Rock Classifications: State of the Art and Prospects for Standardization

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The purpose of this paper is to present a state-of-the-art review of rock classifications and to consider the need and prospects for attaining a standard classification. Recent developments concerning both intact-rock classifications and rock-mass classifications are described. Such engineering applications of the current rock-classification systems as tunnels and chambers, slopes, and foundations are discussed, and it is demonstrated how rock classifications enable estimation of the strength and the deformability of rock masses. It is shown that rock-mass classifications are already in existence that include both intact-rock and rock-mass properties and that correlations have been developed among the main classification systems. It is found that there is a distinct need for limited standardization specifications but that these should be in the form of suggested methods, one for each classification system, which would achieve some degree of standardization without inhibiting the development or improvement of techniques. There does not seem to be a need for one standard classification that has universal application since the various engineering applications have different classification requirements.

Rock classifications have received increasing attention in recent years and have been applied in many countries to different engineering problems. Although the first major rock-classification system was proposed more than 34 years ago by Terzaghi (1), the recent interest in this subject was prompted, on the one hand, by the construction of more-complex engineering structures such as large tunnels and chambers at greater depths and, on the other hand, by the potential of rock classifications as an aid in the design of those projects.

As a result, the original Terzaghi classification for rock tunneling that has steel supports was modified (2) and new rock-classification systems were proposed. These systems accommodated the new advances in rock-support technology, namely, rock bolts and shotcrete, and also addressed specifically different engineering projects such as tunnels and chambers, slopes and foundations, mines, and others. Both intact-rock and rock-mass characteristics were included. Today, there are so many different rock-classification systems that it is necessary to tabulate the more-common ones (Table 1).

Rock classifications have been successfully used in the United States (3-5), Canada (6), Europe (7-13), South Africa (14,15), Australia (16), New Zealand (17), Japan (18), the USSR (19), and China (20). The success of rock classifications stems from the recognition of their potential as a means of correlating the rock conditions at one site with the experience of rock conditions and support requirements gained at other sites (21). On many projects, the classification approach served as the only practical basis for the design of complex underground structures. The most significant recognition of the importance of rock classifications is found in Austria, in which tunnel-construction contracts incorporate a rock-mass classification as a basis for payment in accordance with standard contract documents (22).

However, the widespread use and development of so many rock classifications have also produced some problems. Questions had to be answered such as, Which rock-classification system is the best? Which system should be applied to a given type of engineering project? Are there any correlations among the systems? Can the rock-classification approach adequately replace other design approaches? Some of these questions were considered in the textbooks by Goodman (23) and by Hoek and Brown (21). Studies were also conducted aimed at comparing the various systems (5,24), and correlations were proposed (25,17). In addition, special committees were appointed to study rock-mass classifications. On the international scene, the International Society for Rock Mechanics (ISRM) and the International Association of Engineering Geology (IAEG) have each established a Commission on Rock Classification. In the United States, the Transportation Research Board (TRB) Committee on Exploration and Classification of Earth Materials has the responsibility of application, evaluation, and correlation of all existing and proposed earth-material classifications, and the American Society for Testing and Materials (ASTM) Committee D-18 has been charged with developing a set of rock-classification standards.

The purpose of this paper is to present a state-of-the-art review of rock classifications and to consider the need and prospects of attaining a standard classification. The paper identifies a number of issues and aims at providing a lead for a discussion of this subject in a way that could be of service to both TRB and ASTM.

AIMS OF ROCK CLASSIFICATIONS

Generally, a rock classification has the following aims in an engineering application:

1. To divide a particular rock mass into groups on the basis of similar behavior,
2. To provide a basis for understanding the characteristics of each group,
3. To yield quantitative data for engineering design, and
4. To provide a common basis for communication.

These aims should be fulfilled by ensuring that a classification system has the following attributes:

1. It is simple, easily remembered, and understandable;
2. Each term is clear and the terminology used is widely acceptable;
3. The most significant properties of rock masses are included;
4. It is based on measurable parameters that can be determined by relevant tests quickly and cheaply in the field; and
5. It is based on a rating system that can weigh the relative importance of classification parameters.

CLASSIFICATION PARAMETERS

The greatest problem in rock classifications is the selection of the parameters of greatest significance. There appears to be no single parameter or index that can fully and quantitatively describe a jointed rock mass for engineering purposes. Various parameters have different significance and only if taken together can they describe a rock mass satisfactorily.

In considering the rock-classification systems, one should first distinguish between classifications of intact-rock materials and those of rock masses. A rock mass (also referred to as a rock system or a

Table 1. Major rock classifications in use.

Name of Classification	Originator and Date	Country of Origin	Application
Rock load	Terzaghi, 1946 (1)	United States	Steel-supported tunnels
Strength coefficient	Protodyakonov, 1951 (19)	USSR	Material friction and cohesion
Stand-up time	Lauffer, 1958 (7)	Austria	Tunneling
Rock-quality designation	Deere, 1963 (2)	United States	Core logging and tunneling
Intact strength	Deere and Miller, 1966 (27)	United States	Communication
Tunnel class	Rabcewicz, Pacher, and Müller, 1970 (8)	Austria	Tunneling
Ground support	U.S. Bureau of Mines, 1971 (38)	United States	Mining
Rock-structure-rating concept	Wickham, Tiedeman, and Skinner, 1972 (3)	United States	Tunneling
Geomechanics classification	Bieniawski, 1973 (14, 29)	South Africa, United States	Tunnels, mines, slopes, and foundations
Q-system	Barton, Lien, and Lunde, 1974 (9)	Norway	Tunneling and large chambers
Geotechnical index	Louis, 1974 (10)	France	Tunneling
Strength and block size	Franklin 1975 (6)	Canada	Tunneling
Mine roof	Kidybinski, 1975 (11)	Poland	Coal mining
Weathering	Dearman, 1976 (39)	Great Britain	Granite
Basic geotechnical classification	ISRM, 1977 (28)	International	General
Rock structure	Hwong, 1978 (20)	People's Republic of China	Tunneling and mining
Rock discontinuity	ISRM, 1979 (26)	International	General

rock body) consists of blocks of rock material (also referred to as the intact rock or rock element) separated by various types of discontinuities such as joints, faults, and bedding planes. For engineering purposes, it is such a heterogeneous and anisotropic rock-mass assemblage that is of primary concern. Thus, the rock material--although a part of the rock mass--is not the most significant factor. Nevertheless, it is a necessary factor because the strength of the rock material constitutes the highest strength limit of the rock mass. A sample of the rock material sometimes represents a small-scale model of the rock mass since they have both been subjected to the same geological processes. In some instances, the rock material may be particularly important, as in the case of tunnel-boring machines.

The strength of the rock material is included as a classification parameter in the majority of rock-mass classification systems. This parameter can be determined in the field by means of the index of point-load strength (26). When only the rock-material properties are included, the classification is termed an intact-rock classification.

The second parameter most commonly employed is the rock-quality designation (RQD) (2). This is a quantitative index based on a modified core-recovery procedure that incorporates only those pieces of core 100 mm (4 in) or more in length. The RQD is a measure of drill-core quality, and it disregards the influence of joint tightness, orientation, continuity, and gouge (infilling). Consequently, the RQD cannot serve as the only parameter for the full description of a rock mass.

Other classification parameters used in the current rock-mass classifications are spacing of discontinuities, condition of discontinuities (roughness, continuity, separation, joint-wall weathering, infilling), orientation of discontinuities, groundwater conditions (inflow, pressure), and stress field.

An excellent discussion of the methods for quantitative description of discontinuities in rock masses can be found in a recent ISRM document (26).

I believe that, in the case of surface excavations and those near-surface underground rock excavations controlled by the structural geological features, the following classification parameters will be important: strength of intact-rock material; spacing, condition, and orientation of discontinuities; and groundwater conditions. In the case of deep underground excavations in which the behavior of rock masses can be stress controlled, knowledge of the virgin stress field, the changes in stress, or both can be of greater significance than the geological parameters. Most civil engineering projects, such as tunnels and subway chambers, will fall into the first category of geologically controlled rock-mass structures.

CURRENT ROCK CLASSIFICATIONS

Rock classifications may be conveniently divided into two groups: intact-rock classifications and rock-mass classifications.

Intact-Rock Classifications

The engineering classification of intact rock proposed by Deere and Miller (27) has been widely recognized as particularly realistic and convenient for use in the field of rock mechanics. It has subsequently been slightly modified to conform to the rounded values of the International System of Units (SI) (14). Recently, the ISRM Commission on Rock Classification recommended different ranges of values for intact-rock strength (28), and these are listed in Table 2 with the original Deere-Miller classification. The main reason for the new ISRM ranges was the opinion that the Deere-Miller classification did not include differentiation in the strength in the range below 25 MPa (<4000 lbf/in^2). It should also be noted that Table 2 leads to a recommendation that the convenient value of 1 MPa (145 lbf/in^2) for the uniaxial compressive strength may be taken as the lowest strength limit for rock materials. Hence, the materials with a strength lower than 1 MPa should be considered soils and described in accordance with the practice for soil mechanics.

As stated earlier, the uniaxial compressive strength of intact-rock materials can be determined in the field by means of the well-known point-load strength index. This involves testing on site of unprepared rock cores by using simple portable equipment. A piece of drill core is compressed between two points and the core fails as a result of fracture across its diameter. The point-load strength index is calculated as the ratio of the applied load to the square of the core diameter. A close correlation exists between the uniaxial compressive strength and the point-load strength index, namely, strength = 24 x point-load index. Standard testing procedures are available for point-load testing (26). The appropriate ranges of point-load strength index are included in Table 2.

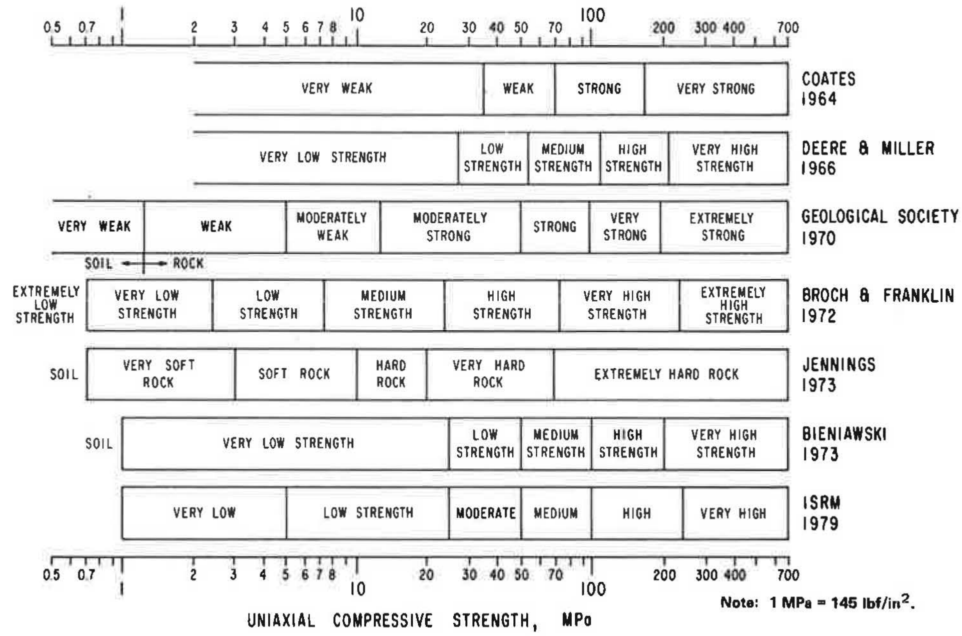
It should be noted that the whole subject of intact-strength classification is a fairly controversial topic since a number of classifications for strength of rock material have been proposed. For the sake of completeness, they are compared in Figure 1.

Table 2. Uniaxial-compressive-strength classifications for intact rock.

ISRM: Commission on Standardization (26) (MPa)	ISRM: Commission on Rock Classification (28) (MPa)	Deere and Miller (27): Strength (MPa)	Deere and Miller (27): Strength (lbf/in²)	Point-Load Strength Index (MPa)
>250 (very high)	>200 (very high)	>200 (very high)	>32 000	>10
100-250 (high)		100-200 (high)	16 000-32 000	4-10
	60-200 (high)	50-100 (medium)	8 000-16 000	2-4
50-100 (medium)		25-50 (low)	4000-8000	1-2
25-50 (moderate)	20-60 (moderate)	<25 (very low)	<4000	<1
5-25 (low)	6-20 (low)			
1-5 (very low)	<6 (very low)			NA

Note: 1 MPa = 145 lbf/in².

Figure 1. Classifications for strength of intact rock.



Some intact-rock classifications also include consideration of the modulus of elasticity of rock materials. The Deere-Miller classification, for example, features a diagram of intact-rock strength versus modulus ratio (strength/modulus) (27).

The major limitation of the intact-rock classifications is that they do not provide quantitative data for engineering design purposes. Therefore, their main value lies in enabling better communication in discussions of intact-rock properties.

Rock-Mass Classifications

Although it is not the function of this paper to review in detail all the rock-mass classification systems, it is appropriate to consider the main features of the more-important systems. From the point of view of the transportation engineer, six rock-classification systems may be selected from Table 1. These are as follows: Terzaghi's rock-load classification (1), Lauffer's stand-up time classification (7), the RQD classification (2), the rock-structure-rating (RSR) concept (3), the geomechanics classification (14), and the Q-system (9).

The United States has been particularly active in the field of rock-mass classifications. The Terzaghi classification and the RQD and RSR concepts were all developed in the United States and the geomechanics classification is being extended in the U.S. field of mining.

The first major classification system, proposed by Terzaghi in 1946, was dominant in the United States for some 30 years. The system is excellent for the purpose for which it was evolved, namely, to select steel supports for rock tunnels. It is not suitable for modern tunneling methods that use rock bolts and shotcrete. It provides no quantitative information on the properties of rock masses.

The Lauffer classification (1958) was a considerable step forward in the art of tunneling since it introduced the concept of an active unsupported span and the corresponding stand-up time as a function of rock-mass quality. The disadvantage of this classification is that the stand-up time of an unsupported span is difficult to establish, and the system depends on practical experience.

The Deere classification was introduced in the United States in 1970 and related his RQD to tunnel support. Although this method is simple and practical, it disregards the influence of joint orientations, continuity, and gouge infilling, which are of great importance in many cases (2).

In 1972, Wickham, Tiedeman, and Skinner proposed a classification called the RSR concept. It had the advantage of using numerical ratings for weighing the relative importance of classification parameters. Its disadvantage was that the concept was evolved primarily for steel supports (3).

Finally, in 1973, Bieniawski proposed the geomechanics classification (14,25) and, after working independently, Barton, Lien, and Lunde proposed the Q-system in 1974 (9). Both these

Figure 2. Relationships between stand-up time and unsupported span for various rock-mass classes.

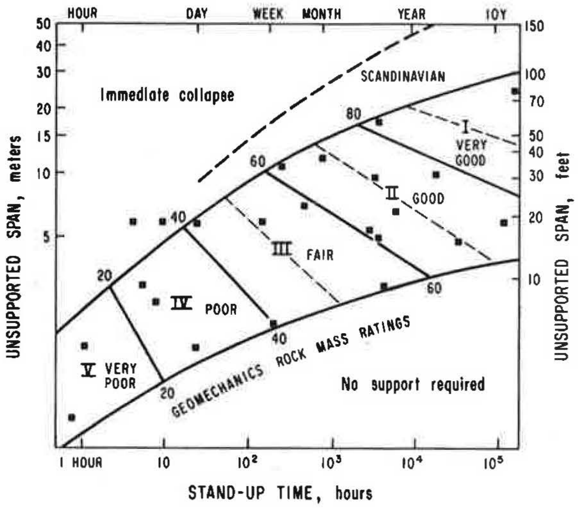
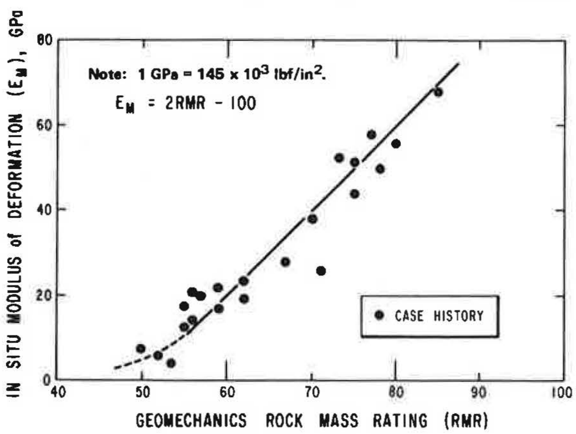


Figure 3. Correlation between the in situ deformation modulus of rock masses and the rock-mass rating from the geomechanics classification.



classifications provide a sound basis for engineering assessment of rock masses and are suitable for rock-bolt and shotcrete support systems. The geomechanics classification is somewhat easier to use and has been widely used in both tunneling and mining. The Q-system is particularly suitable for hard rock tunnels and large chambers (9).

RANGE OF APPLICATIONS

The rock-mass classifications currently in use have reached a high level of development that enables applications to a wide range of engineering problems.

Tunnels and Chambers

The main field of application of rock-mass classifications has traditionally been tunneling. The RSR concept, the geomechanics classification, and the Q-system have all been applied extensively to highway, railroad, and water-conveyance tunnels. In addition, the geomechanics classification and the Q-system were also employed in the design of large rock chambers such as those found in subways and underground hydroelectric schemes. The output of rock-mass classifications for tunneling is the stand-up time of an unsupported roof span. A longer stand-up time can be achieved by selecting suitable rock-reinforcement measures. Today, well-tested support selection guidelines are available for rock tunnels and chambers that feature rock bolts, shotcrete, and steel ribs. However, guidelines for machine-bored tunnels have still to be developed.

The relationships between stand-up time and span length as well as the support guidelines have been developed on the basis of case histories. The geomechanics classification was based on 49 case histories, whereas the Q-system involved 200. Different rock conditions and tunneling practices have clearly affected the selection of stand-up time and length of unsupported spans. As depicted in Figure 2, Scandinavian practice would allow longer unsupported spans than those recommended by the geomechanics classification (29).

Mining

Although mining applications are not within the scope of this paper, they are worth mentioning in passing because mining cases often enable the determination of the limits of rock-mass stability as observed during caving operations. Hence, they are relevant to civil engineering because they offer the opportunity of investigating rock-failure situations. The geomechanics classification has in particular been applied to many mining situations (29) that involved cavability of ore, drift stability, and, more recently in the United States, room-and-pillar coal mining (30).

Rock Slopes

Of the various rock-mass classification systems, only the geomechanics classification has been applied to rock slopes (31,32). For rock slopes, the output from this classification is cohesion and friction data for the five rock-mass classes. In 1976, Steffen classified 35 slopes, of which 20 had failed (32) and, by using the geomechanics classification, he obtained the average values of rock-mass cohesion and friction. With these data, he calculated the factors of safety and plotted the results in the form of a histogram that showed the frequency of occurrence versus the factor of safety. A definite statistical trend was found. However, caution should be exercised when applying this classification to rock slopes since more case histories need to be analyzed. Research in this respect is currently being conducted by K.W. John at Bochum University in the Federal Republic of Germany.

Deformability of Rock Masses

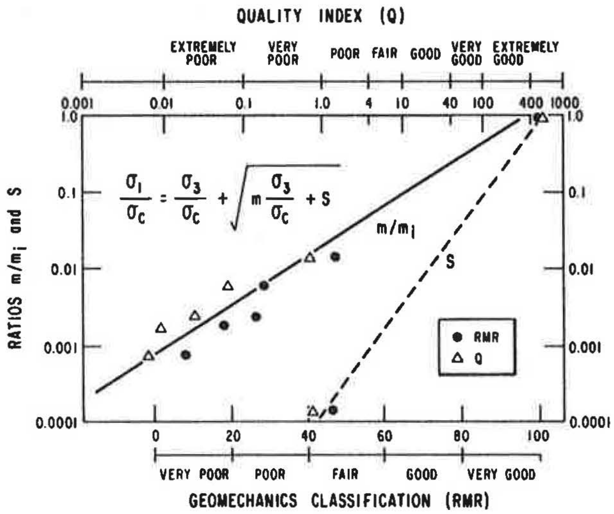
For the design of rock foundations and large rock chambers, knowledge of the modulus of rock-mass deformability is of prime importance. Rock-mass classifications were found useful for estimating in situ deformability of rock masses (33). This is demonstrated in Figure 3, and, as will be seen, the following correlation was obtained:

$$E_M = 2 \times RMR - 100 \quad (1)$$

where E_M is the in situ modulus of deformation in gigapascals (1 GPa = 145 x 10^3 lbf/in^2), and RMR is the rock-mass rating from the geomechanics classification.

The above correlation was derived on the basis of 22 case histories that involved a wide range of in situ tests conducted in various parts of the world. The accuracy of prediction of Equation 1 is about 20 percent, which is quite acceptable for rock-engineering purposes.

Figure 4. Hoek's criterion for in situ strength of rock.



Strength of Rock Masses

Hoek and Brown (21) have recently proposed a method for the prediction of rock-mass strength based on rock-mass classifications. In view of the scarcity of reliable information on the strength of rock masses and the very high cost of obtaining such information, Hoek considers it unlikely that comprehensive quantitative analysis of rock-mass strength will ever be possible. Hence, some general guidance based on rock-mass classifications is justifiable.

Hoek proposed a criterion of failure for rock of the following form:

$$\sigma_1/\sigma_c = (\sigma_3/\sigma_c) + \sqrt{m(\sigma_3/\sigma_c) + s} \qquad (2)$$

where

- σ_1 = major principal stress at failure,
- σ_3 = minor principal stress applied to the specimen,
- σ_c = uniaxial compressive strength of rock, and
- m and s = constants that depend on the properties of the rock and the extent to which it has been broken by being subjected to σ_1 and σ_3.

In Figure 4 [modified from Hoek and Brown (21)], a plot is given of the ratio m/m_i and of the value of s against the geomechanics-classification and the Q-system ratings for Panguna andesite. These relationships may be used as a very rough guide for estimating rock-mass strength. In this procedure, m_i for intact rock is determined from a fit of Equation 2 to triaxial test data. Note that s = 1 for intact rock.

Rippability of Rock

Weaver (34) proposed a rock-mass classification system that enables the assessment of excavation characteristics of earth and rock materials and provided a guide for the assessment of rock rippability. This classification has not found much acceptance. A simpler method was proposed by Franklin, Broch, and Walton (35).

Special Rock Conditions

In situations that involve extremely poor rock conditions, such as swelling and squeezing rock, the Q-system is more effective than the geomechanics classification. The latter is difficult to apply since it was originally developed for shallow tunnels in hard, jointed rock. Although Oliver (36) proposed a rock-durability system for use in conjunction with the geomechanics classification, experience shows (21) that, when work is being done in extremely weak ground, the use of the Q-system is preferable.

RECENT DEVELOPMENTS

Notable developments in the last few years that concern rock classifications fall under the following headings.

Correlations

A number of comparative studies have revealed that there are correlations among the various rock-mass classification systems (17,24,25). In a study of 111 case histories that involved tunnels and chambers in North America, Europe, Africa, and Australia, the following relationship was derived (25):

$$RMR = 9 \log_e Q + 44 \qquad (3)$$

where Q is the rock-mass quality (9).

Recently, Rutledge (17) correlated three classification systems on the basis of his tunneling experience in New Zealand. He derived the following relationships:

$$RMR = 13.5 \log Q + 43 \qquad (4)$$

$$RSR = 0.77RMR + 12.4 \qquad (5)$$

$$RSR = 13.3 \log Q + 46.5 \qquad (6)$$

where RSR is the rock-structure rating mentioned earlier (3).

Use of Borehole Data

A trend has emerged for selection of engineering geological parameters on the basis of borehole data, which alone would be sufficient for rock-mass classification purposes without the need for tests in adits or pilot tunnels. As a result of the availability of more-advanced coring techniques such as directional drilling and oriented-core sampling as well as both borehole and core-logging procedures, rock-mass classifications can be conducted on the basis of input data from boreholes alone.

Monitoring During Construction

Although some classification systems tend to rely exclusively on the accumulated case-study experience, it is more appropriate to back predictions of support based on rock-mass classifications by using a monitoring program during construction. The new Austrian tunneling method is a success story of the benefits that can be derived by combining rock classification and monitoring.

Elimination of Two-Tier Support for Tunnels

The traditional concepts of primary (temporary) and secondary (permanent) support for rock tunnels are losing their meaning since the modern tendency is toward a single support system, that is, rock reinforcement necessary to maintain tunnel stability for the life of the project.

Contracting Practices

Although the tunneling-project contracts in Europe have featured rock-mass classifications as a basis of payment for many years, this matter is now receiving attention in some countries outside Europe.

Analytical Procedures

Analytical techniques in the field of rock mechanics have experienced a tremendous growth and, although analytical design cannot as yet replace empirical and observational designs (mainly due to the difficulty of providing reliable input data for the mathematical models), progress can only be maintained if empirical approaches are backed by analytical studies.

LESSONS LEARNED

After so many years of systematic application, the rock-mass classification situation may be compared with that of rock-stress measurements. By the time the first international conference on rock-stress measurements was held (1969 in Lisbon, Portugal), no fewer than 50 stress-measurement techniques could be counted and the problem was how to stop new techniques from being developed for the sake of development and to direct efforts toward perfecting the most promising techniques. No organized approach was made in this respect, and the second international conference on rock-stress measurements (1976 in Sydney, Australia) was nearly canceled for lack of interest. The reason was discouragement because, after so many years, no single reliable and acceptable technique existed.

The same danger looms in the case of rock classifications. There are too many systems available and not enough attention is being devoted to consolidation of efforts on the more-promising techniques.

Positive Aspects

Since the RSR concept was proposed in 1972 by Wickham, Tiedeman, and Skinner (3), three positive aspects have become evident:

1. No matter what classification system is used, the very process of rock-classification procedures enables the designer to gain a better understanding of the influence of the various geological parameters in the overall rock-mass behavior and hence to gain better appreciation of all the factors involved in the engineering problem. This leads to better engineering judgment. Consequently, the lack of general agreement on a single rock-classification system does not really matter; it is better to try two or more systems and, through a parametric study, obtain a better feel of the rock masses.
2. Once a few rock-classification systems have been applied to a given project, it may be found that a simplified classification system particularly suited for this project will evolve. Examples of this approach are the Drakensberg scheme in South Africa, the Dinorwic scheme in Britain, and the Washington Metro project in the United States.
3. Quite apart from the engineering benefits such as design data, rock classifications have been spectacularly successful in ensuring better communication on the project. This leads to high morale as well as economic and technical benefits.

Negative Aspects

In spite of the overall optimism about rock-mass classifications, there are a few negative aspects.

1. There are instances in which rock-mass classifications simply do not work at all. In one case that involved a large cavern, such excellent rock conditions were found that only spot bolting was used in spite of earlier indications, by using rock-mass classifications, that systematic support would be required. This highlights the problem that very few case histories that involved exceptionally good rock were included in the development of the original rock-mass classifications.
2. Even when effective, rock classifications should not be taken too far as a substitute for engineering design. In the case of very complex rock structures such as large multiple caverns, the classification approaches are not sufficient. In such cases, other approaches such as field monitoring or in situ tests may be preferable (used in conjunction with classifications).
3. There may be a tendency to use rock classifications without full understanding of the input and output implications because of the lack of time or the lack of a correct step-by-step application procedure.

NEED FOR STANDARDIZATION

From time to time, it has been questioned whether standardization is progress or is a retrospective and restrictive step. The argument was advanced that standards tend to be followed blindly and that they inhibit the development of new and improved techniques.

On the other hand, a questionnaire circulated by the ISRM Commission on Standardization has shown (37) that the response of industry is overwhelmingly favorable to some form of standardization. It appears that those who have less-ready access to library facilities and less time to choose among the apparently confusing alternative rock-classification procedures published in the literature would appreciate some guidance in the selection and use of classification systems.

PROSPECTS FOR ATTAINING STANDARDIZATION

I believe that, in view of the many rock-classification systems in existence (which has advantages as well as disadvantages), there is a need for some form of standardization. However, the following precautions should be taken:

1. Rather than being prepared as rigid standards, the documents should be termed "suggested methods," which implies that the user may choose to follow one or the other of several alternative methods or to use methods that seem appropriate for that particular project. Thus suggested methods should be written for each major rock-classification system, in particular for these four: Terzaghi, RQD, geomechanics, and Q-system.
2. Each suggested method should have the following warning included in the introduction: "It should be emphasized that the purpose of these suggested methods is to specify rock-classification procedures and to achieve some degree of standardization without inhibiting the development or improvement of techniques."

If the above two precautions are accepted, then the prospects of attaining a degree of standardization in rock classifications are excellent. The TRB Committee on Exploration and Classification of Earth Materials would have little difficulty in applying, evaluating, and correlating the major existing rock classifications, whereas ASTM Committee D-18 could easily prepare suggested methods for intact-rock classifications as well as for rock-mass classifications. In this respect, it should be noted that the existing rock-mass classifications already include both intact-rock and rock-mass properties.

However, the prospect for developing one standard classification that has a universal application does seem low because there is no need for such a system; various engineering applications may have different classification requirements. In fact, it is an advantage to engineers to try a few classification systems in order to compare the results and to get a feel of the important variables in a given project. Thus the lack of agreement among the various classification systems is not a problem; indeed, it may be an advantage. Furthermore, there is no problem with a classification scheme that includes both intact-rock and rock-mass properties. Such systems are already in existence. Concerning intact-rock classifications, these are considered of limited use since they are unable to provide quantitative engineering design data and their main function is one of improving communication.

ASPECTS THAT REQUIRE DISCUSSION

Before a limited standardization of rock classifications is embarked on, the following aspects merit discussion:

1. Classification requirements of various engineering applications,
2. Classification parameters and their determination in the field,
3. Use of classifications in rock slopes (natural and man-made),
4. Collection of case histories for systematic correlation and evaluation of rock classifications, and
5. Determination of whether classification systems are themselves design methods.

CONCLUSIONS

This state-of-the-art review of rock classifications has led to the following conclusions:

1. Rock classifications have reached a high level of development and have been successfully applied in underground construction projects, excavated rock slopes, rock foundations, rock rippability, and mining.
2. Some current rock classifications provide valuable quantitative design data and are thus important aids for the engineer.
3. Intact-rock classifications are of limited practical value; their main function is one of improving communication.
4. Rock-mass classifications include both intact-rock and rock-mass properties, and four such systems are currently in use in the United States. Correlations are available among the most recent rock-classification systems.
5. The lack of agreement among the various rock-classification systems is not a problem but is rather an advantage in that it enables the engineer to compare the data from the various classification systems, which leads to better understanding of the influence of the design variables.
6. There is a distinct need for limited standardization specifications, but these should be in the form of suggested methods (one for each classification system), which would achieve some degree of standardization without inhibiting the development or improvement of techniques.
7. There does not seem to be a need for one standard classification that has a universal application because the various engineering applications have different classification requirements.

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Uniform Rock Classification for Geotechnical Engineering Purposes

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The Unified Rock Classification System (URCS) is used by a large organization, such as the Forest Service of the U.S. Department of Agriculture, to handle projects of all sizes that involve rock. Existing geologic classifications have not provided the necessary information. The usefulness of URCS is that the pertinent natural conditions related to design and strength are emphasized and can be read at a glance, which allows an immediate assessment. A decision is then made as to the appropriate level of detail and the extent of investigation needed to complete or evaluate the project. Efforts can be concentrated toward the rock conditions that are most critical to the project. The data base that covers rock conditions is, in many instances, too detailed for collective analysis. URCS is a type of engineering shorthand to convey maximum design and construction information and omit specific details unrelated to a general evaluation.

The Unified Rock Classification System (URCS) was originally conceived in 1959 and used in simplified form to perform investigations and explorations for