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Case study on New Ziqiang Tunnel in Hualien-Taitung railway line

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ABSTRACT

In order to improve the transportation efficiency of Hualien-Taitung Railway Line, the authorities carried out Hualien-Taitung Railway Line Electrification Project to save the traffic time. New Ziqiang Tunnel, the critical-path engineering of this project, is located in the east rift valley of Taiwan. The tunnel, with 2,667m in length, is a single-tube, double-track railway tunnel traversing the Wuhe Terrace. The tunnel passes through Lunshan slate, Wuhe conglomerate, Yuli schist, and over 10m-thick silt layer. The silt layer was known as an extremely poor stratum in mountain tunnel.

The project was started on Jan. 16th, 2010. Serious cave-ins, squeezing, and groundwater inflow were encountered in the silt layer section. After the application of auxiliary methods, such as central pilot tunnel method, pre-reinforcement in heading face, compound grouting, and mini bench cut, the 300m long silt layer was successfully overcome. Thus, the tunnel was finally broken through in Dec, 2015. The project officially completed while the tunnel finally started service on Sep. 25th, 2017. Owing to the rare experience of tunneling in silt layer, this paper is aimed to briefly describe the difficulties encountered and relevant countermeasures for future reference.

Keywords: silt layer; central pilot tunnel method; pre-reinforcement; compound grouting; mini bench cut

1 INTRODUCTION

Hualien-Taitung Railway Line Electrification Project was approved by the Executive Yuan on Mar. 13th, 2008 for the purpose of upgrading railway services in eastern Taiwan and thus further promoting the tourism industry there. It is not only completing a modern railway network around the island, but also meant to accommodate fast-growing demand for rapid transport in the eastern region. Spanning about 166.1 kilometers from Hualien Station to Zhiben Station in Taitung County (as Figure 1), the project will electrify the entire route, lay double tracks in the bottleneck sections, rebuild four double-track tunnels and three bridges. After completion of the project, the traffic time is expected to reduce significantly while the maximum vehicle speed will be increased from 110 km/hr to 130 km/hr.

New Ziqiang Tunnel, the most challenging engineering of the project, is located in the east rift valley of Taiwan.(Figure 1) At route selection and planning stage, the regional geology was carefully studied according to the construction history of the nearby existing railway tunnel, Ziqiang Tunnel. The final alignment of New Ziqiang Tunnel was planned to situate at the western side of Ziqiang Tunnel.(Figure 2)

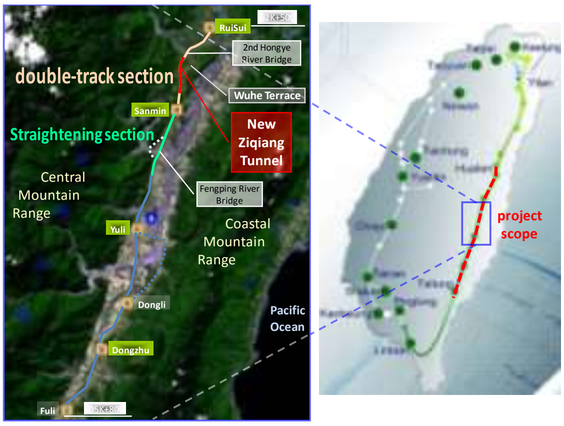

Fig. 1. Site plan of New Ziqiang Tunnel.

Fig. 2. Regional Geology along New Ziqiang Tunnel.

2 DESIGN OF NEW ZIQIANG TUNNEL

2.1 Terrain and regional geology

The east rift valley of Taiwan is located on a convergent plate boundary between the Eurasian plate and the Philippine Sea plate. The collision between two plates results in complex geological system in this area. The origin of Wuhe Terrace is a flooding alluvial plain at the intersection of Hongye River and Xiuguluan River. It becomes what it is today due to crustal uplift and river erosion.(Figure 3)

New Ziqiang Tunnel traverses the Wuhe Terrace of the geological area, and its overburden depth subjected to the tunnel ranges from 10 to 95m. The tunnel passes through LunShan slate, Wuhe conglomerate, YuLi schist, and over 10m-thick silt layer while the silt layer accounts for 11% of total length.(Figure 4)

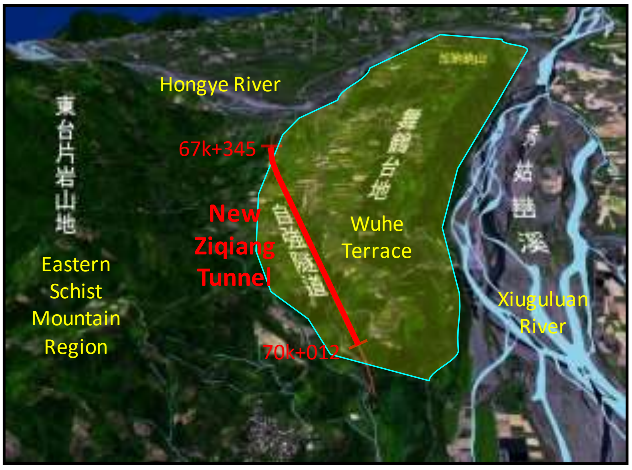

Fig. 3. Aerial view of New Ziqiang Tunnel site.

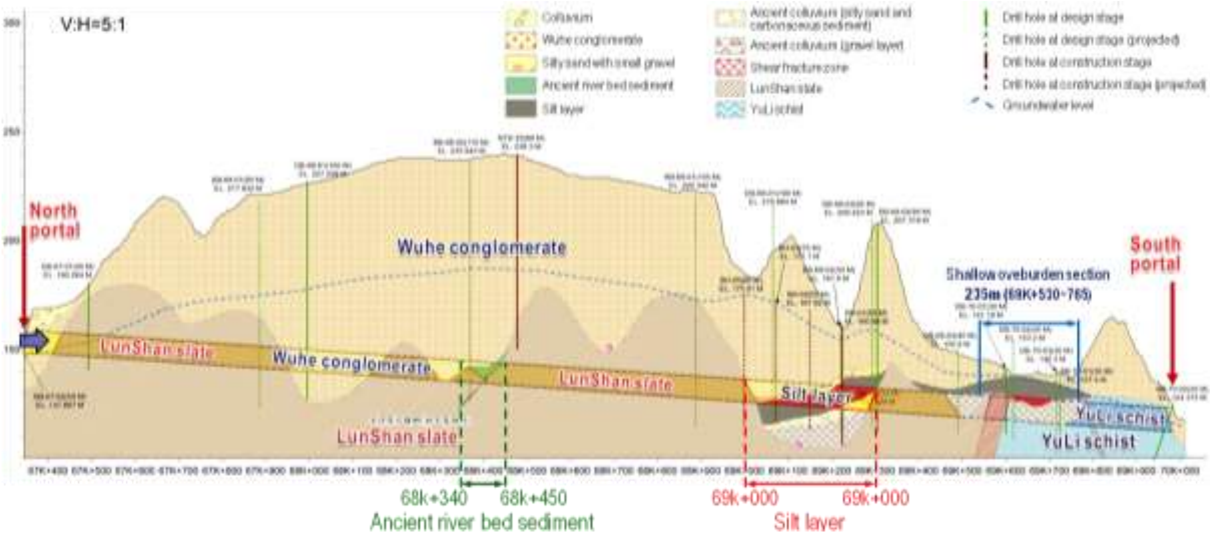

Fig. 4. Geological setting along New Ziqiang Tunnel.

2.2 Rock mass classification and excavation support design

The rock strata along New Ziqiang Tunnel are metamorphic rocks and sedimentary rocks. According to the PCCR system in Taiwan, the metamorphic rocks mainly including slate and schist are classified as rock type A while sedimentary rocks mainly including silt layer and conglomerate are classified as rock type C, and D respectively. Rock type A is subdivided into grade A_{III}~A_{VI} mainly according to RMR while Rock type C, D are subdivided into grade C_{III}, D_{II}, D_{III} according to geological materials and grading proportion.

The tunnelling methods are based on NATM concept. Considering the geological variety and low rock strength along the tunnel, it was designed to excavate by mechanical excavation method with bench cut method.

The excavation support systems are graded as Ⅰ~Ⅴ according to rock mass grade.(Table 1) Three main types of primary support systems, including rock bolts, steel sets, and steel fiber shotcrete are used. In addition, difficulties encountered during the construction of the nearby existing Ziqiang Tunnel were carefully studied

Table 1. Rock mass classification and excavation support classification of New Ziqiang Tunnel.

Rock mass type	Grade	Grading standards	Support grade	Deformation tolerance	Support
A (LunShan slate, YuLi schist)	A_{III}	RMR: 41-60	Ⅰ	10	Bolts, shotcrete, steel sets
	A_{VI}	RMR: 21-40	Ⅱ	15	
	A_{V}	RMR: 11-20	Ⅲ	20	Bolts, shotcrete, steel sets, forepoling
	A_{VI}	RMR: ≦10	Ⅳ	25	
D (Wuhe conglome-rate)	D_{II}		Ⅱ	15	Bolts, shotcrete, steel sets
	D_{III}		Ⅲ	20	Bolts, shotcrete, steel sets, forepoling
C (silt layer)	C_{III}		Ⅴ	25	Shotcrete, steel sets,

forepoling

to draw up countermeasures anticipated to occur during the construction of New Ziqiang Tunnel. Such countermeasures include forward geological exploration, forepoling, grouting, hindrance of groundwater flow, side pilot tunnel method, short bench cut, closure of temporary invert and reinforcement in steel support foot.

2.3 Cross section

The tunnel is a single-tube and double-track railway tunnel. It is 2,667m in length, 11.3 m in net width and 6.75 m in height from top of rail to crown.(Figure 5) In order to improve the safety and appearance, reinforced concrete lining was placed along the entire tunnel. The cross section of reinforced concrete lining is tapered, and the thinnest section is in the center of the crown.

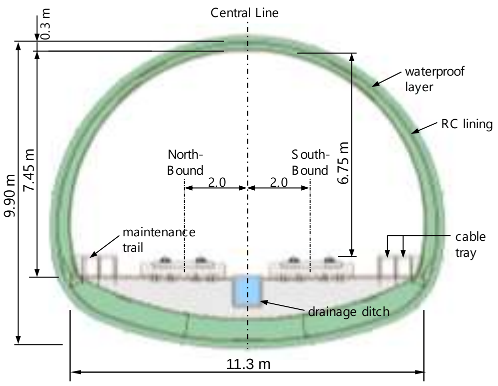

Fig. 5. Cross section of New Ziqiang Tunnel.

2.4 Construction record

The project was started on Jan. 16th, 2010. Cave-ins and groundwater inflow were occasionally encountered during construction while serious cave-ins, squeezing, and groundwater inflow were frequently encountered in the silt layer. Although the silt layer only accounted for 11% of total tunnel length, the difficulty during excavation significantly exceed any other rock types. Even after the application of designed auxiliary methods, the improved results were not obvious.

According to exploring and analyzing the reasons, silt layer is low strength and high sensitivity clayey soil weakened with water significantly. Weakening of silt resulted in the enlargement of disturbed zones around the tunnel and then squeezing of heading face.(Figure 6) In accordance with the grading experimental results, the silt layer encountered in the tunnel was mainly composed of 42.2~97.9% of silt and 1.3~31% of clay.(Figure 7) Due to the even finer particle of the silt layer than microfine cement, cement-based grouting was unable to meet the expected consolidation effects.

According to the construction history of the nearby existing Ziqiang Tunnel, the similar squeezing situation was ever encountered in the same stratum. After the application of NATM with rapid excavation and rapid support as well as high pressure grouting methods, the silt layer section was successfully overcome. However, the cross section area of Ziqiang Tunnel is only 36 m^2 while the cross section area of New Ziqiang Tunnel is 120 m^2, the difficulties during excavation was unable to compare.

During excavation stuck in the silt layer section, the work team took reference of relevant international experience and invited tunnel experts and scholars for construction consultation many times. After careful analysis and review, adjusted the construction countermeasures in the silt layer section as follows.

1. Central pilot tunnel method (Figure 8)
2. Pre-reinforcement in heading face (Figure 9)
3. Compound grouting (Figure 10)
4. Mini bench cut (Figure 11)
5. Other Auxiliary methods, such as lining structure reinforcement, ground improvement grouting in earth surface (Figure 12), double layer GFRP pipe roofing (Figure 9), closure of temporary invert (Figure 8), and reinforced steel pipes in sidewall (Figure 13).

After the application of construction countermeasures as above, the work team successfully overcame the 300m long silt layer.

Fig. 6. Difficulties encountered in the silt layer section.

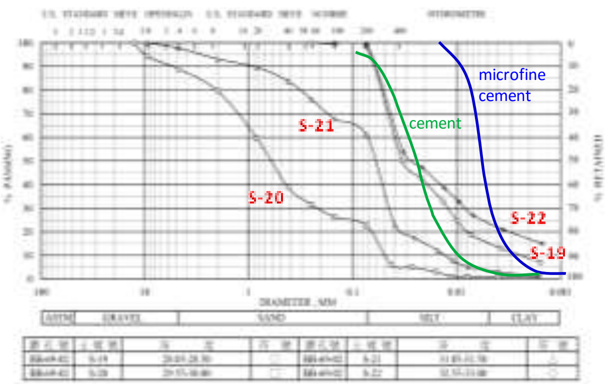

Fig. 7. Particle size distribution curve of the silt layer.

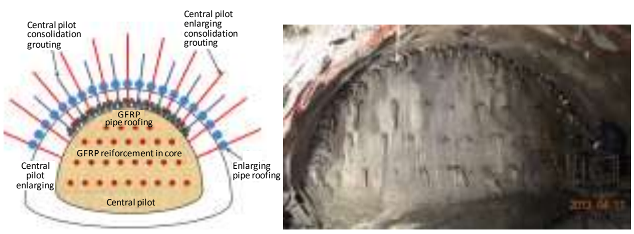

Fig. 9. Pre-reinforcement method in heading face.

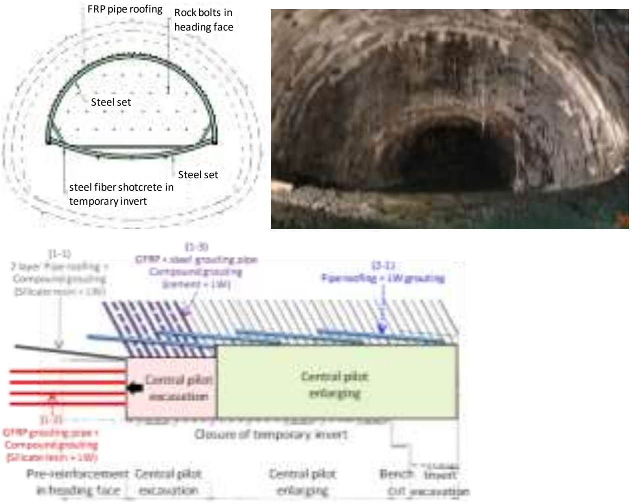

Fig. 8. Central pilot tunnel method in the silt layer.

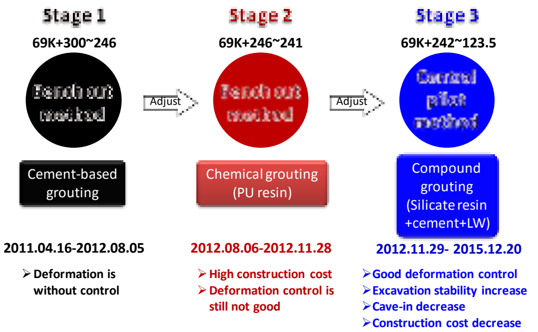

Fig. 10. Stages of tunneling and grouting method in the silt layer.

Fig. 11. Mini bench cut and closure of invert.

Fig. 12. Ground improvement grouting in earth surface.

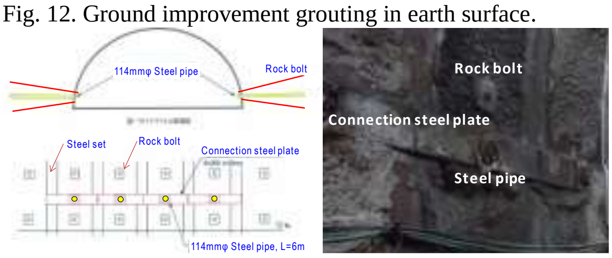

Fig. 13. Reinforced steel pipes in sidewall.

3 CONCLUSION

New Ziqiang Tunnel passes through metamorphic rocks, sedimentary rocks as well as over 10m-thick silt layer, and the overburden depth subjected to the tunnel ranges from 10 to 95 m. The silt layer was a rare encountered extremely poor stratum in mountain tunnel. Countermeasures against the geological difficulties were carefully studied and drawn up according to the case study of nearby existing Ziqiang Tunnel. Due to the characteristics of the silt layer such as low strength, high sensitivity, even finer particle than microfine cement and weakened with water significantly, typical auxiliary methods did not work well. Serious cave-ins and squeezing were still encountered in the silt layer.

After careful study, the work team adjusted the construction countermeasures in the silt layer such as central pilot tunnel method, pre-reinforcement in heading face, compound grouting, and mini bench cut. After the application of adjusted countermeasures, the work team achieve specific benefits such as well-controlled deformation, increased excavation stability, decreased cave-ins, and decreased construction cost. Finally, the 300m long silt layer was successfully overcome.

ACKNOWLEDGEMENTS

I would like to thank each of the officers, engineers and geologists who have contributed their time and knowledge to the project. Although New Ziqiang Tunnel passes through an extremely poor stratum, silt layer, through full cooperation between three groups, Director of Eastern Region Engineering Office, Fortune Construction Co. and Sinotech Engineering Consultants, the tunnel was eventually broken through and started service on schedule under good quality.

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