Stability ranking system of rockmass surrounding a large-scale underground excavations

TAO LIANJIN[1], LI PANFENG[2], ZHANG ZHUOYUAN[3]

[1] *College of Civil Engineering, Beijing University of Technology, Beijing, China*
[2] *Chengdu Hydropower Investigation and Design Institute, Chengdu, China*
[3] *Institute of Engineering Geology, Chengdu University of Technology, Chengdu*

Abstract: Considering the characteristics of underground cavern groups, a stability ranking system was introduced to denote the stability of rock masses surrounding the underground caverns. In this system four factors were used as indices including comprehensive quality level of the rock mass, parameters of wedge (volume, shape and stability), displacement and failure zones, and intensity of rock burst. It also provided excavation schemes and supporting measures according to stability ranks. Then a case study was conducted using the ranking system to evaluate the surrounding rock mass stability of an underground cavern group at a planned hydropower station. The results showed that the stability rank of these caverns was classified as Grade II (In other words, the stability was good). The primary failure modes would be local wedge instability and light to moderate rock burst.

Résumé: Vu les caractéristiques des groupes souterrains de caverne, un système de rang de stabilité a été présenté pour dénoter la stabilité des masses de roche entourant les cavernes souterraines. Dans ce système quatre des facteurs ont été employés comme index comprenant le niveau complet de qualité de la masse de roche, les paramètres de la cale (volume, forme et stabilité), les zones de déplacement et d'échec, et l'intensité de l'éclat de roche. Il a également fourni des arrangements d'excavation et le support des mesures selon la stabilité se range. Alors une étude de cas a été conduite en utilisant le système de rang pour évaluer la stabilité environnante de la masse de roche d'un groupe souterrain de caverne à une station prévue d'hydro-électricité. Les résultats ont prouvé que le grade de stabilité de ces cavernes a été classifié comme catégorie II (en d'autres termes, la stabilité était bonne). Les modes de défaillance primaires seraient instabilité locale et lumière de cale pour modérer l'éclat de roche.

Keywords: underground cavern, surrounding rock mass, stability, classification

INTRODUCTION

The experiential analogy method is one of the important methods in the assessment of the stability of the rock mass surrounding an underground cavern group. The method will show its great efficiency especially in the stage of feasibility study in which the geological information is not sufficient. The most commonly used experiential analogy method is the ranking system method of the surrounding rock mass, i.e. on the basis of the sufficient geological information and analysis, experiences and lessons gained previously are summarized to produce a classification assessment of the stability of the rock mass. Although some research has been carried out in this field (Li 1993, Zhang et al. 1994, Zhang 1999) and relevant codes (such as GB50287-99, [Anon 1999]) have been produced, attention has been paid only to the single underground cavern, that is to say, the effect of a cavern group has not been taken into consideration during the excavation of a large-scale underground cavern group. There are also some researchers who have assessed the stability of some concrete projects, such as the underground cavern groups in the Ertan and Xiaolangdi projects but without definitely proposing an assessment system. With the implementation of the Western Development Strategy in China, many large-scale hydraulic underground cavern groups with complex spatial arrangements, such as those at Laxiwa, Xiluodu, Xiaowan projects, are ready to be constructed or in the research process. With this backdrop, if the characteristic of the underground cavern group can be taken into account, and a suitable ranking system for large-scale underground caverns developed, there is no doubt that it can be applied. According to this idea, a hydraulic underground cavern group ready to be constructed in the north-western area of China is taken as an example. Geological investigation, wedge quality, rock burst intensity, results of numerical modeling were comprehensively considered to establish a suitable ranking system for the rock mass surrounding the underground cavern group. Also, the excavation procedure for the underground cavern group and the advice for liners are proposed on this ranking system.

RANKING SYSTEM FOR THE STABILITY OF THE SURROUNDING ROCK MASS

Choice of the indices of the ranking system

Classification of the stability of the rock mass surrounding an underground cavern group seeks to provide supporting evidence for the design of the liners of the underground caverns and reinforcement of the surrounding rock mass. This is performed on the basis of the classification of the quality of the surrounding rock mass, wedge analysis, secondary stress field, displacement field and the characteristics of the plastic failure zone. Therefore, the indices for the ranking system should adhere to the following principles.

- The indices should show the stability condition of the surrounding rock mass.
- The indices should be as independent as possible.
- The physical meaning of the indices should be definite and easy to be quantified.

According to the principles mentioned above, engineering experience is taken as the reference point with consideration of the particular condition of the underground cavern group under research. On this basis we determine the factors including comprehensive quality level of the rock mass, parameters of wedge, displacement and failure zones, and intensity of rock burst as the ranking indices.

Description of the ranking indices

Comprehensive quality level of rock mass(Tao 1998, Rocscience 1999)

Since the hydraulic underground cavern group is taken as the example, the ranking methods for the rock mass quality such as the Q system (Barton 1988, Barton et al 1975) and the Rock Mass Rating (RMR) system (Bieniawski 1989), which are commonly used internationally, are applied besides the ranking method (shorted for specification method) provided by the specification of the geological survey in hydro-electric projects. All the three methods mentioned above are ranking methods with multi-indices but with small differences with each other in respect of the factors taken into account. The comprehensive consideration of these three methods will make it a more objective and reliable ranking system for the rock mass. We focus more on the specification method and revise in some degree by comparing with RMR and Q system, which is also the common procedure for the large-scale hydro-electric projects. The ranking system of the rock mass can reflect the geological condition of the underground sites.

Parameters of wedge

The instability of rock wedges divided by the joints is one of the primary failure modes of the rock mass surrounding the large-scale underground cavern group. Therefore, it is necessary to take the analysis of the wedges into consideration to determine the stability condition.

UNWEDGE, or graphical methods such as stereographic projection and entity proportional project, can be used to analyze the geometric condition and the stability of the wedges.

Displacement and failure zones

Excavation effects including secondary stress field, displacement field and the characteristics of the plastic failure zone are the primary factors to determine the stability of the surrounding rock mass and the liner procedures. Therefore, we take it as the supporting evidence of the stability of the surrounding rock mass. Displacement of the surrounding and failure zone is taken independently as the assessment factors and the secondary stress field is combined with rock burst intensity.

Displacement and failure zones are commonly analyzed through numerical methods.

The modeling results of the excavation can comprehensively reflect the response of the rock mass to the excavation.

Intensity of rock burst

The underground cavern group is in a relatively high in-situ stress field, which might result in rock bursts. That is why we take the intensity of rock burst as one of the ranking indices. However, the rock burst might not be very intense; moreover, just occurring in some particular places that will not be a direct threat to the stability, we take it as a reference index. The intensity of rock burst can be analyzed by macroscopic geological survey, rock mechanics tests and numerical methods. The result of the rock burst can reflect the comprehensive effect of the excavation effect and the geological condition.

Ranking system

Based on the ranking indices and the principles mentioned above, a preliminary ranking system for the stability of the surrounding rock mass of the underground cavern group is proposed (Table 1). In Table 1, comprehensive quality levels of rock mass, parameters of wedge, displacement and failure zones, intensity of rock burst are independent. Each index is used to perform the ranking and summarized at the end. Since each index can reflect the stability of the underground cavern group at an angle, mostly the final ranking will not be definitely different. When the ranking determined by one index (index A) is lower than the other three indices (index B, C, D), the final ranking can be determined by reducing half level from the index B, C, D or by taking particular measures for the liners for the lower level index with level of the final ranking of the underground cavern group remaining. When the ranking determined by two indices (index A, B) is lower than the other two indices (index C, D), the final ranking should be determined by the lower ranking (index A, B). When the ranking determined by three indices is lower than the other index, the final ranking is determined by the lower ones.

Table 1. Stability ranking system for the rockmass surrounding the underground caverns

Stability rank	Stable	Generally stable	Locally unstable	Unstable
Rockmass structure type	Intact block	Intact-block Joints spacing 300-500 mm	Jointed rockmass	Jointed-broken rockmass
Comprehensive quality level of rock mass	I-II	II-III	III	IV
Wedge	No	Small	Local, medium	Many but small
Displacement of the surrounding rock mass/mm	<20	20-40	40-80	>80
Failure zone of the surrounding rock mass	Small and near excavation	Medium and connected for close excavations	Large and connected for close excavations	Large and connected for all nearby excavations
Rock burst intensity	Minor-moderate	Minor-moderate	Minor	Minor-none
Failure mechanism	Split failure,	Split failure, wedge slip and fall	Surrounding rock mass yields and wedges slip or fall	Surrounding rock mass yields
Suggestions for support and tunneling	Reinforcement with shotcrete and system bolt; smooth blasting; big cross-section excavation	Reinforcement with shotcrete with steelnet, system bolts for wedges; smooth blasting; bench excavation, timely shotcrete	Timely shotcrete reinforcement of shotcrete with steelnet, system bolts and long bolt for wedge; smooth blasting; small bench excavation	Composite supporting system with timely shotcrete, bolt and steelnet. Sometimes cable necessary; smooth blasting; small bench excavation

The rock mass structure of the surrounding rock mass and failure mechanism have been encompassed into the four indices. However, in order to make it convenient to apply and emphasize the internal relationships, rock mass structure and the failure mechanism are added as the supporting evidences for the stability classification when establishing the ranking system of the stability of the surrounding rock mass. Based on the comprehensive consideration of each factor, the stability of the surrounding rock mass is classified and the liners scheme is proposed.

APPLICATION OF THE RANKING SYSTEM OF THE SURROUNDING ROCK MASS

General information about the underground cavern group

The underground cavern group ready to be constructed consists of the following four underground caverns including main underground turbine chamber, transformer chamber, strobe operation room and tailwater tunnel. The sizes of each underground caverns are summarized here. Underground powerhouse 316.75 m × 29 m × 74.9 m (length × width × height); transformer chamber 235 m × 27.5 m × 42.88 m; strobe operation room 188.5 m × 8 m × 76.04 m; two tailwater tunnels are behind the strobe operation room and are constructed independently. The axes of the four underground caverns are parallel with each other whose orientation is N25^{o}E. The spacing between the main underground powerhouse and transformer chamber is 50 m. The spacing between transformer chamber and strobe operation room is 25 m. The spacing between strobe operation room and tailwater tunnel is 35.5 m.

The underground cavern group is located in granite. At the site, the geological condition is simple occupied mostly by the fractures with insufficient drape. The fracture orientations are NWW, NNW and NE-NEE. The former two are mostly common at the site. In respect of the scale, the first group should be put in the first place and the second group and the third follow. According to the results of the in-situ stress from the investigation and the modeling, the underground cavern group is in a relatively high stress field with the major principal stress of 21.9 MPa and in the direction N10°W-N10°E.

Displacement of the surrounding rock mass after excavation and the determination of the failure zone

In order to determine the threshold of the displacement of various types of the surrounding rock mass after excavation and the failure zone, the displacement of the surrounding rock and the failure zone are calculated using the 2D elastic finite element method concerning the four conditions of the surrounding rock mass that are summarized in Table 2 and Figure 1. The threshold of the stability of rock mass can be seen in Table 3.

Classification of the stability of the surrounding rock mass

Based on the ranking system mentioned above, combined with the comprehensive quality level of the rock mass, parameters of wedge, displacement and failure zones, the intensity of rock burst, classification of the stability of the underground cavern group is performed. In view of the concentration of the geological survey near the underground caverns with little information about other areas, the classification is focused on the geological information of the main underground powerhouse. If the geological information is sufficient or if construction is underway, further classification can be performed for other parts of the surrounding rock mass.

Table 2. Displacement values at special points of each cavern with different quality ranks (unit: m)

Rock mass quality	Turbine house				Transformer chamber			
	Ceiling	Floor	Upriver sidewall	Lower river sidewall	Ceiling	Floor	Upriver sidewall	Lower river sidewall
I	0.28/-1.35	0.22/0.81	1.35/-0.44	3.764706	0.63/-1.49	0.63/0.78	0.67/-0.52	0.20/-0.89
II	0.41/-2.01	0.32/1.19	2.00/-0.66	3.481481	0.09/-2.22	0.94/1.15	0.10/-0.78	0.30/-1.32
III	1.13/-5.47	0.86/3.21	5.42/-1.80	3.493151	0.26/-6.03	2.52/3.09	2.69/-2.12	0.79/-3.59
IV	3.78/-18.34	2.88/10.69	18.08/-6.08	3.473469	0.88/-20.23	8.37/10.23	9.00/-7.17	2.61/-12.03
Rock mass quality	**Strobe operation room**				**Tailwater tunnel**			
	Ceiling	**Floor**	**Upriver sidewall**	**Lower river sidewall**	**Ceiling**	**Floor**	**Upriver sidewall**	**Lower river sidewall**
I	0.1875	0.17/0.15	1.52/-0.20	2.054545	0.315068	-0.13333	2.058824	2.938776
II	0.184874	0.27/0.23	2.24/-0.30	2.036585	0.311927	-0.13636	1.583333	2.84
III	0.184615	0.73/0.62	6.04/-0.84	2.031674	0.309645	-0.14286	1.55102	2.919192
IV	0.179091	2.43/2.12	20.1/-2.88	2.013514	0.308586	-0.14454	4.51/-2.45	2.911011

Note: in A/B, A denotes X-displacement, B denotes Y-displacement

Table 3. The critical values of displacement and failure zone with different stability ranks

Stability ranks	Displacement/mm	Failure zone
I	<20	Confined to surrounding rock mass near the excavation
II	20-40	Failure zones are relatively wide and connected for the close excavations
III	40-80	Failure zones are relatively wide and connected for the close excavations
IV	>80	Failure zones are relatively wide and connected

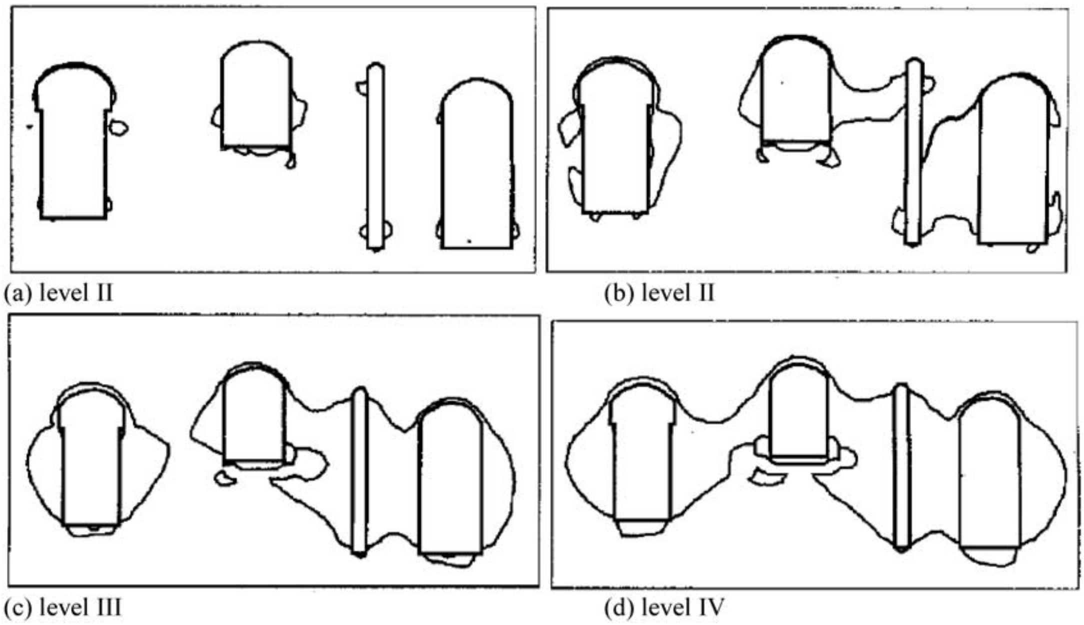

Figure 1. Distribution of failure zones around caverns with different quality ranks

CONCLUSIONS

The author has chosen comprehensive quality level of rock mass, parameters of wedge, displacement and failure zones, intensity of rock burst as the basic indices to establish the ranking system of the stability of the rock mass surrounding a large-scale underground cavern group and taken the underground cavern group for a hydro-electric project in northwestern China as an example. According to the research, the conclusions are summarized as follows:

- Make preliminary establishment of the ranking system of the stability of the rock mass surrounding the large-scale underground cavern group and propose the excavation scheme and the advice for liners for the different stability ranks.
- Rational choice of the ranking indices can reflect the geological environment of the underground cavern group with consideration of the interaction between the different caverns, which is not considered in the commonly used ranking system of the surrounding rock mass (or the classification of the rock mass).
- Make use of the ranking system to assess an underground ground cavern group in the hydro-electric project in northwestern area of China. The analysis agrees with the geological survey, which indicates the ranking system is worthy of application in practice.
- We are sure is that as the work described here is research, there are improvements we can make to the ranking system of the stability of the surrounding rock mass when it is tested by further engineering experience.

Corresponding author: Prof Lianjin Tao, Beijing University of Technology, No.100 Pingleyuan, Chaoyang District, Beijing, 100022, China. Tel: +86 10 67391162 Email: ljtao@bjut.edu.cn

REFERENCES

ANON. 1999. *Code for water resources and hydropower engineering geological investigation (GB50287-99)*. Beijing: China Planning Publishing House, 78-81.

BARTON, N. 1988. Rock mass classification and tunnel reinforcement selection using the Q system. *In: Proceedings of the Symposium on Rock Classification for Engineering Purposes.* American Society for Testing Materials, Special Technical Publication 984, Philadelphia, 59-88.

BARTON, N., LIEN, R. & LUNDE, J. 1975. *Engineering classification of rock masses for the design of tunnel support.* Publication 106, Norwegian Geotechnical Institute, Oslo.

BIENIAWSKI, Z.T. 1989. *Engineering rock mass classifications.* Wiley-Interscience, New York.

LI SHIHUI. 1993. Theory and practice on typical analogical analysis method. *Journal of Engineering Geology*, **1**, (2), 52-61.

TAO LIANJIN, ZHANG ZHUOYUAN & JIANG DEYI. 1998. *Method and practice of complicated engineering rock mass stability assessment.* Chengdu: Publishing House of Chengdu University of Technology and Science, 44-51.

ROCSCIENCE. 1999. Unwedge User's Guide. 3D visualization of potentially unstable wedges in the rock surrounding underground excavation and calculation of factors of safety and support requirements for these wedges. Rocscience, Inc.

ZHANG ZHUOYUAN, WANG SHITIAN & WANG LANSHENG. 1994. *Fundamentals of engineering geological analysis (2nd edition).* Beijing: Geological Publishing House, 409-412.

ZHANG BIN. 1999. Engineering-geological study of underground building system of Ertan hydroelectric power station. *Journal of Engineering Geology*, **7** (suppl.), 86-101.