Characteristic design and construction challenges for a metamorphic rock tunnel in Taiwan

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ABSTRACT

The highway tunnel is the critical path of the cross southern island highway improvement project in Taiwan. The inrush water, time-dependent deformation and changing geology were the challenges during excavation. The maximum amount of the inrush water was up to 27 ton per minute once. So, characterizing fractures to mitigate inrush of water into the tunnel and shaft using hydrogeological approaches are utilized for mitigation. Another construction challenges included the cracks in the shotcrete lining due to time-dependent deformation. The conquering experiences for those mentioned problems will be introduced first. Finally, this paper will try to introduce the special considerations and for the design of this tunnel and upgrade construction techniques.

Keywords: tunnel; shaft; tunnel ventilation; earthwork reuse; water inrush

1 PREFACE

Taiwan Provincial Highway No. 9 is the main transportation route in Hualien and Taitung area of eastern Taiwan as well as in Kaohsiung and Pingtung area of southern Taiwan. However, due to limitation of terrain conditions, low design standards for existing roads, poor road alignment, large longitudinal slope change, insufficient road width and mostly high slope, it is easy to cause traffic disruption due to natural disaster hazard.

In addition to the loss of life and property, it also has a major impact on regional economy and industrial transportation. To coordinate with the policy of domestic industry's eastward shift and the development of regional balance, the government are promoting this project actively. This case is about the C2 tunnel bid.

2 ENGINEERING GEOLOGY

The geological formations of the project area are mainly the Chaochow layer, the river terrace deposit layer and the recent alluvium. The lithology of the Chaochow Formation is dominated by slate and argillite with occasional sandstone. The recent alluvium is mainly composed of gravel sand. There are no active faults within the planned route. The main geological structure of this region is folds. Drag folds are quite common along the route. The development of the shear zone of the cleavage in slate is also quite common. In addition, the stratum is relatively fracturing. According to the variation of rock attitude, the main geological structure of this route consists of 3 anticlines and 1 syncline. The details of the geological exploration work of this project are shown in Fig. 1.

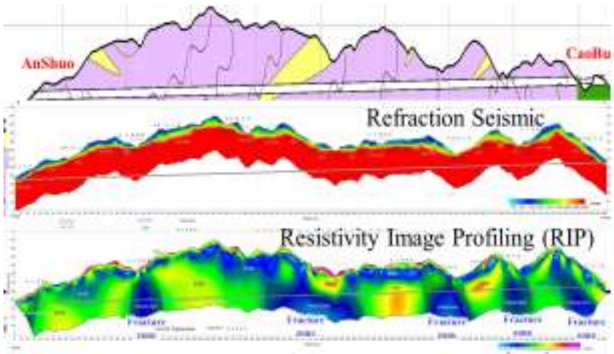

Fig. 1 Geophysical exploration results along the main tunnel

It is the first time in Taiwan that geological investigation in the design stage adopted 600m long horizontal drilling hole, and used the ground resistance image profile exploration (RIP) in the tunnel to reduce the tunnel construction risk. The results of geophysical exploration show that the shallow layer (depth <50m) near the shaft is the weathered or broken argillite, and the stratum with a depth of more than 50m is a sandstone/argillite layer with slightly developed cleavage or fissures. The groundwater level is high and abundant. According to the classification of the rock mass in Taiwan and the tunnel support system-PCCR, the metamorphic rocks in the central mountain range are mainly composed of the A-rocks except for the portal and the special geological section.

3 SPECIAL CONSIDERATION FOR TUNNEL DESIGN

The length of the tunnel is 4,602.5 m of northbound and 4,617.5 m of southbound. The tunnel is designed with a two-tube one-way lane. Other facilities for the main tunnel include the cross passage, the machine room and the auxiliary machine room. The tunnel is designed and constructed by NATM. The concept of green energy, disaster prevention, ecology and green engineering is introduced into the design so that the friendly environment, carbon reduction and energy saving have been implemented in the design and construction. The main special considerations in the design are as the following.

3.1 Route design

a) Set up E & M room inside the tunnel

To avoid the demolition of the tomb and the reduction of land acquisition, it is the first time that the south portal E & M room is placed inside the tunnel.

b) Adjust the longitudinal slope of the tunnel

In the design stage, the longitudinal slope of the tunnel was adjusted from 3% of the original plan to 2%. In addition to increasing the operational safety of the tunnel, it can also reduce the fuel consumption of the vehicle during operation and meet the world trend of long tunnel longitudinal slope.

c) Reduce carbon emissions

Through further collection of local data and detailed project drew up, the design team adjusted the tunnel length from 5,000m in the planning stage to approximately 4,600m in the design stage. The 400m shortage of tunnel was replaced by a medium-long span bridge The reducing of the excavation and the material use of structural and building are effective ways to save energy and reduce carbon.

3.2 Design of tunnel ventilation and disaster prevention

a) Ventilation shaft outside the tunnel and point-extraction ventilation system

To adapt to the landform terrain and reduce the impact on the environment, it is the first time in Taiwan that the ventilation shaft has been placed outside the long tunnel, as shown in Fig. 2. In addition to the use of the world's advanced longitudinal point-extraction ventilation system, it can quickly eliminate the smog, allow water fogs to reduce the temperature of the fire hazard, and set up a complete fire warning system of disaster prevention, which is conducive to the safe escape of personnel and improve disaster rescue.

b) Longitudinal slope of the tunnel get smoother

Adjusting the longitudinal slope of the tunnel from the planned 3% to 2% so that the exhaust emissions of the vehicle climbing slope reduced, only 80% of the original plan, the total dilution ventilation can meet the ventilation requirements. It can save power and slow down the speed of oil leakage caused by collision or overturning. Moreover, it can suppress the spread of fire and speed up the escape of passers-by, which is conducive to disaster prevention and safety.

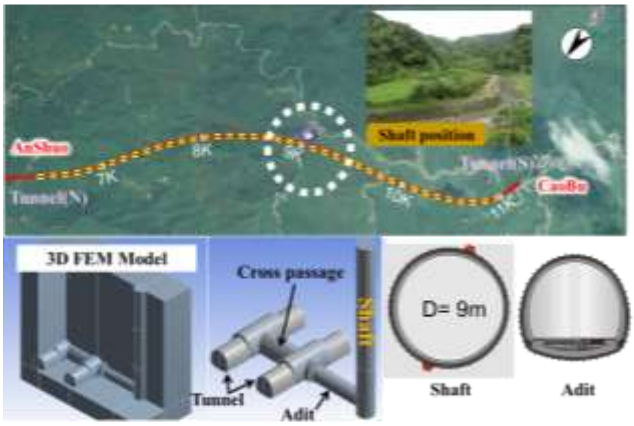

Fig. 2 Sketch of ventilation shaft and cross passage

3.3 Reduction of remaining earthwork

a) Shorten the length of tunnel, shaft and maintenance road

The original planned long tunnel (length 4,840 m) and a short tunnel (length 180 m) were changed to one long tunnel (about 4,600 m in length), reducing the total length of the double tunnel to be about 800 meters. The shortened planned shaft depth is reduced from 140 m to 112 m, the maintenance road for the shaft construction is reduced from the planned 600 m to about 250 m, reducing the impact of the road slope excavation on the environment.

b) Backfill and reuse

The remaining earthwork of the tunnel excavation, in addition to being used for backfilling and reusing of adjacent embankments, can also be reused in the earthwork adjacent to the artificial beach in Dawu Fishing Port and protect existing Taiwan Provincial Highway No. 9 as well as maintain traffic safety. This planning and design is a pioneering work in Taiwan, as shown in Fig. 3.

c) Three sections for ventilation

It is the first time in Taiwan by means of increasing the strength of tunnel lining concrete (from 245 kg/cm2 to 280 kg/cm2) is to reduce the thickness of the lining, the excavation, earthwork and transportation, which will also be advantage of energy saving and carbon reduction.

3.4 Design considerations for complex fold and gushing geological formations

a) Water inrush and convulsion

The geological structure in this tunnel is mainly affected by the fold effect. The fractured zone is easily formed in the shaft portion of syncline, and the groundwater is easily accumulated in the inclined shaft portion. Geological disasters, such as water inrush and convulsion, are likely to occur during tunnel construction.

Fig. 3 Reuse of the remaining earthwork in Dawu Fishing Port (Fowei No. 2 satellite imagery

3.5 The full life cycle of tunnel

a) Design for long-term stability

For the long-term stability, the tunnel design shall consider the clearance of maintenance, drainage facilities, water pressure on lining, the long-term monitoring of key sections and the monitoring of the operation and maintenance on the full life cycle.

b) Monitoring in operation

The design stage shall take into account the monitoring during operational stage, including the displacement monitoring layout of the tunnel concrete lining. The slope monitoring equipment during the construction period shall be handed over to the operation and maintenance unit after the tunnel completion to facilitate the maintenance management in the operation stage.

c) Shaft structure design for operation and maintenance

The shaft structure shall be subject to subsequent operation and maintenance. Stairs shall be designed in the shaft to provide personnel for inspection and maintenance of shaft lining and pipelines. In addition, equipment material holes shall be reserved in the first floor of the shaft room, which will be provided by temporary work frames. The inspection instrument performs routine testing or, if necessary, provides maintenance personnel with structural reinforcement.

4 UPGRADE CONSTRUCTION TECHNIQUES TO OVERCOME DIFFICULT GEOLOGY

4.1 The research and treatment of the water inrush path of the site before the construction

In view of the special situation of large amount of water inrush in the tunnel shaft construction, it is the first time in Taiwan that the hydrogeological theory is used to characterize the infiltration characteristics to study the water inrush path and develop countermeasures and verification, so as to effectively obtain the hydrological characteristics of the site and solve the construction problems of a large amount of water inrush in the shaft with a more economical and efficient water inrush treatment.

Lin et al. (2015) uses the geological analysis of three-point orientation method to estimate the direction and inclination of the fracture zone. Also, in conjunction with the surface geological investigation and the geological record at excavation surface of tunnel, the overall evaluation results show that the position of the fracture zone coincides with the location of the water inrush and the convulsion. The geology of the jobsite is affected by the dragging folds, the regional syncline structure and the shear zone. It may cause an eruptive water inrush when excavation breaks through the water storage layer, the seepage water will bring out the fine material between the cracks, which will reduce the strength of the rock mass and may lead to tunnel convulsion.

In addition, Wang et al. (2017) carried out in-hole photography in the 4 supplementary drilling holes and obtained more than 3,400 crack positions and attitude positions. By means of stereoscopic projection analysis, statistical analysis and in conjunction with surface geology, it shows that 5 main fissures and their spatial distributions can be summarized. Also, the hydrogeological models can be established to provide the location, extent and direction of possible groundwater flow paths to be served as the basis for mitigating water inrush.

The specific solution to the problem of water inrush from the shaft is to determine the water inrush path by characterizing the permeability of the jobsite and to perform the water stop grouting on the surface. The deep well de-watering can accurately be carried out when the depth and direction of the gushing area are obtained. Based on the rating of fracture and permeability of the rock mass, the water inrush path and area are studied and the water stop grouting will be carried out in the well (Fig. 4).

4.2 Overcoming the 3rd highest record of Taiwan tunnel water inflow (27 tons / min)

An large amount of water inrush occurred on the right side of the excavation face (Fig. 5) when the southbound(NS) was excavated to at station of 7K+200.5 (688 rounds).The water volume reached 27 tons/min, causing the tunnel to be interrupted. The amount of water inflow is only less than that of the new Newyongchun tunnel (83 tons/min) and the Hsuehshan tunnel (45 tons/min) in Taiwan.

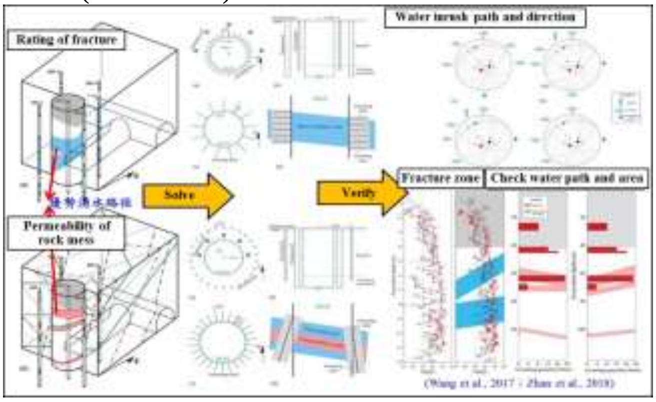

Fig. 4 Analysis of the water inrush path, Wang et al. (2017).

Fig. 5 Eruptive massive inflow at station of 7K+200.5

The construction team immediately implemented the stability of the tunnel excavation face and carried out an emergency treatment of water conducting outside the tunnel. Geological drilling and hydrological investigations were carried out in the surface of disaster site. A long-distance horizontal geological exploration and TSP ground detection in the tunnel have been done to accurately understand the geological and hydrological conditions. Systematic drainage drilling was carried out to disperse the water pressure and water volume from the excavation surface before ground grouting for stopping water. The tunnel will restore to excavate after the water discharge of the excavation surface is reduced.

5 CONCLUSION

Taiwan Provincial Highway No. 9 is the main transportation route in Hualien and Taitung area of eastern Taiwan as well as in Kaohsiung and Pingtung area of southern Taiwan. The promotion of this project will not only provide the local residents with a safe road to home, but also balance the development of the regional economy and industry. To avoid affecting the development of local rich natural ecological landscape, the concepts of green energy, disaster prevention, ecology and sustainable engineering were introduced into the design. Through the precise route selection, the remaining earthwork of the excavation was reduced. In response to the public opinion, the portal machine room was placed inside the tunnel to avoid the problem of land acquisition and make full use of the space. The project introduced the world's most advanced longitudinal point-extraction ventilation system, and drew up emergency plans to ensure the safety of pedestrians. In the design stage, 24-hour infrared monitoring was installed, and the ecological protection fence was set at the tunnel portal to preserve the species diversity and reduce the ecological impact. It is the first time in Taiwan that the residual earthwork of the tunnel excavation is applied to artificial beaches adjacent to Dawu Fishing Port, which has benefits of both ecology and carbon-reducing. From perspective of the full life cycle, the maintenance management has been considered in the design to prevent the redevelopment of the project from affecting the ecological environment.

The tunnel project passes through the central mountains. The tunnel construction encountered special geological conditions, such as geological fracture zone and water gushing zone. The long-distance horizontal drilling and full-line RIP investigation are initiated in the design stage to reduce the risk of tunnel construction. During the construction period, the geological investigation and related auxiliary engineering measures will be added so that the difficulties encountered in the construction have been overcome one by one.

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