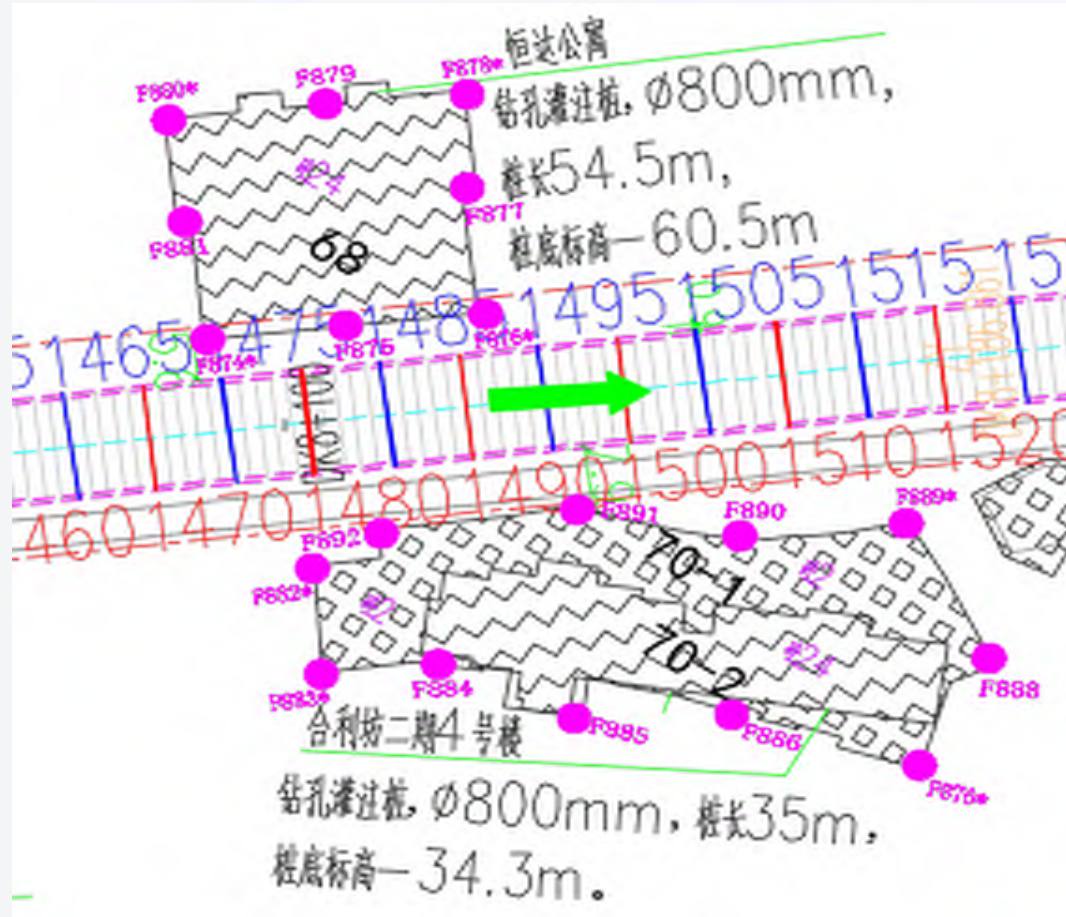
Instrumentation – Ground Settlement



Ground Settlement Marker

For ground settlement markers layout, every 6m(3 rings) a 3-marker section was set and 48m(24 rings) a 13-marker big section was set along tunnel axis. At TBM launching and receiving sections , more markers were put.

Instrumentation – Building Monitoring



Incline Meter

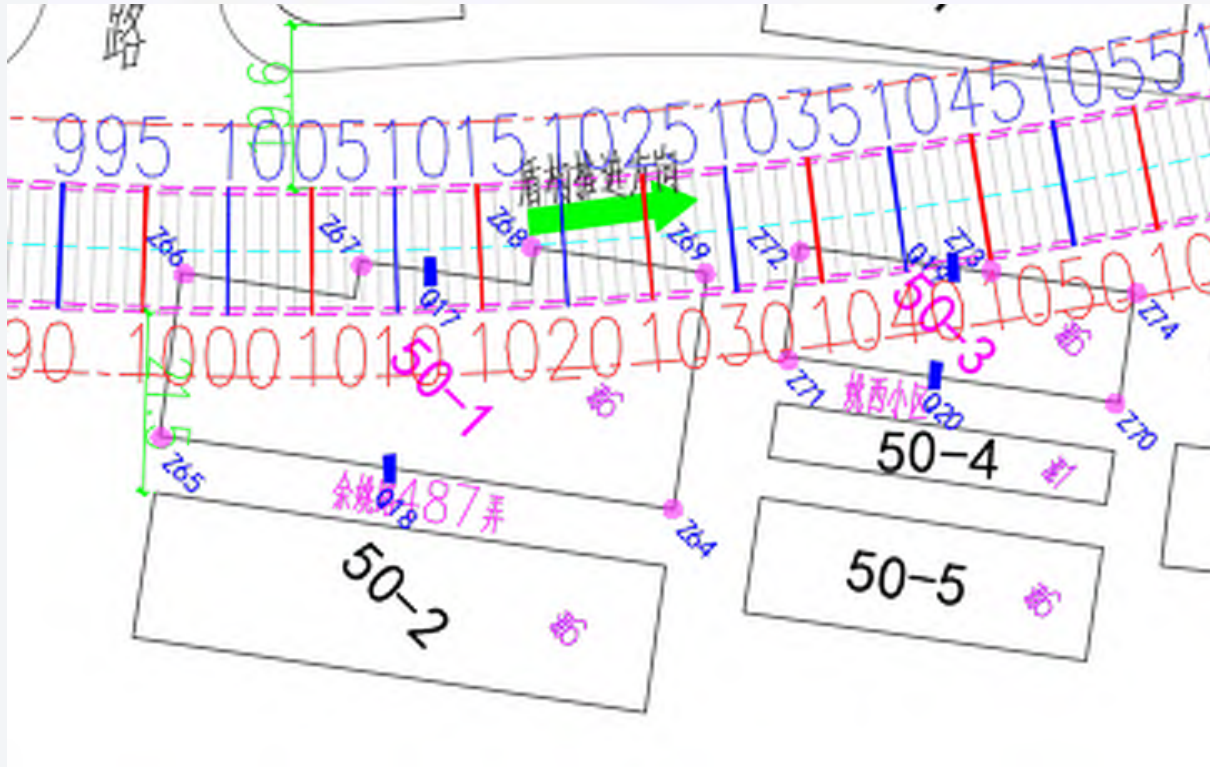
Items:

- Settlement
- Incline
- Cracks development



Building Settlement Marker

Instrumentation – Building Monitoring



Hydrostatic Leveling System



In case of high risks including 14 buildings, the automated monitor — Hydrostatic Leveling system were used.

General Mitigation / Preventive Measures

No.	Items	Measures
1	Face Pressure Control	According to the overburden and the geological condition
2	Pressure Fluctuation	-0.005~+0.005MPa
3	Advance Speed	20 ~ 30mm/min
4	Grouting Pressure	0.55~0.70 MPa
5	Grouting Volume	110%~130% of theoretical gap volume
6	Grout Quality	Slump = 14 ± 2 cm
7	Tail Grease Injection	180kg/ring, Front/Middle/Back chamber = 50: 60: 70
8	Ring Build	The jacks are retracted one by one 2-3 minutes after advancing, and then the segments are assembled.
9	TBM Control	For settlement control in front of TBM, the TBM should advance at a constant speed., and should avoid alignment correction

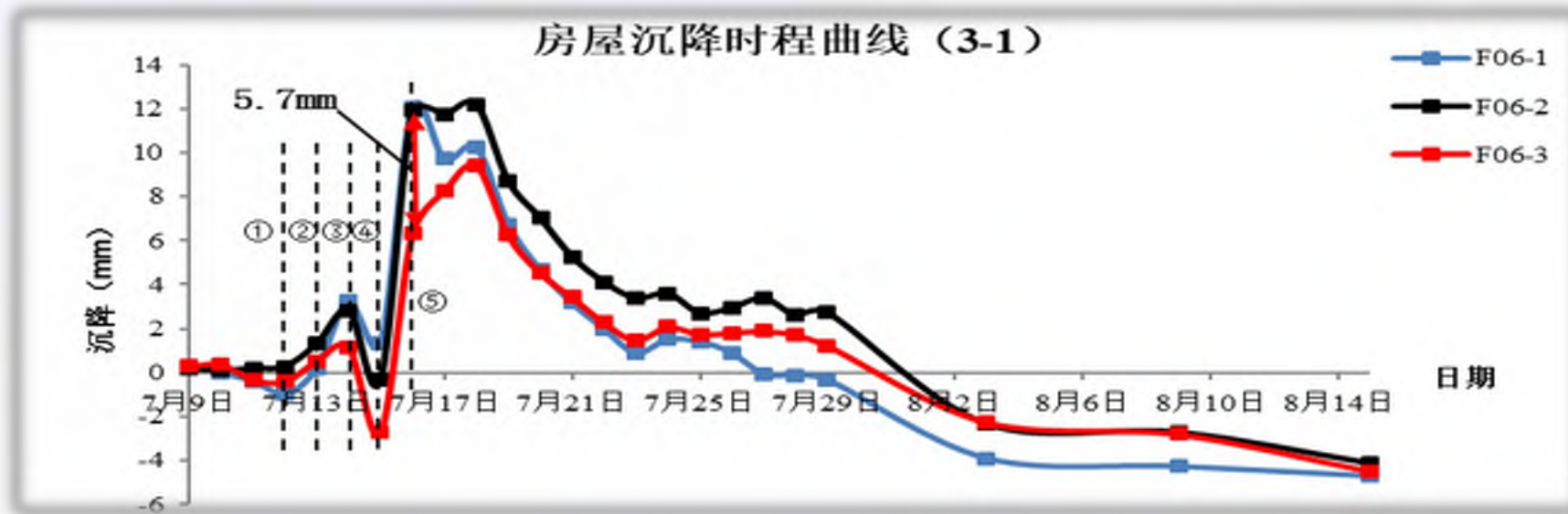
Other Special Measures

- **Building Protection**
- **Real-Time Monitoring**
- **Early-Strength Primary Grout if required**
- **TBM Shield Annulus Grouting**
- **Increase Emergency Response Level**

Results

To date, 6.2km (96.9%) bored tunnel has been completed and the TBM has tunnelled through 85 nos. buildings successfully without any incidents. Instrumentation results revealed that all structures are well within the allowable deformation and settlement.

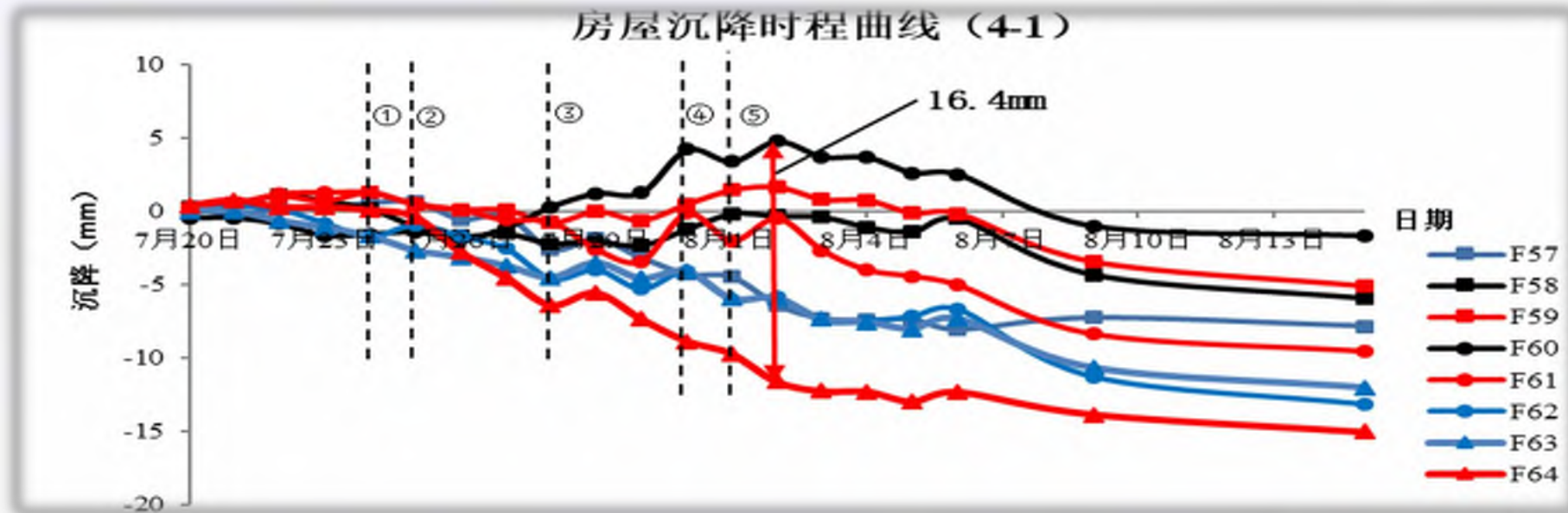
Results – Tunnelling Under Zhaofeng Villa



Tunnelling under the Zhaofeng Villa (3-1) :

- The overburden is 14.8m, less than the TBM diameter;
- Horizontal curve R500, Gradient = 3.8% downhill;
- Maximum heaving: +12mm, maximum settlement -4mm, maximum differential settlement 5.7mm

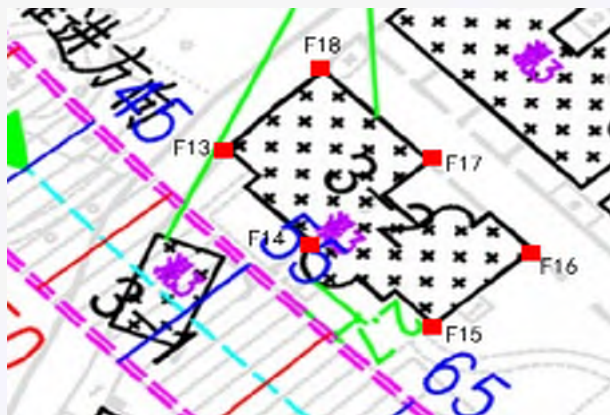
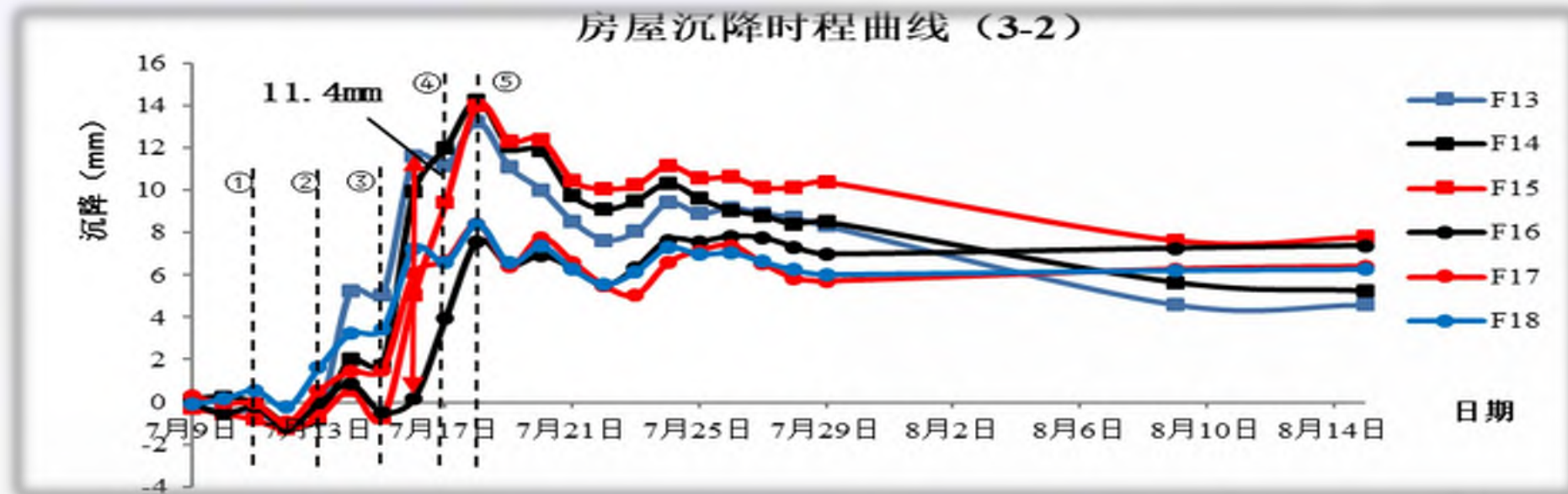
Results – Tunnelling Under Xunfa Apartment



Tunnelling under the Xunfa Apartment (4-1) :

- Overburden is 21~22m, more than the TBM diameter;
- Horizontal Curve R=500, Gradient =3.8% downhill;
- Maximum heaving: +5mm, maximum settlement -15mm, maximum differential settlement 16.4mm

Results – Tunnelling Beside Zhaofeng Villa

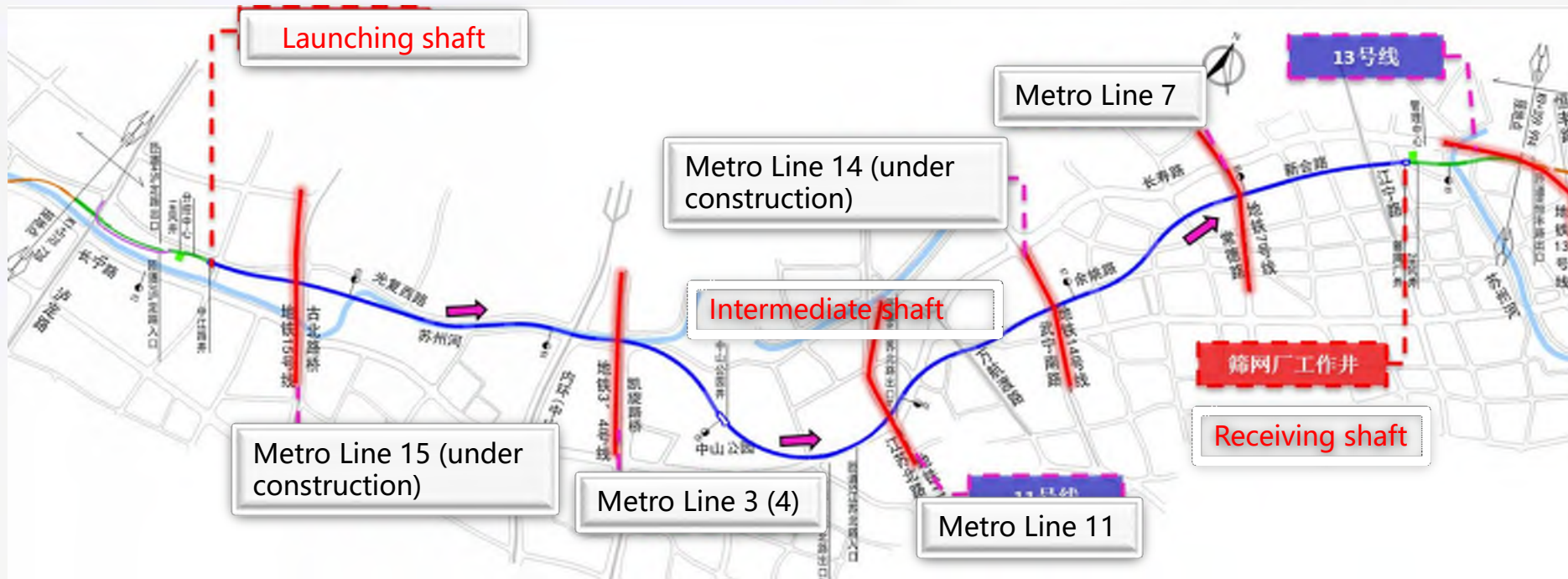


Tunnelling beside Zhaofeng Villa (3-2):

- Overburden is 15~16m
- Horizontal curve $R=500$, Gradient = 3.8% downhill;
- Maximum heaving: +13mm, maximum settlement -1mm, maximum differential settlement 11.4mm

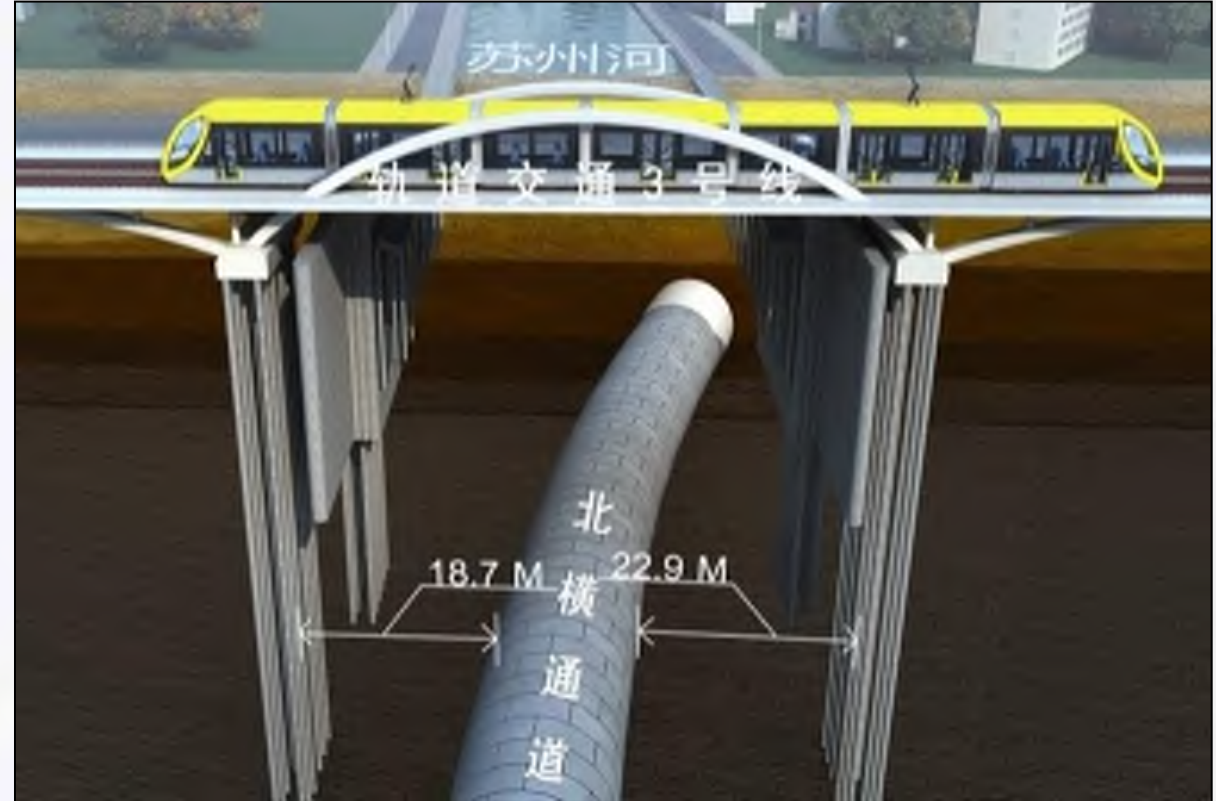


3 Metro Lines Under-crossed



For the 2nd drive, the TBM under-crossed 3 running metro lines, namely, line 3(4), line 11 and line 7. Line 3(4) is a elevated bridge and line 11, 7 are bored tunnels.

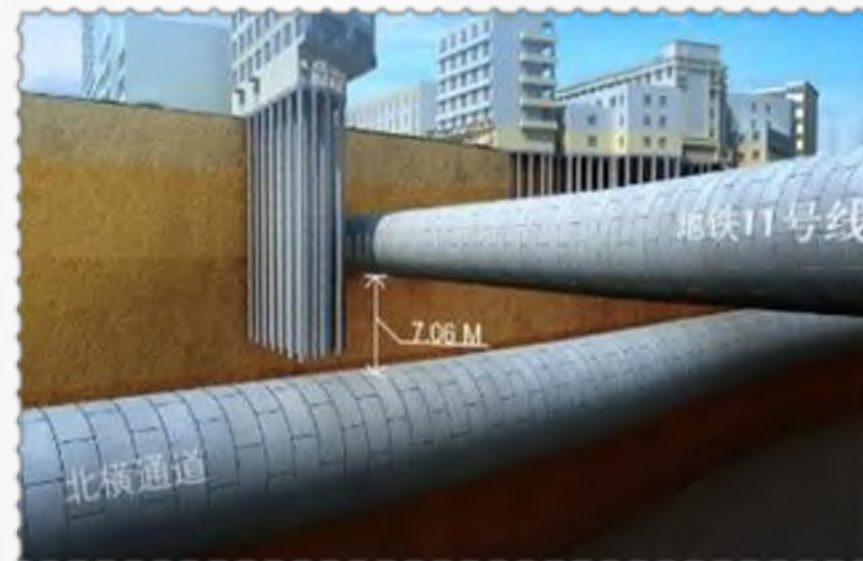
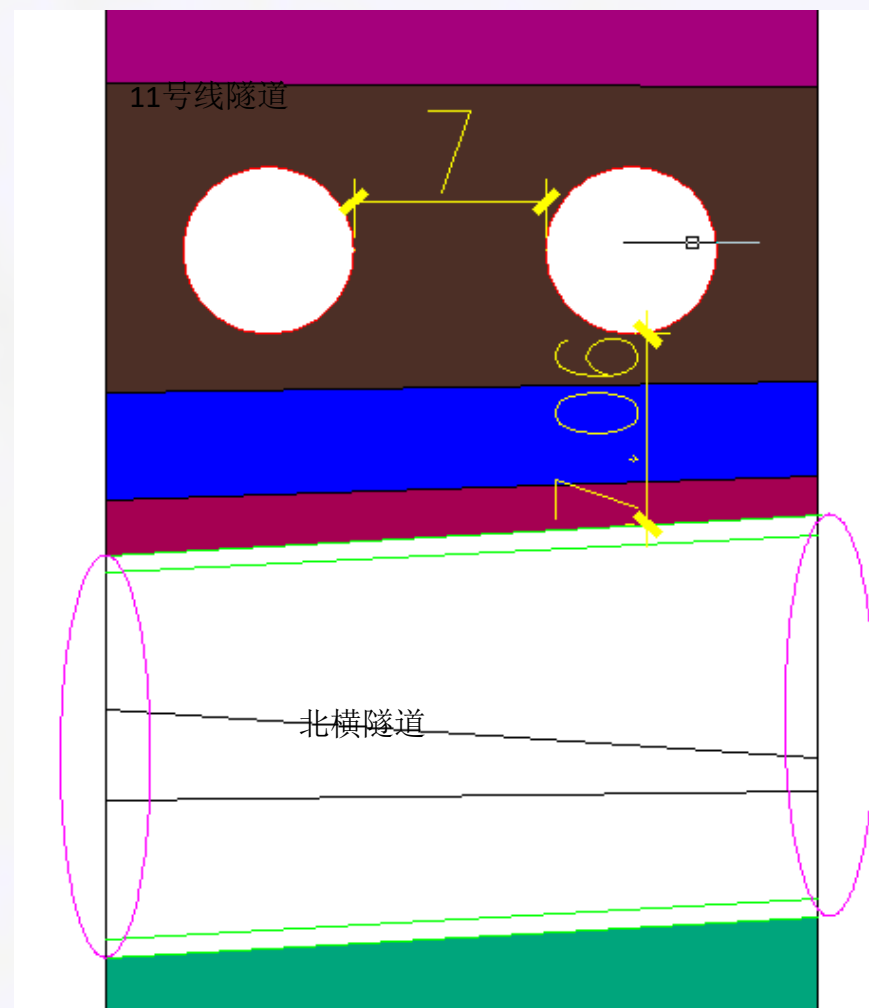
Metro Line 3 (4)



Tunnelling Under Metro Line 3(4)



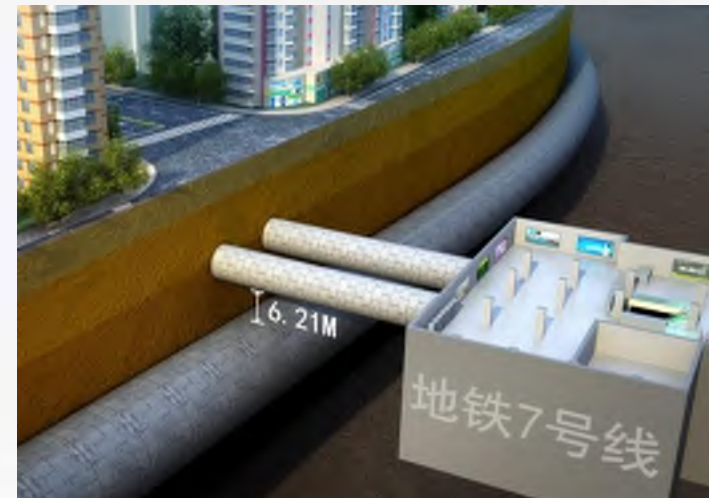
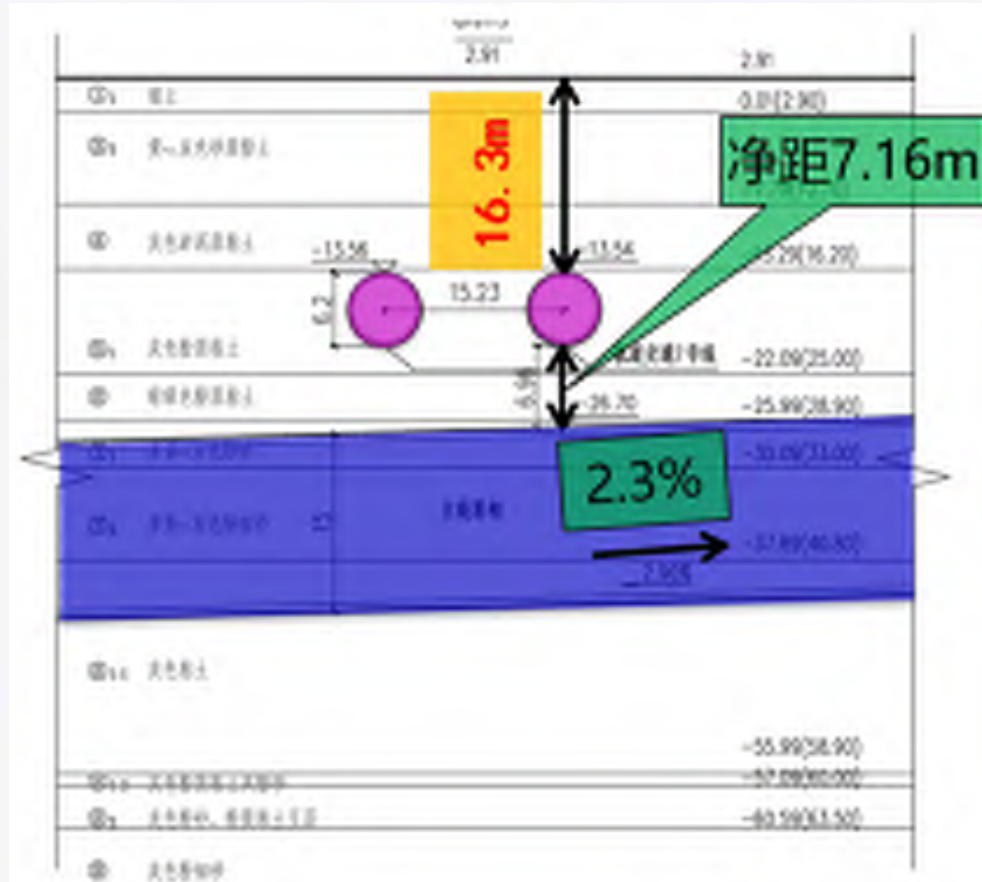
Metro Line 11



At Junction of Changning Road & Jiangsubei Road of Metro Line 11



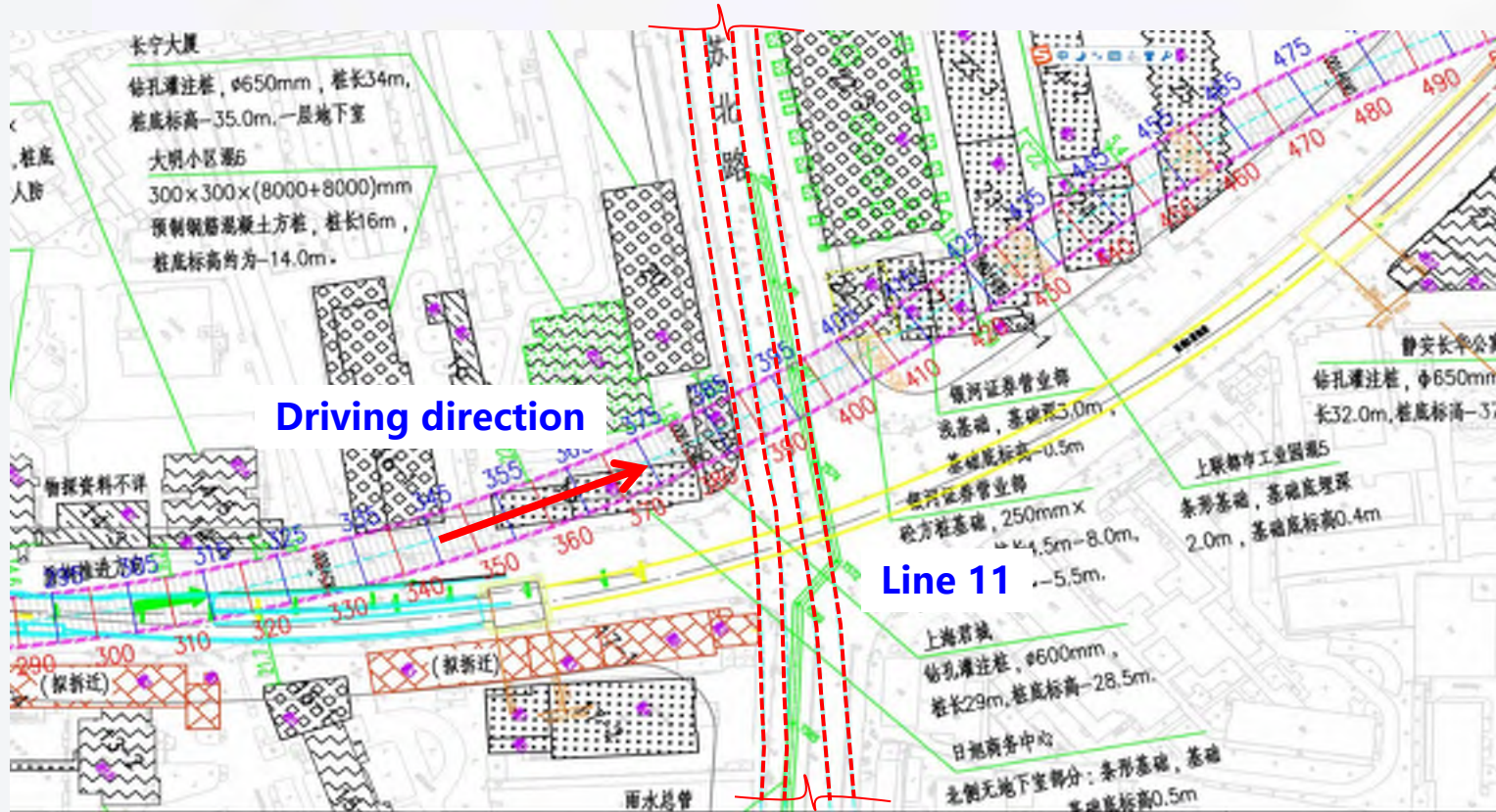
Metro Line 7



At Junction of Changde Road & Xinhui Road of Metro Line 7



Under-crossing Line 11



The Cutterhead is at ring No. 381, and Tailskin leaves at ring No. 402. Thus the influence range is from Ring 381 to Ring 402 (22 rings in total).



Under-crossing Line 11

	Description	Advantages	Disadvantages
Option 1: Intermittent driving	Stopped during daytime when the metro is operating	Guarantee the safety of subway operations	<ul style="list-style-type: none"> ➤ Slow advance speed: 2rings/day; ➤ Slow production rate will cause the under-crossing duration to overlap the National day, when the work must be stopped ➤ The TBM would be shut down repeatedly, which is a major risk to settlement control and to the construction management
Option 2: Continuous driving	5 rings/day, around the clock	Construction process is continuous, which is conducive to construction management and reduces disturbance	<ul style="list-style-type: none"> ➤ The metro operators are required to assess the impact on the subway according to the deformation control result and must be prepared to take corresponding preventive measures



Under-crossing Line 11

Displacement and Deformation criterion:

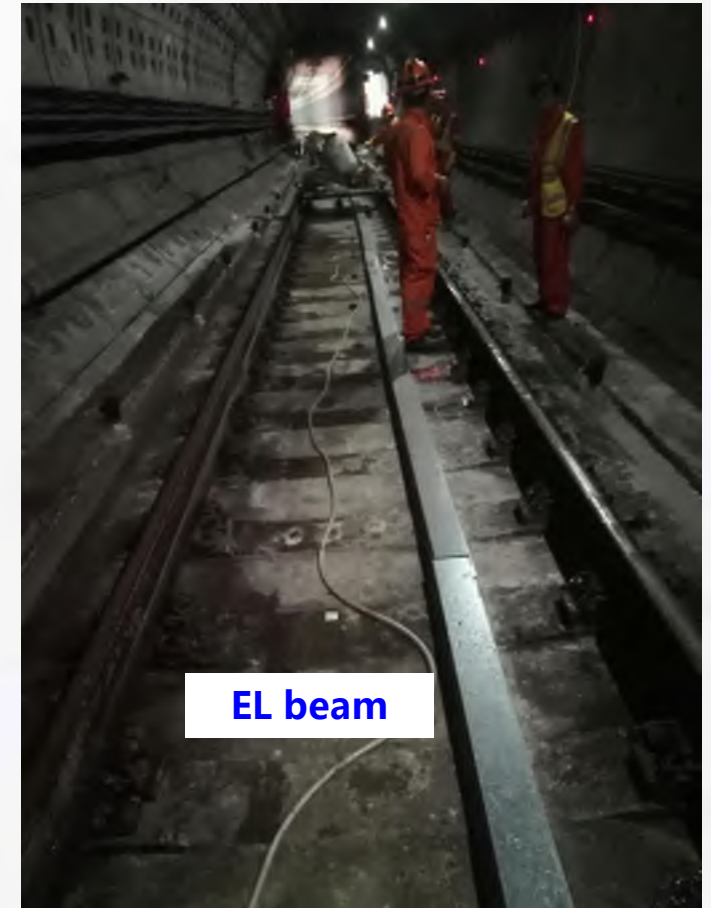
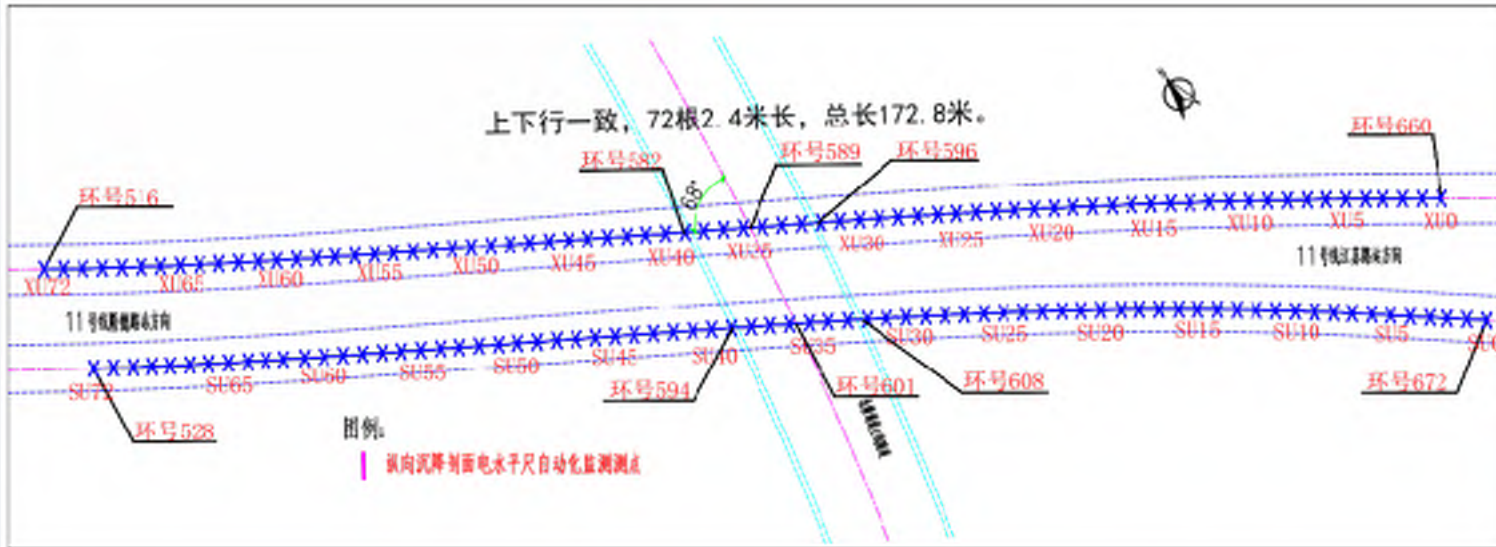
After detailed analysis, investigation and debate, all stakeholders agreed that the metro tunnel displacement and deformation control criterion is set at between -20mm to +20mm.

Construction Window:

To minimize the impact to the live metro lines, long period holidays such as 7-day national holiday or 2-days weekend was set as construction window for tunneling through the metro lines.



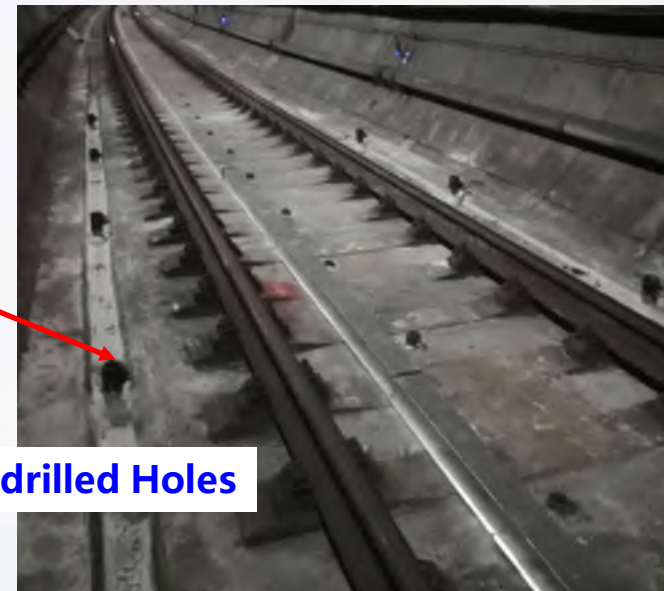
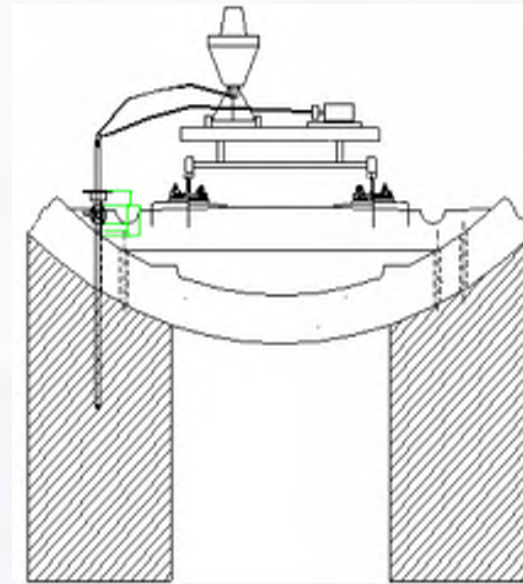
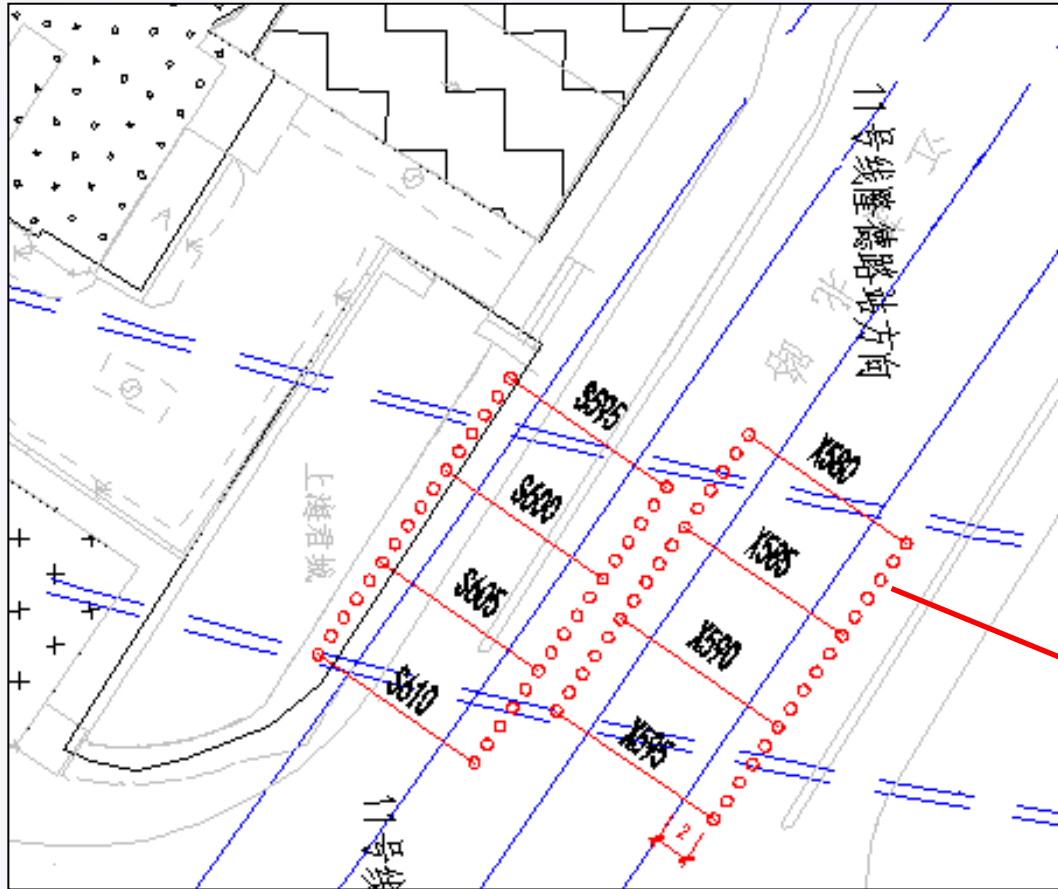
Under-crossing Line 11



Automatic monitoring include EL beam and laser convergence survey were used. Monitoring zone on the existing Metro Line 11 Tunnel is 80m from both sides of the Beiheng Tunnel centreline and cover a total length of 172m.



Under-crossing Line 11 – Contingency Measures



Pre-drilled Holes

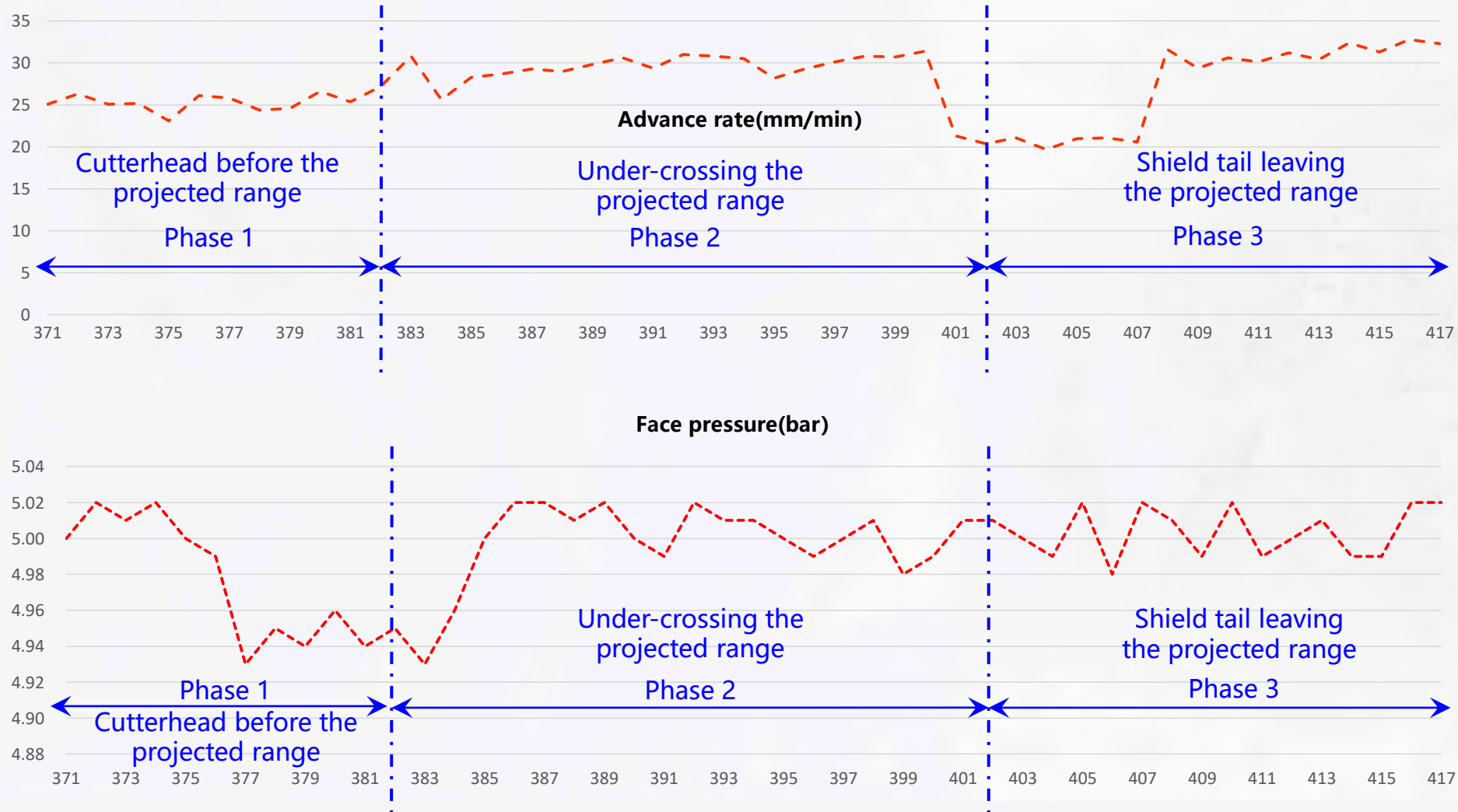


Under-crossing Line 11

Phase	Construction Stage	Ring No.	Working Condition		
			Date	Rings Completion	TBM and the Metro's location
1	Cutterhead before the projected range	371-381	13 th Nov (TUE)	2.5 (371-373)	20~14m from upline
			14 th Nov (WED)	3.5 (374-377)	15~10m from upline
			15 th Nov (THU)	4.0 (378-381)	8~0m from upline
2	Under-crossing the projected range	382-402	16 th Nov (FRI)	5.0 (371-373)	Cutterhead 0~10m beyond upline
			17 th Nov (SAT)	7.5 (387-394)	Under-crossing the upline
			18 th Nov (SUN)	7.5 (395-401)	Under-crossing the downline
			19 th Nov (FRI)	1.5 (402-403)	Shield tail 0~2m away from downline
3	Shield tail leaving the projected range	402-417	20 th Nov (TUE)	1.0 (404-404)	4m away from downline
			21 st Nov (WED)	2.5 (405-407)	6~9m away from downline
			22 nd Nov (THU)	5.5 (408-412)	11~22m away from downline
			23 rd Nov (FRI)	6.0 (413-418)	11~22m away from downline

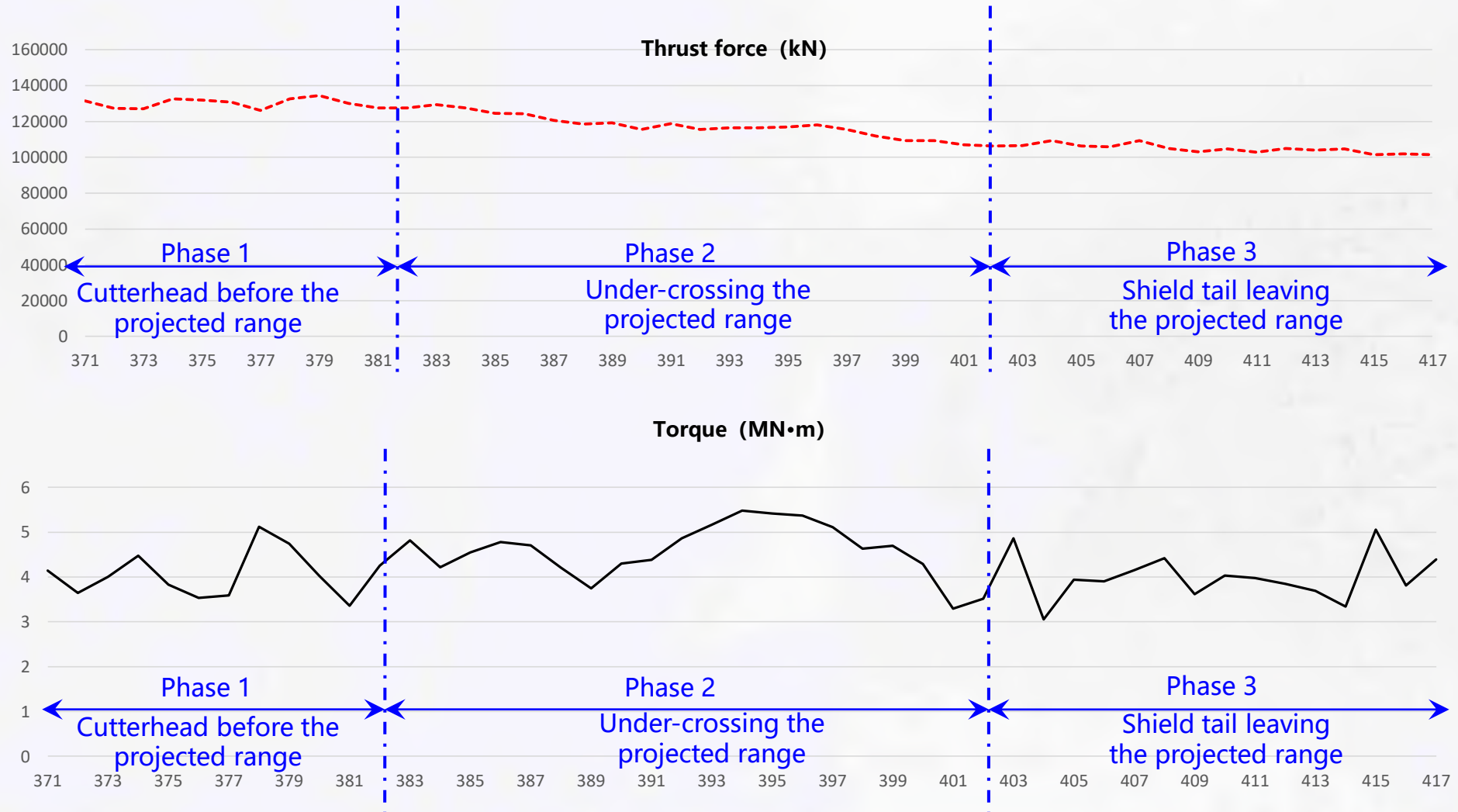


Under-crossing Line 11



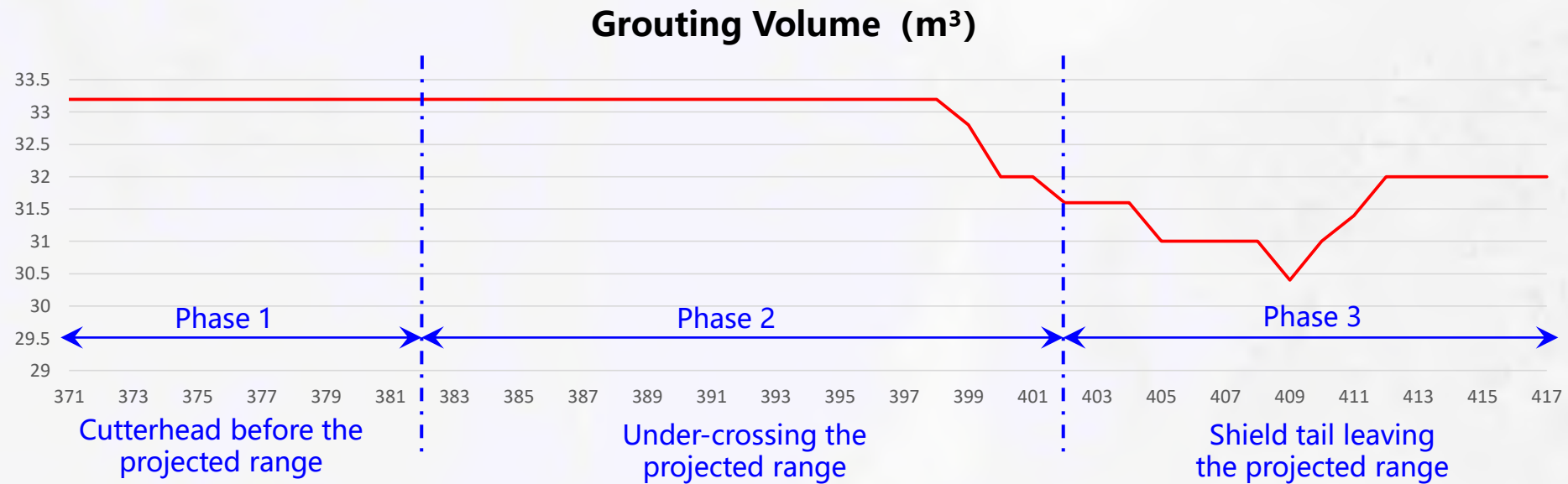


Under-crossing Line 11



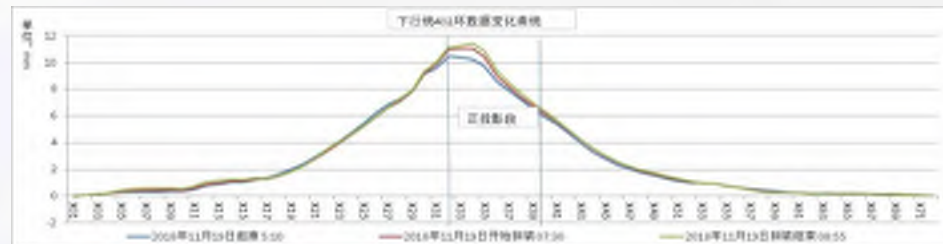
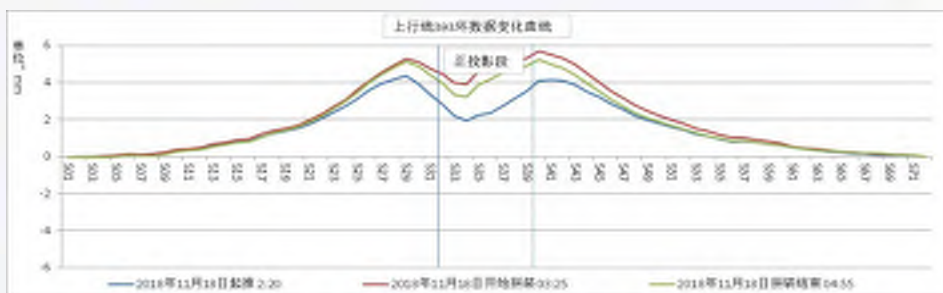
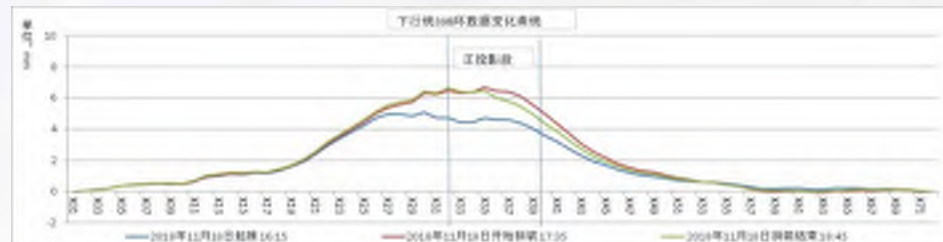
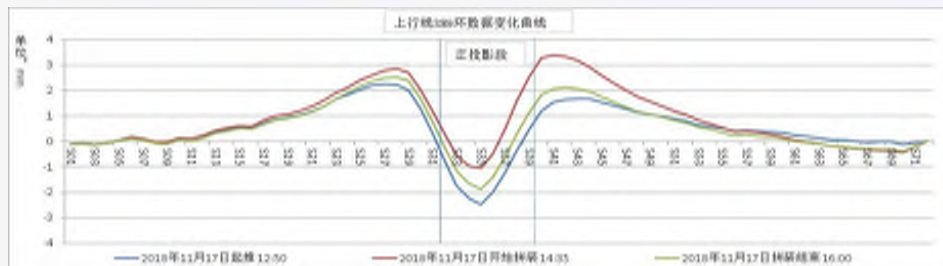
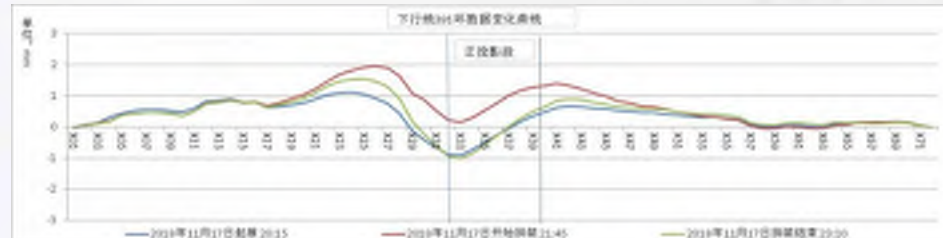
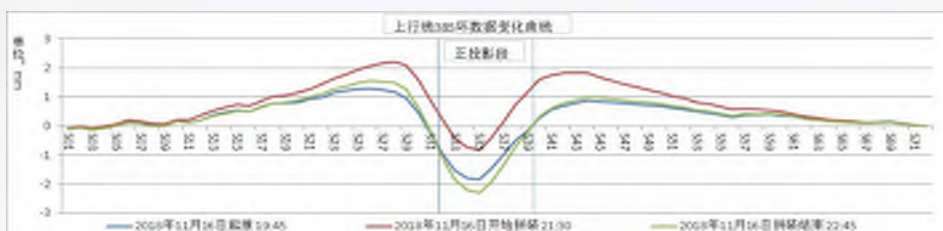


Under-crossing Line 11



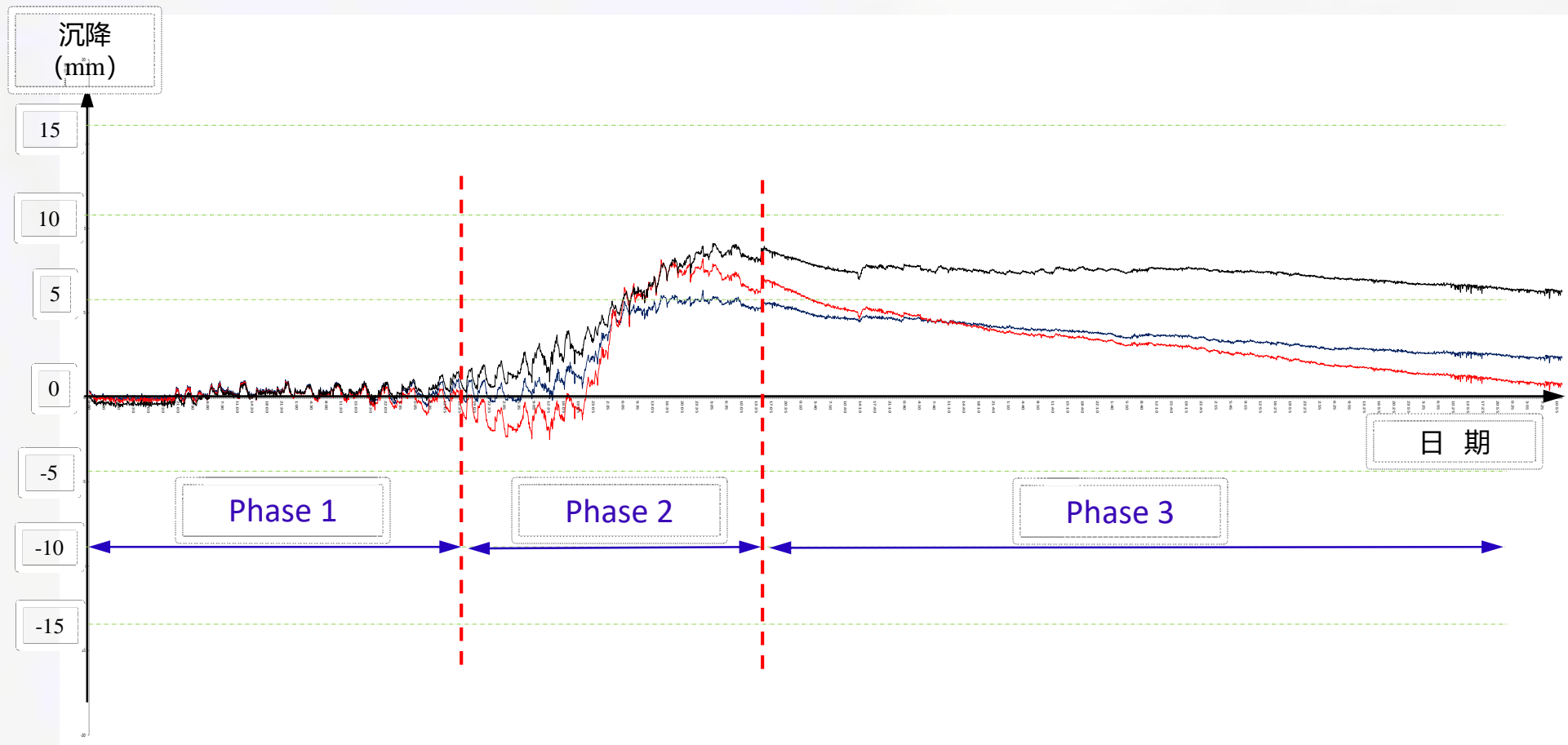


Under-crossing Line 11





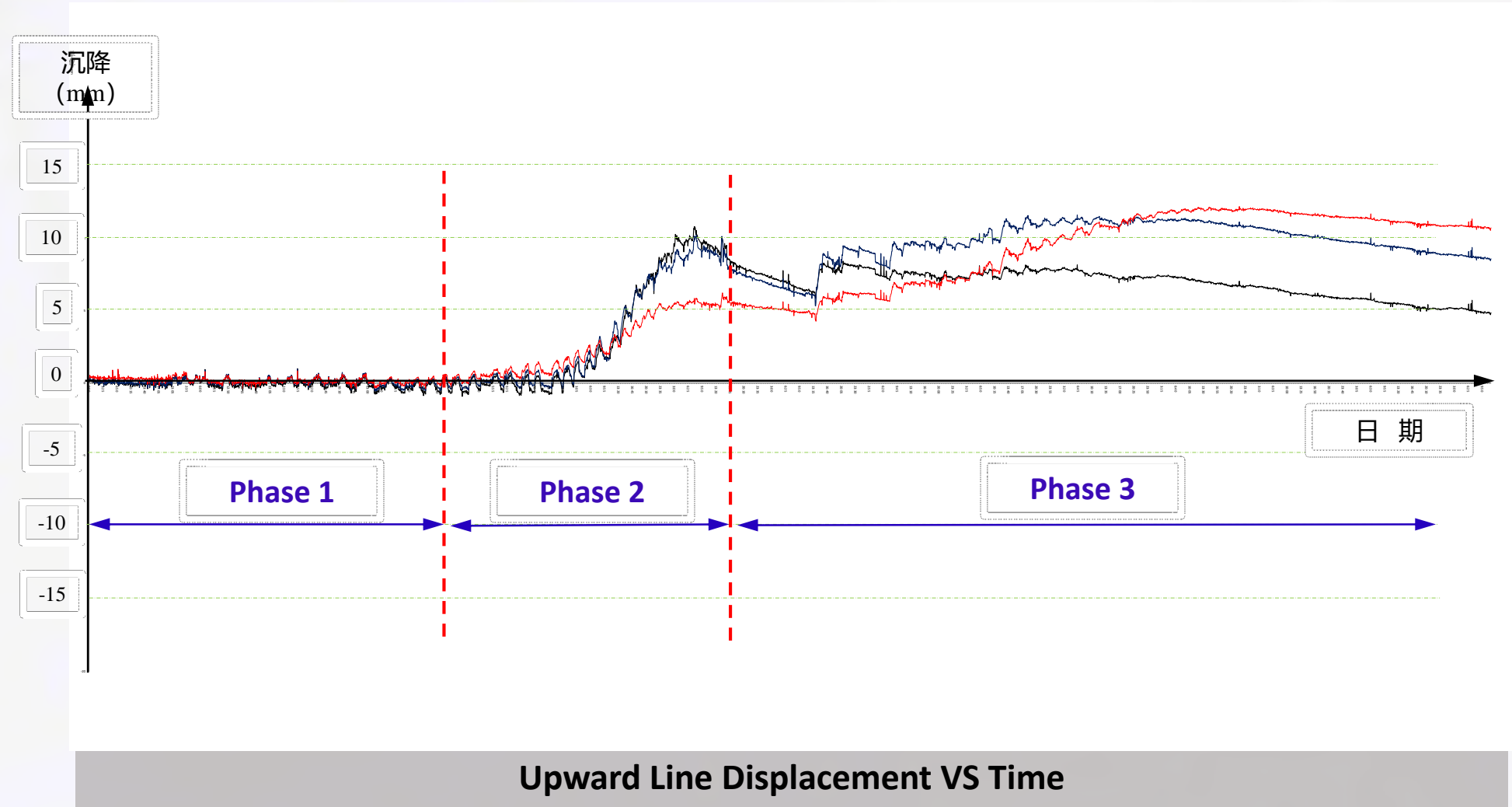
Under-crossing Line 11



Downward Line Displacement VS Time



Under-crossing Line 11





1. Project Overview

2. TBM Specifications

3. Overcoming Challenges

4. Conclusions



(1) Large Diameter Tunnelling In Urban Areas

The 15m diameter bored tunnel runs along dense residential and commercial corridor. Numerous factors like large TBM section, tunnel alignment with tight curves and stringent environmental requirements made this project one of the most challenging job.

(2) Tight Horizontal Curves

To negotiate the continuous curve sections, special design for both TBM and segment lining were considered and highly précised control measures were adopted. All the tight curve sections were completed successfully, and results proved that all the measures implemented were effective.



(3) Under-cross Sensitive Structures

- **Unprecedented challenge for the \varnothing 15m TBM to tunnel through a great number of buildings. The 89 buildings within influence zone were classified into 3 groups by risk assessment;**
- **For identified high risks category, numerous additional measure like automated monitor, early-strength primary grout and shield injection were used.**
- **To date, the TBM has successfully tunnelled through all 85 buildings within the specified values for settlement and building deformation.**



(4) Under-cross Live Metro Lines

- **Unprecedented under-crossing of ‘Live’ Metro tunnels by a 15m diameter TBM with small separation distance.**
- **The control criterion, construction window, site organization and contingency measures were intensely studied and reviewed.**
- **Making good use of two-days weekend for the TBM under-crossing and based on real time monitoring data, tunnelling parameters were constantly reviewed and revised during excavation to ensure the stability of the metro tunnels and seamless operation of the Metro lines.**



(5) Our Experience

Throughout, we have accumulated a vast amount of data and experiences. Lessons and experiences gained from this job provide a good reference for future projects such as Beiheng Expressway Eastern portion and North-South Expressway in Shanghai, or even other similar projects around the world.

STEC Completed Projects (Part 1)

No.	Name of Project	Location	TBM Tunnel Distance (m)	TBM Types	Diameter of Tunnel (OD) (m)	Year of Completion
1	Shenzhen Mawan tunnel	Shenzhen	2060×2	T.B.A.	15.5	Ongoing
2	Shanghai Beiheng Expressway package II	Shanghai	2761+3664	1 Herrenknecht Mixshield	15.0	Ongoing
3	Wenzhou Oujiang tunnel	Wenzhou	2664×1	1 Herrenknecht Mixshield	14.93	Ongoing
4	Shanghai Zhou Jia Zui Road River Crossing Motorway	Shanghai	2572×1	1 Herrenknecht Mixshield	14.93	2018
5	Shanghai Zhuguang Road Tunnel	Shanghai	1390×1	1 Herrenknecht EPBM Ex Auckland Waterview TBM	14.41	2018
6	Shanghai Yanjiang A30 Motorway	Shanghai	5090×2	2 Herrenknecht Mixshield	15.43	2018
7	Wuhan Sanyang tunnel Metro /Road and River Crossing	Wuhan	2590×2	2 Herrenknecht Mixshields	15.76	2017
8	Zhuhai Hengqin Tunnel	Zhuhai	1082×2	1 Herrenknecht Mixshield	14.93	2016

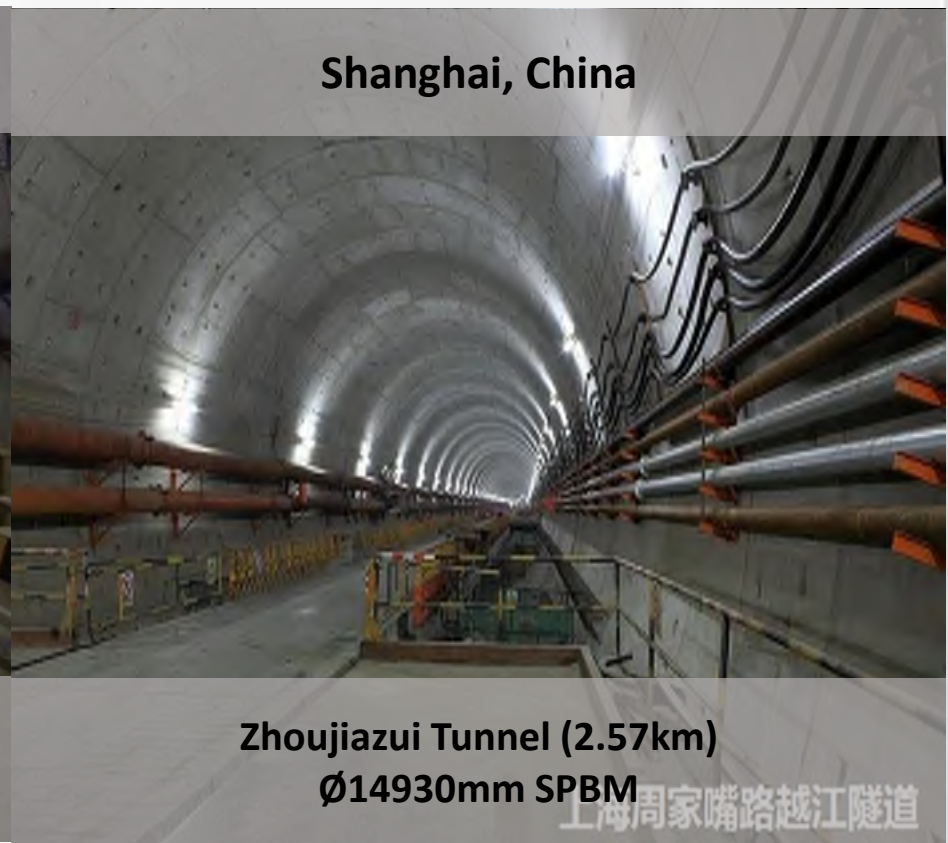
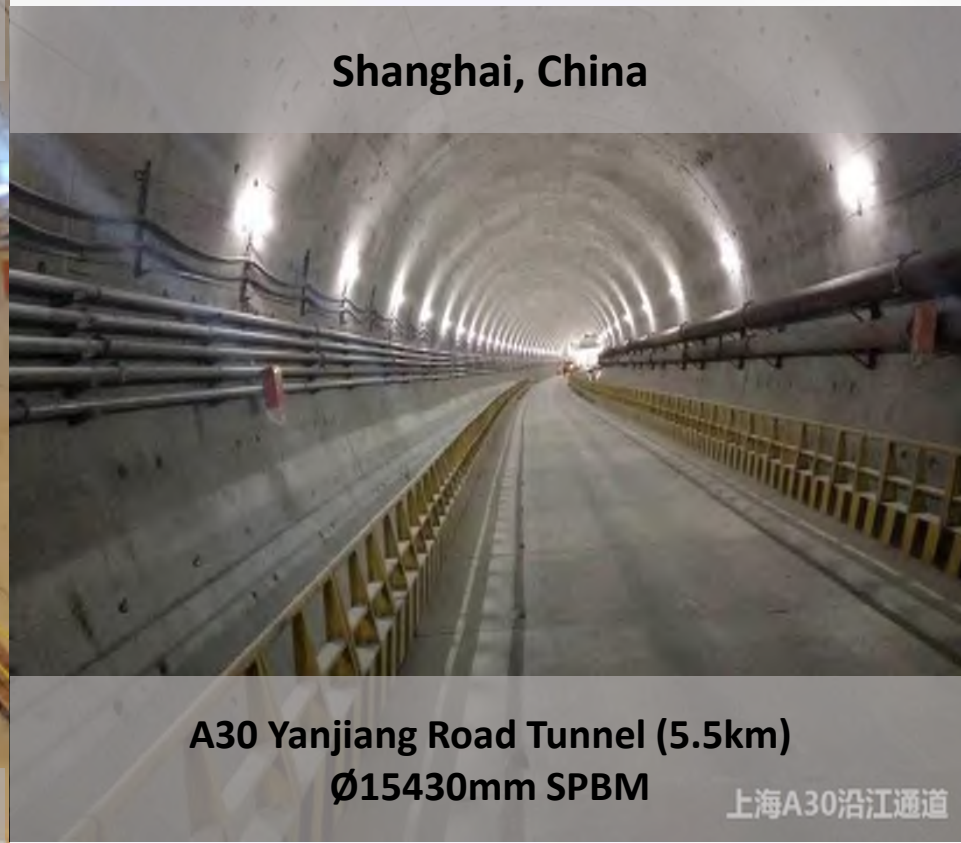
STEC Completed Projects (Part 2)

No.	Name of Project	Location	TBM Tunnel Distance	TBM Types	Diameter of Tunnel (OD)	Year of Completion
9	Shanghai West Changjiang Road Tunnel	Shanghai	1445×2	1 Herrenknecht Mixshield	15.43	2015
10	Shanghai South Hongmei Road	Shanghai	3390×2	1 Herrenknecht Mixshield	14.93	2014
11	Shanghai Yinbingsan Road Tunnel	Shanghai	1860×1	1 Mitsubishi EPB	14.27	2013
12	Hangzhou Qianjiang Under River Tunnel	Hangzhou	3251×2	1 Herrenknecht Mixshield	15.43	2012
13	Shanghai Bund Tunnel	Shanghai	1097×1	1 Mitsubishi EPB	14.27	2010
14	Shanghai Jungong Road Tunnel	Shanghai	1499×2	1 NFM Mixshield	14.87	2010
15	Shanghai Yangtze River Tunnel	Shanghai	7475×2	2 Herrenknecht Mixshield	15.43	2009
16	Shanghai Shangzhong Road Tunnel	Shanghai	1274×2	1 NFM Mixshield	14.87	2008

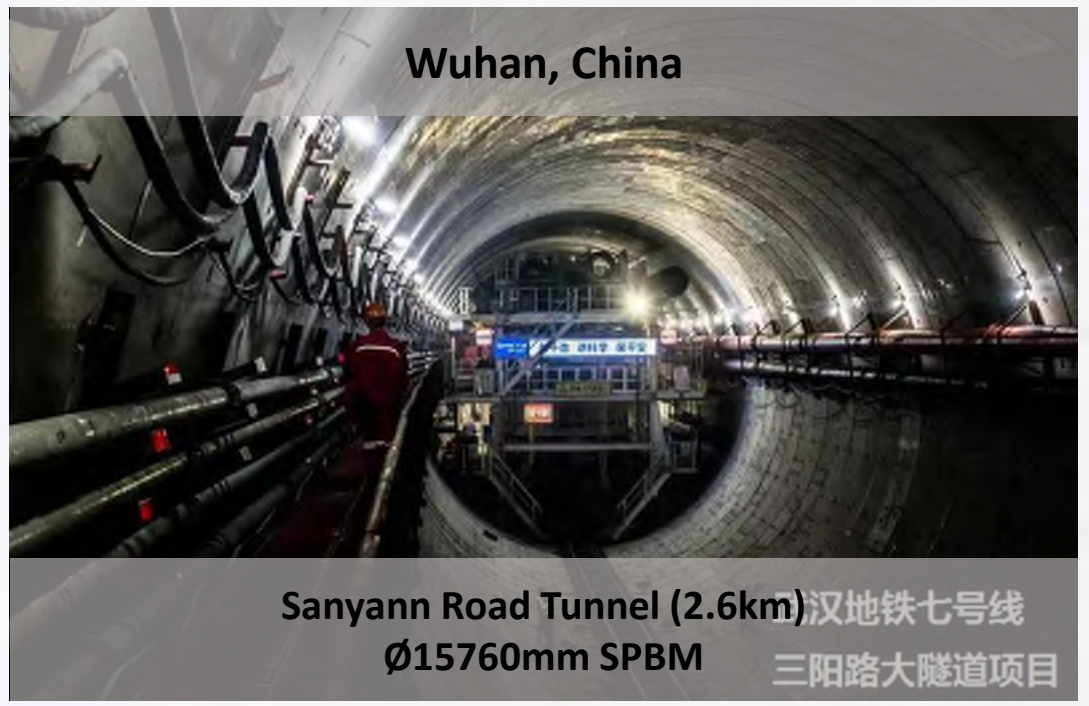
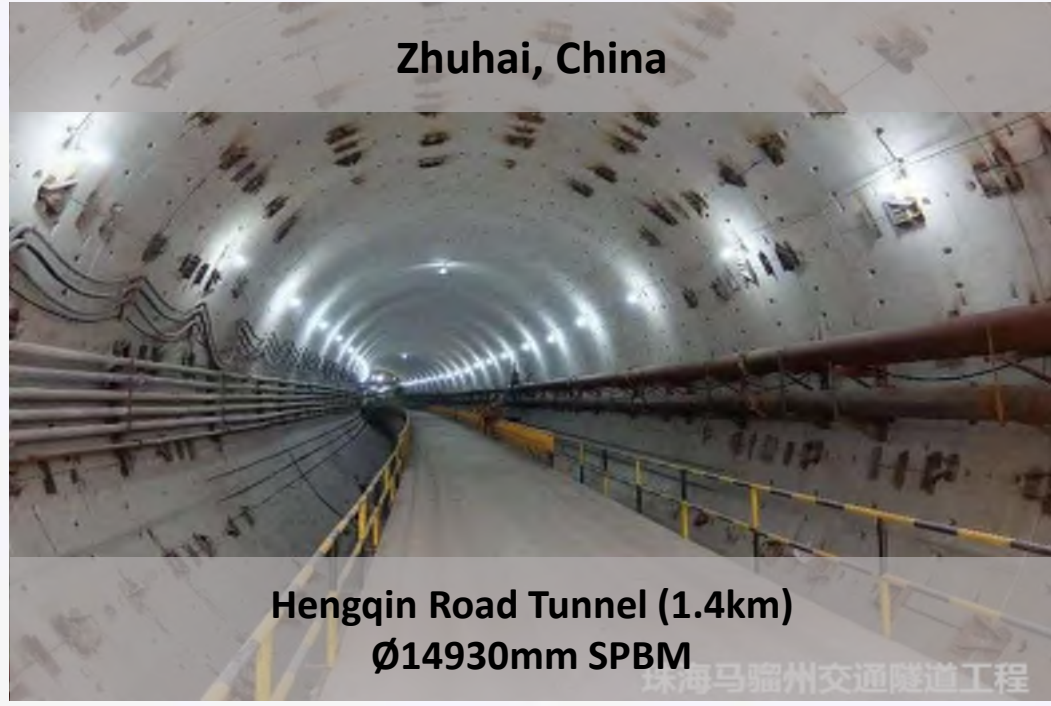
Summary of Projects to Date:

Total number of large dia. projects completed : 16
Tunnel diameters : 14.41m to 15.76m
Total tunneled : more than 67km

Large Diameter TBM Projects Completed by STEC



Large Diameter TBM Projects Completed by STEC



THANK YOU



隧道股份 上海隧道