Rock mass classification for an underground hydroelectric power house on the Lanchang River

SHUQIANG LU[1] & MO XU[2]

[1] *Chengdu University of Technology. (e-mail: lsq2197@163.com)*
[2] *Chengdu University of Technology. (e-mail: xm@cdut.edu.cn)*

Abstract: Nuozadu Hydro-electrical Power Station, which is associated with a 261.5 m high dam and has 5,850 MW installed capacity, is planned to be built on the middle-lower reaches of Lanchang River near Shimao, Yunnan Province, China. It is planned to construct a rockfill dam and underground powerhouses in the left bank. The underground cavities mainly include three large cavities, comprising a main powerhouse with size 418 × 29 × 77.6m, alternative cavity 345 × 19 × 22.6m and the three tailraces 84 × 20 × 83.87m.

In the area of the left bank, the rock mass is mainly composed of Permian Period~Triassic Period granite. Triassic Period siltstones and mudstones are distributed above 690-810m on the left bank and the rock mass has been more faulted. In addition, there also exists a lot of joints and the rock mass structure is complex.

Based on the abundant field investigation and statistical data, different classification methods for rock mass quality were used, and are described in this paper, to evaluate the rock mass quality of the underground building. By contrasting and analyzing the results, a reasonable, scientific outcome was obtained. Based on the evaluation of these results, a zoning map of rock mass quality of the left bank to 625m elevation was made which will benefit the subsequent construction work.

Résumé: La centrale hydraulique Nuozadu comptant construit se trouve sur le fleuve Lanchang dans la commune de la ville Shimao de la province Yunnan. La hauteur du barrage est de 261.5M. La capacité installée est de 5 850MW. Il compte du barrage d’enrochement et la centrale hydraulique souterraine au rive gauche. L’usine électrique principale est de 418m x 29m x 77.6m. La salle alternative principale est de 345m x 19m x 22.6m. la salle de contrôle de pression de sillage est de 84 x 20 x 83.87m et le tunnel de sillage, qui composent un groupe complexe des tunnels souterrains. La hauteur et la travée de la centrale hydraulique sont les premières des travaux construits et en cours dans le pays même à l’étranger.

Les travaux souterrains au rive gauche sont composés par les granites de la deuxième période à la troixième période. Au dessus de la hauteur de 690-810m, la pente est légère qui est composée par le sable marneux et la marne de la troxième période. Dans la zone des travaux, il y a beaucoup de failles et des fissures de faillage discontinuées qui se forment la structure de roche complexe.

Selon des recherches des données de l’enquête et de la statistique sur site, il est utilisé de différente méthode de clasification pour la qualité de différentes roches et d’après l’évaluation précise de la qualité de roche d’une centrale hydraulique souterraine se trouvant au rive gauche du fleuve Lanchang, finalement, on a obtenu la grade raisonable, scientifique et synthétique d’après les comparaisons et les analyses des différents résultats. Selon ses resultats d’évaluation, on a fait le plan de la qualité de roche dans la zonz de recherche à la hauteur de 625m. Jetant la base nécessaire pour le choix de référence.

Keywords: Hydro-electrical power station, underground powerhouse, rock mass classification, comprehensive appraisal, Lanchang River, granite

INTRODUCTION

Nuozadu Hydro-electrical Power Station, which is associated with a 261.5 m high dam and has 5,850 MW installed capacity, is planned to be built on the middle-lower reaches of Lanchang River near Shimao, Yunnan Province, China. It is planned to construct a rockfill dam and underground powerhouses in the left bank. The underground cavities mainly include three large cavities, i.e. main powerhouse with size 418 × 29 × 77.6m, alternative cavity 345 × 19 × 22.6m and the three tailraces 84 × 20 × 83.87m.

In the area of the left bank, the rock mass is mainly composed of Permian Period~Triassic Period granite. Triassic Period siltstones and mudstones are distributed above 690~810m on the left bank and the rock mass has been more faulted. In addition, there also exists a lot of joints and the rock mass structure is complex.

Therefore, it was very important to study the rock mass quality classification and properly assess the stability of the rock mass surrounding the large span and high sided wall underground powerhouse as this not only determines the success of the project, but effects the cost and programme.

Rock mass is a geological body which includes many structural features. Rock mass classification is controlled by rock property, structure of rock mass and the geological environment. These factors may effect directly or indirectly on the strength of many factors and parameters, such as bulk specific gravity, Uniaxial compressive strength of rock material, Rock Quality Designation index (RQD), sound wave velocity of rock, rock mass weathering and unload conditions, condition of discontinuities, field stress and groundwater conditions therefore, the rock property, structure of rock mass and the geological environment control the basic rule of rock mass failures and determine the mechanical property and quality of rock mass. They are the fundamental factor.

The controlling factor mentioned above, the rock property, integrity of rock mass, condition of discontinuities, condition of stress and weathering conditions are the primary factors. The primary factors are made up of many subordinate factors, such as discontinuity length, roughness and infilling of discontinuity conditions. The combination of subordinate factors represents the characteristic of the primary factor. The different combination of the primary factors reflect the difference of rock mass quality, therefore, the rock mass quality depend on the coupling of various geological factors.

ROCK MASS CLASSIFICATION SCHEMES

Rock mass classification schemes have been developing for over 100 years. At present, there are many classification systems, which can be generalized into two types. Some classification schemes can be used on all kinds of projects; these adopt a single-parameter and function as simple guidance, such as Deere's RQD. The others are technical classification schemes which are instituted for some specific projects and these are multi-parameter classification schemes, such as the national standard for engineering classification of rock masses (GB50218-94), Q-system and RMR-system.

Different classification systems place different emphasis on the various parameters, and it is recommended that at least two methods are used for all sites during the early stages of a project.

Based on the characteristics of the rock mass structure of the underground powerhouse and the manoeuvrability of the classification systems, four kinds of systems are were reviewed. From this, a method of evaluating the rock mass mechanism of the left bank rock mass was achieved. Some rock mass classification schemes are introduced below.

National standard for engineering classification of rock masses (GB50218-94)

This standard is formed of two steps. The first step is the rock mass basic quality classification, which arrives at a numerical value of BQ according as the hardness and intactness of the rock mass. The second step is the modifications to BQ, which take into account the influence factor, such as subsurface groundwater, natural stresses and the orientation and inclination of dominant discontinuities. The rock mass basic quality classifications are reproduced in Table 1.

Table 1. Engineering rock mass basic quality classification

Rock mass class	Rock mass characteristic	Rating
I	Very hard, very intact	>550
II	Very hard, intact Hard, very intact	550 - 451
III	Very hard, crushed Hard, intact Soft, very intact	450 - 351
IV	Very hard, very crushed Hard, crushed - very crushed Soft, intact - crushed Very soft, very intact - intact	350 - 251
V	Soft, very crushed Very soft, crushed - very crushed Decomposed	•250

The numerical value of the index BQ is defined by:

$$BQ = 90 + 3Rc + 250Kv$$

$$[BQ] = BQ - 100 (K_1 + K_2 + K_3)$$

where BQ is the rock mass basic quality classification index, Rc is the uniaxial compressive strength of rock material in kPa and Kv is the intactness index of rock mass and where [BQ] is the modification of the rock mass basic quality classification index, K_1 is the modification factor of groundwater, K_2 is the modification factor of the orientation and inclination of dominant discontinuities and K_3 is the modification factor of natural stresses.

Surrounding rock engineering geological classification according to Hydroelectric Standard (GB50267-99)

This classification includes information on the strength of the intact rock material, the intactness of the rock mass, the condition of discontinuities, the influence of groundwater and the orientation and inclination of dominant discontinuities. The sum value of which is the basic criterion. The stress ratio of the rock strength is the restriction criterion. This classification is presented in Table 2.

Table 2. Surrounding rock classification according to Hydroelectric Standard

Rock mass class	Stability of surrounding rock mass	Rating (T)	stress ratio of rock strength (S)
I	absolute stability	T > 85	> 4
II	stability	85 ≥ T > 65	> 4
III	Fair	65 ≥ T > 45	> 2
IV	Instability	45 ≥ T > 25	> 2
V	Very instability	T ≤ 25	

Geomechanics Classification

Bieniawski (1976) published details of a rock mass classification called the Geomechanics Classification or the Rock Mass Rating (RMR) system and made significant changes in the ratings assigned to different parameters in 1989. The following six parameters are used to classify a rock mass using the RMR system:

- Uniaxial compressive strength of rock material.
- Rock Quality Designation (RQD).
- Spacing of discontinuities.
- Condition of discontinuities.
- Groundwater conditions.
- Orientation of discontinuities.

Each of the six parameters give a rating according to the characteristic of each parameter. These ratings are summed to give a value of RMR which is presented in Table 3.

Table 3. Rock mass classes determine from total ratings

Rating	100 - 81	80 - 61	60 - 41	40 - 21	> 21
Class number	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

Rock Tunnelling Quality Index, Q

On the basis of an evaluation of a large number of case histories of underground excavations, Barton et al (1974) of the Norwegian Geotechnical Institute proposed a Tunnelling Quality Index (Q) for the determination of rock mass characteristics and tunnel support requirements. The numerical value of the index Q varies on a logarithmic scale from 0.001 to a maximum of 1,000 and is defined by:

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$$

where RQD is the Rock Quality Designation, Jn is the joint set number, Jr is the joint roughness number, Ja is the joint alteration number, Jw is the joint water reduction factor and SRF is the stress reduction factor.

There are similarities between Q and RMR system from the use of identical, or very similar, parameters in calculating the final rock mass quality rating. Both methods incorporate geological, geometric and design/engineering parameters in arriving at a quantitative value of their rock mass quality. Table 4 is reproduced from this classification system.

Table 4. Rock mass classes determine from total ratings

Class number	I	II	III	IV	V
Description	Very good	Good	Fair, Poor	Very poor	Extremely poor
Rating	> 40	40 - 10	10 - 1	1 - 0.1	< 0.1

THE BASIC INDEX OF ROCK MASS CLASSIFICATION

Field investigation of the rock mass classification basic index is the basal work. The rock mass classification basic index mentioned above includes the rock strength, RQD, the joint set number, the joint Spacing, the orientation of dominant discontinuities, the condition of discontinuities, the intactness index of rock mass, the groundwater, in situ stresses, and so on. The method of obtaining these basic indexes is now described. Rock compressive strength is obtained by point-load strength test. RQD is obtained by combining accurate measurement of discontinuity traces in exploration adits and drill core logs. The joint set number, the joint Spacing and the orientation of dominant discontinuities may be estimated by numerous in situ measurements and analytical findings. The condition of discontinuities including separation, infilling and roughness maybe estimated by the field description and the condition of weathering. The intactness index of rock mass is computed by using wave velocity or RQD. The influence of subsurface groundwater may be estimated by the general conditions in adits such as Dripping, Flowing, and so on. The value of stresses adopt the major principal stress in the field.

THE SYNTHETICAL CLASSIFICATION OF ROCK MASS SYSTEMS

Four different rock mass classification systems have been described above. Now, the synthetical classification of rock mass systems can be presented. The synthetical classification of rock mass mostly includes indexes as follows: rock mass structure, Rock Quality Designation (RQD), Uniaxial compressive strength of rock material and the intactness indexes as rock mass. The synthetical classification of rock mass systems can reflect all kinds of classification index are presented by synthesis from some of the above parameters. The principal of the rock mass classification of underground powerhouse in the left bank is summarised in Table 5.

There are five kinds of rock mass classification systems according to the principal of rock mass classification described above. Table 6 considers some of the classification systems given and presents the classification of individual pieces from the exploration adit. The results of the synthetical classification are given in Table 5, which is the final production of the rock mass classification of underground powerhouse in the left bank.

Table 5. The principia of synthetical classification

Rock mass class	Weathering rating	rock mass structure	RQD	Rb	Kv
I	Slightly weathered - Unweathered	Intact rock	> 90%	> 60 MPa	> 0.75
II	Slightly weathered - Unweathered	Blocky rock	75% - 90%	> 60 MPa	0.75 - 0.55
III	Slightly weathered - Moderately weathered	Blocky and seamy rock	55% - 75%	> 60 MPa	0.55 - 0.35
		Crushed but chemically intact rock	25% - 55%	> 60 MPa	0.15 - 0.35
IV	Moderately weathered	Crushed rock	15% - 25%	15 - 60 MPa	< 0.15
	Highly weathered	Crushed rock	15% - 25%	< 15 MPa	< 0.15
V	Decomposed	Decomposed	< 15%	< 15 MPa	< 0.15

Table 6. Surrounding rock mass classification

Station	Length of adits	Rock mass classification												
		The national standard			Hydroelectric Standard			RMR			Q		Rating in suit	Synthetical rating
		Basic value	modified value	Rating	Basic value	modified value	Rating	Basic value	modified value	Rating	value	Rating		
main powerhouse	252~277	541.92	521.92	II	82.06	77.06	II	74	69	II	17.32	II	II	II
	277~286	461.92	441.92	III	69.26	64.26	III	65	60	III	3.43	III	III	III
	286~382	516.92	496.92	II	81.06	76.06	II	74	69	II	16	II	II	II
	382~408	446.92	426.92	III	69.86	64.86	III	64	59	III	8.84	III	III	III
	408~427	484.42	464.42	II	75.39	70.39	II	69	64	II	11.43	II	II	II
	427~469	441.92	411.92	III	64.06	59.06	III	52	47	III	3.75	III	III	III
	469~525	484.42	454.42	II	77.36	72.36	II	66	61	II	13.58	II	II	II
	525~535	421.92	391.92	III	49.86	49.86	III	47	42	III	0.73	IV	IV	IV
	535~564	509.42	489.42	II	81.86	76.86	II	66	61	II	21.12	II	II	II
	564~573	221.6	201.6	V	29.86	29.86	V	35	30	V	0.12	V	IV	V
	573~580	315.2	295.2	IV	54.06	54.06	III	57	52	III	7.37	III	IV	III
Installation site	580~613	491.92	471.92	II	76.06	71.06	II	61	56	II	11.8	II	II	II
	613~639	511.92	491.92	II	83.26	78.26	II	87	82	I	50.35	I	I	I
Subsidiary powerhouse	639~663	509.42	489.42	II	82.86	77.86	II	77	72	II	16.55	II	II	II
	663~697	511.92	491.92	II	83.26	78.26	II	87	82	I	52.26	I	I	I

The results of the rock mass classification shows the distribution of all kinds of rock mass in the underground powerhouse by zoning map, which evaluates the rock mass quality and the distribution characteristics, in order that the project uses the better quality rock mass.

How to draw the zoning map is a problem that is not confirmed when the plan and profile is drawn. The principal of drawing if described in the following text. Based on the rock mass classifications of exploration adits, the description of the drill core and, the value of RQD, in conjunction with taking into account the synthetic fault traces, the zone of weathering and the geological trend of the adjacent profile, the zoning map can be compiled and is presented in Figure 1; this best illustrates the practical situation.

CONCLUSIONS

Based on the abundant field investigation and statistical data, four different types of classification methods for rock mass quality are used in this paper to evaluate the rock mass quality of the underground building on the left bank. By contrasting and analyzing the results, a reasonable and scientific achievement was obtained. Based on the evaluation results a zoning map of rock mass quality on the left bank to 625m elevation was made which will benefit to succeeding work.

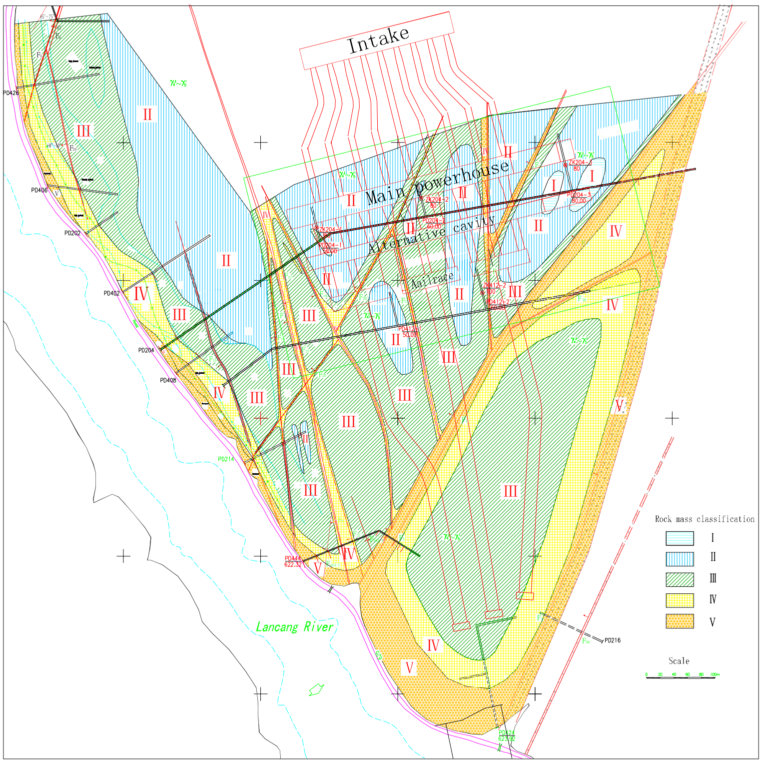

Figure 1. Zoning map of rock mass quality of left bank 625m elevation

Corresponding author: Dr Shuqiang Lu, Chengdu University of Technology, 1# Erxianqin East Street, Chengdu, Sichuan, 610059, China. Tel: 86-28-66834607. Email: lsq2197@163.com.

REFERENCES

DEXIN NIE & LONG CHEN. 2002. A study on quantative theoretical zoning of weathering zones in rock mass. *Engineering Geology for Developing Countries - Proceedings of 9th Congress of the International Association for Engineering Geology and the Environment.* Durban, South Africa, 1258–1265.

EVERT HOEK. 2001. Rock mass classification. *Rock Engineering.* A.A. Balkema Publishers, Rotterdam, Netherlands, 40–60.

JOHN, A. HUDSON & JOHN, P. HARRISON. 2000. Rock mass classification. *Engineering Rock Mechanics.* Imperial College of Science, Technology and Medicine University of London, UK, 193–206.

MINISTRY OF POWER INDUSTRY. 1999. *Investigation Code of Water Conservancy and Hydropower Engineering Geology (National Standard of PRC, GB50287–99)* . China Planning Press. Beijing, China (in Chinese).

MINISTRY OF WATER RESOURCES. 1994. *Standard for engineering classification of rock masses (National Standard of PRC, GB50218–94)* . China Planning Press. Beijing, China (in Chinese).

WANG YU & SHUQIANG LU. 2004. Rock mass quality classification of underground building on the left bank in a hydroelectric station. *Mineral resources and geology*, **18**(3), 282–286 (in Chinese).