Case study on the design and construction of Dongao Tunnel

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ABSTRACT

As the critical-path engineering along the Suao-Dongao section of Suhua Highway Improvement Project, Dongao Tunnel is a twin-tube highway tunnel located between Suao and Nanao of Yilan county. The tunnel, with 3.32 km in length, traverses Mt. Houi and Dongao Ridge. At route selection and planning stage, the regional hydro-geological model and potential of groundwater inflow were carefully studied according to the case histories of two nearby existing railway tunnels, Yungchun Tunnel and New Yungchun Tunnel.

The engineering, which is the most difficult one of the section, was started on Dec. 15th, 2012. Serious cave-ins, large deformation and groundwater inflow were encountered during construction. Considering the difficulty encountered during the construction stage of two existing railway tunnels, countermeasures were carefully studied, such as geological exploration, hydro-geological surveys, forepoling, water stop and drainage method. Besides, pre-reinforcement in heading face was used in poor ground. The northbound and southbound of tunnel were broken through on April 26th and Jul 7th, 2016, respectively, while the tunnels started service on Feb. 5th, 2018. Since the tunnel case passes through an area with complicated metamorphic rocks and abundant groundwater, this paper is aimed to briefly describe the design and construction experience for future reference.

Keywords: fault; hydro-geological model; groundwater inflow; cave-ins; pre-reinforcement

1 INTRODUCTION

The Suhua Highway is a 118-km section of the Provincial Highway No. 9. With many portions of this section built alongside steep cliffs and accompanied with unstable geological conditions, landslide disasters occurred frequently in recent years. In order to provide a safe and reliable way between north and east Taiwan, Suhua Highway Improvement Project was launched in 2008. The project, which includes three improvement route sections, Suao-Dongao section, Nanao-Heping section and Hezhong-Daqingshui section, is 38.8km in total improvement length.

As the critical path along the first open traffic section of this project, Suao-Dongao section, the final alignment of Dongao Tunnel was planned to situate at the eastern side of Yungchun and New Yungchun railway tunnels.(Figure1)

Fig. 1. Site plan of tunnel

2 DESIGN OF DONGAO TUNNEL

2.1 Terrain and regional geology

Dongao Tunnel starts from south of Yongle Railway Station, and stretches southward through Dongao Ridge to the valley of Dongao Creek. Dongao Ridge and Mt. Houi are the watersheds of Suao Creek basin and Dongao Creek basin. All the mounts in the region, at an elevation of 600~1000 m, belongs to the northeast section of Central Mountain Range. Two existing railway tunnels, Yungchun Tunnel and New Yungchun Tunnel, are located at the west side of Dongao Tunnel.(Fig.1)

The tunnel passes through Suao Formation, Xiaomaoshan Fault, Nansuao Formation, Houishan Fault and Dongao Schist.(Fig.2) The overburden depth subjected to the tunnel ranges from 7 to 515 m. The lithological strata along Dongao Tunnel consist of slate, argillite, metamorphic sandstone, diabase, schist, marble and amphibolite.(Fig.3) Due to the multi-phase of metamorphism, the strata are highly deformed and characterized by complex folds and fault structures. Two major thrust faults, Houishan Fault and Xiaomaoshan Fault, intersect with the tunnel at the northern section. In addition, several strike slip faults in strike of south-north distributed at both side of Dongao Tunnel. These thrust and strike slip faults accompanied with well-developed fractured zone and tensile cracks formed well flow path of groundwater. Tunnelling through these fractured rocks has high potential to encounter huge groundwater inflow.

2.2 Consideration of route selection

At route selection and planning stage, the regional hydro-geological model and potential of groundwater inflow were carefully studied according to the case histories of two nearby existing railway tunnels, Yungchun Tunnel and New Yungchun Tunnel. The latter case even encountered a peak groundwater inflow of 80 T/min during construction. The final alignment of Dongao Tunnel was planned to situate at the eastern side of Yungchun and New Yungchun railway tunnels with a distance of 50~200m and a higher elevation of 20~35m to avoid possible high-pressured groundwater inflow.

2.3 Rock mass classification and excavation support design

At the design stage of Dongao Tunnel, according to the PCCR system in Taiwan, the rock strata along Dongao Tunnel are metamorphic rocks which is classified as rock type A and graded as A_{II}~A_{VI} mainly according to RMR rating. The tunnelling methods are based on NATM concept. Contractors are allowed to excavate by mechanical excavation method or drilling and blasting method with bench cut method.

The excavation support systems are graded as Ⅰ~Ⅴ according to rock mass grade. Three main types of primary support systems, rock bolts, steel sets, and steel

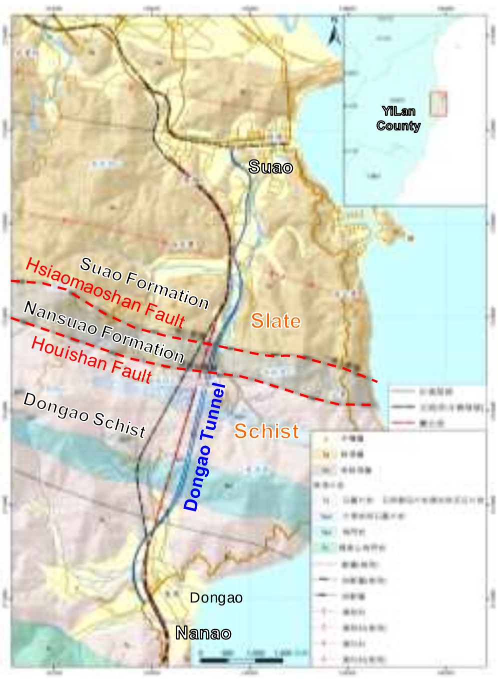

Fig. 2. Regional geology plan of tunnel.

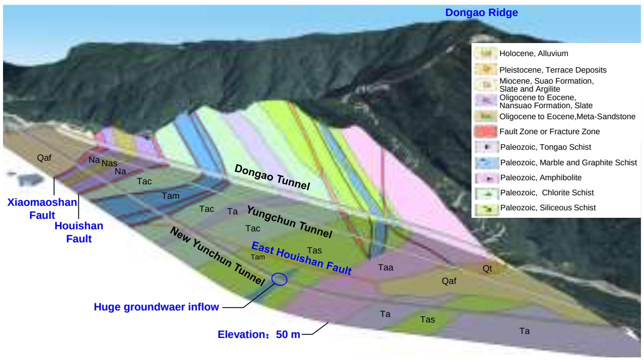

Fig. 3. Geological setting along Dongao Tunnel.

fiber shotcrete are used. In addition, difficulties encountered during the construction of two nearby railway tunnels were carefully studied to draw up countermeasures anticipated to occur during the construction of Dongao Tunnel. Such countermeasures include geological exploration, forepoling, grouting, and hindrance of groundwater flow. Besides, pre-reinforcement in heading face was used in poor ground. (Fig.3, Table 1)

2.4 Cross section

Dongao Tunnel is a twin-tube highway tunnel which is 3.32 km in length, 11.52 m in net width and 4.6 m in net height of driving space.(Figure4) In order to improve the safety, appearance and ventilation effect, reinforced concrete lining was placed along the both bounds of entire tunnel. The cross section of reinforced concrete lining is tapered, and the thinnest section is in the center of the crown.

The highway tunnel is also the first case equipped with semi-transverse ventilation and spray system in Taiwan. The air conduit of each tunnel, of which the cross section is 13.55 m^2, is separated from driving space by RC partition.

Table 1. Major difficulties encountered and countermeasures during the construction stage of Yungchun Tunnel and New Yungchun Tunnel.

Tunnel	no.	Sta.	Geolody and difficulties	Countermeasures
Yungchun Railway Tunnel	1	6k+128	Geology varies greatly, fault fracture zone, muddy water, result in the stuck of Big John	106.7m long by-pass pilot tunnel to the front of Big John while it was dissassembled, bottom pilot tunnel method, enlarging and excavation of upper half
	2	6k+128~ 6k+800	Phyllite, chlorite schist, fault fracture zone, soft rock and huge groundwater inflow	Bottom pilot tunnel method, enlarging and excavation of upper half
			Cave-ins, groundwater inflow and excessive deformation	Support reinforcement, forward horizontal geological exploration
			Huge groundwater inflow with sediment and gravel during fracture zone	Real time steel plate cover, small pilot tunnel method, reduce the spacing of steel sets to 80cm
	3	7k+522~ 7k+756 7k+818~ 7k+840	About 4 squeezing fracture zones	Bench excavation
			fracture zone with groundwater inflow, serious cave-ins	Bench excavation, steel sets of H200 with lateral welding H125 or H150
	4	8k+185~ 8k+240	Squeezing ground	Reduce the spacing of steel sets to 90cm
	5	7k+805~ 9k+474	Continuous groundwater inflow during operation	Additional water collecting pipe on invert, longitudinal and tranverse drainage ditch
New Yungchun Railway Tunnel	6	6k+650	200m of fracture zone with fault gauge and groundwater inflow	Shorten the advance distance, forepoling, partial enlarging and excavation, support reinforcement, long drilling drainage
	7	7k+030~ 7k+060	A substantial increase in groundwater pressure result in uplift of 30cm of railroad tracks	Drainage ditch on both sides, drainage holes@30m
	8	8k+058	Huge groundwater inflow of max. 80t/min result in buried cave-in length of 540m	Long horizontal drilling drainage, drainage hole, realignment of groundwater inflow zones, application of hot asphalt grouting

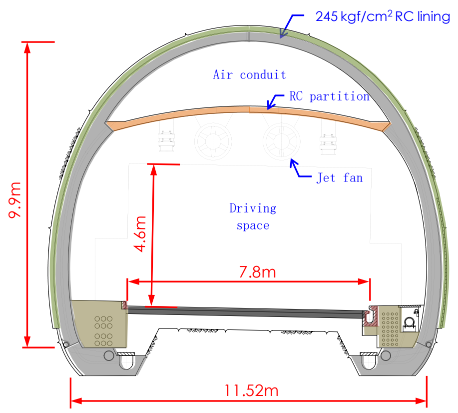

Fig. 4. Cross section of tunnel.

2.5 Construction record

The project was started on Dec 15th, 2012. Serious cave-ins, large deformation and groundwater inflow were still encountered during construction.

According to the analysis of accident notifications, 12 serious cave-in accidents occured in the northbound of Dongao Tunnel, while 24 serious cave-in accidents occured in the southbound. And cave-in notifications occured 81 times in the northbound of tunnel, while cave-in notifications occured 95 times in the southbound of tunnel. Compare the major disaster sites of Yungchun Tunnel, New Yungchun Tunnel and Dongao Tunnel as Fig. 5. Serious cave-in accidents along the both bounds of Dongao Tunnel mainly distributed in Hsiaomaoshan Fault zone (7 times), highly disturbed zone between two faults (7 times) and Houishan Fault zone (8 times). Besides, serious cave-in accidents were occasionally encountered 14 times when excavated during southern shear fracture zones and interface between marble and schist formations. And large deformation was experienced when excavated through sta. 4k+462~800 during highly disturbed zone between two faults. (Shau et al., 2017)

As for huge groundwater inflow accidents along the both bounds of tunnel mainly distributed in Hsiaomaoshan Fault zone, Houishan Fault zone, and marble formations. The max. groundwater inflow happened during sta. 5k+300. The max. groundwater inflow approaching heading face was about 2 T/min while the max. accumulative groundwater inflow at tunnel portal was about 12 T/min.

Countermeasures against the geological difficulties during construction of Dongao Tunnel, such as cave-ins and groundwater inflow, were carefully studied and drawn up according to the case study of two nearby existing railway tunnels. Countermeasures, including geological exploration, hydro-geological surveys, forepoling, grouting, and hindrance of groundwater flow, and pre-reinforcement in heading face, were carried out to reduce the construction risks.(Table 2)

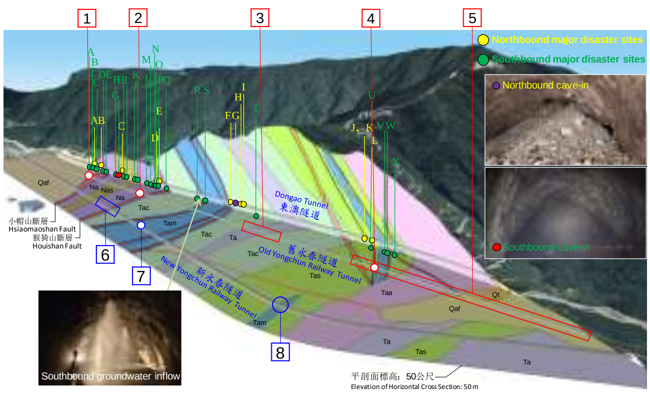

Fig. 5. Comparison of major disaster sites of Yungchun Tunnel, New Yungchun Tunnel and Dongao Tunnel.

Table 2. Major difficulties encountered and countermeasures during the construction stage of Dongao Tunnel.

Tunnel	no.	Sta.	Geology and difficulties	Countermeasures
Dongao Highway Tunnel	1	4k+230~ 4k+400 Hsiaomaoshan Fault zone	Slate, phyllite, metamorphic sandstone, diabase, high water content, fracture zone with shear gauge, groundwater inflow. 7 serious cave-ins	Shotcrete cover with wire mesh, geological exploration, long horizontal drilling drainage in side wall, forepoling or pipe roof in crown of heading face, consolidation grouting, shorten the advance distance
	2	4k+400~ 4k+710 Highly disturbed zone between two faults	Diabase, metamorphic sandstone, phyllite, schist, geology varies greatly, disturbed by two faults, fracture zone with shear gauge, weakened with water, large deformation. 7 serious cave-ins	Shotcrete cover with wire mesh, GFRP grouting, steel rib of H beam, long horizontal drilling drainage in side wall, forepoling or pipe roof in crown of heading face, consolidation grouting and water-stop grouting, shorten the advance distance
	3	4k+700~ 4k+890 Houishan Fault zone	Slate, phyllite, metamorphic sandstone, diabase, schist with marble and amphibolite, fracture zone with shear gauge, weakened with water, groundwater inflow approaching heading face. 8 serious cave-ins	Shotcrete cover with wire mesh, reinforced rock bolts, steel rib of H beam, long horizontal drilling drainage in side wall, forepoling or pipe roof in crown of heading face, consolidation grouting and water-stop grouting, reinforced rock bolts in steel support foot, shorten the advance distance
	4	5k+290~ 5k+380 Northern Marble section	Marble, marble with chlorite schist, chlorite schist, shear zones with striations due to inter-layer sliding, obvious groundwater inflow. (195L/min-m in the NB while 250L/min-m in the SB.) 6 serious cave-ins	Shotcrete cover with wire mesh, geological exploration, long horizontal drilling drainage in side wall, forepoling or pipe roof in crown of heading face, consolidation grouting and water-stop grouting, settlement monitoring
	5	6k+100~ 6k+200 Southern Marble section	Black schist, chlorite schist, interbedded layer, amphibolite, shear zones mixed with shear gauge due to interlayer sliding, groundwater inflow. 6 serious cave-ins	Shotcrete cover with wire mesh, consolidation grouting and water-stop grouting, long horizontal drilling drainage in side wall, forepoling or pipe roof in crown of heading face, steel rib of H beam, shorten the advance distance

3 CONCLUSION

Dongao Tunnel passes through an area with complicated metamorphic rocks and abundant groundwater, and the overburden depth subjected to the tunnel ranges from 7 to 515 m. Due to the multi-phase of metamorphism, thrust faults and several strike slip faults, tunnelling through these fractured rocks has high potential to encounter serious cave-ins and huge groundwater inflow. Countermeasures against the geological difficulties during construction of Dongao Tunnel were carefully studied and drawn up according to the case study of two nearby existing railway tunnels. Countermeasures, including route selection, geological exploration, hydro-geological surveys, forepoling, grouting, and hindrance of groundwater flow, and pre-reinforcement in tunnel heading, were carried out to reduce the construction risks. The project eventually completed successfully and started service in 2018.

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