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Route selction of Dongao Tunnel, Suhua Highway of Provincial Highway No.9 Improvement Project

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ABSTRACT

As a main part of the Suao-Dongao section of the Improvement Project of Suhua Highway (Provincial Highway No. 9), Dongao tunnel is a two-way, twin-tube tunnel and in the length of 3.32 km. At its route selection and planning stage, the regional hydrogeological model and potential of groundwater inflow were carefully studied according to the case histories of two existent railway tunnels, which are Yungchun and New Yungchun tunnels. The latter encountered huge groundwater inflow with peak volume of 80 T/min during construction. The final alignment of Dongao tunnel was planned to be located at the eastern side of Yungchun and New Yungchun railway tunnels with a distance ranging from 50~200m and an elevation of 20~35m higher.

Various hydrogeological surveys, including groundwater level observation, measurement of groundwater inflow along tunnel and accumulative inflow at tunnel portal, and 3D hydrogeological modelling, were performed during tunnel construction stage. The maximum groundwater inflow near heading face was about 2 T/min while the maximum accumulative groundwater inflow at tunnel portal was about 12 T/min. These surveys show an approximate consistency with previous assessment.

1. INTRODUCTION

Located on a convergent plate boundary between the Eurasian plate and the Philippine Sea plate, the collision of two plates results in complex folds and faults system in the mountainous area of Taiwan. Highly fractured rocks provide well flow path and storage space for groundwater. In addition, Taiwan has plentiful rainfall with average annual rainfall of 2,500 mm and in some windward mountain areas, it is up to 6000 mm/year. Abundant rainfall and broken geological conditions make Taiwan's mountain areas rich in groundwater. Therefore, huge groundwater inflow was often encountered during construction of mountain tunnels.

The Suhua Highway is a 118-km section of the Provincial Highway No. 9, which runs north to south along eastern coast of Taiwan. With so 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 improve the safty and reliability of this highway, Improvement Project of Suhua Highway was launched in

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2008.

This Improvement Project includes three route sections, Suao-Dongao section, Nanao-Heping section and Hezhong-Daqingshui section. Aiming to provide a safer highway service, most part of these three sections were designed as tunnels. Dongao tunnel, as a main part of the Suao-Dongao section, is a two-way, twin-tube tunnel with the length of 3.32 km (Fig. 1).

Dongao tunnel starts from south of Yongle Rail Station, and stretches southward through Dongao Ridge to the valley of Dongao Creek. There are Mt. Xiaomao, Mt. Houi and Mt. Ximao on the west side of the tunnel, and Mt. Nansuao and Dongao Ridge on the east side. Dongao Ridge and Mt. Houi are the watersheds of Suao Creek basin and Dongao Creek basin. Two existent railway tunnels, Yungchun Tunnel and New Yungchun Tunnel, are located at the west side of the Dongao Tunnel.

At route selection and planning stage, the regional hydrogeological model and potential of grounewater inflow were studied according to the case histories of Yungchun and New Yungchun tunnels. The latter encountered huge groundwater inflow with peak volume of 80 T/min during construction.

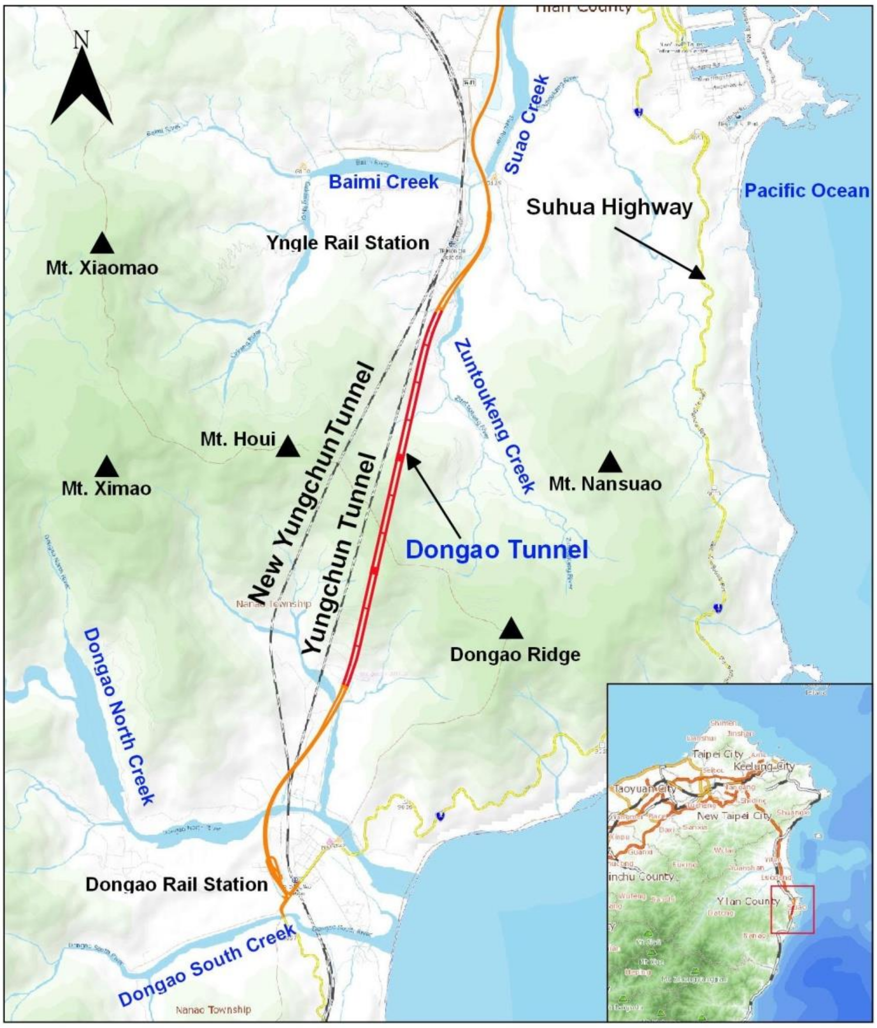

Fig. 1 Location of Dongao Tunnel

2. GEOLOGICAL BACKGROUND

The lithological strata along Dongao Tunnel consist of slate, argillite, metamorphic sandstone, schist, marble and amphibolite(Fig. 2). Having encountered 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 at the northern part of the tunnel. Two thrust faults with south dipping are approximately parallel and strike east-west. In addition, several transverse faults in strike of south-north distributed at both east and west side of Dongao Tunnel. These thrust and transverse 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.

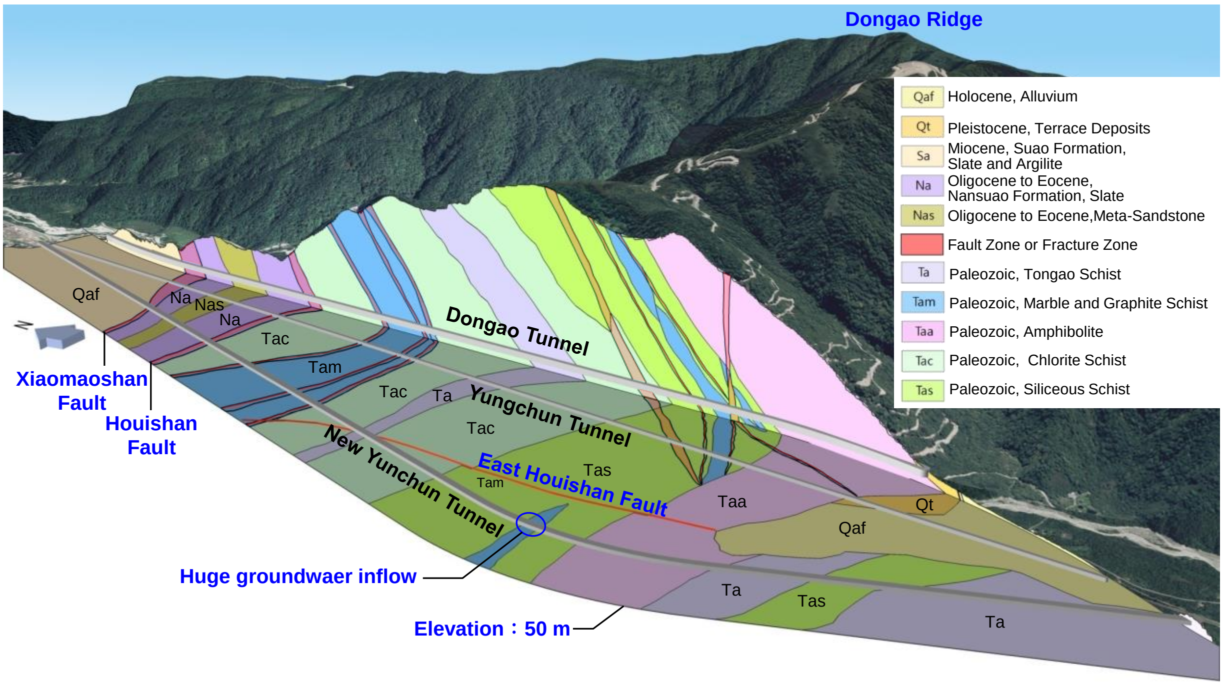

Fig. 2 Geological setting along Dongao Tunnel

3. CASE HISTRY OF NEW YUNGCHUN TUNNEL

AT the construction stage, both of Yungchun Tunnel and New Yungchun Tunnel, encountered the groundwater inflow disaster when tunneling through fault zone, especially the New Yungchun Tunnel. On October 24, 1998, when the excavation of New Yungchun Tunnel had advanced to 1,812m from south portal(Fig. 2), a huge groundwater inflow with volume of 25 T/min initially occurred at heading face, and water inflow increased to 80 T/min later(Fig. 3). More than 15,000 m^3 of collapsed debris came out in the water, burying more than 540 m length of the excavated tunnel. According to comprehensive investigations, the huge groundwater inflow occurred at broken marble layer with well-developed opening joints and fractured rocks (Wang et al. 2011). The thickness of marble layer is about 70 m and diminishes to the east. The very high water pressure of 5.0MPa was measured in the place where thickness of overburden was only 260m. This high water pressure originated from the west side mountain range and pressed the wall rocks around the tunnel through the flow path with high permeability. The gouge filled in fracture or fault zone in the boundary between the marble and schist was destroyed and caused massive water inflow and collapse of tunnel. It took approximate four years to overcome the groundwater inflow disaster and the tunnel was broken through on September 5, 2002.

Fig. 3 Huge groundwater inflow disaster of New Yungchun Tunnel (Wang et al. 2011)

4. CONSIDERATION OF ROUTE SELECTION

According to the case histories of Yungchun Tunnel and New Yungchun Tunnel, and comprehensive investigation results performed at route selection stage, the hydrogeological model of Dongao Area was established. Fig. 4 shows the geological profile perpendicular to the alignment of tunnels and through the Dongao Ridge.

The transverse fault, East Houishan Fault in the general south-north strike, exists between Yungchun Tunnel and New Yungchun Tunnel. This fault blocks groundwater at west side of the fault and isolates high pressure groundwater in the marble layer. It also separates the east groundwater system from the west groundwater system. The west groundwater system connects with the abundant and high pressure groundwater resources within Central Mountain of Taiwan. The east groundwater system sources form the eastern side funnel-like fracture concentration zone around Dongao Ridge. Comparing to the west groundwater system, the groundwater pressure and discharge volume of east are relatively small. The case history of Yungchun Tunnel also showed that the groundwater pressure and volume of inflow encountered during construction were much smaller than that of New Yungchun Tunnel.

Taking the hydrogeological condition of Dongao area into account, the final alignment of Dongao tunnel was planned to be located at the eastern side of Yungchun Tunnels with a distance ranging from 50 to 200m and an elevation of 20~35m higher. The high pressure and abundant west groundwater system separated by East Houishan Fault would not affect the Dongao tunnel construction (CECI 2010).

On the other hand, the probable groundwater inflow during construction of Dongao Tunnel will mainly come from the groundwater within the fracture concentration zone near Dongao Ridge. Tunnelling in Dongao Ridge still has potential risk of encountering relatively large water ingress.

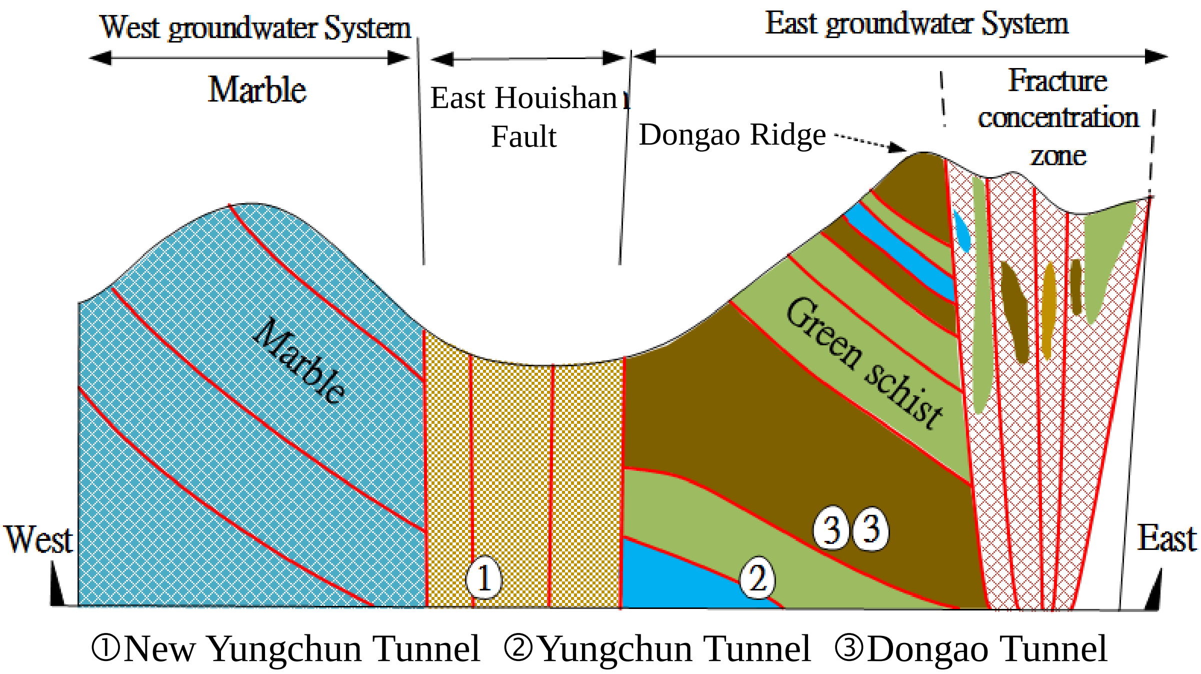

Fig. 4 Groundwater system in the region of Dongao Ridge (Shau 2015)

4.GROUNDWATER INFLOW MEASUREMENT IN CONSTRUCTION STAGE

At the design stage, 3D hydrogeological modelling was performed to assess the probable amount of groundwater inflow. The modelling results predicted that groundwater inflow will occur at Xiaomoashan fault zone, Houishan fault zone, marble layers and the tunnel section near the fracture concentration zone. The maximum water inflow near heading face will occur at Houishan fault zone with the amount of 1.6 T/min (20m interval) and maximum accumulative inflow will be about 17 T/min at north portal.

At the construction stage of the Dongao Tunnel, several weirs which were used to measure the amount of water inflow were installed at the tunnel portal and at the site near the heading face. The maximum groundwater inflow was measured with the amount of 2 T/min at heading face in the fractured marble layer. Maximum accumulative groundwater discharge with the amount of 12 T/min was measured at north portal when excavation reached the same fractured marble layer. These surveys show an approximate consistency with assessment results at the design stage.

The 3D hydrogeological conceptual model and hydraulic parameters were calibrated continuously by adopting the geological mapping data and measured discharge data during tunnel excavation. The final adjusted 3D hydrogeological conceptual model are shown as Fig. 5. The calibrated results of the tunnel inflow are illustrated in Fig. 6; the dotted lines indicate the modelling results of discharge and the solid lines indicate the field measurements of discharge. The calibrated simulation results are generally consistent with the field measurements, indicating that the proposed 3D modelling could well describe the hydrogeological condition around Dongao Tunnel (Sinotech 2017).

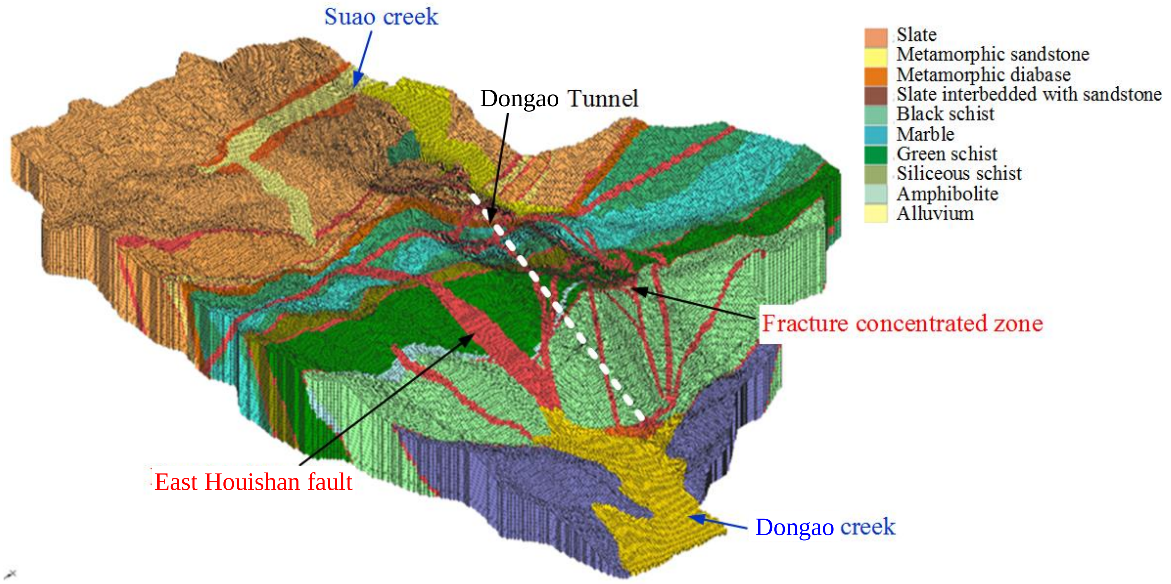

Fig. 5 3D hydrogeological conceptual model (Sinotech 2017)

5. CONCLUSIONS

In this paper, how the existent case history contributed to judgement of route selection were proposed. Table 1 shows the maximum records of groundwater inflow and collapse of New Yungchun and Dongao Tunnel. Both volumes at Dongao Tunnel were apparently smaller than those at New Yungchun Tunnel. It indicates that the risk of huge groundwater inflow was successfully reduced by taking case history into account at the route selection stage.

With complex geological and groundwater conditions, route selection in Taiwan mountainous area often faced many uncertain factors. Appropriate case history study and comprehensive investigations are proven to be helpful in making appropriate judgement.

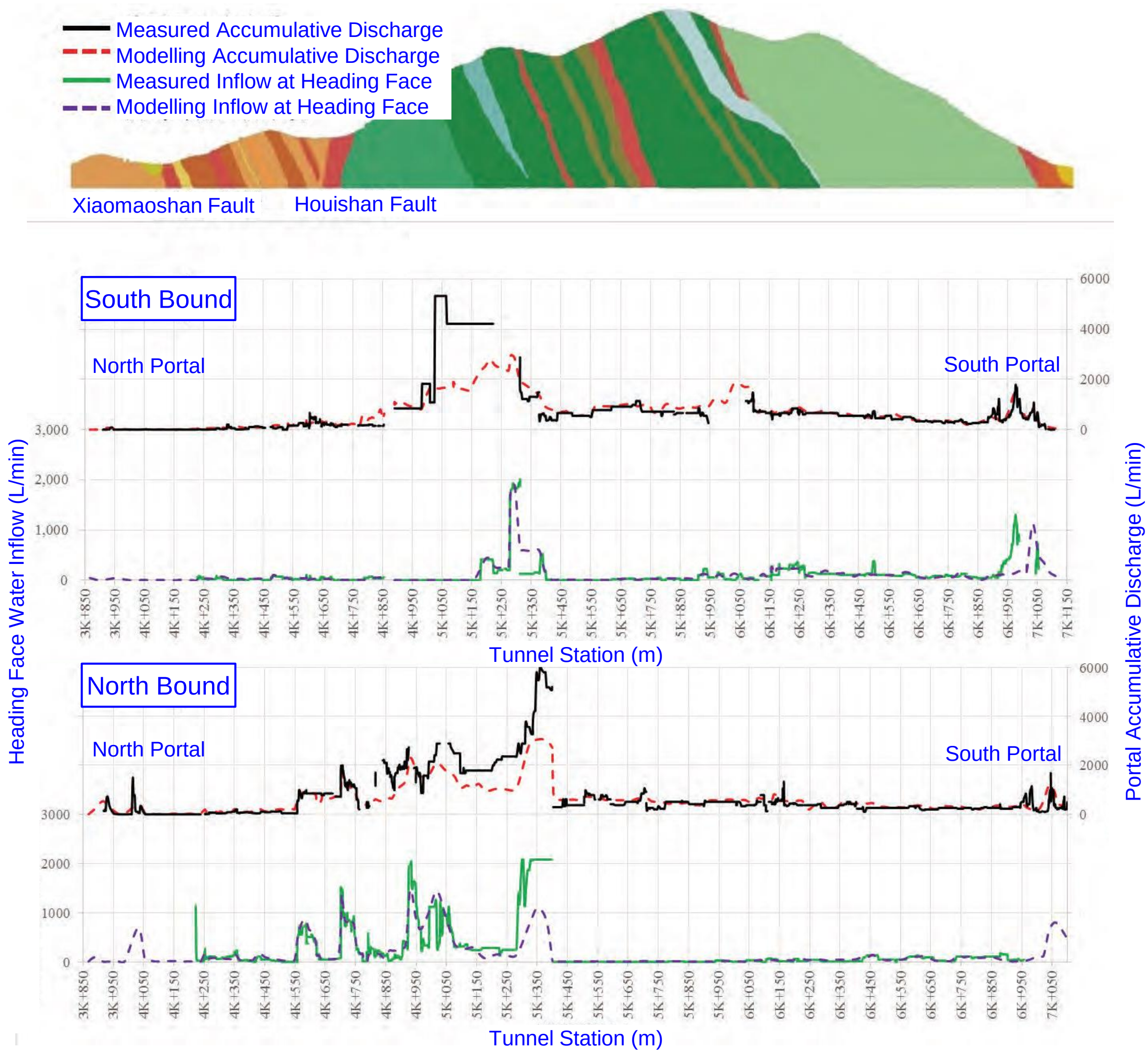

Fig. 6 3D hydrogeological conceptual model (Sinotech 2017)

Table 1 Groundwater inflow and Collapse records of New Yungchun and Dongao Tunnel

Tunnel Name	Maximum Groundwater Inflow at Heading Face	Maximum volume of Collapsed Debris
New Yungchun	80 T/min	15,000 m^3
Dongao	2 T/min	3,000 m^3

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