Treatment Technology of Closed Tunnel Filled with Water

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Abstract. During the construction of No.3 connection gallery between huyong station and lvdaohu station of first phase project of Line 2 Foshan Rail Transit, water and sand kicks caused the large-scale settlement of tunnel segments. After comparison and selection of schemes, the rehabilitation scheme of abandoning the existing right line tunnel, shield machine starting from huyong station and heading to Lvdaohu Station by changing the line, is finally adopted. In order to prevent secondary disasters caused by the collapse of abandoned tunnels, the ground boreholes are used to fill the abandoned tunnels. During the construction, a series of key construction technologies have been formed, such as sectional backfill of abandoned tunnel, alternate backfill of underwater concrete and mortar, and prevention of pipe blockage. The results of core-drilling test and subsequent construction procedures show that the treatment scheme of abandoned tunnel is reliable and feasible, which can provide reference for similar projects.

1. Introduction
With the rapid development of the urban rail transit industry in China, more and more unprecedented issues have emerged in the engineering construction. In the existing reports, the treatment of underground spaces mainly focuses on the treatment of karst caves and karst cavities. For example, Liu Tongjiang introduced the treatment technology of the giant karst cave passed through by the Gaoshan Tunnel of the Qianjiang-Changde Railway. Lin Bentao introduced the treatment technology of the extra-large karst cavity passed through by No.2 Zhushabao Tunnel of Changsha-Kunming Railway. Engineering practice for the backfilling of completed closed underground spaces has not been reported. This paper took the tunnel restoration project in the Huyong Station-Lvdaohu Station Right Line Section of Line 2 Foshan Rail Transit (hereinafter referred to as "Hulv Section") as an example to introduce the backfilling technology for closed underground spaces. Compared with karst caves and karst cavities, the underground space introduced herein has the characteristics of being completely enclosed, full of confined water and huge in volume. There is no relevant engineering experience for reference and the project implementation is extremely difficult.

2. Project overview
The large mileage direction of the right line tunnel was blocked with a safety door immediately after the occurrence of water and sand kicks in the No.3 connection gallery in the Hulv Section of Line 2 Foshan Rail Transit Phase I, as shown in Fig. 1. The water and soil pressure inside and outside the
tunnel was balanced through water recharging in the tunnel. The detection result of current conditions of segments showed serious misalignment of segments near the initial leakage point of the accident and the failure of conventional grouting measures. That is, the hydraulic connection inside and outside the tunnel cannot be cut off. After comprehensive comparison, the scheme of re-selecting the right line of the section and abandoning the original right line tunnel is adopted. The abandoned tunnel must be backfilled in order to eliminate the risk of large-scale ground collapse completely.

The original right line tunnel has been filled with recharged water of about 22,000 m³. As the tunnel was connected with underground confined water, it was not allowed to open the portal to discharge water. The transverse cross-section of the tunnel is shown in Fig. 2. Therefore, the proposed tunnel backfilling is the backfilling of a closed space filled with water and there is no relevant engineering experience for reference.

3. Research on the treatment scheme of the abandoned tunnel

3.1. Backfilling method
The tunnel in the Hulv Section is located in the water-rich silt and fine sand stratum with extremely complicated hydrogeological conditions, in which serious accidents have occurred [9]. At present, segments have serious misalignment near the leakage point. It must be ensured that segments are not excessively disturbed during hole opening. Therefore, the ground opening scheme is adopted, under which a 168 mm steel sleeve is selected and a geological drilling rig is used to perform segment hole opening operations as shown in Fig. 3. After the opening is completed, the steel sleeve is used as a conduit for filling backfill materials. Conventional underwater pouring technology cannot be used for backfilling due to the small diameter of the steel sleeve and the closed water-filled space in the tunnel. The method of pump backfilling with pressure can be used for backfilling, as shown in Fig. 4. As the backfill section of the tunnel is 784m long, segmented backfilling can ensure the backfilling quality to the greatest extent.
3.2. Single-hole backfill control
A hole is drilled directly above tunnel segments and a conduit is placed down. The hole that has not been backfilled is used as the drainage and exhaust hole, as shown in Fig. 5. The sleeve is pulled up and backfilling continues when the pressure of the vehicle-mounted pump reaches 3 MPa or the concrete surface near the hole rises to 2 m. It is necessary to ensure the absolute safety of the portal in the entire backfilling process. Backfilling should be suspended when the water level at the portal rises by 4 m and may only continue when the water level falls to the safety range.

4. Implementation of abandoned tunnel treatment

4.1. Implementation of the first backfill section
According to the detection result of current conditions of segments, segments from Ring 340 to the portal were intact. Rings 352~358 were selected as the first backfill section. Underwater concrete was used as the backfill material to cut off the hydraulic connection between the intact tunnel from Ring 340 to the portal and the outside of the tunnel and lower the water level at the portal to ensure its safety. At the same time, the backfill section was used as the test section to determine various parameters in the backfilling process to provide technical support for subsequent backfilling.

Holes were opened on the top of Rings 352, 353, 354, 356 and 358 successively and backfilled from low to high. When the steel sleeve floated up during concrete pumping, backfilling of Ring 358 was stopped and Rings 356, 354, 353 and 352 were backfilled successively. A blockage occurred continuously in the backfilling process and all the backfill holes were blocked eventually. Judging by the water level at the portal, the first backfill section failed to separate the intact tunnel from the groundwater. That is, the purpose of backfilling was not achieved. Fig.6 is the flow chart of first backfill implementation.
4.2. Analysis of backfilling process

Statistics are made on the single-hole concrete filling amount, the time interval of blockages and the number of drainage and exhaust holes according to the analysis of the backfilling process in the first stage, as shown in Table 1. It can be found that with the decrease of drainage and exhaust holes, the amount of concrete that can be poured into a single hole and the time interval of blockages decrease sharply, as shown in Fig. 7. Only the weep hole at the portal was used as the drainage and exhaust hole during the backfilling of Ring 352. A blockage occurred during the change of the concrete tanker, which is obviously different from the conventional blockage caused by the initial setting of concrete. It can be judged that the blockage occurring during the backfilling of the closed tunnel is not caused by the initial setting of concrete. Further analysis found that all blockages occurred after the vehicle-mounted pump stopped working and that no blockage occurred during its continuous operation. When a blockage occurred, the sleeve could not be cleared even when the instantaneous pressure of the pump reached 30 MPa. It was found through subsequent measurements of the concrete surface elevation by hole opening in the area that the tunnel was not densely packed and the buried depth of the sleeve was not more than 1m. Therefore, conditions that the tunnel has been densely packed or the sleeve is buried too deep can be excluded from the reason for blockage.

| Ring No. | Number of exhaust | Stopping time before blockage (min) | Concrete filling (m³) | Remarks |
|----------|-------------------|------------------------------------|-----------------------|---------|
| 358      | 4                 | 0                                  | 240                   | No blockage occurred |
| 356      | 3                 | 55                                 | 160                   | 354, 353 and 352 were exhaust holes |
| 354      | 2                 | 48                                 | 155                   | 3353 and 352 were exhaust holes |
| 353      | 1                 | 10                                 | 70                    | 352 was the exhaust hole |
| 352      | 0                 | 2                                  | 12                    | The pressure relief hole of the safety door was used as the exhaust hole |
According to the analysis of the backfilling scheme and the underwater concrete pouring method, it can be found that the concrete backfilling method is not underwater concrete pouring and that it is difficult to carry out underwater pouring due to the lack of bottom sealing conditions [10-12]. In addition, there were abnormalities in the backfill construction process: (1) When the buried depth of the sleeve in the concrete was more than one meter, the pressure of the vehicle-mounted pump rose sharply and the sleeve jumped up. Therefore, it was difficult to meet the technical requirement for the buried depth of 2m~6m in the case of underwater concrete pouring; (2) It can be judged that swell occurred in the tunnel during the backfill construction according to the change of the water level in the drainage and exhaust holes and the water level pipe at the portal. Therefore, the blockage is the result of the special pouring method (small diameter of the sleeve) and the special environment of the closed space (filled with a large amount of water) [13,14].

The cause of the blockage is further analyzed. Due to the inability to achieve bottom sealing, the water level in the steel sleeve was always flush with the confined water level, and the concrete had been basically segregated after being transported in the steel sleeve. During concrete pumping by the vehicle-mounted pump, the concrete was pumped into the tunnel under intermittent pressure provided by the piston pump. That is, there was a vacuum section in the pump tube. Once the vehicle-mounted pump stopped working, the segregated concrete aggregate in the tunnel would be sucked into the sleeve under the action of the water head difference and the vacuum in the pump tube if the pressure in the closed tunnel was not fully released. The aggregate sucked into the sleeve did not have fluidity due to the small diameter of the sleeve, resulting in the blockage. It can be found from the relationship between the number of drainage and exhaust holes and the time interval of blockages that the fewer the drainage and exhaust holes are, the more likely the blockage occurs. According to the analysis of blockage reasons, this phenomenon can be explained as below. The fewer the drainage and exhaust holes is, the more difficult it is to release the pressure in the tunnel when the concrete is pumped, resulting in greater pressure difference between the tunnel and the outside of the pump tube. That is, the blockage is more likely to occur.

4.3. Implementation of the second backfill section
In response to frequent blockages during the implementation of the first backfill section which resulted in the failure to achieve the purpose of backfilling, the following measures were taken during the
implementation of the second backfill section. (1) The number of exhaust holes was increased. At least 4 drainage and exhaust holes were provided during backfilling to ensure smooth pressure relief in the tunnel and reduce the pressure difference between inside and outside. (2) Site layout was made in a reasonable way to ensure continuous backfilling operations and uninterrupted operation of the vehicle-mounted pump and avoid the stoppage for tanker replacement, as shown in Fig. 8. A lot of practice shows that there is an obvious relationship between the displacement of the vehicle-mounted pump and the blockage rate. An excessively large or small displacement of the vehicle-mounted pump will increase the blockage rate. The reasonable displacement range of the vehicle-mounted pump is 20%~25% under similar backfilling conditions, as shown in Fig. 9.

![Fig.8 Photo of continuous backfill](image)

![Fig.9 Schematic diagram of relationship between displacement of vehicle mounted pump and plugging rate](image)

4.4. Implementation of the third backfill section

After the second backfill section was completed, the backfilled area was cored. As the backfilled concrete was basically non-condensing, shaped core samples cannot be taken, as shown in Fig. 10. The backfill material was changed to M10 mortar from C20 underwater concrete to complete all tunnel backfilling.

![Fig.10 Coring in backfilled concrete area](image)

5. Treatment effect analysis

A total of 5,445 m$^3$ of C20 underwater concrete and 12,944 m$^3$ of M10 mortar were backfilled within the tunnel backfill area, and the tunnel filling rate was 0.83. The overall overview of the backfill is shown in Fig. 11. The backfilled mortar solidified well after the safety door was removed, as shown in Fig. 12, which cut off the hydraulic connection between the tunnel and the groundwater successfully and created favorable conditions for the smooth implementation of subsequent renovation works.
6. Conclusion and discussion

There is no relevant experience in the backfilling of closed tunnels for reference. This paper introduced the relevant construction experience in the backfilling of closed tunnels based on the pipe blockage and the failure in the condensation of backfill materials encountered in the treatment of the abandoned right line tunnel in the Hulv Section of Line 2 Foshan Rail Transit, providing valuable practical experience. The following conclusions are made as follows.

(1) Underwater concrete pouring cannot be carried out for the backfilling of the closed tunnel. The blockage was caused by the combination of the special backfilling construction technology and the external environment. The blockage mechanism needs to be further studied;

(2) Practice shows that measures such as increasing drainage and exhaust holes, maintaining the continuity of the backfilling process and controlling the displacement of the vehicle-mounted pump can reduce the probability of blockages and improve the backfill effect;

(3) Underwater concrete backfill cannot guarantee the backfilling effect. It is recommended to use mortar for backfilling, which can greatly improve the backfilling effect.

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