RESEARCH ON ROCK MASS CLASSIFICATION FOR LONG TBM HYDRAULIC TUNNEL AT DEEP LEVEL

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ABSTRACT

Since the conventional rock mass classification schemes for hydraulic tunnels have been developing from engineering case histories constructed using drill and blast methods at shallow levels, they aren't proper to the long TBM tunnels at deep levels. In this paper, the characterization of the long tunnels at deep level and the main potential geotechnical risk of TBM tunneling are discussed. Based on the rating of rock mass stability and boreability, as well as geotechnical risk factors such as effects of rock burst, excessive soft rock deformation, high external water pressure, large inflow and so on, a new engineering rock mass classification scheme is proposed for long TBM hydraulic tunnel at deep level in an attempt to provide initial data for design of tunnel support, selection of TBM type and counter-measures against possible geotechnical risk.

Keywords *: long hydraulic tunnel at deep level, geological investigation, engineering rock mass classification*

1. INTRODUCTION

There are many classification systems available for tunneling rock mass at home and aboard, amongst which the Engineering Classification System after the Chinese Standard GB50487 Code for engineering geological investigation of water and hydropower projects, Rock Quality Designation (RQD, Deere 1964), Tunneling Quality Index (Q, Barton et al. 1974; Barton 1991, 1995) and Rock Mass Rating (RMR, Bieniawski 1973, 1984, 1989) systems are widely accepted in China for engineering rock mass classification of hydraulic tunnel. However, these systems were developed from drill-and-blast cases at shallow levels without taking the characterization of the long tunnels at deep levels and the main potential geotechnical risk of TBM tunneling into consideration, they aren't proper to the long TBM tunnels at deep levels due to the following aspects: (1) The abovementioned classification systems are developed from the opening cases excavated at surface or shallow levels, the objective conditions at deep to extremely deep levels may be ignored. (2) Effect of TBM boring rate cannot be evaluated in the classification systems developed from drill-blast tunnel-ing cases. (3) It is impossible to identify the rock mass stability before segment support and verify the reliability of predicted rock mass class for Double-shield TBM tunneling. (4) The type and magnitude of the geotechnical risk for TBM use cannot be accurately predicted so that no corresponding counter-measures can be proposed. (5) Some parameters can seldom be obtained at deep level during the pre-investigation and design period, for example, the conditions of discontinuities and groundwater at deep levels.

Consequently, several authors have made an effort to conquer the aforesaid limitations. Professor N.Barton of the Norwegian proposed a new QTBM model (Barton 2000) on the basis of Q system. Based on the tunneling cases at home, Chinese authors (He et al.2002; Li and Peng 2006; Wu et al.2006; Li 2010;Xue et al.2018; et al) have modified the classification systems from TBM tunneling efficiency and performance factors, who proposed that the wear resistance and hardness of rocks are also important factors affecting TBM tunneling efficiency in addition to the parameters in conventional classification schemes. Given the characterization of TBM tunneling, Zhang (2010) have described a modified system on the basis of the classification system in the Chinese Standard GB50487 by adjusting it to account for high ground stress and external water pressure. The common characteristic of the aforementioned studies is that the original rock ratings are adjusted according to the geotechnical risk and the contributing factors of TBM tunneling efficiency that are considered as adjoint factors affecting rock mass stability, arising a problem that the modified rock mass rating depict neither the actual stability of rock mass nor the TBM geotechnical risk and tun-neling efficiency.

Based on the conventional rock mass classification system, a new engineering classification scheme is proposed for long TBM tunnel at deep level in this paper by comprehensively considering the characterization of the long hydraulic tunnel at deep level, available geological data in stages, the boreability of rock mass, and the main potential geotechnical risk of TBM tunneling including effects of rock burst, soft rock deformation, high water pressure and permeability, etc.

2 CHARACTERIZATION OF LONG TUNNEL AT DEEP LEVEL

There are currently no uniform grading criteria of tunnel. In the Chinese Standard GB50487, tunnels having a cover of greater than 600m high are called tunnels at deep level, and having a length of more than 10km are long tunnels. There are several long hydraulic tunnels at deep level in China, some are still ongoing as list in Table 1:

Table 1 : Some buried long hydraulic tunnels in China.

Name	Length (km)	Maximum depth (m)	State
Hanjiang-to-Weihe River Water Diversion Project	98.02	2012	Ongoing
Xinjiang Water Diversion Project	283	774	Ongoing
Water diversion project in central Yunnan Province	62.6	1450	Ongoing
JinpingIIHydropower Station	16.67	2525	Completed

2.1 Complex engineering geological conditions

Long tunnel at deep level often runs through geological units with various features in respects of topography, hydrogeology and geological structures, resulting in tunneling conditions are generally very complex given the depth to be headed.

2.2 High geotechnical risk due to complexity of tunneling conditions.

Compared to the shallow tunnels, the deep tunnels have more prominent engineering geological problems and higher geotechnical risk. The potential sources of engineering geological problems in long tunnels at deep levels include high earthquake intensity and active faults, stability of rock mass, rock burst, excessive deformation of soft rock, high water and mud inflow, high external water pressure, more abrasive and/or harder rocks, radioactive elements, harmful gases and high ground temperature, etc.

2.3 TBM often used in long tunnels at deep level.

Because of no suitable site available for construction adit generally in views of terrains and the increasing requirement on environmental protection, TBM excavation becomes a consequent choice for long tunnel at deep level. However, in the process of TBM tunneling, there are no conditions for conventional geological activities, i.e. geological logging cannot be carried out, especially for Bi-shield TBM. It is impossible to directly observe the surrounding rock conditions and it is difficult to collect first-hand data.

2.4 Extent of pre-investigation restricted by available technical methods and theory.

On one hand, it is difficult to obtain accurate engineering geological data at deep levels due to lack of effective investigation methods, especially at a depth of greater than 1000m. At present, only geophysical exploration techniques can be used to indirectly extrapolate the geological conditions, which accuracy cannot be verified in the early stage. On the other hand, there are no sophisticated engineering geological analysis and evaluation methods for long tunnels at deep levels, such as rock mass behaviors at deeper depth, mechanism of rock bursts, conditions for excessive deformation of soft rocks, prediction of high water/mud inflow, etc.

3. GENERAL PRINCIPLES OF TBM ROCK MASS CLASSIFICATION

TBM rock mass classification is intended to provide initial data for design of tunnel support, selection of TBM type and counter-measures against possible geotechnical risk. The classification of TBM rock mass is proposed following the general principles as below:

(1) Adjust and/or refine the contributing parameters as defined in widely acceptable tunneling rock mass classification as much as possible so as to maintain continuity with relevant implication.

(2) Add factors of TBM advance rate and geotechnical risk, such as effects of rock burst, excessive soft rock deformation, high large inflow, external water pressure and so on.

(3) Take into account the characterization of the long tunnels at deep level and TBM boring, in combination with available data in stages.

(4) Classification criteria should be well-understood and convenient to perform with clear and doable classification parameters, and consequently the rock mass class shouldn't too complicate to use.

(5) It is convenient for tunnel design and construction.

4. CLASSIFICATION SCHEME OF TBM ROCK MASS

4.1 Classification Conception

The potential geotechnical risk in the construction of long tunnel at deep level include rock burst and excessive deformation of soft rock caused by high stress, high inflow and external pressure of groundwater, radioactive elements, harmful gases and high ground temperature, etc., of which high ground temperature, harmful gases and radioactive elements have little to do in the selection of TBM and cannot be properly treated by engineering measures so that they are not considered in the classification of TBM tunneling rock mass.

According to the general principles described in Section 3, the classification scheme of TBM tunneling rock mass is taken the conventional stability classification of tunnel rock mass as basic class, subsequently adjusted the resulting class to allow for the type and magnitude of potential geotechnical risk of TBM tunneling, and boreability of rocks (Fig.1).

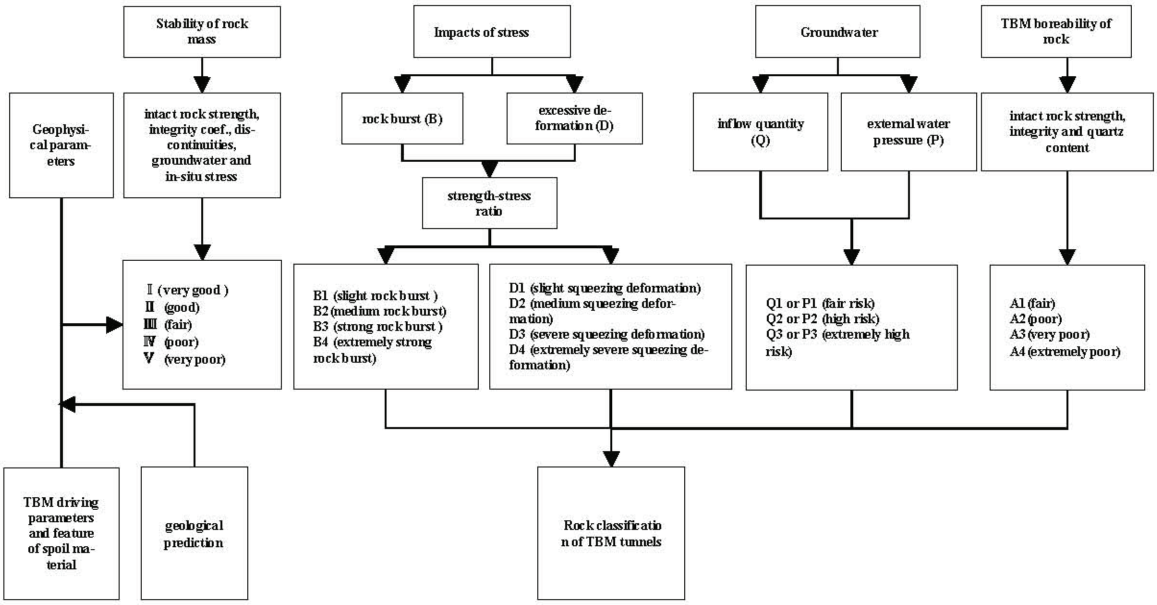

Figure 1 : Classification scheme of TBM Tunneling Rock mass

4.2 Stability ratings of tunneling rock mass

The stability of the rock mass surrounding the tunnel is affected by many parameters and different classification systems place different emphases on the various parameters. The parameters used in 41 conventional classification schemes are summarized as shown in Fig.2.

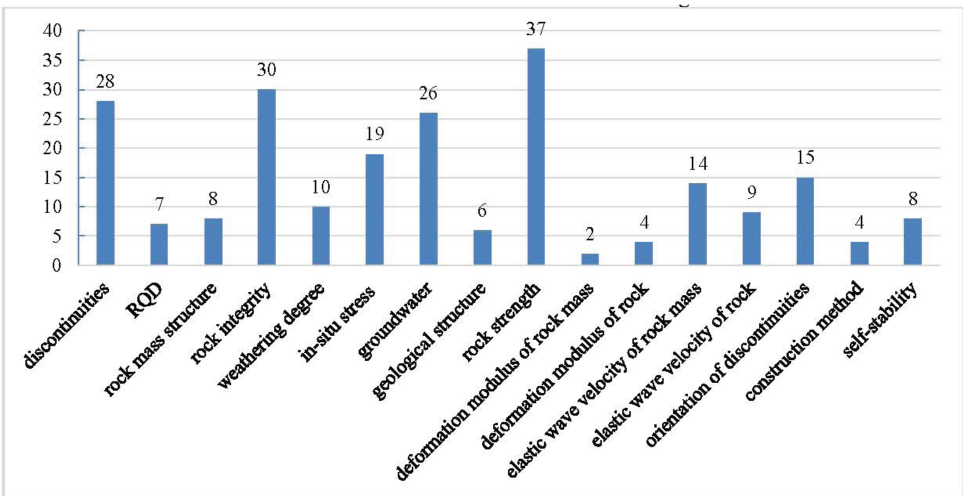

Figure 2 : Frequency of Parameters used in 41 conventional classification systems

It can be seen that intact rock strength is used in 37, rock mass integrity in 30, condition of discontinuities in 28, groundwater in 26 and ground stress in 19 classification schemes, indicating that the five parameters are the main factors to evaluate the stability of tunnel surrounding rocks. For long tunnel at deep level and shield TBM advance, the chance to obtain condition of discontinuities is little, while the rock mass structure has great influence on the stability of surrounding rock. Therefore, given the characterization of the long tunnels at deep level and the available geological data in design stages, put the intact rock strength, integrity of rock mass and rock mass structure as the critical parameters, the included angle between the strike of bedding and the direction of tunnel axis, and the hydrogeological condition as auxiliary factors, the stability of tunnel surrounding rock is divided into five grades as detailed in Table 2.

The route of long tunnel is commonly detected by geophysical profiling techniques such as magnetotelluric sounding during investigation stage of the project, so the stability of the tunneling rock mass can be toughly classified according to the results of geophysical prospecting in the early stages, and adjusted or verified in line with the results of probe geological prediction, TBM tunneling parameters and features of spoil material in the construction stage.

Table 2 : Classification of tunnel surrounding rock stability.

Grade of rock mass stability	Rock type	rock mass integrity	Rock mass structure	Description of rock mass quality classification
Ⅰ、Ⅱ	hard rock	good	massive or very-thickly bedded	Ⅰ(hard rock), Ⅱ(medium hard rock)
Ⅱ、Ⅲ		fair	blocky to sub-blocky structure, well interlocked	Ⅱ(hard rock), Ⅲ(medium hard rock & thinly bedded)
Ⅱ、Ⅲ			thickly or medium-thickly bedded, hard contact of thin beds/foliation	
Ⅲ、Ⅳ			interlayered structure	Ⅳ (angle between the tunnel axis and the strike of bedding is less than 30°)
Ⅲ、Ⅳ		poor	thinly bedded	Ⅲ (uniform quality without weak seam)
Ⅲ			mosaic texture	
Ⅳ、Ⅴ		very poor	very blocky/disturbed	Ⅴ (having groundwater)
Ⅴ		extremely poor	fragmented or disintegrated	
Ⅲ、Ⅳ	soft rock	good	massive or very-thickly bedded	Ⅲ(medium soft rock),Ⅳ(soft rock)
Ⅳ、Ⅴ		fair	blocky to sub-blocky structure, well interlocked	Ⅳ(medium soft rock), Ⅴ(soft rock)
			thickly or medium-thickly bedded, interlayered structure	
		poor	thinly bedded	Ⅳ (medium soft rock without weak seam)
		very poor	very blocky/disturbed	Ⅳ(medium soft rock)
Ⅴ		extremely poor	fragmented or disintegrated	——

4.3 Risk rating of high ground stress

Geotechnical risk caused by high ground stress includes rock burst and excessive deformation of soft rock. According to the rock strength-stress ratio, the risk of rock burst is divided into 4 grades, i.e. slight rock burst (B1), medium rock burst (B2), strong rock burst (B3), and extremely strong rock burst (B4). According to the rock strength-stress ratio and the relative deformation of the surrounding rock during construction, the risk of soft rock deformation is divided into 4 grades, i.e. slight squeezing deformation (D1), medium squeezing deformation (D2), severe squeezing deformation (D3), and extremely severe squeezing deformation (D4).

4.4 Groundwater risk rating

Geotechnical risk caused by groundwater includes inflow and high external water pressure. According to the amount of water/mud inflow and possible hazards, the risk of water inflow is divided into fair (Q1), high (Q2) and extremely high (Q3). According to the magnitude of external water pressure and the difficulty of engineering treatment, the risk of external water pressure is also divided into fair (P1), high (P2), and extremely high (P3).

4.5 Boreability rating of rock

Very hard massive rock or very abrasive rock would seriously wear TBM cutter that has to be frequently shifted, which consequently reduces the advance efficiency. The boreability of rock mass is affected by intact rock strength, integrity of rock mass and quartz content, according to which, the boreability is rated into four grades: fair (A1), poor (A2), very poor (A3) and extremely poor (A4).

4.6 Expression of tunneling rock mass classification

In this paper, the classification of tunneling rock mass is expressed using the combination rating of rock mass stability, geotechnical risk and tunneling rock boreability, in which the Roman numerals I ~ V are used to indicate the stability rating of rock mass, the subscripts indicate the geotechnical risk and magnitude, and the superscripts indicate the boreability rating of tunneling rock.

For example: IB3A3 means that this is Class I rock mass with strong rock burst and very poor boreability. IIIP2A1 means that this is Class III rock mass with high water pressure and fair boreability.

5. CONCLUSION

The traditional rock mass classification schemes for hydraulic tunnels were developed from the shallow drill-blast tunnel case histories, which cannot take the characterization of the long tunnels at deep level and potential geotechnical risk of TBM tunneling into consideration. Based on the conventional stability classification of tunnel rock mass, this paper puts forward a new classification scheme of TBM tunneling rock mass through added subscripts on the resulting class to allow for evaluation of potential geotechnical risk of TBM tunneling such as rock burst, excessive soft rock deformation, large inflow and high external water pressure, and superscripts for boreability of rocks. Thus, this classification can provide initial data for design of tunnel support, selection of TBM type and counter-measures against possible geotechnical risk.

6 DISCUSSION

Due to the multi-interpretation and accuracy limitations of geophysical data, how to accurately interpret the engineering geological natures and behaviors of tunneling rock through the geophysical exploration results, and establish the correspondence between the physical property parameters and the rock mass class need to be further researched in the future. In addition, how to use TBM driving parameters (torque, reasoning, speed) and spoil material features to judge or verify the tunneling rock mass class also needs to be further studied.

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