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Rock Mass Classification and Its Use in Blast Design for Tunneling

Chang-Ha Ryu[1)]*, Choon Sunwoo[1)] and Byung-Hee Choi[1)]

암분류기법과 터널굴착을 위한 발파설계에의 활용

류창하, 선우춘, 최병희

Abstract : Building tunnels means dealing with what rock is encountered. Relocation of the site of the underground structure is rarely possible. Tunneling engineers and miners have to cope with the quality of the rock mass as it is. Different tunneling philosophies and different rock classification methods have been developed in various countries. Most of the rock classification methods are based on the response of the rock mass to the excavation. Tunnel support requirements could be assessed analytically, supplemented by rock mass classification predictions, and verified by measurements during construction. Rock mass classifications on their own should only be used for preliminary, planning purposes and not for final tunnel support. Design of blast pattern in tunneling projects in Korea is also mostly prepared according to the general rock classification methods such as RMR or Q. They, however, do not take into account the blast performance, and as a consequence, produce poor blasting results. In this paper, the methods of general rock classification and blast design for tunnel excavation in Korea are reviewed, and efforts to develop a new classification method, reflecting the blasting performance, are presented.

Key words : tunneling, blast design, rock mass classification, B-RMR

초 록 : 터널굴착이나 사면절취 등과 같은 굴착문제에 있어서 굴착방법을 결정하기 위해 대상암반에 대한 리핑암이나 발파암의 구분이 우선되며, 다음에 발파에 의한 굴착방법이 선정되었을지라도 화약량 및 종류, 천공방법 등 발파설계를 위해서 추가적으로 발파암에 대한 세부적인 분류가 필요하다. 일반적으로 RMR이나 Q 시스템과 같은 암반분류법이 많이 사용되고 있지만, 발파암에 대한 표준적인 암반분류법이 없으며, 국내에서도 발파암 분류에 대한 연구가 거의 전무한 상태로 발파암의 분류요소로 사용될 수 있는 요소를 구하기 위한 연구가 필요하다. 본 논문에서는 앞으로 국내에서 발파암 분류연구에 대한 방향제시를 위해서 발파와 암석의 역학적 특성, 지질구조와 불연속면의 특성과의 관계나 굴착과 관련된 암반분류에 대한 여러 논문사례를 통하여 발파암의 분류요소와 분류방법 등을 분석한다.

핵심어 : 터널굴착, 발파설계, 암반분류기법, B-RMR

1. Introduction

The rock mass classification systems are used as the semi-quantitative tool of empirical design approaches that relate experience encountered at previous projects to the conditions anticipated at proposed site. The rock mass classifications have been recently widely employed in the rock engineering and being used in feasibility design. In fact, on many projects, the rock classification approach serves as the practical basis for the design of complex rock structures. Design of blast pattern in tunneling projects in Korea is mostly prepared according to the general rock classification methods such as RMR or Q. They, however, do not take into account the blast performance, and as a consequence, produce

1) 한국지질자원연구원
* Corresponding author : cryu@kigam.re.kr

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poor blasting results. In this paper, the methods of general rock classification and blast design for tunnel excavation in Korea are reviewed, and efforts to develop a new classification method, reflecting the blasting performance, are presented.

2. Design of Blast Pattern

The New Austrian Tunneling Method (NATM) is mostly used to excavate all types of tunnels in Korea. The rock support in NATM can be determined based on the interaction between support and surrounding rock behavior during excavation For the estimation of the total cost of supports and excavation for tunneling project in design stage, another type of rock mass classification is required. The rock mass to be excavated is classified using the data obtained from initial site investigation, and support design is then made based on the classification. In order to estimate the excavation cost, blast pattern should be provided in advance. The blast design such as hole pattern, length of holes, and specific charge has generally been pre-determined according to the rock type used for support design.

Fig. 1 and 2 show the examples of support and blast patterns used in a highway tunnel for rock type IV, respectively. The rock mass has RMR value ranging from 21 to 40.

Blast patterns are provided by the Clients in general. They have tried to establish a standard blast pattern to yield optimum blasting performance corresponding to each classified rock type. In spite of the effort, blast patterns prepared in design stage are still quite different from those used in construction.

3. Parameters of Rock Mass Classification for Support Design

Quantitative classification of rock masses has become very popular since it provides a rapid means of assessing the quality of a mass and support requirement. Two classification methods have stood out, the Q System and Geomechanics Classification System.

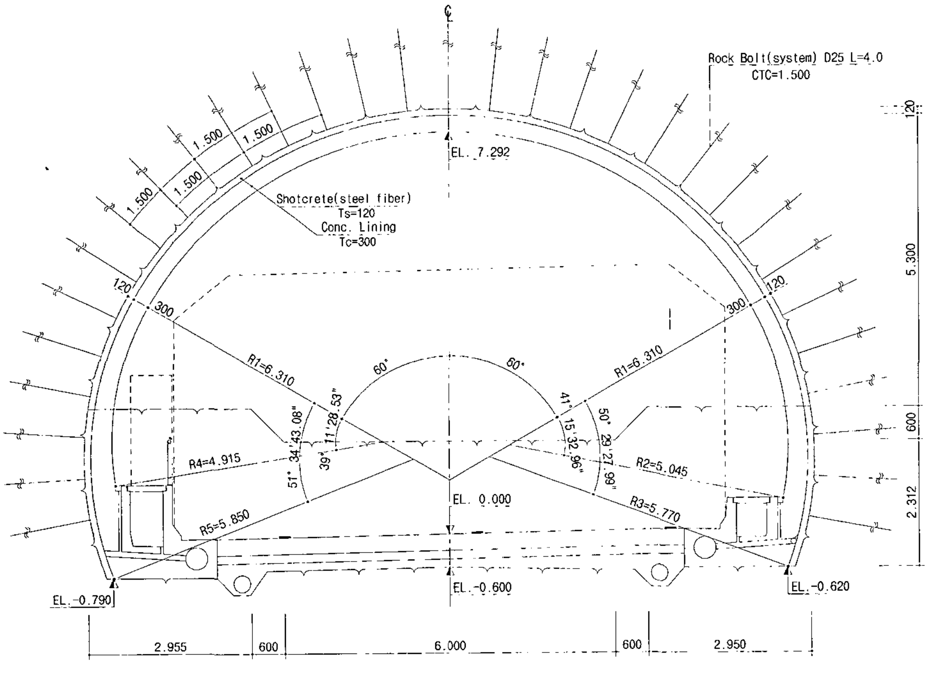


Fig. 1. An example of support pattern for rock type IV.

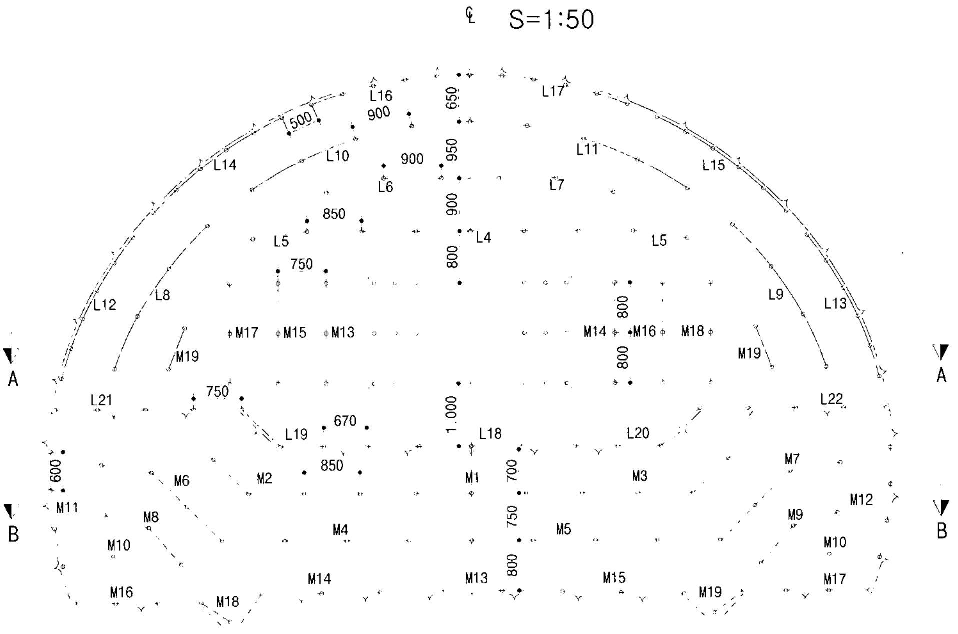


Fig. 2. An example of blast pattern for rock type IV.

3.1 Q System

From the study of about 200 case histories of tunnels and caverns, Barton et al. (1974) proposed a very detailed rock classification system. The classification is based on three aspects:

- rock block size (*RQD/Jn*)
- joint shear strength (Jr/Ja)
- confining stress (Jw/SRF)

The six parameters are as follows:

RQD	: rock quality designation
Jn	: joint set number
Jr	: joint roughness number for critically oriented joint set
Ja	: joint alteration number for critically oriented joint set
Jw	: joint water reduction factor
SRF	: stress reduction factor

These parameters are combined in the following way to give the rock mass quality Q:

$$Q = \frac{RQD}{Jn} \cdot \frac{Jr}{Ja} \cdot \frac{Jw}{SRF}$$

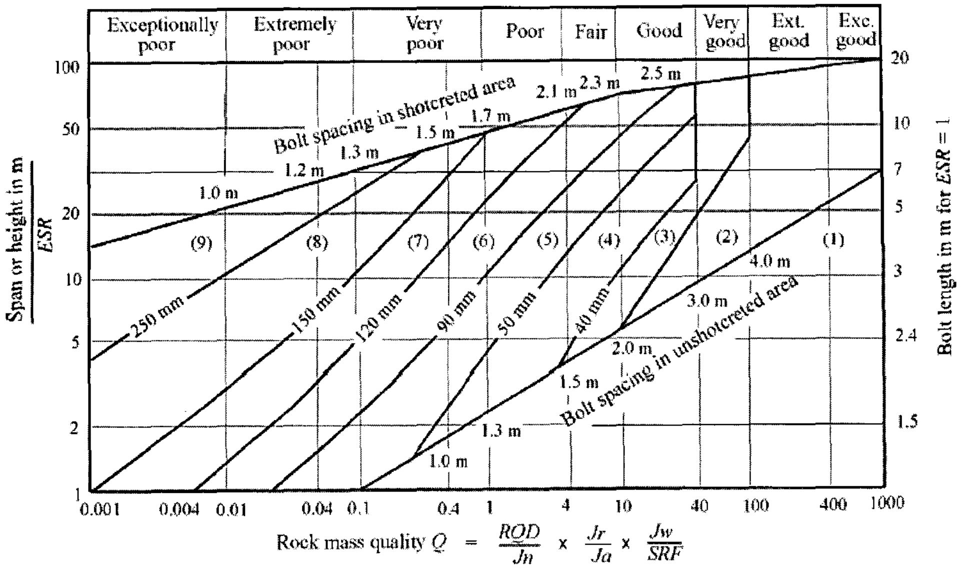
A detailed relationship was developed between the Q value and the support measures required. This was done by analyzing the case records until a consistent relationship was obtained between Q value, the equivalent dimension of an underground excavation, the factor of safety (Excavation Support Ratio, ESR) and support actually used (see Fig. 3).

3.2 Geomechanics Classification

The Geomechanics Classification System developed by Bieniawski (1973) derives a rock mass rating (RMR), obtained by summing five basic parameter values and adjusting this total by taking into account the joint orientations. The parameters included in the system are:

- uniaxial compressive strength of intact rock
- rock quality designation, RQD
- joint spacing
- joint condition (joint roughness and separation), and
- ground water condition

The RMR value has a range from 0 to 100,



REINFORCEMENT CATEGORIES

1) Unsupported
2) Spot bolting
3) Systematic bolting
4) Systematic bolting with 40-100 mm unreinforced shotcrete
5) Fibre reinforced shotcrete, 50 - 90 mm, and bolting
6) Fibre reinforced shotcrete, 90 - 120 mm, and bolting
7) Fibre reinforced shotcrete, 120 - 150 mm, and bolting
8) Fibre reinforced shotcrete, > 150 mm, with reinforced ribs of shotcrete and bolting
9) Cast concrete lining

Fig. 3. Estimated support categories based on the tunneling quality index Q.

and with its five finger parameter scale, this system is conceptually easier to apply than the Q system.

Fig. 4 shows the weighting of parameters used in the RMR.

4. Rock Mass and Blast Design

Two different rock masses, when subjected to identical blast geometry and energy input from explosives, will produce quite different degrees of fragmentation. This is because the rock masses have inherently different resistance to fragmentation by blasting. That is, the two rock masses have a different ease with which they can be fragmented by blasting. The parameters influencing blasting results fall into two groups. The first group is the intact rock properties, which includes strength, elastic properties, deformability, density of rock, etc. The second group is the discontinuity structure that consists of orientation, spacing and extent of discontinuities, types of filling material and tightness of the joints, etc. In situ rock stress would also affect blasting performance in deep geological condition.

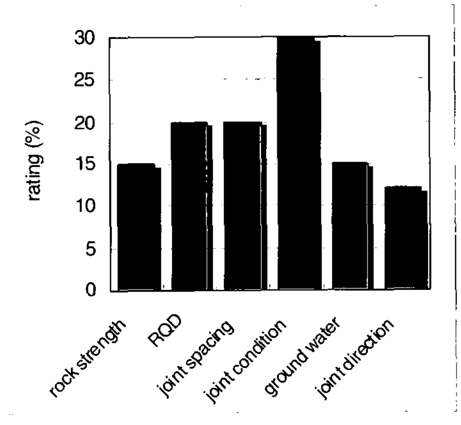


Fig. 4. Parameters used in RMR and weighting.

The Q system does not take the rock material strength into account explicitly, although it is implicitly included in arriving at the SRF. The joint orientation is also not taken into account. The RMR does not take account of the confining stress in the rock mass, nor explicitly the number of joint sets. Considerable weight is given to block size since both RQD and joint spacing are classification parameters.

Some parameters have similar effects on both stability of rock structure and blastability of the rock, while some others do not. For example, a set of joints with specific direction may be very favorable to the stability, but unfavorable to the blastability. Weighting of the parameters should, therefore, be different according to whether it is for assessing the stability or blasting performance. Some parameters, which may be trivial in stability, are but significant in blastability.

5. Experimental Results and Discussion

5.1 Experiment and Results

In order to find new parameters and establish a new classification for rock blasting, the possibility of the use of several indices was investigated such as Protodyakonov index, cratering index, and blasting coefficient. Protodyakonov's strength coefficient, f, is obtained from the drop hammer test for rock samples as follows:

$$f = 20 * \frac{n}{l}$$

where n is the number of drops, and l is the height of total fragments with size under 0.5 mm after drop impact.

Crater index, n, is the ratio of radius of crater, R, formed after blasting to burden, B (n=R/B). Blast coefficient, c, is calculated by multiplying the constants defined by rock type, explosive properties, and stemming condition.

P-wave velocity and uni-axial compressive strength of intact rock have been used to determine the excavation method of the rock mass, ripping or blasting, in domestic projects. It has often been a question due to disagreement between the criterion and field condition. Fig. 5 and 6 show the plots of the relationship between the parameters. For the same value of Protodyakonov index, a considerable scattering of P-wave velocity was shown (Fig. 6). It seems due to that P-wave velocity is largely affected by the joints distribution, but Protodyakonov index is not. The P-wave velocity in weak rock shows a lower limit. It is about 430 m/sec which corresponds to 27 of Protodyakonov index.

Crater index for weak rock may be derived from the lower limit of P-wave velocity. The rock with crater index, n between 0.55 and 0.85 is shown to be classified as weak rock requiring blasting for excavation. Blasting coefficient for weak rock may be derived from the lower limit of P-wave velocity. P-wave velocity and uniaxial compressive strength of intact rock have been used to determine the excavation method of the rock mass, ripping or blasting, in domestic

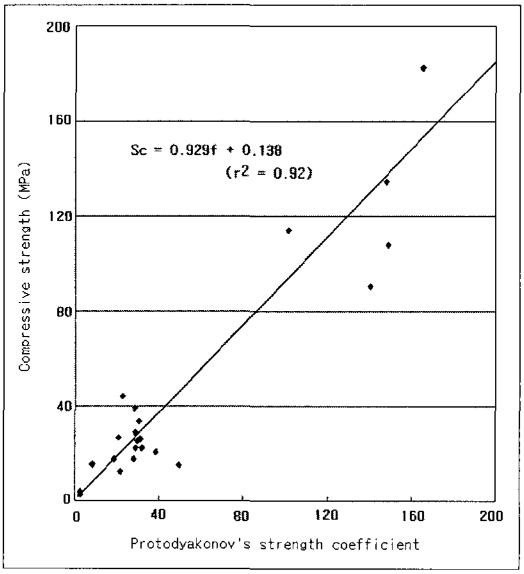


Fig. 5. UCS vs. Protodyakonov coeff.

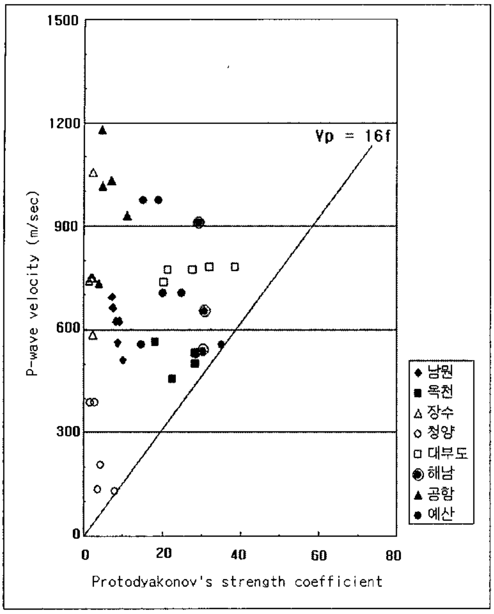


Fig. 6. P-wave vel. vs. Protodyakonov coeff.

projects. It has often been a question due to the disagreement between the criterion and field condition.

The testing result shows that the Protodyakonov index, crater index, and blasting coefficient together with P-wave velocity would become more effective guide to the criterion. It may also be used as parameters of rock classification for blasting. Field observations also show that joints affect the crater shape after blasting and hence that another type of crater index needs to be introduced to indicate the difference from ideal cone shape.

5.2 Rock Classification

Several types of approach have been taken into account to establish a standard blast pattern yielding optimum blasting performance. One is to optimize blast patterns corresponding to each rock type classified based on the existing rock classification methodology. Most Clients have provided blast patterns in this way. It is very practical, but has unavoidable limitations due to the different impact of parameters on support requirement and blastability of rock mass. The second is to develop a whole new classification system using new parameters appropriate for assessing blast performance and to optimize blast patterns corresponding to each rock type. The Protodyakonov index, crater index or other parameters may be introduced as shown in this paper. However, some difficulties are expected. Another work of rock characterization would be required for blast design in addition to that for support design. Some additional laboratory tests are also required. It is unfavorable for practical use, and, consequently, may not be used widely. An alternative is to utilize most of the parameters in current classification system and to give different weightings. A couple of parameters may be added. RMR for support design and B-RMR for blast design can be easily calculated using an appropriate software.

6. Summary and Conclusions

From all rock mass systems available, the Q system and Bieniawski's RMR seem to be the most suitable ones for rock mass characterization for support design purposes. Because parameters used in the classification methods would have different effects depending on the design purposes, weighting should be different according to whether it is for assessing the stability or blasting performance. Efforts have been made to find new parameters for rock characterization through field and laboratory experiments. It is shown that some parameters could be introduced for more effective assessment of the blastability.

For practical use, it is suggested to utilize most of the parameters in current classification system and to give different weightings. It has an advantage that one would get information both for support and blast design within a frame of current investigation system. The validity of the weighting of parameters should be provided through field observations.

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최 병 희
1988 서울대학교 공과대학 자원공학과 공학사
2002 전남대학교 대학원 자원공학과 공학석사
2005 전남대학교 대학원 지구시스템공학과
공학박사

현재 한국지질자원연구원 지반안전연구부 선임연구원
(E-mail : bhchoi@kigam.re.kr)

류 창 하
1976 서울대학교 공과대학 자원공학과 공학사
1979 서울대학교 대학원 자원공학과 공학석사
1989 미국 유타대학교 대학원 공학박사

현재 한국지질자원연구원 지반안전연구부 책임연구원
(E-mail : cryu@kigam.re.kr)

선 우 춘
1978 서울대학교 공과대학 자원공학과 공학사
1984 서울대학교 대학원 자원공학과 공학석사
1988 프랑스 Paris VI 대학 지구구조학과 이학박사

현재 한국지질자원연구원 지반안전연구부 책임연구원
(E-mail : sunwoo@kigam.re.kr)