ITA TUNNELLING AWARDS 2019

Entry Title: Intersecting and Overlapping (Twisted) Tunnel Group Construction Technology for Tianjin Metro Lines 5 and 6 Lot 1

Country: China

Submitted by: Wang Changhong

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Project Stakeholders

Name of entity	Participant	Country
Tianjin Metro Group Co., Ltd.	Hu Hao; Wang Shuxiong; Lin Feng; Song Yongzhi; Yin Xiangjjian	China
Guangzhou Metro Design & Research Institute	Zi Lijun	China
China Railway Tunnel Group Co., Ltd.	Li Jiangao; Dong Zilong; Pei Chao; Yang Yi; Liu Yonghong; He Hongyuan; Li Dong	China
Tianjin Complete Sets of Equipment Engineering Supervision Co., LTD.	Zhang Zhiwei	China

Chapter I ：Project Overview

Chapter II ： Project Challenges and Innovative Technology

Chapter III ： Project Performance Assessment

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Chapter I ： Project Overview

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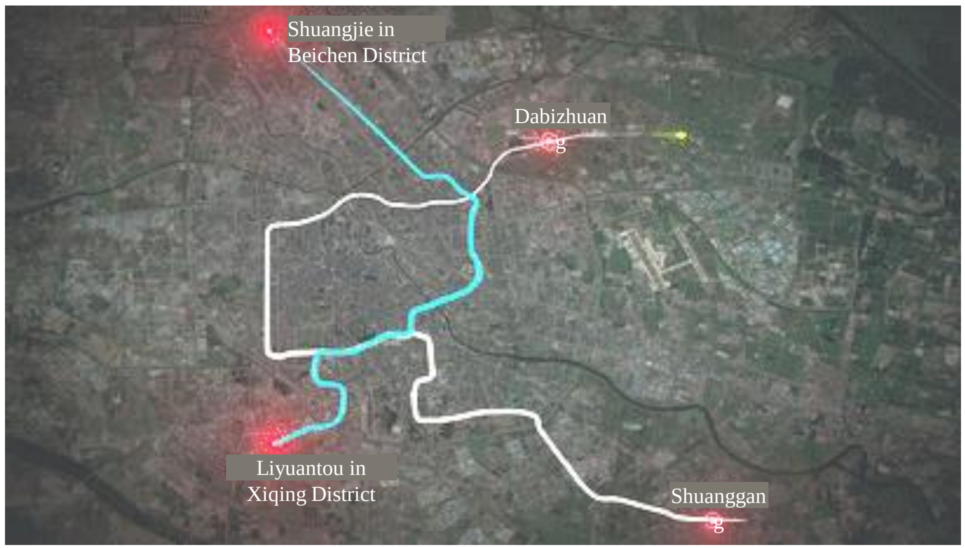
1. Project Background

As urban development accelerates there is a need for early establishment of a complete rail transit system to address urban transport issues and support urban development. The planned Tianjin rail transit network consists of 4 commuter lines (520km) and 18 urban lines (695km) totaling 1215km. Based on passenger flow characteristics, Metro Lines 5 and 6 are **combined into a loop** to facilitate the formation of a multi-center city and a complete "loop + spoke" rail network while making rail transit become the backbone mode of transport in the city proper.

2. Geographic Position of the Project



The Intersecting and Overlapping (Twisted) Tunnel Group for Tianjin Metro Lines 5 and 6 Lot 1 is arranged under Binshui Road in Nankai District as part of the parallel section of the two lines. It makes cross-platform transfer possible, thus increasing the convenience of passengers and facilitating their rapid distribution. The project was constructed in 33 months (from May 3, 2015 to December 30, 2017) at a cost of €101 million for civil works.

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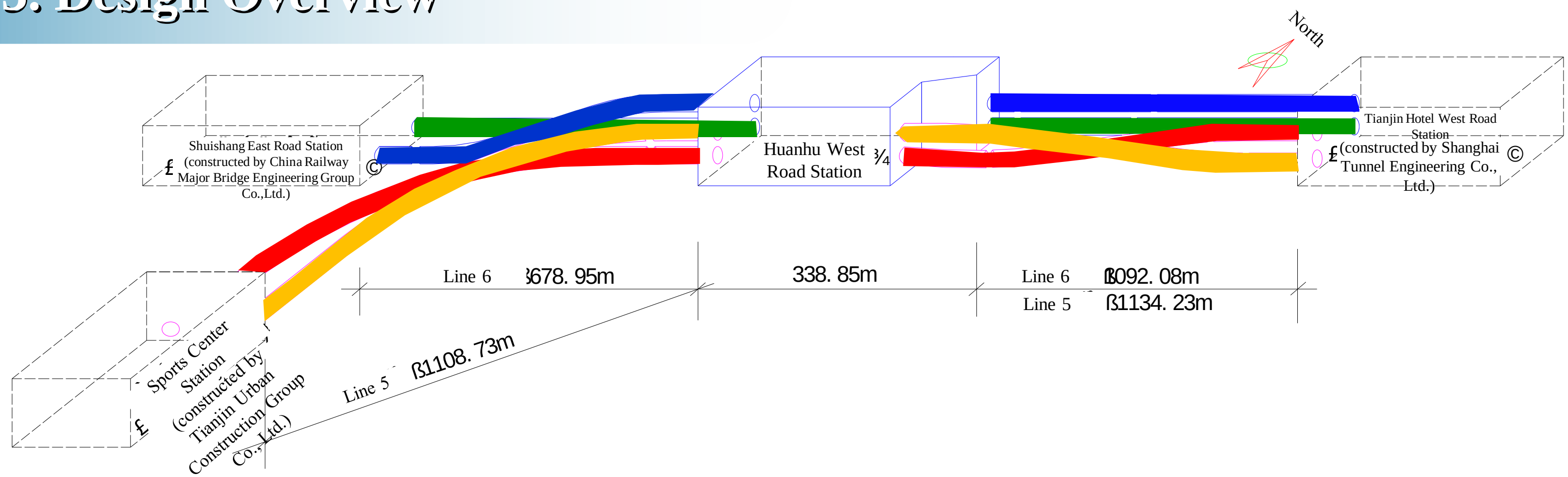
3. Design Overview

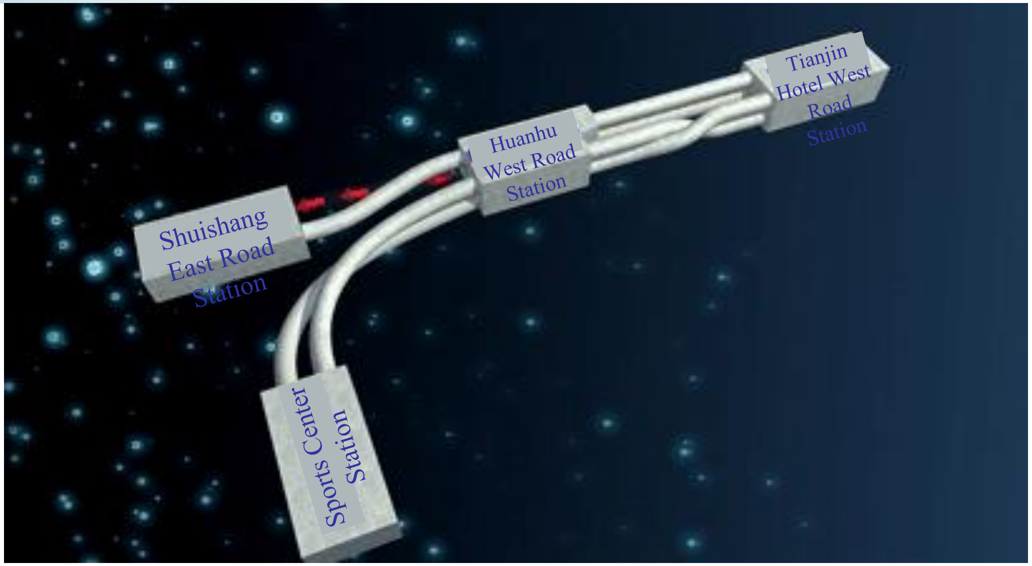


The Project includes one station and four sections. Tunnels within these sections were all constructed by TBM. They have a circular cross section with an inside diameter of 5500mm and outside diameter of 6200mm. Each tunnel is 8028m long.

After departure in parallel from Shuishang East Road Station the Line 6 tunnels within sections transition to intersecting and overlapping form when entering Huanhu West Road Station, from which they extend in a top-right-and-bottom-left configuration all the way to Tianjin Hotel West Road Station.

After departure in a top-right-and-bottom-left configuration from Tianjin Hotel West Road Station, Line 5 tunnels within sections twist and run in a top-left-and-bottom-right configuration into Huanhu West Road Station, from which they leave in a top-bottom configuration and transition to intersecting and parallel form toward Sports Center Station.

3. Design Overview



Section	Section length (m)	Length of overlapped portion(m)	Overburden thickness (m)	Maximum longitudinal gradient	Minimum radius	Minimum clear spacing(m)
Shuishang East Road Station - Huanhu West Road Station section of Line 6	678	196	6.56-10.96	21.9‰	350m	1.9
Huanhu West Road Station – Sports Center Station section of Line 5	1108	174	7.95-16.75	24.6‰	300m	1.9
Huanhu West Road Station - Tianjin Hotel West Road Station section of Line 6	1092	1092	8.45-11.1	8.5‰	400m	1.9
Tianjin Hotel West Road Station - Huanhu West Road Station section of Line 5	1134	196.4+225.2=421.6	10.05-20.01	25.5‰	400m	1.9

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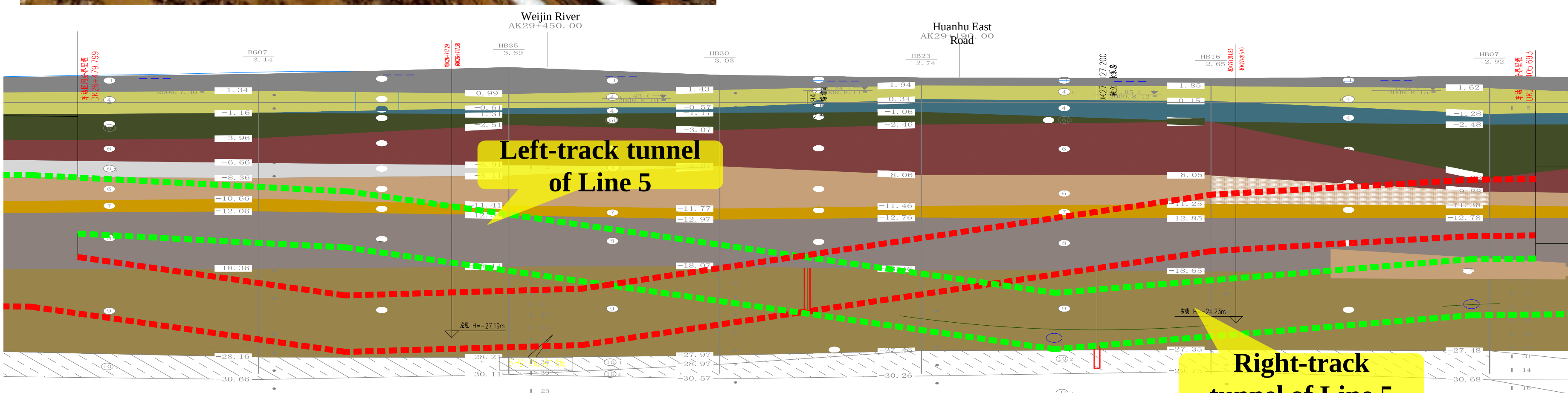
4. Hydrogeololgy

The tunnel group pass through silty clay and water-rich silt and silty sand strata.

Groundwater in these layers is pore-phreatic water mainly contained in layers ④ and ⑥ and recharged by atmospheric precipitation and surface water. Its static water table is at 0.9-4.8m depths and varies in a range of 0.5-1m annually.



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5. Surrounding Buildings/Structures

The Intersecting and Overlapping (Twisted) Tunnel Group passes up to 28 surrounding buildings, which are mostly multi-storey, shallow foundation residential buildings constructed in the 1970s, the closest one just 0.6m away. In particular, the CT room of a tumor hospital and Yuxianli Residential Building at the launch site at Huanhu West Road Station have low resistance to deformation but have to experience 5 disturbances from station and tunnel construction.

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Chapter II: Key Technical Innovation

1. Project Significance

Located in a well-established block in the city of Tianjin, the Project has to handle high passenger volumes from 100,000 permanent residents nearby, a tumor hospital serving 3,000 patients a day from the entire North China, the Sports Center (with a seating capacity of 60,000) which hosts large events frequently and the Cultural Center -- the largest public cultural facility in Tianjin integrating urban garden, citizen recreation center and youth activity venue. This places a greater demand on metro travel convenience, lower transfer rate and rapid distribution of high passenger volumes on a routine basis.

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1. Project Significance

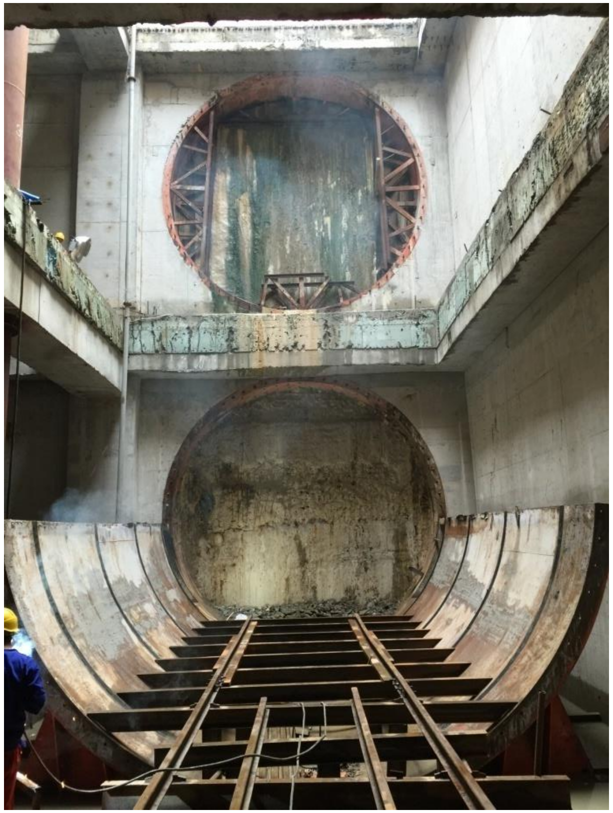
Binshui Road is a narrow street in the old urban area of Tianjin where four tunnels arranged side by side would have unavoidably involved a high cost of building demolition. To save cost and reduce occupation of urban land, 8 tunnels within four sections in this area are designed as intersecting and overlapping (twisted) tunnels. Most important, this design enables cross-platform interchange, thus increasing metro travel health index, passenger convenience in transfer between lines and the ability to quickly distribute high passenger volumes on a routine basis.

2. Challenges

Challenges

- Multiple launches and arrivals of TBMs at the same end in weak ground and artesian aquifer
- Complex alignment, small clear spacing, long distance, small radius and thin overburden of the tunnels
- Mutual construction interference between overlapping and intersecting (twisted) tunnels
- The safety of old buildings/structures in close proximity would be affected by superimposed settlement when the tunnels pass them.
- How to minimize micro resonance effect between overlapping tunnels during operation

3. Key Technical Innovation - small and medium clear distance and multiple launches and arrivals in water-rich strata



Both launch and arrival ends of the tunnels are in artesian aquifer. The clear distance between the tunnels is merely 1.9m. There are extremely sensitive old buildings nearby, which have to experience 4 disturbances from TBM operation while limiting their settlement to 10mm. The same end needs to experience 4 launches at the risk of inflow. Water/mud burst risks during launches and arrivals at portals need to be addressed.

3. Key Technical Innovation - short steel box and steel casing

To ensure launch safety the effectiveness of launch and arrival end reinforcement was inspected and weak areas were additionally reinforced with large-diameter jet grouting piles. All launches at basement level 2 were performed using a short steel box; all launches at basement level 3 were performed using a steel casing. This put the TBM in a closed enclosure before launch. A novel filling material was employed to solve problems of launch seepage and TBM torsion. Spacer bars were used to prevent falling of segments in the steel casing.

3. Key Technical Innovation - innovative construction technology for closely spaced, overlapping and intersecting tunnel group

The minimum clear spacing of the overlapping and intersecting tunnels is about 1.9m. TBM operations in the water-rich and weak strata exerted superimposed disturbances on surrounding ground, leading to its plastic deformation and failure. This might cause settlement and deformation of completed tunnel structure, existing buildings/structures and ground surface. Meanwhile the simultaneous construction of closely spaced tunnels might lead to a host of problems such as variation in internal force and resonance between tunnels.

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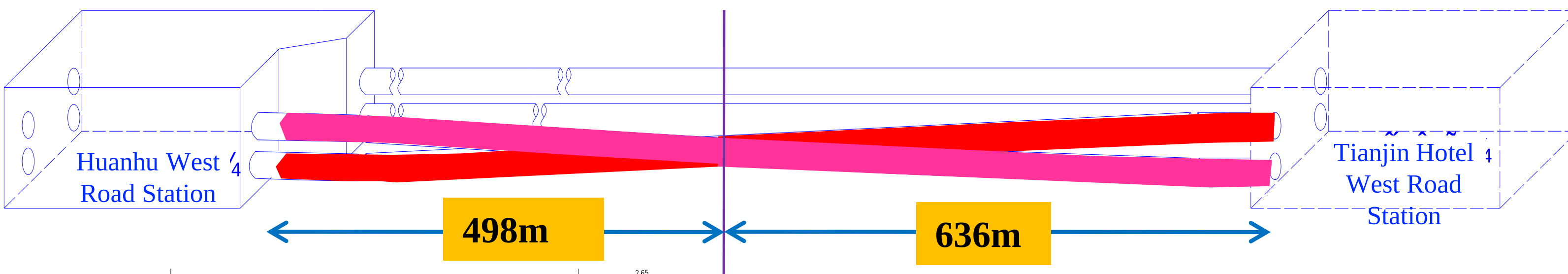
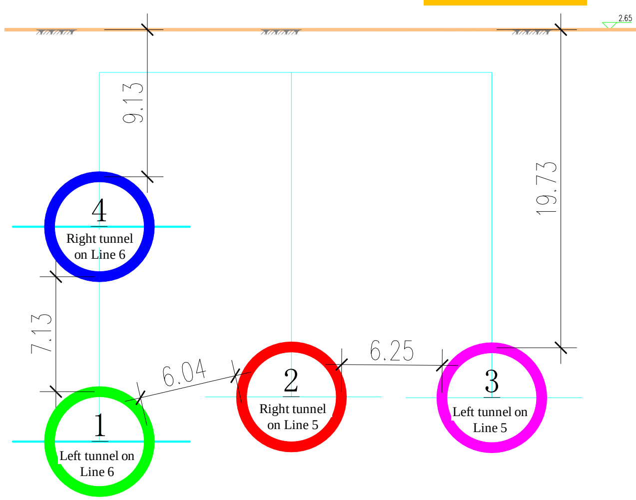
3. Key Technical Innovation - construction organization





Using ANSYS (finite element software) and FLAC3D (numerical modeling software for geotechnical analyses of soil and rock) two construction sequences, namely top before bottom and bottom before top, were simulated and analyzed. Based on the analysis result the "bottom before top" construction sequence was selected. With Huanhu West Road Station - Tianjin Hotel West Road Station section of Lines 5 and 6 as an example, the construction organization is as follows:

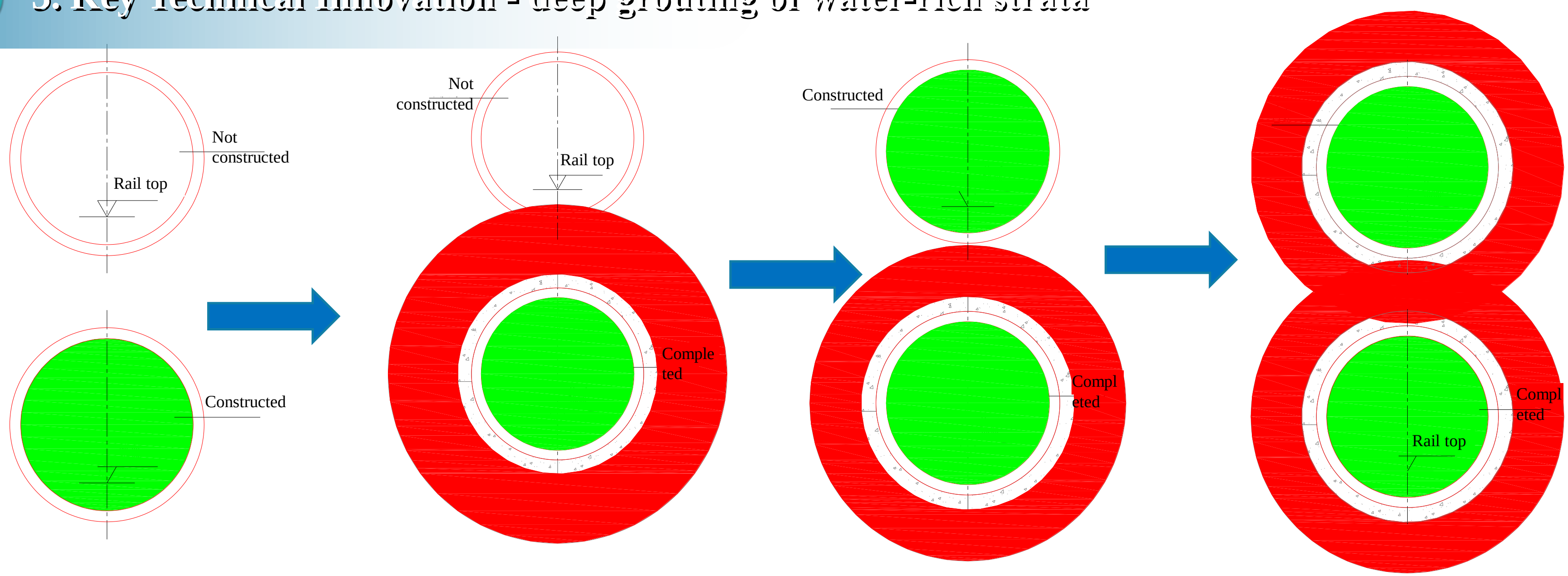
◆First of all, construct 1# tunnel for the left track of Line 6.

◆Second, simultaneously construct left and right tunnels from the ends toward the middle for Line 5 in Huanhu West Road Station - Tianjin Hotel West Road Station section. Construction of the right tunnel of Line 5 needs to start in advance so as to ensure the left and right tunnels reach the middle point at the same time.

◆Last, construct the right tunnel (4# tunnel) for Line 6.

◆To ensure 2# and 3# TBMs reach the intersection point at the same time, 3# TBM should be launched 15-20d ahead of 2# TBM.

3. Key Technical Innovation - deep grouting of water-rich strata



Step 1: Construct bottom tunnel.

Step 2: Perform full-face grouting on bottom tunnel.

Step 3: Construct top tunnel.

Step 4: Perform full-face grouting on top tunnel.

Full-face grouting was performed on top and bottom tunnels in the overlapping section to reduce tunnel deformation. The strata to be grouted are located in an artesian aquifer and susceptible to water inrush when drilling holes. In addition the reinforcement scope shall be strictly controlled during grouting to avoid interference with advancing the follow-up tunnel and damage to the completed tunnel. This problem was solved by applying hole head sealing technique and precision grouting control technique.

3. Key Technical Innovation - intelligent supporting carriage

Prior to construction of the top tunnel, the bottom tunnel was supported using a movable carriage for a length from 15m ahead of the cutterhead to 30m beyond the shield tail. During construction of the top tunnel the movable carriage moves in tandem with the TBM in the top tunnel, providing passive support to crown and in tight contact with segments.

- Resist the shear force between segment ring joints of top and bottom tunnel due to vertical dislocation during construction of the follow-up tunnel;

- Distribute loadings on the bottom tunnel more evenly to increase its bearing capacity and reduce its vertical bending deformation;

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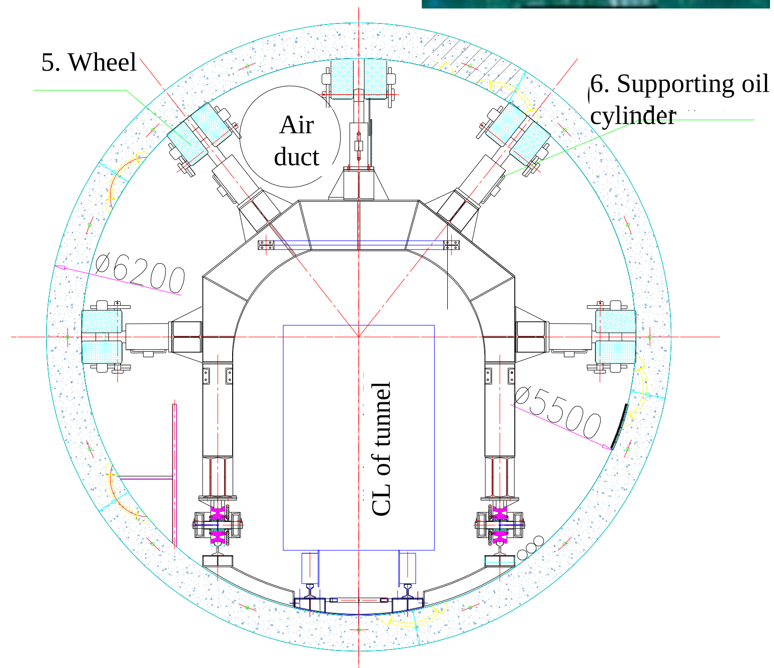
3. Key Technical Innovation - intelligent supporting carriage



The intelligent supporting carriage is composed of 5 wheel-type arms. The supporting points avoid longitudinal joints and manholes. The arms are hydraulically operated. The carriage performs the following functions:

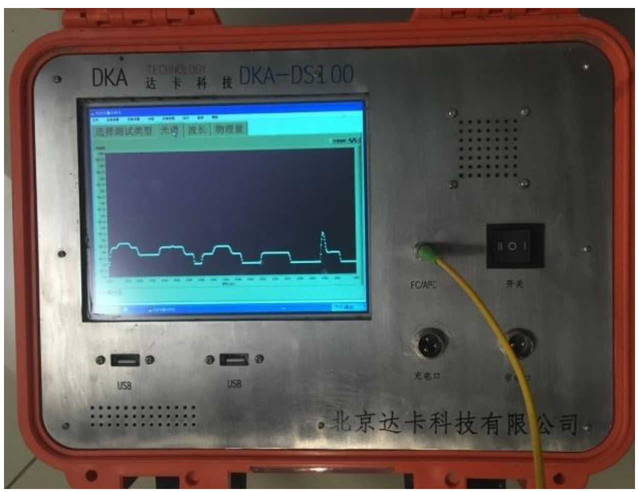
1. Self-propelled movement along the rails in tandem with advance of the top tunnel.
2. Ensure normal construction conditions for the bottom tunnel.
3. Adjust the supporting axial force depending on external force and tunnel deformation and move forward without unloading force.

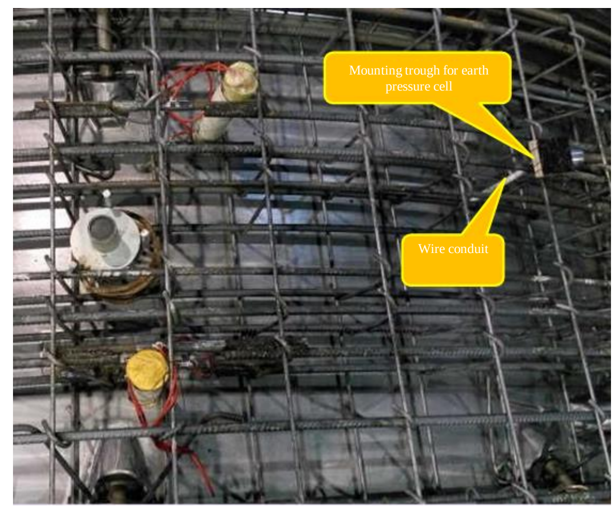
3. Key Technical Innovation - simultaneous construction of top and bottom tunnels

The Project had a very tight schedule that required 8028m of tunnels be completed in 10 months. To achieve this the top and bottom tunnels must be constructed simultaneously. Through reasonable arrangement and orderly connection of the processes and application of associated smart supporting carriage and movable platform for erection, synchronous construction of the top and bottom tunnels was realized, and efficient advance of the tunnels by TBM was accomplished.

3. Key Technical Innovation - intelligent monitoring measurement

When constructing and grouting overlapping or side-by-side tunnels, the pressure behind segments, segment joint stress and internal force in segments were monitored by fiber grating strain gauges, earth pressure cell, steel bar stress gauge and other instruments installed in the completed tunnel for timely optimization of construction parameters based on monitoring data.





3. Key Technical Innovation - innovative protection technology for building group in close proximity and subject to repeated disturbances

There are many residential buildings surrounding the tunnels, the closest one only 0.6m away. These buildings are mostly brick-concrete structures with strip foundations and have extremely poor resistance to deformation but had to experience disturbances from construction of the station and 4 tunnels. This made settlement control very difficult. During construction by TBM excessive heaving/settlement of ground surface, building tilting and cracking might cause adverse social impact.

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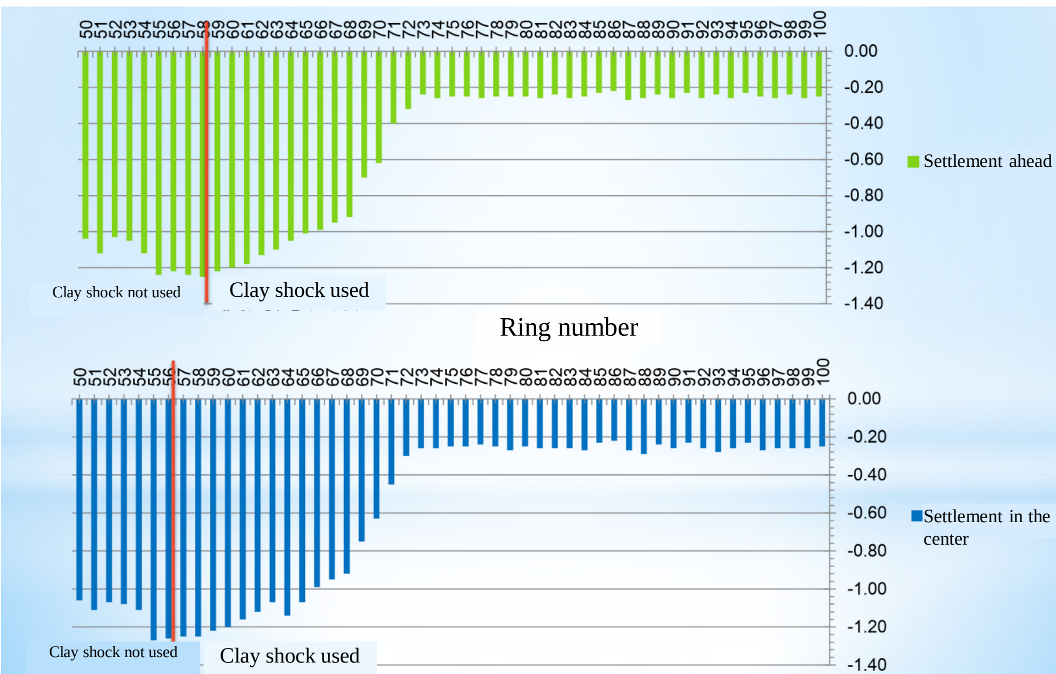
3. Key Technical Innovation - novel filling material

To ensure the safety of buildings and control settlement over the TBM when the tunnel passes old buildings, a novel filling material was injected through reserved grout holes in the TBM body. This material has better waterproofing and flow plastic properties than ordinary material, with adjustable hardness and is injected using specialized equipment that can control pressure in real time.



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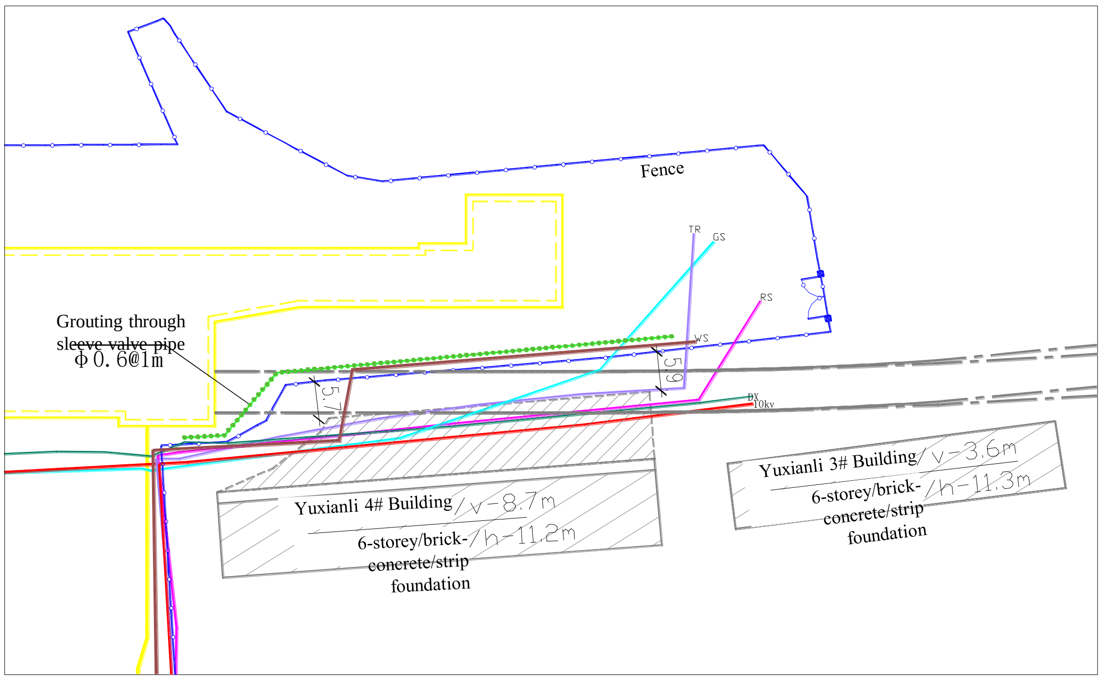
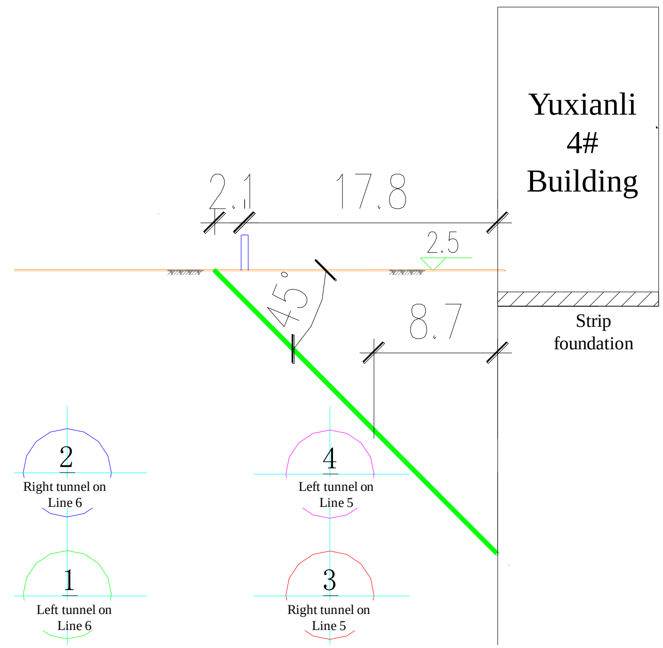
3. Key Technical Innovation - pre-grouting technique





Critical buildings/structures along the line were pre-grouted prior to construction and grouted during construction based on monitoring data.

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3. Key Technical Innovation - remote monitoring

An information-based construction philosophy was put into full effect by providing visualization equipment in the tunnels and uploading real-time data and monitoring result via internet to remote monitoring platform. In case of any anomaly the monitoring platform will automatically send information to relevant management personnel for quick response.

3. Key Technical Innovation - environmental protection technique

A green worksite concept was fully implemented. All exposed ground surfaces were sodded or covered. Monitoring devices were provided at critical locations of the construction site in conjunction with other means to control fugitive dust and address environmental pollution. The ground surface was cleaned using street-sweeping car with mist spray function to effectively prevent the generation of fugitive dust when cleaning pavement.

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Chapter III : Project Performance Assessment

1. Performance of Project Execution

(1) The use of movable supporting platform in lieu of temporary steel support enabled simultaneous construction of top and bottom tunnels, accomplished an advance rate of 1238m/month by two TBMs, reduced construction duration by 10 months and saved €536,000.

1. Performance of Project Execution

(2) Tunnel axis deviation was kept within 20mm and tunnel deformation maintained within 10mm. TBM constructed sections were safe, dependable and of high quality;

1. Performance of Project Execution

(3) During construction the settlement of surrounding buildings/structures was kept within 20mm. The accumulated settlement was kept within 5mm and deformation within 3mm after two years of tunnel operation.

1. Performance of Project Execution

(4) Since the tunnels became operational the Huanhu West Road Station has handled an average daily volume of 1,289,600 passengers and up to 167,400 interchange passengers in rush hours.

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2. Honors and Achievements

(1) Won Tianjin Quality Project Award.
(2) Obtained one construction method certified by Tianjin City and another certified by Guangdong Province.
(3) Granted 8 invention patents and 2 utility model patents.
(4) Applying for State-level Scientific and Technological Progress Award (the application is ongoing because the Project was completed just recently)

Certificate of Honor

津建协(结构)17405/418

天津地铁5、6号线工程文化中心部分第1合同段（5号线宾馆西路站–环湖西路站盾构区间）

该工程经企业自愿申报，协会组织专家严格评审，监督部门审核同意

通过2017年度天津市建设工程“优质结构评价”

承建单位：中铁隧道集团有限公司　　项目经理：马宏建

建设单位：天津市地下铁道集团有限公司

监理单位：天津市成套设备工程监理有限公司

特发此证

天津市建筑施工行业协会

2018年3月

Document from Tianjin Municipal Commission of Housing and Urban-Rural Development

JJK [2018] No. 550

Tianjin Construction Committee Notice on Announcing Municipal-level Construction Method in Urban-Rural Development in Tianjin

滨海新区建交局、各区建委、海河教育园经建局、各集团（总）公司、各有关单位：

按照《工程建设工法管理办法》（建质〔2014〕103号）规定，结合我市城乡建设发展实际，我委组织开展了2018年天津市城乡建设领域市级工程建设施工工法申报和评审工作。经企业申报、专家评审和公示，确定2018年市级工程建设施工工法65项，现予以公布。

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ITA AITES Miami, USA 18th November 2019

China Railway Tunnel Group Co., Ltd.
Intersecting and Overlapping (Twisted) Tunnel Group Construction Technology

3. Conclusion

1. Innovative design philosophy

The ingenious design of overlapping and intersecting (twisted) tunnels solved the planning problem in confined underground space in a busy urban setting and enabled cross-platform interchange between metro lines, thus increasing the convenience of passengers and facilitating their rapid distribution.

2. Innovative construction technology

Through development and application of comprehensive construction technology a series of solutions for construction of closely spaced tunnels in weak strata were offered to effectively address multiple launches and arrivals in water-rich, weak ground; control of old building/structure settlement under multiple disturbances; and mutual construction interference between closely spaced intersecting (twisted) tunnels. The feasibility of closely spaced intersecting (twisted) tunnels design was verified.

3. Significant social benefit

By avoiding the impact of land requisition and demolition the Project construction did not cause any adverse effect on surrounding residents. The ingenious design of intersecting and overlapping tunnels reduced land requisition by 8,900m² and saved €107,000,000 in investment, eliminating uncertainties during land requisition and demolition and yielding good social and economic benefits.