Engineering 4 (2018) 167–169

Contents lists available at ScienceDirect

Engineering

journal homepage: www.elsevier.com/locate/eng

News & Highlights

The Undersea Tunnel on Qingdao Metro Line 8

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1. Project overview

With a full length of 60.7 km, Qingdao Metro Line 8 runs from Jiaozhou North Railway Station in Jiaozhou City to Wusi Square in Shinan District. It has 15 stations in total, a type B six-car formation, and a maximum traveling speed of 120 $km \cdot h^{-1}$. Qingdao Metro Line 8 links the new Qingdao Station on the Jinan–Qingdao High-Speed Railway with Qingdao Station on the Qingdao–Lianyungang Railway; connects large traffic terminals such as Jiaozhou North Railway Station, Qingdao Jiaodong International Airport, Qingdao North Railway Station, and Wusi Square; and passes through five administrative or functional zones (Jiaozhou City, Hongdao Economic Zone, Licang District, Shibei District, and Shinan District). It is a rail transit line that connects the east-coast downtown area with the north-coast area of Qingdao City, and radiates out to peripheral clusters.

With a full length of about 8.1 km (including an undersea section of about 5.5 km), the undersea tunnel on Qingdao Metro Line 8 runs from Dayang Station in the Hongdao Economic Zone of Qingdao City and passes under Jiaozhou Bay to reach Qingdao North Railway Station in Licang District, Qingdao; it is the longest undersea metro tunnel in China. To meet operation needs in this section, a total of three underground fan substations and pump stations will be provided. Construction on the project started in October 2016, with a scheduled 43-month period for civil works, into which a total of 2.44 billion CNY will be invested.

2. Key and challenging points in the engineering design of the tunnel

Key and challenging points in the engineering design of the undersea tunnel include the following:

(1) As it is difficult to carry out disaster prevention and rescue in a super-long undersea tunnel, and as it is impossible to provide ventilating shafts under the water, multiple techniques including train operation methods, signals, ventilation, and civil works will be utilized to determine a ventilation and exhaust scheme, and a tunnel section and construction scheme.

(2) In light of the complex undersea geological conditions, the tunnel profile design needs to take the construction method into account in order to minimize engineering risks.

(3) A justified construction method that may be used under adverse geological conditions such as composite strata and fractured zones must be studied.

3. Using a combined mining tunneling and shield method to minimize risk and difficulty

At the tunnel site, 10 fault fractured zones were identified, including six on land and four under the sea (the latter were labeled as F3, F4, F5, and F6). The regional faulted structure is dominated by a compress-shear fracture. The F4 fault fractured zone is located in the middle of the undersea section, with a 440 m wide fracture; it is the largest fault fractured zone identified at the tunnel site. The rock in the fractured zone is broken with an uneven hardness and is under the strong influence of tectonic movement. During the survey, a water gush occurred suddenly with a high confined water head. Construction is being carried out by a combined mining tunneling and shield method; the tunnel sections constructed using the mining tunneling method are jointed under the sea with those constructed using the shield method. The undersea tunnel section constructed using the mining tunneling method is 2532 m long, and is provided with a composite lining; the undersea tunnel section constructed using the shield method is 2965 m long and uses two composite slurry balance shields with diameter of 7.1 m (Fig. 1).

To accomplish construction using the combined mining tunneling and shield method, the profile of the line requires proper design. For the section using the shield method, an excessive buried depth will require passing through a considerable amount of hard rock strata; this will make construction more difficult by decreasing the construction efficiency, causing an increased load on segments, and causing additional difficulties in structural waterproofing. For the section using the mining tunneling method, an insufficient buried depth will increase the risks of collapse and water gush in tunnel excavation. Considering the various geological conditions of the tunnel, an engineering analogy and theoretical analysis were carried out, which determined the following criteria: For the section using the shield method, the buried depth of the tunnel shall not be less than 1D (where D is the diameter of the tunnel); for the section using the mining tunneling method, the buried depth shall not be less than 25 m.

4. Solving the problems of disaster prevention and exhaust fumes

The section using the mining tunneling method has a separated double-tube structure and a horseshoe-shaped section, whereas the section using the shield method is provided with an outside

https://doi.org/10.1016/j.eng.2018.03.012

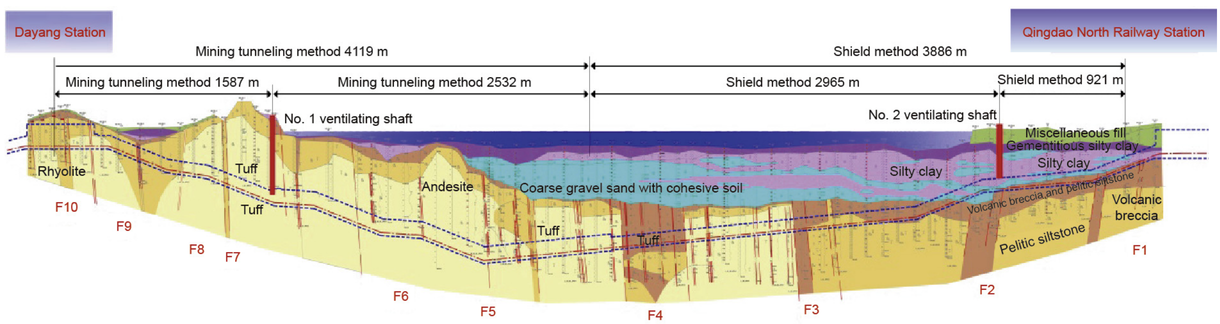

Fig. 1. Geological profile of the undersea tunnel on Qingdao Metro Line 8.

diameter of 6.7 m segment lining using a 350 mm thick segment with a breadth of 1.5 m. Since the construction section can be adjusted flexibly when using the mining tunneling method, an exhaust air duct of 9.5 m^2 will be provided at the tunnel arch, extending from the #1 ventilating shaft toward the bottom of the sea, with a smoke vent arranged in the middle of the tunnel. This will realize section-wise longitudinal ventilation and exhaust for the tunnel.

To meet the requirements for tunnel disaster prevention and evacuation, connecting passages are arranged between the two tubes every 300–600 m. In addition, an evacuation platform is provided along most of the tunnel; this has a width of 2 m in the mining section and a width of 1 m in the shield section (Fig. 2).

5. Providing a maintainable tunnel waterproofing and dewatering system

Given its V-shaped longitudinal gradient, the undersea tunnel requires mechanical drainage during both construction and operation; therefore, the waterproofing and dewatering system for the tunnel needs to be strengthened and a discharge limit must be established to reduce tunnel water discharge. In addition, the tunnel drainage system must remain functional and maintainable in order to reduce water discharge costs during construction and operation.

For the tunnel construction, three advanced water-detecting holes at the tunnel arch have been proposed in order to detect water yield and pressure beyond the tunnel face; on this basis, the advanced pre-grouting scheme and design parameters will be determined before the frontal surrounding rock is consolidated through pre-grouting for water blocking. This effort will effectively reduce the risk of water gush when the tunnel passes through adverse geological sections. To achieve limited discharge, pre-grouting and radial supplementary grouting will be used in order to reduce the surrounding rock permeability; this will limit the single-tube water seepage in the mining section to 0.2 $m^3 \cdot (m \cdot d)^{-1}$. A maintainable waterproofing and dewatering system has been adopted for the tunnel, with drainage manholes arranged along the tunnel at intervals of 80 m in order to facilitate the regular maintenance and repair of longitudinal drain pipes during operation.

6. Risk control for the key techniques of long-distance shield boring in complex undersea strata

The shield cutters will be properly configured based on the geological survey data on water in order to meet the boring needs. Wear and replacement of cutters are inevitable; therefore, cutter replacement will follow the principles of being reasonable, rapid, batched, and scheduled, since cutter replacement is difficult under the sea, where the water pressure is high. To ensure safety during cutter replacement, improve the efficiency of this process, and reduce the project duration and investment, different cutter replacement schemes have been adopted for the project, depending on the stratum conditions and operation characteristics. For adverse strata such as full-face weak strata, soft-hard water-rich

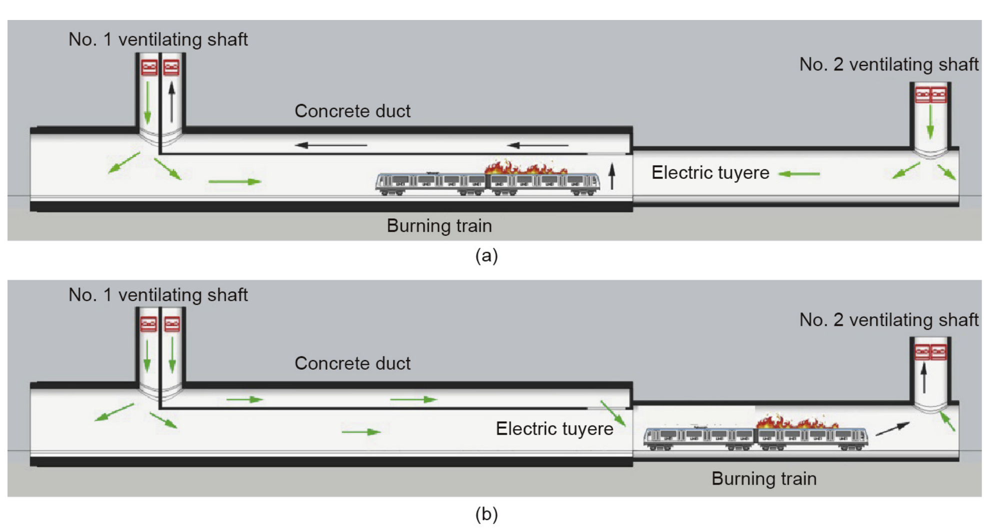

Fig. 2. Diagram of exhaust flow organization for the tunnel. (a) Burning train in No. 1 ventilating shaft; (b) burning train in No. 2 ventilating shaft.

strata, and rock fractured zones (i.e., fault zones with developed fissures and high permeability), cutter replacement is carried out under pressure in the soil chamber of the shield-tunneling machine. For undisturbed strata or a consolidated body with good integrity and undeveloped fissure water, where the tunnel face is capable of self-stabilization, strata behind the shield or outside the shield shell will be subject to waterstop treatment in the tunnel before cutters are replaced in the soil chamber. For weak water-rich strata where a considerable amount of operation or cutting and welding is required in the chamber, the strata will be consolidated for the purpose of stopping water until they have gained some strength; the shield will then be driven to the pre-consolidation position before the chamber is entered for cutter replacement. A technology that involves entering the soil chamber under reduced pressure and limited water drainage has been established: The chamber is entered under pressure and with some level of self-stabilization for the tunnel face; if the peripheral waterstop treatment fails to open the chamber under normal pressure (i.e., if the water level in the chamber is controllable or the tunnel face is fully capable of self-stabilization), a low pressure may be applied to prevent groundwater and stabilize strata, thus improving the work efficiency when entering the chamber under pressure.

Up to now, the supporting constructed using the mining tunneling method is 398 m long; the shield launching shaft is under construction; and two slurry balance shields are expected to start working on 2018 July 1.