Study on the Waterproofing and Drainage System of Qingdao Jiaozhou Bay Undersea Tunnel, China

J.X. Yan, S.J. Ye
China Railway Southwest Research Institute Co., Ltd., Chengdu, P.R. China

1. Outline of Project

Qingdao Jiaozhou Bay Undersea Tunnel, with a total length of 7800m and undersea section of 3950m, consists of 3 tubes, two main tunnels, three lanes for each tube and a service tunnel between the two main tunnels. The design speed is 80km/h for the tunnel, which is a city rapid road. The longitudinal profile of tunnel is "v" shape, the lowest point of right main tunnel is -83.28m and -83.15m for the left main tunnel. The overburden of tunnel in the undersea section varies from 25m to 35m. The maximum depth of water is 42m. The two main tunnels are 55m apart with a service tunnel between. The two main tunnels are connected every 250~300 m by cross passages for people and every 750~1 000 m by cross passages for vehicles[1]. The tunnels are constructed by D&B method.

With heaving topography, the seabed are exposed rocks, including thin layer middle weathered granite and slightly weathered granite. The integrality of rock is quite good. Around 50% of rock belongs to Class II and III( according to Chinese Tunnel Rock classification, 6 classes from Class I( very good) to Class VI(very proof))and 43% belongs to Class IV and the rest is Class V. [1]In the area of tunnel, there is no big fracture structure and the fractures found are mainly compresso-shearing fractures with steep angles. The width of the fractures varies from several meters to dozens of meters. Only few fractures are extension fractures. In the undersea section, above the depth of 25m of rock, the activity of ground water is clear and below that depth, the rock is poor in water and the permeability of rock goes down notably. In the land sections, the ground has less water.

2. Principle of Waterproofing and Drainage Design

The supply of sea water to the tunnel could be infinitude if grouting has not been taken. In consideration of cost for pumping water out of the tunnel, it is not reasonable to adopt "Taking drainage as a major measure" for undersea tunnel even if the ground is good . And at the same time, it is not realistic neither to seal the tunnel completely as in this case, the lining structure shall bear all the water load which is around 80m high water table and requires a strong structure.

In order to ensure the Class I waterproof standard, which means no seepage and no wet area on the surface are allowed, the following principles for waterproof and drainage design are considered:

(1) The waterproofing and drainage design shall follow the principle” Limiting the water into tunnel, Combining waterproofing with drainage measures, Taking drainage as the same important as waterproofing”. “Limiting the water into tunnel” means grouting shall be taken to limit the water from surrounding rock into the tunnel to a certain less amount. Regarding the water already into tunnel, drainage capacity shall be big enough to drain the water completely to avoid any pressure built-up. In this condition, waterproof shall be done as good as possible. In the past, engineers
usually paid more attention to waterproofing but ignored the importance of drainage which results in leakage.

(2) Waterproofing measures shall be available for maintenance to some extent during operation. To meet this requirement, waterproofing membrane shall be partitioned with waterstops and injection hose through which grouting can be done to seal leakage during operation. For the construction joints, besides ordinary waterstops and seals, measures such as hose reserved for grouting shall also be installed to seal leakage from the joint if any. It is important to maintain the waterproofing system to seal any leakage easily.

(3) Drainage system shall also be available for maintenance as much as possible to ensure the reliability of drainage system. It is important to keep the longitudinal drainage pipes clear, for which maintenance shall be available. It means the pipes can be cleared by high pressure water and shafts for checking and maintenance shall be installed with some interval.

Regarding the limitation standard for quantity of ground water seepage from ground to tunnel, as the geology is in general quite good, hard rock with low permeability, we use a higher standard, 20l/min/100m. On the basis of this standard, it is calculated that the limitation quantity is 1152m3/d for each tunnel (tube) in the undersea section (around 4km long). However, the data from survey shows the original one is much bigger that this, which means measures such as pre grouting, shall be taken in the unfavorable faults to limit the quantity of ground water from the ground into tunnel.

3. Design of Waterproofing and Drainage System

The design of waterproofing and drainage system is showed in general in the Fig.1, one used for sections with invert and another for sections without invert. Half-around membrane (2mm thick ECB, 600g/m2 geotextile) is adopted for all sections. The waterproofing membranes is partitioned with water stops every 10m and hoses for post grouting are reserved within each partitioned cell and connected inside tunnel which can be used for grouting easily when any leakage happens. Water tightness is also required to the shortcrete and the second lining concrete, which is C35 and P8 for the shortcrete and C50 and P12 for the lining concrete.

Three kinds of waterproofing measures for construction joints have been considered: 1) used for sections with less groundwater and low water pressure, such as the section under land area; 2) used for sections with more ground water but the water table is not high; 3) used for sections with much ground water and high water pressure. The measures for the three application are showed as follows.

(1) For construction joints in the sections with less groundwater and low water pressure, waterstop pastes with high performance and maintainable injection hose are used, see the drawing Fig.2. The paste is a sealing gule which expands with water and stop water. The paste shall be extruded continuously and evenly. The cross section of the extruded material shall be 8mm × 15mm on the surface of construction joint. Moreover, the distance between the extruded
material and the edge of construction joint shall not be less than 10 cm. The hose for post grouting shall be installed on the surface of construction and connected inside the tunnel and fixed on specified location for easily grouting during operation when leakage happens.

Fig.2 waterstop pastes with high performance maintenance injection hose

Fig.3 waterstop belt + waterstop+ injection hose + maintainable injection hose

(2) For the construction joint in the sections with more ground water but the water table is not high, one waterstop belt welded on the waterproofing membrane + waterstop+ injection hose is used (Fig.3). The reversed hose is easy for construction and good for waterproofing if the grouting material is reliable. Voids and gaps will be sealed with injected material to stop leakage.

(3) For the construction joint in sections with much ground water and high water pressure, double waterstop belts welded on the waterproofing membrane + waterstop+ injection hose is used.

The drainage system consists of three parts: a) drainage membrane with a width of 0.5m-1m is installed around the tunnel with an interval of 3m and horizontally in both side walls along the tunnel. b) Two drainage and convection pipes are installed at the foot of side walls along the tunnel. The pipe is 200 mm in diameter and shaft with a size of 60cm width and 100cm length (Fig.5) is installed every 50m for checking and clearing the pipes. c) 500 Main convection pipes. For the tunnel in the sections with invert, the two main pipes below the road are just for conveying water which is collected from the side drainage pipes. However, for the tunnel in the sections without invert, the main pipes below the road function as both water drainage (collecting water from the ground) and convection. So they are different type of pipes. The shaft with a diameter of 100cm for maintaining the main convection pipes is set every 100m (Fig.6). The reason why the convection pipes are set just below the shoulders is to ensure no much influence of maintenance on operation. For the tunnel sections with invert, drainage ditch and pumping pits shall be installed to drain the water below the invert to provide a dry surface for constructing the invert concrete.

Fig.5 shaft for checking and clearing the pipes in side walls.
4. Waterproofing and Drainage Material

As Class I of waterproofing is required for Qingdao Jiaozhou Bay Undersea Tunnel, which is quite high requirement. Moreover, it is undersea tunnel, so the ground water (similar to the seawater) has some influence to some waterproofing material. Tests of waterproofing and drainage material have been done to check if they are sensitive to salted water. It is required that the material shall be good enough in the condition of salted water. The physical and mechanical performance shall not be lost 20% after the material has been dipped in 10% salted water, 23°C, for 28 days. The following main materials have been used for Qingdao Jiaozhou Bay Undersea Tunnel[2].

Waterproofing membrane: 2mm thick ECB. The main physical and mechanical performances are: extension strength ≥15MPa, extension rate when breaking ≥400%, permeability: no leakage under 0.5MPa water pressure for 72 hours.

Geotextile: 600g/m² geotextile is used. The main physical and mechanical performances: longitudinal extension strength (N/50mm) ≥900, transverse extension strength (N/50mm) ≥950, permeability of (cm/s) ≥5.5×10⁻².

Back welted waterstop belt: The same material as waterproofing membrane is required to ensure good welding.

Waterstop paste which expands with water and stop water. The extension rate after solidifying ≥500%, compressive strength ≥0.3MPa, swelling volume (%) <50 of the original volume after 7 days in water.

Drainage and convection pipe: Φ200 PVC pipe, which functions as both drainage and convection. The loop rigidity of the pipe shall be ≥8.0 kN/m². The pipe shall not be damage under the water pressure when cleaning.

Main convection pipe: Φ500 PVC pipe which shall be not damage when it is cleaned by high pressure water. Moreover, it shall not deform, not be broken during construction of the concrete pouring and construction vehicle running on it above.

Drainage membrane: it is a PE membrane, 1mm thick, concave and protruding shape, with a protruding thickness of 20mm, air volume per unit area 14 l/m², drainage capacity of 13 l/s.m.

5. Control of Construction Quality

The quality of construction shall be well controlled, which is one of key factors to good waterproofing. Thus, standards for quality requirements have been brought forward to ensure the construction quality of waterproofing and drainage system, such as requirement standards on surface of base for waterproofing membrane, installation requirement on geotextile and waterproofing membrane, back welded waterstop belt, waterstop paste, injection hose as well as
drainage spacer membrane, drainage pipe and main convection pipe etc. The flatness of substrate surface for waterproofing membrane and the installation quality are the most important ones of them.

Flatness of substrate surface is required as \( D/L \leq 1/6 \), but \( D/L \leq 1/8 \) for the roof area on shotcrete \((D: \text{the depth of a concave}, \ L: \text{length of a concave})\). Any protruding head of reinforced bars, bolts, wire mesh or sharp rock shall be covered by mortar to avoid damage to the waterproofing membrane. Before the installation of waterproofing membrane, rainy water shall be treated by grouting or drained properly to provide a dry condition for construction. Requirements on installation of waterproofing membrane: The membranes shall be welded on fixing discs with a distance of 0.5~0.7m on the roof and 1.0~1.2m on side walls. The membranes shall be welded by double welding lines and the gap between the two welding lines shall be tested by air. When the air pressure in the gap goes up to 0.25MPa, keep it for 15min. If the pressure loses within 10\%, then the quality of welding meets the requirement.

6. Conclusion

Waterproofing is one of the key issues for undersea highway tunnels. Leakages will reduce the durability of concrete, make the electrical and mechanical facilities rusty and even endanger the safety of traffic safety, which shall be dealt with properly. However with high water pressure, abundance water and without natural water outlets, waterproofing and drainage for undersea tunnel is more complicated to be dealt with than common mountainous tunnels. On the basis of practical condition of Jiaozhou Bay Tunnel, principle and system of waterproofing and drainage and material specification as well as quality control of construction has been studied and designed which have been used for the tunnel project to reduce potential leakage.

References