Technology on Settlement Control of Large Diameter Shield Traversing Closely Beneath High-pressure Gas Pipeline for Metro Tunnel

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Abstract. Taking the project of sectional tunnel traversing closely beneath high-pressure gas pipeline on Weiqing Line between Xinglong Station and Tianfuxin Station in Chengdu Metro Line 18 for an example, the technology controlling the settlement is studied. Based on the reinforcement isolation grouting with inclined boreholes, driving control parameters of shield and grouting behind the sectional tunnel lining with deep holes, the control technology on the large diameter shield passing closely beneath high-pressure gas pipeline is established for metro tunnels. The application of this technology controls the settlement of high pressure gas pipe within - 4mm, less than - 5mm, which verifies the practicability of this technology. At the same time, it greatly improves the stability of pipeline, guarantees the safety of pipeline operation, and provides the reference for similar projects in the future.

Keywords: Metro; Sectional Tunnel; Large Diameter Shield; High-pressure Gas Pipeline; T Settlement Control.

1. Introduction
With the development of urban subways in China, the geological and environmental conditions are becoming more and more complex. For example, the section from Heshan Road Station to Suzhou Leyuan Station on Suzhou Line 3 encounters a soft upper and lower hard composite strata[1], Beijing Metro Line 14 Section 03 It is a double-hole single-line mining tunnel underneath the existing pipe corridor section of the mid-line of the South-to-North Water Transfer Project that has been built and operated [2], and the shield section of Nanjing Metro Line 1 underneath the large underground structure of the Xuanwu Lake municipal road tunnel in small intervals[3][4]. Moreover, there have also been cases where subway lines cross each other and the subway underpasses the high-speed rail. For example, the section between Jinjihu West Station and Dongfangzhimen Station of Suzhou Metro Line 3 underpasses Line 1 project [5], Shenzhen Metro Line 7 Sungang The section between the station and
Honghu station adopts overlapping shield tunnels to pass through 26 strands of the Guangzhou-Shenzhen high-speed railway [6]. Measures must be taken to control the settlement of the operating line to ensure the safety of the line during the underpass construction period.

The shield in the section between Xinglong Station and Tianfu New Station of Chengdu Metro Line 18 passes under the high-pressure gas pipe Weiqing Line at a close distance, with a pressure of 4MPa and a clear distance of 5.2m. The Weiqing line was constructed by cut-and-cover and backfilling. The soil around the pipeline is soft. The large-diameter shield in the subway section tunnels underneath the pipeline at a short distance and disturbs the surrounding soft soil, causing a large amount of settlement, leading to cracking, leakage, and even explosion. Diameter shield tunneling has extremely high safety risks in construction underneath, and effective settlement control measures must be taken for the high pressure gas pipe.

At present, there are not many researches on the construction control measures of shield tunneling through high-pressure gas pipes in China: Huang Lei used finite element software to analyze the disturbance influence of Shenzhen subway shield tunneling through LNG high-pressure gas pipes, and put forward effective and reliable measures to ensure Construction safety[7]; Tang Yanmei et al. proposed measures to control ground subsidence to reduce the deformation of high-pressure gas pipelines and ensure safety [8]; Zhang Zhuqing passed the specification for the shield machine under the high-pressure gas pipe in the water-rich silt sand formation. The combing, theoretical calculations and case analysis of the subway shield tunnels summarized the distance requirements for the subway shield tunnel to pass through the high-pressure LNG pipeline and the settlement control standard calculation formula that is consistent with the actual construction level [9]. Zhou Jun took the Shanghai Hongbei South Road tunnel underpassing Jinshan-Wujing ethylene pipe as the object, introduced the setting of the tunneling parameters of the ultra-large diameter mud-water balance shield in the underpass, and verified the feasibility of the parameters through the surface settlement monitoring data [10].

At present, China has not seen any research on settlement control caused by the construction of high-pressure gas pipes constructed by undercutting and backfilling of large-diameter earth pressure balance shield machines. In order to ensure the safety of operation of the overlying high-pressure gas pipelines in the underpass construction and reduce construction safety Risk, it is of great significance to carry out research on the settlement control technology of large-diameter shield tunneling through the high-pressure gas pipe at close distance.

2. Relying engineering overview.

The shield tunnels between Xinglong Station and Tianfu New Station of Chengdu Metro Line 18, civil engineering 4, pass under the high-pressure gas pipe Weiqing Line at a short distance. The model is DN720, the pressure is 4MPa, and it is supplied to 1/3 of Chengdu. The distance between the top of the tunnel and the bottom of the tunnel is 5.2m, and the buried depth of the pipeline is 6.5m. The high-pressure gas pipe is a threaded steel pipe with a thickness of 8mm, and the outer pipe is a DN1500 concrete pipe. The stratum of the section shield tunneling is moderately weathered mudstone (5-1-3). The Weiqing line adopts open cut and backfill construction. The stratum is loose and the construction of the large-diameter shield tunneling underneath can easily cause the settlement of the high-pressure gas pipe, leading to cracking, leakage, and even explosion. Settlement control measures must be taken to ensure the safety of underpass construction.

The section between Xinglong Station and Tianfu New Station exceeds 5km. In order to ensure that the air shaft is used as the shield launching and receiving shaft during the construction period, the section is divided into 4 sections, The middle air shaft-Tianfu New Station, the left line is 2712.018m long, and the right line is 2714.291m long. Each section adopts a ZTE8600 earth pressure balance shield machine developed by China Railway Construction Heavy Industry Group Co., Ltd. The pipe keeps breathing. The inner diameter of the tunnel is 7.5m, the outer diameter is 8.3m, the thickness of the segment is 0.4m, the width of the segment is 1.8m, and the excavation diameter of the shield machine is 8.65m.
3. Settlement Control Technology of Short-distance Passing Down High-Pressure Gas Pipe

3.1. Inclined borehole grouting reinforcement isolation

(1) Drilling tilt angle

The pipeline is laid by cut and cover, and the soil around the bottom is not dense. The vertical drilling is too close to the pipeline to form a hole, and the upper part of the pipeline cannot withstand excessive loads such as drilling rigs, resulting in high operational risks. Therefore, a test drilling with a tilt angle was carried out, and the difficulty of drilling control and the hole formation rate at 30°, 45°, 60° angles were compared and analyzed, combined with the influence distance of different angles and pipelines, as shown in Table 1, the final selection The optimal 45° tilt angle.

Table 1. Parameter Comparison of Different Inclination Angle

| slope | 30° | 45° | 60° | slope | 30° | 45° | 60° |
|-------|-----|-----|-----|------|-----|-----|-----|
| rig relative distance/m | 16.6 | 9.7 | 5.5 | Disturbance range for backfill% | 46 | 56 | 80 |
| Inclined drilling length/m | 19.3 | 13.7 | 11.2 | Proportion of drilling holes in undisturbed soil% | 12 | 20 | 35 |
| Drilling disturbance backfill distance/m | 2.3 | 2.8 | 4 | Pass rate of hole formation% | 38 | 86 | 90 |
| Angle control accuracy% | 32 | 74 | 83 | Comprehensive comparison | Poor | Excellent | Good |

(2) Grouting parameters

The grouting test was carried out in this formation. The water-cement ratio was 0.6:1, 0.9:1 and 1.1:1, and the grouting pressure was from 0.2MPa to 0.8MPa. When the water-cement ratio is 0.9:1 and the grouting pressure is 0.6MPa, the compactness after reinforcement reaches the maximum 92%. The principle of "low pressure, low pressure and pressure" is adopted for the cement slurry, so the water-cement ratio of the slurry is 0.9:1, and the grouting pressure is 0.6MPa.

Compared with the sleeve valve tube (timing, quantitative, positioning), the steel flower tube is more flexible, better strength and depth, and is not easy to be damaged. The grouting test was carried out by using four kinds of steel flower tubes (Ø 42, Ø 48, Ø 50 and Ø 60) in the stratum under the water cement ratio of 0.9:1, and the compactness were 90%, 89%, 81% and 75%, respectively. Therefore, the diameter of Ø 42mm steel flower tubes was selected for grouting.

According to the different footage, the measurement control is carried out. According to the test data, the adjustment accuracy of inclination angle reaches 95% per footage of 20cm, which meets the requirements of drilling angle control.

(3) Reinforcement effect

The spatial relationship of high-pressure gas pipe under the subway section tunnel in close distance is shown in Fig. 1 (a), and the reinforcement range on the plane is 42m * 20M (as shown in Fig. 1 (b)).

The vertical longitudinal distance between the inclined drilling pipe and the gas pipeline is more than 1m, the length of the inclined drilling hole is 13.7m, the horizontal distance between the drilling position and the gas central line is 9.67m, and the distance between the lowest point of the drilling hole and the top of the tunnel is 3.5m. The drilling angle shall be strictly controlled to avoid drilling through the gas pipe. The hole positions are distributed on both sides of the gas pipeline with a distance of 1m, and the drilling reinforcement shall be carried out within the extension range of 8 m on both sides of the shield tunnel. After 14 days of grouting, 84 steel flower tubes on both sides of the pipeline were sampled and tested. Through isolation and reinforcement, the soil reinforcement area under and on both sides of the pipeline reaches 1.5m. The density of soil is 98% from 55%, and the average density is 97.6%. At the same time, four inclined drilling pipes on both sides of the tunnel axis are used as tracking grouting
pipes to track grouting according to the monitoring data of ground surface and pipeline settlement at the construction site.

![Image](image-url)

**Fig.1** Reinforcement Isolation Grouting with Inclined Borehole

### 3.2. Parameter control of shield tunneling under gas pipe

1. **Optimization of driving parameters**

   Based on the field adjustment test of shield tunneling parameters of 200m interval tunnel passing through high-pressure gas pipe, the excavation parameters are optimized according to the surface settlement monitoring caused by construction. The obtained shield tunneling parameters are listed in Table 2.

   **Table 2. Driving Parameter of Shield Passing beneath High-pressure Gas Pipeline**

   | parameter                | parameter | parameter | parameter                        |
   |--------------------------|-----------|-----------|----------------------------------|
   | Driving speed mm / min   | 55-60     | 35-40     | Reduce soil disturbance          |
   | Cutter head speed r / min| 1.3~1.5   | 1.0~1.2   | Reduce soil disturbance          |
   | Total thrust kN          | 2000~3500 | 1800~2300 | Reduce soil disturbance          |
   | Cutter head torque kn. M | 3000~5000 | 2400~3500 | Reduce soil disturbance          |
   | Grouting pressure        | 2~3bar    | 3~5bar    | Grouting is full, pressure is maintained and settlement is reduced |
   | earth pressure           | 0.6~1.0bar| 0.8~1.4bar| Keep pressure and reduce settlement |
   | Grouting quantity        | 10~12m³   | 11~13m³   | Filling is full, formation loss is less than 1.0%, and settlement is reduced |

2. **Driving effect**

   Through the application of the optimized parameters, the shield crossing section is 45m, the tunneling speed is 40 ~ 50mm / min, the speed is stable and uniform, and the formation loss rate is reduced from 1.12% to 0.87%, which reduces 0.25%. It took 5 shifts to complete the underpass excavation, with an average of 5 rings / shift, and the width of each ring was 1.8m, that is, the footage per shift was 9.0m.

### 3.3. Grouting for deep hole behind segment lining wall

1. **Optimization of grouting parameters**

   Through the parameter improvement test of 200m before crossing the high-pressure gas pipe, it is concluded that the optimized deep hole grouting behind the tunnel wall is listed in Table 3.
Table 3. Grouting parameter with Deep Hole

| parameter                | parameter | parameter | parameter                      |
|--------------------------|-----------|-----------|---------------------------------|
| Grouting pressure (main) | 1.5~2.5bar| 3~4bar    | Improve plumpness and compactness|
| Grouting amount (auxiliary) | 0.5~1m³  | 1~1.5m³  | Improve plumpness               |
| Grouting depth            | 0.2m      | 0.5m     | Expand the scope of reinforcement|
| Grouting speed            | 1m³/h     | 0.5m³/h  | Increase infiltration range     |
| Type of grout             | Single slurry | Double slurries | Accelerate solidification stability |
| Slurry ratio              | 1:1       | 0.8:1:1  | Shorten setting time            |

(2) Effect of deep hole grouting
By optimizing the application of grouting parameters and the principle of "high pressure, low amount of deep hole for many times", the permeability effect of mudstone stratum is limited. Compared with the conventional secondary grouting, the penetration depth of deep hole grouting increases from 0.2m to 0.5m within 180° of the arch crown behind the wall, which expands the reinforcement scope, as shown in Fig. 2.

4. Settlement control effect
Nine settlement observation points are arranged along the pipeline direction, with the depth of 6.5m and the spacing of 4m. After the open excavation, the measuring points are directly connected to the concrete casing by the steel head, and the steel cover plate is made. After the application of the comprehensive settlement control technology, such as grouting reinforcement and isolation by inclined drilling, tunneling parameter control of shield under crossing gas pipe and grouting in deep hole behind segment lining wall, the maximum settlement of high-pressure gas pipeline caused by large shield tunneling under high-pressure gas pipe construction is only 4mm, less than the control value of 5mm, which meets the requirements of settlement control and ensures the shield underpass construction. The operation safety of medium and high-pressure gas pipe solves the technical problem of settlement control of large-diameter earth pressure balance shield passing through high-pressure gas pipe in close distance.

5. Summary
Relying on the large-diameter earth pressure balance shield passing through the high-pressure gas pipe Weiqing line from Xinglong Station to Tianfu new station section of Civil Engineering Section 4 of Chengdu metro line 18, the field tests are carried out to determine the drilling inclination angle, slurry ratio and grouting pressure, grouting pipe type and diameter, and each footage length. The excavation
parameters of the under-crossing gas pipe shield and the parameters of deep hole grouting behind the tunnel wall are carried out Numerical experiment optimization. Based on the reinforcement and isolation of inclined borehole grouting, the control of shield tunneling parameters and the grouting of deep hole behind the tunnel wall, the settlement control technology of large shield tunneling through high-pressure gas pipe in close distance is established. The maximum settlement value of high-pressure gas pipeline is only 4mm, which is less than the control value of 5mm. The monitoring results verify the practicability of the technology, and it is worthy of popularization and application.

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