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PRINCIPAL CONVERSION METHODS FOR ROCK MASS CLASSIFICATION SYSTEMS USED AT HOME AND ABROAD

MÉTHODES COMPARATIVES DES DIFFÉRENTS SYSTÈMES DE CLASSIFICATION DES ROCHES UTILISÉS EN CHINE ET À L'ÉTRANGER

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Abstract

This paper presents the purposes and significance of rock mass classification systems. It further proposes the contrast and conversion among the principal rock mass classification systems and outlines its foundations, principles and methods. For the convenience of engineering application, the contrast and conversion tables and some practical examples are also demonstrated here.

Résumé

Cet article présente les buts et la signification des systèmes de classification des roches. Il propose ensuite une méthode permettant de comparer les principaux systèmes en soulignant les buts, principes et méthodes. Pour la commodité des applications pratiques, des tableaux de comparaison et quelques exemples sont également présentés.

1. Introduction

Under the situation of reform and open policy in full swing in China, there have been more and more academic exchange, engineering cooperation and other activities in the field of underground engineering between China and foreign countries. Facts have proved that the determination of a required support system by use of a certain form of rock mass classification system is a universally acknowledged practical design method, both economic and reasonable. Therefore, it is a pressing matter of the moment to study the problem of conversion among the principal rock mass classification systems at home and abroad, and to put forward a comparative scientific, reasonable, simple and practical contrast and conversion method for the principal rock mass classification systems used at home and abroad, which can be publicly examined and contributes to its supplementation, amendment and development later. That is the theme of this article for discussion.

2. Purposes and Significance of Rock Mass Classification Systems

Engineering rock (called rock mass for short) means natural rock foundation, side slope, surrounding rock of underground project, which are parts of a geological body and are regarded as a part of a project separately. The part of a rock mass around an underground cavity which is disturbed and influenced by excavation is usually called the surrounding rock mass. The surrounding rock masses can be classified on the basis of their load-bearing capacities or their state of stability. Geology is the first determinant in designing underground projects. If the work of classifying and assessing the integral stability of the surrounding rock masses is not looked on as the key point of geological exploration, and if this work is not combined with the design of support, it is impossible for engineers to utilize such kind of fragmentary material piles, even though there is a detailed geological description and careful experimental data of the physical mechanics for rocks [1].

Rock mass classification systems are mainly used to solve problem of designing the support of an underground project. The acquired engineering experience can be summed up within the framework of the rock mass classification systems. The rock mass classification systems can be used to relate the engineering environment one has encountered to what others have met for drawing an analogy. All such rock mass classification systems actually play the role of a bridge [2]. The rock mass classification systems of our time are ones starting from the purposes of engineering applications and with the stability of the surrounding rock masses as their bases. Their practical value has been universally acknowledged by the underground engineering field at home and abroad.

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Table 1 : Main Factors Considered in Rock Mass Classification Systems

Serial No.	Country	Factors / Nomenclature	Rock Strength	Rock Mass Integrity	State of Structural Surface	Initial Stress State	Ground Water	Combination Relationship of the Structural Surface with the Project Axis	Acoustic Wave Velocity
1	China	National Standard for Engineering Classification of Rock Masses (Draft for Examination and Approval, 1991)	√	√	√	√	√	√	√
2	China	National Standard for Geologic Exploration of Water Conservancy and Hydropower Projects (Draft for Examination and Approval, 1991)	√	√	√		√	√	
3	China	Technical Specification for Rock-Bolts and Shotcrete Support (GBJ 86-85)	√	√		√			√
4	China	Rock Mass Classification Systems for Tunnel Projects (Appraised by the Engineer Department, General Staff in 1985)	√	√	√	√	√	√	√
5	Austria	Geomechanics Classification for Jointed Rock Masses (Bieniawski Z.T., 1973)	√	RQD (Joint Spacing) √	√		√	√	
6	Norway	Indices of Tunnel Quality (Barton and al., 1974)		RQD Jn √	Jr, Ja √	SRF √	JW √		
7	South Africa	Rock Structure Assessment (Wickham G.E., 1972)	(A) √	(B) √			(C) √	(B) √	

3. Proposition of the Contrast and Conversion among the Principal Rock Mass Classification Systems

With the popularization and application of the New Austrian Tunnelling Method (NATM) in underground projects in recent years, various rock mass classification systems have been put forward at home and abroad in order to give full play to the mechanical efficiency of the rock mass structure. They have general characteristics, but vary with their own special districts and engineering backgrounds. There is still no universally acknowledged and unified rock mass classification system up to now. Through the practice of production for so many years, China is drawing up National Standard for Engineering Classification of Rock Masses on the basis of standards for rock mass classification promulgated by various professional systems, and attempts to bring them into line with the National Standard gradually [3].

Facing more and more academic exchange, technical consultation, and engineering cooperation between China and foreign countries, it is necessary for us, especially for those foreign companies which have entered into contracts for underground projects with China, to adopt worldwide methods for rock mass classification. As for some large scale and important projects at home, usually two to three methods of the world are required for reference in classifying the rock masses for the convenience of mutual comparison and rectification so that onesidedness and voluntariness can be avoided. In view of the above-mentioned facts, there is a great need to put forward a correct principle and method for conversion of principal rock mass classification systems at home and abroad in order that a common understanding can be reached in economical and technical activities.

4. Foundation of Conversion for Rock Mass Classification

4.1. Tendency for Consideration of Leading Factors in Rock Mass Classification

The principal factors used at home and abroad in rock mass classification include rock strength, rock mass integrity, initial stress state of surrounding rock, ground water, relationship of the structural surface with the project axis, acoustic wave velocity. (For details, see Table 1). There are many factors having influence over the stability of the surrounding rock masses, which can be summarized as following two aspects : one is geological, the other is engineering (i.e. factor of engineering structure and factor of construction). The geological factor is considered as the main one among the two aspects.

The study of engineering geomechanics of rock masses and the practice of underground projects indicate that so many factors which influence the stability of the surrounding rock masses are not equal. Among them, rock strength and rock mass integrity are the leading factors. They are also the main factors used in most rock mass classification systems to determine the fundamental quality of the rock masses and types of surrounding rock masses, and to control the stability of surrounding rock masses. Other factors are subsidiary factors for amendment. Look through some imposing and main methods for rock mass classification at home and abroad for several decades, and you can find that there is a distinct tendency for factors of rock mass classification to approach the two leading factors. The engineering geomechanics theory of rock masses provides a very important foundation and prerequisite for clarifying the viewpoint that it is entirely possible for the main rock mass classification systems to be converted one to another [4].

4.2. Guiding Role of Systems Sciences Methodology

Each joint and each crack in a rock mass, and each piece of rock has several different geometrical parameters and mechanical parameters separately, the sum total of which is too numerous to count. In the process of tunnel excavation, the surrounding rock mass comes into being and it forms an open complex giant system.

The testing areas and means, and the methods to acquire the factors for rock mass classification are quite different, while the materials acquired, the indices or the expression of assessment for the calculation of the rock mass quality are also different. In addition, there exist some discrepancies in taking the value owing to the different experience and sense perception of people. Considering all these factors, it appears to us that the study of rock mass classification is very complicated, while the conversion among different methods of classification on the basis of different rock mass classification systems is even more complicated.

Practice has proved that the methods only through qualitative description of geology or mathematical mechanics analyses can hardly be applied effectively to tunnel projects, for the subjective and objective factors are so complicated. The only effective method is the combination of scientific theory, empirical knowledge and expert judgement [5] [6], i.e. Meta-Synthesis Engineering. It is required to adhere to the principle of combining engineering geomechanics analysis with microscopic observation of systems sciences, and to adopt Meta-Synthesis Engineering from qualitative analysis to quantitative analysis and to their combination. As for methodology, all those play an important and guiding role in effective treatment of very complicated problems of the rock mass classification and conversion among these classification systems.

4.3. The Quantitative Relationship Existing between the Classification Systems

As early as 1946, K. Terzaghi advanced a rock mass classification system. So did I. Stini, H. Lauffer and L.V. Rabcewicz later. All those classification systems are synthetic ones with the combination of qualitative analysis and quantitative analysis. D.U. Deere and others related them to one another by means of average spacing of joints and RQD (rock quality designation) [4]. The imposing classification systems in the world at present, such as the Geomechanics classification for Jointed Rock Mass RMR by Z.T. Bieniawski and Tunnelling Quality Index Q by N. Barton all use RQD as an important index to judge and discriminate the rock mass structure. The Rock Structure Rating RSR by G.E. Wickham bears some relationship with RMR and Q Classification Systems. Z.T. Bieniawski, J.G. Rutedge and others put forward relevant relations among RSR, RMR and Q. The rock mass classification systems, imposing and main in China, all regard the rock mass integrity in assessing rock mass structure as the main index for assessment of rock mass quality. The approximate quantitative relationship which exists objectively among the classification systems has aroused people's attention and will be studied more thoroughly and continuously.

5. Principles and Methods of Conversion for Rock Mass Classification Systems

The complex nature of rock mass classification systems makes the conversion among the systems even more complicated. The reasonableness and practicality of contrast and conversion cannot be ensured, unless a common foundation for conversion, principles which conform to reality and feasible methods are provided in the process of conversion.

5.1. Principles of Conversion for Rock Mass Classification Systems

A. Several main rock mass classification systems which are widely used at home and abroad should be selected for conversion.

B. The original fundamental factors of the above-mentioned classification systems should be used as the factors of conversion among the classification systems.

C. In the conversion among the classification systems, the value of their factor indices selected should be comprehensively measured and should be generally reasonable. As for concrete value, it is strictly forbidden to piece together figures. The results of conversion should not be influenced by a few changes of the value, and that is the key for determining whether the conversion is reasonable.

D. The methods should be simple, convenient, feasible and easy to master.

E. They can stand up to all public inspection.

5.2. Methods of Conversion for Rock Mass Classification Systems

A. Five classes or grades are usually adopted by the main rock mass classification systems in the World and it is the same with the National Standard for Engineering Classification of Rock Masses which will be promulgated in China. Starting from the actual situations at home and abroad, we suggest that the five classes should be used to carry on the conversion among the rock mass classification systems.

Table 2 : The Contrast and Conversion Table for Main Rock Mass Classification Systems at Home and Abroad

Serial No.	Country	Nomenclature	Bases and Code Name	Class of Classification				
1	China	National Standard for Engineering Classification of Rock Masses (Draft for Examination and Approval, 1991)	Basic Quality Index of Rock Masses Q	I	II	III	IV	V
2	China	National Standard for Geologic Exploration of Water Conservancy and Hydropower Projects (Draft for Examination and Approval, 1991)		I	II	III	IV	V
3	China	Technical Specification for Rock-Bolts and Shotcrete Support (GBJ 86-85)		I	II	III	IV	V
4	China	Rock Mass Classification Systems for Tunnel Projects (Appraised by the Engineer Department, General Staff in 1985)	Quality Index of Rock Mass Rm or Rs	I	II	III	IV	V
5	Austria	Geomechanics Classification for Jointed Rock Masses (Bieniawski Z.T., 1973)	RMR	I	II	III	IV	V
6	Norway	Indices of Tunnel Quality (Barton and al., 1974)	Q	40.0	10.0	1.0	0.1	
				Exc Good Ext Good Very Good	Good	Fair Poor	Very Poor	Ext. Poor Exc. Poor
7	South Africa	Rock Structure Assessment (Wickham G.E., 1972)	RSR	85	65	45	25	

B. In the conversion among the rock mass classification systems, the fundamental rock mass quality or the basic classification of the surrounding rock mass should be determined first in the light of the main classification factor indices of classification systems. Then other classification factors which have not been included should be considered for proper revision.

C. As for the criteria to draw limit lines in each classification system and that of qualitative and quantitative indices of classification factors, the original and widely used differentiating criteria of classification system should be adopted.

D. The value for drawing the limit line of the conversion among the classification systems cannot be correctly obtained, if the classification factor indices for determining the lower limit of each classification system have not been first found on the basis of data statistics of engineering surveying in-situ (The data are not isolated and arbitrarily selected). Only after the data are summed and sorted, can the indices for the limit line of surrounding rock mass quality of each classification system be separately determined.

E. The main rock mass classification systems of our time are generally the synthetic ones with multiple factors and multiple indices. If their original quantitative indices can meet the requirements of computation, the conversion among them can thus be carried on. As for those classification systems, the test data of which are incomplete or short of a certain item of quantitative indices and thus cannot meet the requirements of computation, the index scope of classification factors should be determined and contrasted in the light of their qualitative description, and consequently they can be regarded as approximate quantitative indices for determining rock mass classification systems.

6. Contrast and Conversion Table for the Main Rock Mass Classification Systems at Home and Abroad

Table 2 is worked out in order to provide a brief, quick, and practical conversion tool for underground engineering circles to carry on technical consultation and cost estimates. The bases of the table are as follows :

6.1. Analyse the implication and index (value) scope of classification factors of various classification systems. Handle each factor or index in various classification systems by means of mergence, combination, simplification, synthesis and contrast for the convenience of contrast and conversion.

6.2. Carry on the contrast and conversion among the main rock mass classification systems at home and abroad in light of conversion principles and conversion methods of rock mass classification.

6.3. Select nine practical engineering examples for practical contrast, conversion, test and verification by means of different classification systems.

In developing the contrast and conversion table for the rock mass classification systems, meta-synthesis engineering of combining theory with experience and judgment is used. On the premise of overall consistence of qualitative and quantitative assessment, the classification limits have been merged, sort out (take RSR for example, its assessment scope value is only 25-100), and slightly but necessarily adjusted.

7. Practical Engineering Examples

7.1. Contrast and Conversion for Surrounding Rock Masses of Nine Projects

Take a section from each of nine projects – Left Bank Diversion of Lubuge Hydro-Power Station etc.* Suppose the surrounding rock masses of each section belong to Class I, III, V separately, the conversion among the classification systems can be carried on according to the principles and methods for contrast and conversion discussed in this article, and by means of their original data and seven classification systems such as engineering classification of rock masses and geomechanics classification for jointed rock masses.

From Table 3, we can find that the conversion among the majority rock mass classification systems is consistent, while the conversion among some classification systems is near upper limit or lower limit of indices, and only few examples have the difference of 0.5-1.0 class. Take No. 2 project in Table 3 for example : According to the rock mass classification system for tunnelling projects, it is slightly bigger than the limits between Class I and Class II, and Rm is 60.7 (The value is bigger than limit value 60). According to the engineering classification of rock masses, it is close to the upper limit of Class II, and Q is 521.40 (The value of limit is 450-550). According to the standard for geologic exploration of water conservancy and hydropower projects, it is close to the upper limit of Class II and total value is 83 (The value of limit is 65-85). Another example is No. 3 Project in Table 3. According to the standard for engineering classification of rock masses, it is close to the lower limit of Class III and Q is 368 (The value of limit is 350-450). If it is classified in the light of geomechanics classification for jointed rock masses, it may belong to the upper limit of class IV and total value is 40 (The value of limit is 21-40). No. 8 Project in Table 3 is classed as one in the lower limit of Class IV and Q is 266 (The value of limit is 250-350) on the basis of the standard for engineering classification of rock masses. It is classed as one in the lower limit of Class IV and total value is 27 (The value of limit is 21-40) according to geomechanics classification for jointed rock masses, while it may belong to Class V and its total value may be 21 (The value of limit is less than 25) if it is classed in terms of the standard for geologic exploration of water conservancy and hydropower projects.

The practical engineering examples indicate that they generally conform to the contrast and conversion table proposed in this paper and the table can be used for reference.

7.2. The Rock Mass Classification of Xiaolangdi Project by General Geologic Survey Brigade in Contrast to Prof. N. Barton's Suggestion for It

The contrast and conversion table for main rock mass classification systems at home and abroad listed in Table 2 of this paper was once used to check and verify the rock mass classification of Xiaolangdi Project on the Yellow River in its underground engineering technology consultation by the group leader of this research task, Prof. Li Shihui in the winter of 1991. The rock masses of that project is defined as the poorer surrounding rock masses of Class II or that of Class III by the General Geologic Brigade of Reconnaissance Planning & Design Institute of Yellow River Conservancy Committee (YRCC) according to the design specification for water conservancy projects and with reference to the value of Q, i.e. the Indices of Tunnel Quality which was put forward by Prof. N. Barton who once came to Xiaolangdi Project personally and gave technical advice. With reference to Prof. N. Barton's suggested value, The General Geologic Brigade defined the Q value as 4.14-5.7 (The average value is 4.80) and 11.20-22.20 (The average value is 15.28) respectively**. In comparison with Table 2 in this paper, when the value of Q is 4.8 it is the middle value of Class III (The value of limit is 1.0-10.0), and when the value of Q is 15.28 it means the surrounding rock masses are poorer among those of Class II (The value of limit listed in the table is 10.0-40.0). This practical engineering example shows that the contrast and conversion relationship proposed in this paper and the literature [1] is consistent with the real value of Xiaolangdi Project and the proposals by Prof. N. Barton himself. Generally it conforms to reality.

8. Analysis and Discussion

8.1. Generally speaking, the result of any rock mass classification system by qualitative method is not completely consistent with that by quantitative method. The author of this article and his colleague have experienced the practical surveying work of 34 underground projects and data acquisition work of 8 underground projects and his work in these projects has involved more than 400 sections in total. Qualitative method and quantitative method have been respectively used for

* The original data for contrast and conversion are adopted from National Science and Technology Key Task Items of Sixth Five-Year Plan by Kunming Investigation & Design Institute of the Ministry of Water Conservancy and Power. Serial No. : Collection of Achievements of 15-2-1 in 1986, 175-303.

** (A Report on the underground Powerhouse Scheme of Xiaolangdi Project on Yellow River) by Investigation, Plan and Design Institute of Yellow River Conservancy Committee, Ministry of Water Resources in april, 1991.

Table 3 : The Contrast and Conversion Table for the Surrounding Rock Masses of Class I, III, V

Serial No.	Name of Project	Geological Description	Engineering Classification of Rock Masses		Standard for Geologic Exploration of Hydro-Power Projects		Technical Specification for Rock Bolts and Shotcrete		Rock Mass Classification System for Tunnel Projects		RMR		Q		RSR		Remarks
			Value	Class	Value	Class	Value	Class	Value	Class	Value	Class	Value	Class	Value	Class	
1	Diversion Tunnel of Gu County Reservoir nearby Luo River 0+140-0+160 Right Bank	Slightly Weathered Quartz-Porphyry with Good Stability	557.6	I	80	II (the upper)	R_b>60 K_v>0.75	I	64	I	82	I	46.9	(I) Very Good	88	I	
2	A Certain Tunnel Project (No. 16-9)	Crystal Tuff with Undeveloped Joints, Integral Structure	521.4	II (the upper)	83	II (the upper)	R_b>60 K_v>0.75	I	60.7	I	84	I	41.6	(I) Very Good	92	I	
3	A Certain Tunnel Project (No. 13-5)	Not Weathered Granite with Undeveloped Joints, Integral Structure	608.5	I	91	I	R_b>60 K_v>0.75	I	85.9	I	86	I	45.3	(I) Very Good	90	I	
4	Left Bank Diversion Tunnel of Lubuge Hydro-Power Station 0+37-0+200	Mid-thick Stratum Limestone, Lined with Thin Stratums of Marlite. Stratifications, joints > 2 Groups. The activities of Seasonable Ground Water Are Acute. Surrounding Rock Masses Stability Is Not Good.	368	III (the lower)	45	III	R_b>30 K_v>0.50	III	21.5	III	40	IV (the upper)	1.1	(III) Poor	47	III	
5	Intake Tunnel of Yuzixi Class Two Hydro-Power Station 5+483-5+490	Mid-Grain Granodiorite with Block-Type Structure	360.5	III (the lower)	54	III	R_b=30 K_v>0.50	III	19.2	III	50	III	7.1	(III) Fair	59	III	
6	Xierhe Class Three Hydro-Power Station 2+680-2+731	Mica-Quartz-Schist with Stratum-Type Structure	423	III	65	III	R_b=60 K_v=0.60	III	19.4	III	50	III	6.0	(III) Fair	61	III	
7	Intake Tunnel of Yuzixi Class Two Hydro-Power Station 3+263-3+462	Fractured Glasstone and Breccia with Loose Structure	242	V	4	V	R_b<5 K_v=0.56	V	0.5	V	19	V	<0.1	(V) Extremely Poor	23	V	
8	Wujiang Pengshui Key Water Control Project, Underground Powerhouse	Exceptionally Laminated Marl-Shale or Laminated Limestone Lined with Thin Stratums, Fractured Structure	266	IV (the lower)	21	V	R_b>10 K_v>0.50	IV	5.5	IV (the lower)	27	IV (the lower)	>0.1	(IV) (the lower) Very Poor	29	IV (the lower)	
9	A Certain Tunnel Project (No. 18-22)	Tuffaceous Sandstone, Weakly to Strongly Weathered, with Fine Developed Joints, Open and Lined with Mud, Loose Structure	139.6	V	15	V	R_b=40.7 K_v=0.05	V	2.0	V	23	IV (the lower)	<0.01	(V) Exceptionally Poor	33	IV (the lower)	

these rock mass classifications and their results are as follows : The probabilities of consistence by two methods for the rock masses of Class I, II, III, IV and V are 97 %, 82 %, 73 %, 69 % and 94 %. The average probability of consistence is 83 %*. Among them, the qualitative classification and quantitative classification for the surrounding rock masses of Class I with very good stability and those of Class V with extremely poor stability are very consistent with each other; while for the surrounding rock masses of Class II, III, IV, their consistency is not good enough.

The results achieved through the qualitative classification and quantitative classification for even one kind of surrounding rock mass are still somewhat out of accordance with each other, to say nothing of the classification systems by means of various methods. Some inconsistency appearing in the contrast and conversion work is inevitable.

8.2. In spite of the inconsistency, the contrast and conversion among the classification systems is still tenable. M. Tallon *et al.* studied RMR, Q, RSR, the three kinds of classification methods which had been widely used to determine the numerical value among the quality indices of rock masses in the world and they put forward following conclusive opinions [8] :
Even though each classification method adopts different criteria of judgement in acquiring quality indices, all the three classification methods with similar results of rock appraisal can obtain the numerical value with few differences.
Even though this kind of related factors are obtained in different places, with the indices from slightly similar rocks by different personnel, and even though these classification methods have their limitations, the way now taken to assess the rock masses is considered correct and valid.

From the expressions of main different rock mass classification systems at home and abroad, it can be seen that the main factors for computation of quality indices of rock masses and assessment of stability of rock masses are generally in accordance. Therefore, we can say that the contrast and conversion among different rock mass classification systems have certain objective foundations.

8.3. The author suggests that certain inconsistency appearing in the conversion among the classification systems should be adjusted and handled according to the following principles :

A. When the difference is within one class, the classification which is consistent with the majority of the classification systems or the lower classification among them can be adopted after comprehensive analyses. The factors which can be considered include the characteristics and applicable conditions of different classification systems (For example, it would be best if the classification system of quality index Q for tunnel projects or the rock mass classification system for tunnel projects can be selected to determine the surrounding rock masses of poor quality or even extremely poor quality), the degree of difference between the calculated value and the limit value of corresponding classification system, the importance of the project, the personal experience in using various methods for rock mass classification.

B. When the difference is in two classes, and when the conversion results are the lowest or highest among the classification systems, the selected value of various factor indices should be reexamined and recalculated respectively. As the difference is reduced to one class, the adjustment will proceed in the light of the above-mentioned A principle.

C. When the difference between the classification systems with the lowest or highest results after reexamination and recalculation is still in two classes, the comprehensive analyses can proceed according to the above-mentioned A principle with the lowest or highest results being abandoned, or the domestic classification systems of one's own industry can also be adopted.

9. Conclusions

The theory of rock mass engineering geomechanics and its practical applications to projects indicate that the contrast and conversion among the main rock mass classification systems at home and abroad is feasible. The crux of the matter is to start from the reality of the rock mass classification systems, to master and to apply the Meta-Synthesis Engineering which includes the combination of qualitative analyses with quantitative analyses and final determination by quantitative method. The examples of practical applications to the projects show that the principles and methods of contrast and conversion among the rock mass classification systems proposed in this paper can be used in projects for reference.

The rock mass classification systems and their conversion methods involve many factors and complicated relationship, and the above-mentioned proposals in this paper await further examination, supplement and amendment in the practical applications to projects.

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