Appendix. Collection and Processing for Engineering Application Data

1.1 Project Overview

The reconstruction and expansion project of Lushui to Tengchong section in Yunnan is an important section of the national highway G219 Kanas to Dongxing highway in Yunnan. The route starts from the south side of Lushui City in Nujiang Prefecture, the west bank of Dananmao Nanba Bridge, and ends at Nandongping in Tengchong. The total length of the route is 131.14 km. China Railway Tunnel Co., Ltd.undertakes the construction of the main line SG-2 bid and the first contract section of Gaoligongshan Tengyue Tunnel (Parallel pilot tunnel entrance). The SG-2 bid section is located on the water side. The starting point of the bid section is located on the right side of Baihualing Hanlongzhai, with a total length of 5.844 km. The total length of the entrance of the Tengyue Tunnel in Gaoligong Mountain is 5.423 km, the length of the Tengyue Bridge is 183.538 m, and the length of the two sections of the subgrade is 237.036 m. The total length of Tengyue Tunnel (Parallel pilot tunnel) in Gaoligong Mountain is 10.3 km, and the entrance section of the first contract section is 5.4 km. The main tunnel of Tengyue Tunnel is parallel to the parallel pilot tunnel. The horizontal height difference of the tunnel is 1 m, and the average distance between the two tunnels is 30 m.

1.2 Construction Significance

After the completion of the national highway G219, it plays an important role in building a large cycle of tourism in western Yunnan, improving the layout of highway network in Baoshan, Nujiang and other places, poverty alleviation, improving the level of transportation services, and promoting local economic and social development along the line.

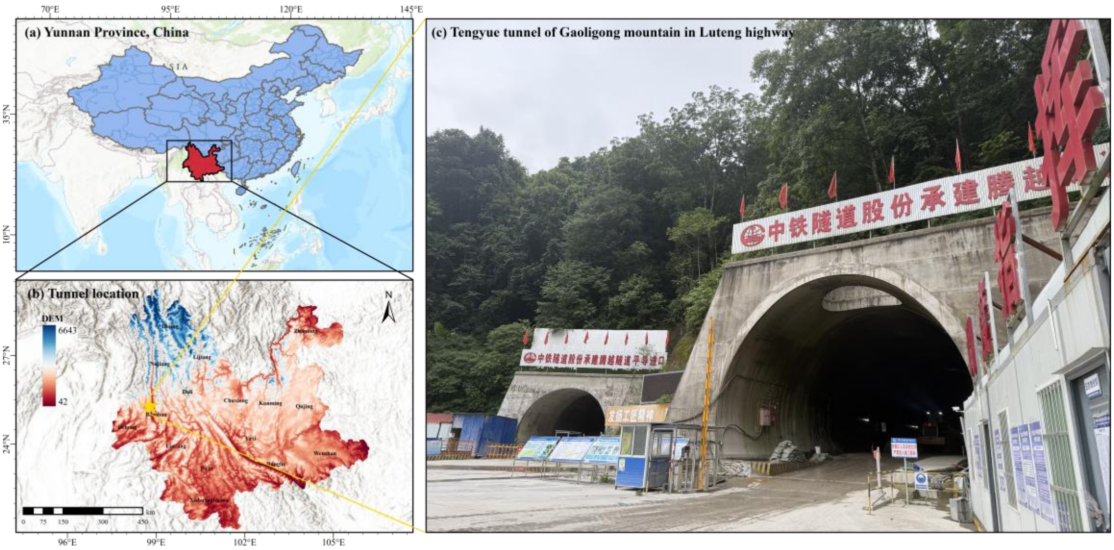

Fig 1 Location of the Gaoligongshan Tengyue tunnel

1.3 Environmental Characteristics

The project is located at the southern end of the western Yunnan longitudinal valley of the Hengduan Mountains. The terrain is complex and diverse. The lowest altitude is 535 m, the highest altitude is 3780.9 m, and the average altitude is about 1800 m. It is a low-latitude mountain subtropical monsoon climate. It is located in a low-latitude plateau with complex topography and landforms. It has three-dimensional climate characteristics of one mountain in four seasons and ten miles in different days. The annual rainfall is 1500~2000 mm. Close to the Baihualing eco-tourism area of Gaoligong Mountain, Gaoligong Mountain Nature Reserve is the world 's biosphere natural protection base, with extremely rich biodiversity; it is the location of the ancient famous southern silk road yongchang ancient road gaoligong mountain section. The requirements for ecological protection and forest fire prevention are particularly high. The construction of the project is subject to the characteristics of the terrain, and the construction site is particularly narrow.

1.4 Geological characteristics

The activity characteristics of the main faults mainly develop three major fault systems. The western part belongs to the Longchuanjiang fault system, the middle part belongs to the Lushui-Ruili arc deep fault system, and the eastern part belongs to the Nujiang fault system. The rock mass along the fault zone is generally strongly deformed and has poor integrity, mainly distributed along the Gaoligong Mountain in a nearly north-south direction. Complex tectonic stress field environment. The design of the tunnel area predicts a daily maximum water inflow of 10095 m^3/d. The main adverse geological conditions that the project may encounter are high ground stress, fault fracture zone, weak surrounding rock, rock burst, mud inrush and water gushing and high geothermal.

1.5 Water inflow prediction related data processing

1.5.1 Water inflow calculation

According to the results of the 'hydrogeological report' of the tunnel, the prediction of the tunnel water inflow is based on the calculation results of the groundwater dynamics method, that is, the normal water inflow is 34526 m^3/d, and the maximum water inflow is 98581 m^3/d. The normal water inflow of the east slope is 23394 m^3/d, and the maximum water inflow is 66785 m^3/d. The normal water inflow of the west slope is 11132 m^3/d, and the maximum water inflow is 31796 m^3/d. The maximum water inflow calculated by the Goodman formula is 58214 m^3/d, of which the eastern slope is 39556 m^3/d and the western slope is 18658 m^3/d. The statistical calculation table is shown in Table 1.

Table 1 Calculation table of tunnel water inflow by groundwater dynamics method

Segmented mileage	Lithology combination	Permeability coefficient K(m/d)	The distance between the water level and the middle of the hole L(m)	Length of tunnel section H(m)	The maximum water inflow of main tunnel by Goodman formula method (m^3/d)	Railway empirical formula method	
						Normal water inflow (m^3/d)	Maximum water inflow (m^3/d)

Using the Goodman empirical formula of groundwater dynamics method and the empirical formula of railway survey specification to calculate the unit water inflow of the tunnel engineering section (Yiming Luo et al., 2023):

$$Q = L\frac{2\pi \cdot K \cdot H}{\ln\frac{4H}{d}} \tag{1}$$

$$Q = LHK(0.676 - 0.06K) \tag{2}$$

$$Q_{max} = L(0.0255 + 1.9224HK) \tag{3}$$

Where Q is the normal water inflow (m^3/d) of the tunnel passing through the water-bearing section, Q_{max} is the maximum water inflow (m^3/d) of the tunnel passing through the water-bearing section, L is the length of the tunnel passing through the water-bearing section (m), H is the distance from the static water level to the bottom of the tunnel (m), K is the permeability coefficient of the water-bearing section (m/d), d is the equivalent circle diameter of the cross section of the tunnel.

1.5.2 Calculation method of Water Yield Property

Water Yield Property (Unit water yield capacity) refers to the water yield per meter of tunnel length per unit time (Usually taken per hour), commonly used unit is m^3/(h m). In tunnel construction, it is usually assumed that the tunnel is an equivalent cylindrical excavation body and is regarded as a line source passing through the aquifer, which corresponds to the radial seepage mode of hydraulic equilibrium steady state. According to Darcy's law, a typical Thiem formula can be obtained for steady seepage to estimate the water inflow per unit length of the tunnel (Wang et al., 2020). Since the tunnel project cases are confined aquifers, and the groundwater level is higher than the tunnel floor to form a stable head difference, the basic form of hourly water production per unit length is as follows:

$$\frac{Q}{L} = \frac{2\pi KH\left(h_0 - h_L\right)}{\ln(R/r)} \tag{4}$$

Among them, the permeability coefficient of the aquifer (m/d) is the effective thickness of the aquifer (m), the difference between the groundwater level and the water level in the tunnel (m), the equivalent radius of the tunnel, and the influence radius. This formula can be regarded as the application of Thiem formula in groundwater dynamics.

The shape of tunnel face (circle, ellipse, rectangle, etc.) itself does not change the principle of Darcy seepage equation. In the application of the above formula, the calculation is carried out by introducing the equivalent circular radius or geometric parameters. The equal area method or the equivalent perimeter method is used to convert any section into an equivalent circular section. The section area of the tunnel is 128.76 m^2, that is, the calculated equivalent circular radius $r=\sqrt{S/\pi} = \sqrt{128.76/\pi} \approx 6.4020\text{m}$, and the influence radius is 20 times the equivalent tunnel diameter of 128.04 m.

1.5.3 Empirical estimation method and derivation process of core quality index (RQD)

In the absence of direct core observation data at the engineering site, this paper adopts an empirical method based on BQ classification information to reverse the RQD value, and combines the rock mass structure parameters and industry experience to realize the rapid estimation and verification of the RQD index of each section. According to the 'Engineering Rock Mass Classification Standard' (GB / T 50218-2014) (Ministry of Housing and Urban-Rural Development of the People’s Republic of China, 2014), the BQ index is determined by the saturated uniaxial compressive strength R_c of rock and the integrity coefficient K_v of rock mass. The calculation formula is:

$$BQ = 90 + 3R_c + 250K_v \tag{5}$$

Among them, R_c reflects the strength grade of rock, and K_v is derived from the longitudinal wave velocity ratio, which indirectly characterizes the development degree and integrity of rock mass fractures.

Rock Quality Designation (RQD) is defined as the percentage of the total length of the core with a length greater than 10 cm in the borehole to the total drilling footage. It is a commonly used indicator to characterize the structural integrity of rock mass. RQD and J_v are widely used to represent the joint degree of rock mass, because both factors comprehensively reflect three important geometric parameters, namely, the number of joint groups, joint durability and joint spacing of rock mass (Zheng et al., 2020). Palmstrom (2005, 1982) proposed a widely accepted empirical formula for estimating RQD from volumetric joint number J_v:

$$RQD = \begin{cases} 100 & J_V < 4 \\ 110 - 2.5J_v & 4 \le J_V \le 44 \\ 0 & J_V > 44 \end{cases} \tag{6}$$

Among them, J_v is the number of all joints per unit volume of rock mass (strips/m³), which is usually estimated according to the number and spacing of the main joint groups.

After estimating the RQD of the tunnel engineering section, in order to further check the rationality of the estimated value, this paper establishes the following empirical mapping table Table 2 by referring to the corresponding relationship between the RQD classification standard and the rock mass description, and verifies the rationality of the RQD estimation value through the joint development degree and the rock mass structure description.

Table 2 BQ rock mass classification information and RQD interval experience mapping table

Rock mass structure description	**Joint spacing**	**Empirical RQD range**
Complete rock mass	>1.5 m	90–100%
Relatively complete rock mass	0.6–1.5 m	75–90%
Medium integrity (Denser joints)	0.2–0.6 m	50–75%
More broken (Obvious joints, Structural plane development)	0.06–0.2 m	25–50%
Extremely broken or chaotic structures	<0.06 m or disordered	0–25%

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