Study on the comprehensive logging experiment of the Nibashan Tunnel, China

Yong REN(1), Jun WU(2), Xiyong WU(1)(3), Chunwei SUN(1)

(1) Faculty of Geosciences and Environmental Engineering, Southwest Jiaotong University, China
E-mail: ng_iln@hotmail.com; wuxiyong@126.com
(2) Guizhou Expressway Group Co. Ltd., Guizhou Province, China
(3) Moe Key Laboratory of High-speed Railway Engineering, Southwest Jiaotong Unviersity, China

Abstract

Nibanshan Tunnel located in the core of the Daxiangling Anticline, Sichuan Province, China. The strike of the axial line is mainly NW which varies SN at the tunnel section, and the tunnel goes through the anticline which contains 16 structural fracture zones. The bed rocks, the various petrographic formation and the structural fracture zones constitute a complicated hydro-geological system. Many field tests were carried out in the purpose of clarifying the hydro-geological framework of the tunnel zone. Taking the ZK No.2 logging as an example, the use of the comprehensive logging experiment as an investigation method of the hydro-geological framework is introduced in this paper.

Keywords: Comprehensive logging experiment; hydro-geological framework; Nibanshan Tunnel; solution resistivity; longitudinal wave velocity; lateral resistivity

1. Introduction

As a kind of linear underground building, the tunnel will inevitably pass through different hydrology geology in the construction process. Water inflow is a common geological disaster and the main inducement cause of other disasters (e.g., Kong, 2011).

The Nibashan tunnel is located in the edge of Longmeshan fault. The maximum depth of the tunnel is 1701 m, and about 5 km length of the tunnel is deeper than 1600 m. As a result, a large number of underground water is stored in the igneous rock fissures and joints in mountain. The formation of water inrush passages is mostly the geological flaws, including fault, fracture, joints and unfavorable section in the surrounding rock over a tunnel (Shi and Singh, 2001). Some scholars have researched the microscopic pore characteristics in acidic volcanic reservoir from the oil and gas exploration (Pang et al., 2007). The water reservoir space has characteristics of complexity, instability and heterogeneity, because of the nonuniformity of the igneous compositions, the condensation environmental differences and the uneven degree of porosity and fissures (Holmøy and Nilsen, 2014). The water inrush is likely to occur in the fault zone and joint fissures developing zone, but the fault seal capacity is not yet discussed (e.g., Lv and Ma, 2003). Therefore, it is essential to carry out comprehensive logging experiment to understand the underground water reservoir characteristic of the igneous rocks and the permeability of the fault zones in the purpose of safety construction (e.g., Li, 2003).

2. Engineering geological conditions

Nibanshan Tunnel located in the core of the Daxiangling Anticline, Sichuan Province, China, and it is the dominant project of the Yaan-Lugu expressway. As the watershed of the Daduhe water system and the Qingyijiang water system, Daxiangling Mountain is an important climatic boundary, the north section (Ya-an direction) is humid and rainy while the south section (Lu-gu direction) is dry.

The lithology of the tunnel is mainly composed of rhyolite (69%), andesite (21%) and granite in the lower series of Proterozoic, Sinian System, clastic rock in Sinian System, Cambrian System, Ordovician System and Permian System, and Quaternary overburden layer.

The structure of the Nibashan Mountain is considered as a diapir structure which displays the “Ω” form (Fig.1; Ling et al., 2015). The reverse fault (F_2 and F_7) located in the sides of the anticline, making the anticline into a symmetrical form. The No.2 logging (ZK_2) which goes through the Fx_2 fault located in the north part of the tunnel and has the elevation and depth of about 1953 m and 450.5 m respectively and the elevation and depth of the tunnel in the logging's position is 1527m. The anticline profile, geological structure and boreholes' positions are shown in Fig.1.

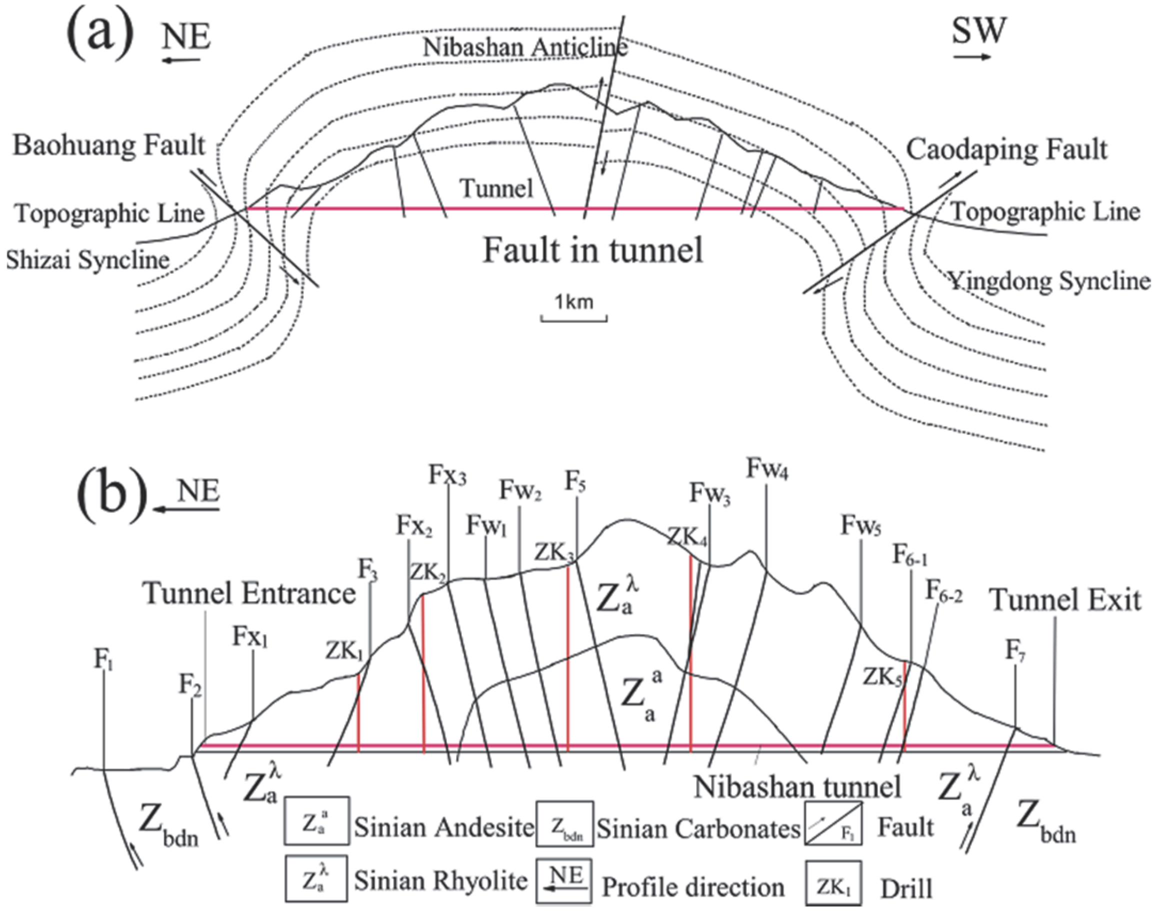

Fig. 1 The anticline profile and geological structure diagram of the Nibashan tunnel. (a) The structural characteristics of the Nibashan tunnel; (b) The sketch map of the relative position of the faults and the boreholes

3. Comprehensive logging experiment

Borehole logging is a very robust tool to accurately locate transitions between weathered layers and fractures in hard rock settings; therefore, it can help substantially in the construction of regional and local hydrogeological models (e.g., Chandra et al., 2008, 2014; Chatelier et al., 2011; Dewandel et al., 2010; Chen et al., 2008).

3.1 Salt solution resistivity method

In this single logging method, the JGS-1 comprehensive logging instrument made by Chongqing Geological Instrument Factory was applied.

After the instrument was assembled, the salt solution resistivity probe was put down into the borehole to measure the resistivity. Sampling interval was set at 1.0 m, the downward speed was set at 4 m/min. And after the first curve was acquired, the fluid of the borehole was salinized by salt. The salt bags were fixed on the cable every 0.1 m and opened almost at the same time to make sure that the fluid of the borehole was salinized uniformly. Then the salt solution resistivity was measured every 2 hours and the sampling interval and speed were the same as above.

One original curve ρ_0 was gained in the first measurement, after the water was salinized, 4 other recovery curves were measured (ρ_1~ρ_4), and the last recovery curve (ρ_4) was very close to the original curve (ρ_0). The curves gained in the experiment are shown in Fig.2.

As is shown in the diagram: the resistivity in the 0~253 m section of the well recovered very fast to the original status, indicating that the liquid was diluted, which meant that there were productive aquifers in the section; the productive aquifers were deduced to host in at the depth of 36 m, 96 m and 146 m, because of the abnormal resistivity changes at the positions ($\rho_{0,}$ ρ_2). All the curves changed abnormally at the depth of 146m, which indicated that there was serious water inflow at that depth. The resistivity catastrophe appeared at the depth of 253 ~ 260 m and the curves below got recovered slowly (almost 10 h), which shown that there was no aquifer below.

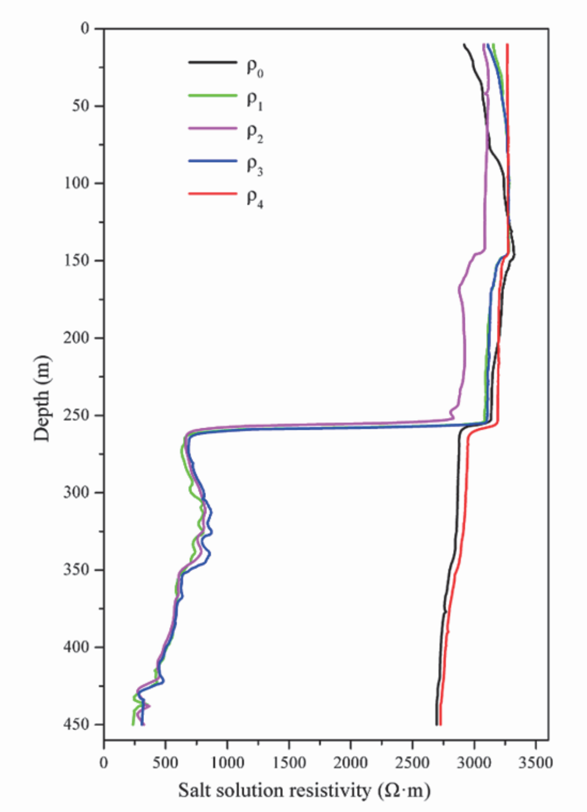

Fig. 2 The salt solution resistivity recovery curve

3.2 Longitudinal wave velocity and lateral resistivity method

After the resistivity was measured, X411 3-lateral resistivity probe and S523 acoustic wave probe were installed to measure the lateral resistivity and longitudinal wave velocity respectively.

First of all, the probe was put down to the bottom of the well, and then the measurement began from the bottom to the top. Sampling interval was set at 0.5 m, and the downward speed was set at 10 m/min.

3.2.1 3-lateral resistivity

As is shown in Fig.3, the result of the lateral resistivity measurement is quite clearly: the 1.5~21.5 m section owns the lowest resistivity, with an average value of 443.6 Ω·m; the 149.5 ~ 267.5 m section has the average value of 875.5 Ω·m. The two lowest resistivity sections refer to the surface weathered zone and the fault fracture zone respectively, which are supposed to be the productive aquifer. Other sections with lower resistivity value are 268.0 ~ 347.0 m and 384.0 ~ 414.0 m, and the average value is 2077.8 Ω·m and 2563.1 Ω·m respectively, which refer to the fracture development surrounding rock mass. The segmentation and the qualitative assessment of the surrounding rock are shown in Table 1.

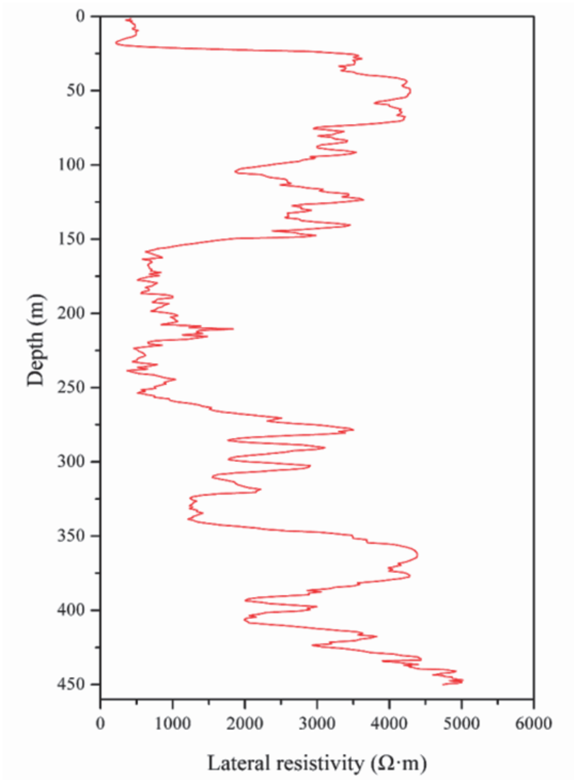

Fig. 3 The 3-lateral resistivity curve

Table1. Segmentation and the qualitative assessment of the surrounding rock

Depth (m)	Number	Range value (Ω·m)	Average value (Ω·m)	Assessment
1.5~21.5	41	214.3~1190.2	443.6	Strongly~ weakly weathered zone
22.0~149.0	255	1552.1~4288.1	3274.66	Fracture~Blocky rock mass
149.5~267.5	237	367.3~1904.7	875.5	Fault fracture zone
268.0~347.0	159	1211.4~3501.9	2077.8	Fracture development rock mass
347.5~383.5	73	3062.2~4386.9	4002.4	Intact rock mass
384.0~414.0	61	1991.3~3419.57	2563.1	Fracture development rock mass
414.5~450.0	72	2929.2~5020.0	4102.1	Intact rock mass

Table 2. Segmentation and the qualitative assessment of the surrounding rock

Depth (m)	Number	Range value (km/s)	Average value (km/s)	Assessment
1.5~34.5	67	1.18~3.91	2.87	Strongly~ weakly weathered zone
35.0~143.0	217	3.67~4.43	4.08	Blocky rock mass
143.5~176.5	67	3.28~3.98	3.54	Fault fracture zone
177.0~395.0	437	3.55~4.70	4.21	Blocky rock mass
395.5~407.5	25	3.41~3.93	3.56	Fracture development rock mass
408.0~450.0	85	3.86~4.75	4.48	Intact rock mass

3.2.2 Longitudinal wave velocity

The borehole can be divided into 6 parts according to the longitudinal wave velocity: 1.5 ~ 34.5 m section belongs to the strongly~ weakly weathered zone which has the minimum velocity value of 2.87 km/s in average; 35.0 ~ 143.0 m and 177.0 ~ 395.0 m sections belongs to the blocky rock mass and the velocity value are 4.08 km/s and 4.21 km/s respectively; the fault fracture zone identified in this method is not that thick than the method above which only hosts in the 143.5 ~ 176.5 m section; the 395.5 ~ 407.5 m section has the second lowest average value of 3.56 km/s which refers to the fracture development rock mass and the 408.0 ~ 450.0 m section has the maximum average value of 4.48 and is considered as the intact rock mass. The segmentation and the qualitative assessment of the surrounding rock are shown in Table 2.

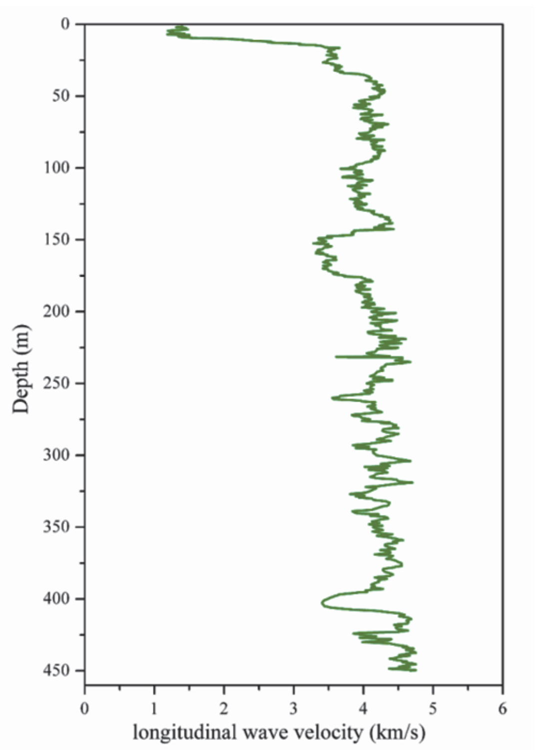

Fig.4 The longitudinal wave velocity curve

4. Discussion and result

The distinguishability of the longitudinal wave velocity method is not that good as the 3-lateral resistivity method, the fracture development rock mass in the depth of about 268.0~347.0m is not been recognized, but the segmentation and the qualitative assessment of the surrounding rock match well in general.

According to the comprehensive logging experiment, the thickness of the weather zone is about 30m, and the fault fracture zone hosts in the depth of about 140 ~ 270 m. The hanging wall of the Fx_2 fault has lower 3-lateral resistivity and longitudinal wave velocity values which indicated that the fracture developed better in the hanging wall of the Fx_2 fault, and based on the salt solution resistivity recovery curve, the hanging wall is much productive an aquifer than the footwall, so that water inflow may easily occur in the hanging wall during construction.

According to the 3-lateral resistivity and longitudinal wave velocity experiment, there is a fracture development rock mass section in the depth of about 380~420m, which owns lower 3-lateral resistivity and longitudinal wave velocity values, though the facture is always thought to be tightly closed in such a depth. So there might be a rhythmic layering in the depth of about 380 ~ 420 m with an elevation of 1513m, which is close to the elevation of the tunnel (1527m), but we are not sure about that because of the lack of the borehole (there are only 4 borehole in the whole length of the tunnel). Yet the influence of the rhythmic layering should be taken into account during construction, and the comprehensive logging experiment can still be an effective method in the investigation of the hydro-geological framework.

5. Conclusion

The investigation of the hydro-geological framework of Nibashan tunnel in Sichuan Province, China is quite difficult because of the steep topography. Three types of curves are gained in comprehensive logging experiment during the field investigation and the conclusion obtained from the present study can be drawn as follows:

(1) The thickness of the weather zone is about 30m, and the fault fracture zone hosts in the depth of about 140 ~ 270 m.

(2) The fracture developed better in the hanging wall of the Fx_2 fault, and water inflow may easily occur in the hanging wall during construction.

(3) There might be a rhythmic layering in the depth of about 380 ~ 420 m which is very close to the depth of the tunnel and the influence of the rhythmic layering should be taken into account during construction.

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References

Chandra, S., Ahmed, S., Ram, A. and Dewandel, B. (2008): Estimation of hard rock aquifers hydraulic conductivity from geoelectrical measurements: A theoretical development with field application, Journal of Hydrology, Vol. 357, No. 3-4, pp. 218-227.

Chandra, S., Boisson, A. and Ahmed, S. (2014): Quantitative characterization to construct hard rock lithological model using dual resistivity borehole logging, Arabian Journal of Geosciences, (published online), doi: 10. 1017/s12517-014-1148-1

Chatelier, M., Ruelleu, S., Bour, O., Porel, G. and Delay, F. (2011): Combined fluid temperature and flow logging for the characterization of hydraulic structure in a fractured karst aquifer, Journal of Hydrology, Vol. 400, No. 3-4, pp. 377-386.

Chen, Q., Zhou, K., Long, T. and Gao F. (2008): Single-borehole measuring method for broken rock zone in gently inclined thin layer weakness structure, Journal of Coal Science and Engineering (China), Vol. 14, No. 2, pp. 200-204.

Dewandel, B., Perrin, J., Ahmed, S., Aulong, S., Hrkal, Z., Lachassagne, P., Samad, M. and Massuel, S. (2010): Development of a tool for managing groundwater resources in semi-arid hard rock regions: application to a rural watershed in South India, Hydrological Processes, Vol. 24, No. 19, pp. 2784-2797.

Holmøy, K.H. and Nilsen, B. (2014): Significance of geological parameters for predicting water inflow in hard rock tunnels, Rock Mechanics and Rock Engineering, Vol. 47, No. 3, pp. 853-868.

Kong, W.K. (2011): Water ingress assessment for rock tunnels: a tool for risk planning, Rock Mechanics and Rock Engineering, Vol. 44, No. 6, pp. 755-765.

Li, B. (2003): Some knowledge on interpretation of comprehensive logging curves, Uranium Geology, Vol. 19, No. 1, pp. 48-52, 57 (in Chinese with English abstract)

Ling, S., Ren, Y., Wu, X., Zhao, S. and Qin, L. (2015): Study on reservoir and water inrush characteristic in Nibashan tunnel, Sichuan province, China, XII IAEG Conference, *Engineering Geology for Society and Territory*, vol. 6, pp. 577-582. doi: 10.1007/978-3-319-09060-3_104

Lv, Y. and Ma, F. (2003): Controlling factors and classification of fault seal, journal of Jilin University (Earth science edition), Vol. 33, No. 2, pp. 163-166 (in Chinese with English abstract)

Pang, Y., Zhang, F., Qiu, H. and Zhan, J. (2007): Characteristics of microscopic pore structure and physical property parameter in acidic volcanic reservoir, Acta Petrolei Sinica, Vol. 28, No. 6, pp. 72–77 (in Chinese with English abstract)

Shi, L. and Singh, R.N. (2001): Study of mine water inrush from floor strata through faults, Mine Water Environment, Vol. 20, No. 3, pp. 140–147.