*From Palmström A.: RMi – a rock mass characterization system for rock engineering purposes.
PhD thesis, Oslo University, Norway, 1995, 400 p.*

Chapter 9

DISCUSSION AND CONCLUSIONS

> *"A complete understanding of the features and mechanisms involved in the strength of rock masses presents formidable theoretical and experimental problems and, hence, simplifying assumptions are required in order to provide a reasonable basis for estimating the strength of jointed rock masses for engineering design purposes."*
> Evert Hoek (1986)

The steadily increasing trend in the field of engineering geology and rock mechanics to substitute the geological reality with mathematical idealizations often causes reduced interest in the quality of the input parameters representing reality. As mentioned in the introduction the main objective in this work has been to involve and represent geological parameters better in rock engineering and design. In addition important goals have been to:

- improve the measurements and descriptions of important rock mass parameters used in a general rock mass index, RMi, which characterizes the relative strength of a rock mass.
- develop well defined characterizations which will improve quality of geological input data and thus contribute to improved communication between people involved in rock engineering.

In addition to definitions the methods presented are backed by expressions and equations; many of them are supported by diagrams and tables. As this work relates to the field of rock construction, civil engineering and design, it involves, as Bieniawski et al. (1993) point out, three main disciplines, namely:

- engineering geology, which provides the framework for collecting and developing facts of the nature of the rock mass,
- rock mechanics, which provides the theory and empirical rules of rock deformation and failure, and
- rock engineering, which is the practical application of engineering geology, rock mechanics, and geohydrology to design of rock structures.

With so many topics covered a detailed discussion would tend to be comprehensive; therefore, 'local' discussions, comments and summing-ups have been outlined in many of the chapters and sections.

9.1 ON THE LAYOUT OF THE RMi SYSTEM

Central to the process of developing the RMi system and its use in practical rock engineering has been to arrive at:

- a simple structure for the RMi to characterize rock masses; such that its
- parameters can be applied to several engineering purposes; and that it can be
- applied both for preliminary estimates as well as for more accurate calculations and assessments based on the quality of its input parameters.

This is well in accordance with Lane (1948) who, in his critique of Casagrande's original published proposal of the Unified Soil Classification, listed four requirements that should be satisfied in any classification system of natural materials [1] for engineering purposes:

i. *It should describe the 'material' in well-understood terms that convey an idea of its type and behaviour.*
ii. *The system should furnish an indication of 'material' properties and performance.*
iii. *It should be applicable from visual examination, both in a simplified form and, with experience, in a more refined form.*
iv. *It should employ a simple system of notation for graphic abstracts of boring logs (sections, plan maps, contract specifications, reports) on drawings recording boring information.*
The fourth requirement is not outlined in this work, but the methods presented may well be further developed to also cover such purposes.

RMi is a numerical, general characterization of rock masses. As a measure of the rock mass properties, it includes only inherent parameters of the rock mass. When applied in practical rock engineering RMi is adjusted for the local features of significant importance for the actual use, work or utility. It is thus a flexible system applicable to many different purposes related to rock construction as indicated in Fig. 9-1.

To avoid confusion in a field, which is already crowded with classification methods and systems, RMi is tied to basic characteristics of geologic materials. Thus, few new terms or parameters have been introduced.

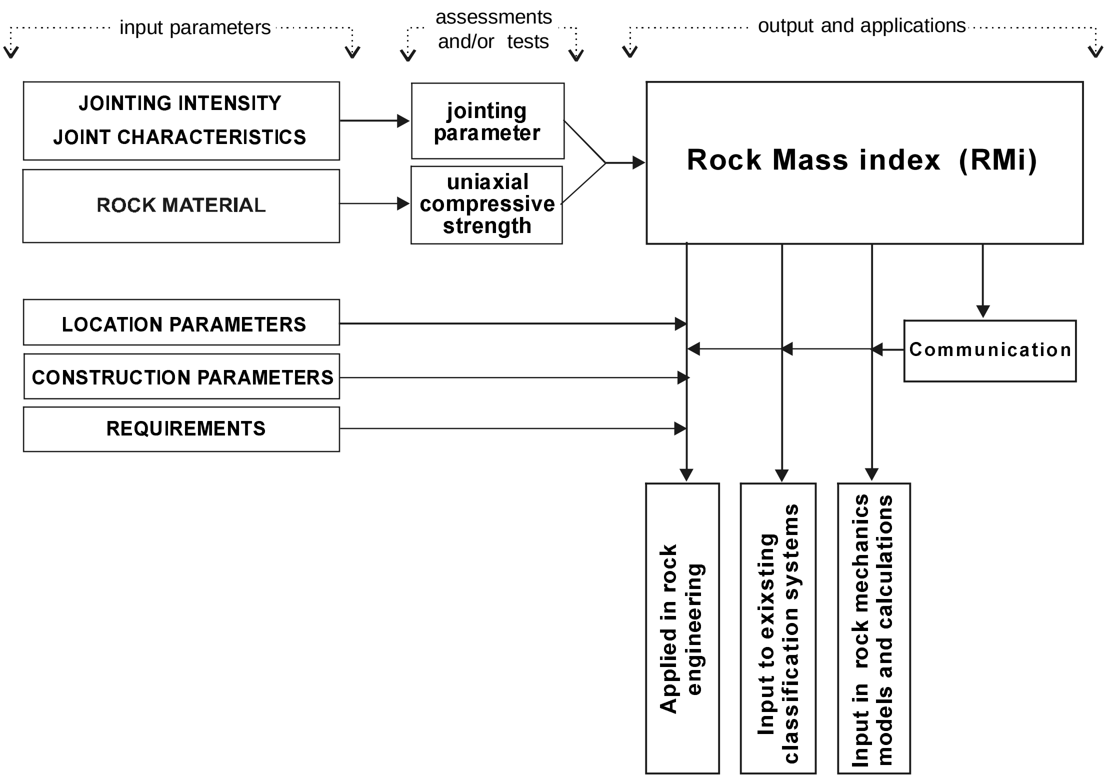

Fig. 9-1 Geological properties/parameters are quantified and combined to a general rock mass index RMi. RMi and/or its parameters can be applied as input in various types of rock engineering.

[1] In the statements below, the word 'material' has been applied instead of 'soil'.

9.1.1 Comparisons with the principles in other rock engineering systems

Chapters 6 - 8 show that RMi and/or its parameters have many applications in rock mechanics and rock engineering. The same principle has been presented both by Castelli (1992) using a 'basic rock mass quality factor' as the general factor, and by Hack and Price (1993) introducing the term 'reference rock mass' for the same. This is shown in Figs. 9-2 and 9-3 respectively.

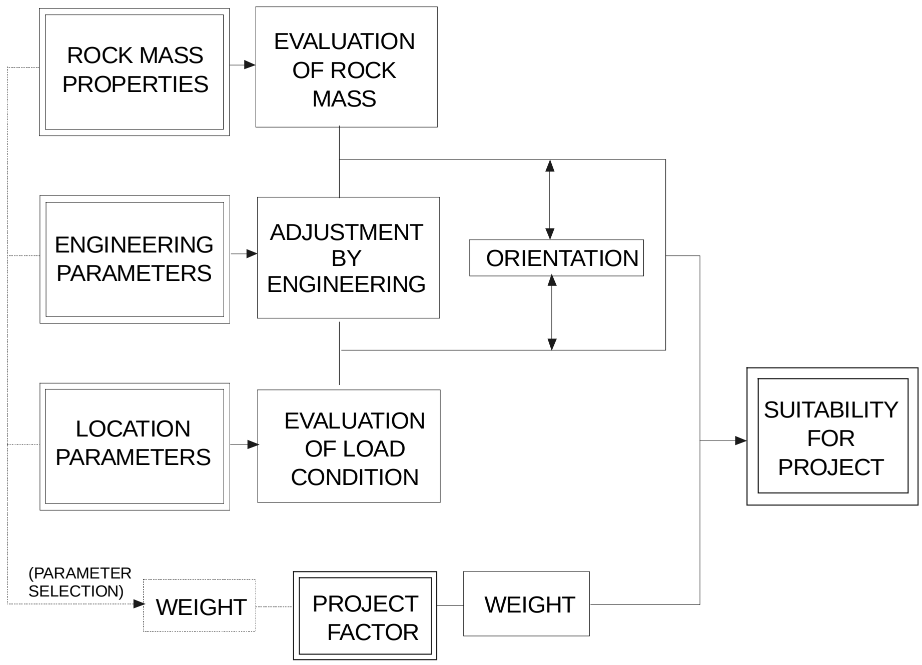

Fig. 9-2 Layout of the classification system by Castelli (1992).

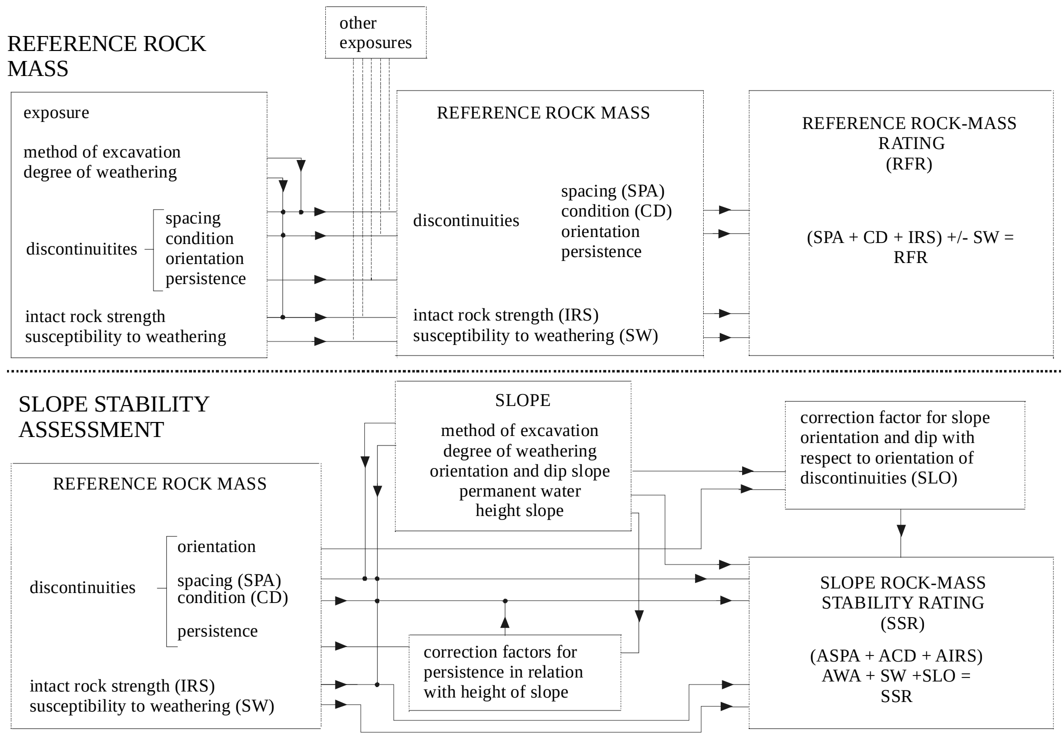

Fig. 9-3 Layout of the classification system by Hack and Price (1993).

Bieniawski (1984, 1989) applies also a similar principle when the RMR system is used in rock support recommendations in mining. The basic (common) RMR value is adjusted for stresses, blasting damage and for faults as shown in Fig. 9-4.

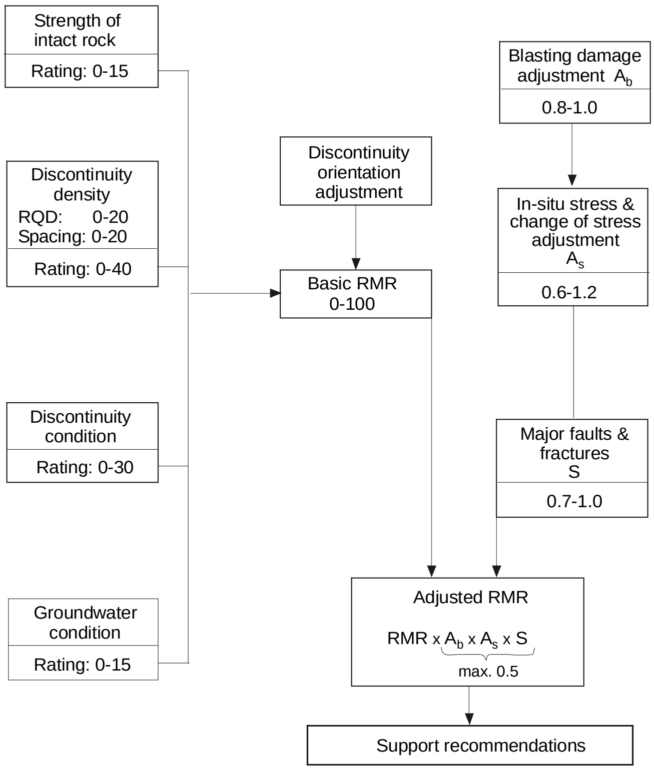

Fig. 9-4 Layout of the RMR classification when applied in mining (from Bieniawski, 1984)

Similarly, in the draft of 1993 for "The Chinese National Standard for Engineering Classification of a Rock Mass" a 'rock mass basic quality index' is suggested (Xuecheng, 1993).

It is important that when a general index or basic factor is chosen, it characterizes those properties of the material which are significant in engineering. In this way the index or factor is useful in communication as well as where comparisons are made between various localities. As mentioned in Chapter 4 there is a need, also in the field of rock engineering, to report the properties of the material (rock mass) used in the construction.

9.2 ON THE STRUCTURE OF THE RMi

The rock mass index, given as RMi = $\sigma_c \times$ JP, is used to estimate the strength properties of a rock mass based on combinations of important rock mass features [2]. As outlined in Chapter 4, RMi can be compared with the 'unconfined compressive strength of rock masses' in the Hoek-Brown failure criterion for rock masses given as $\sigma_{cm} = \sigma_c \times s^{½}$.

Hoek and Brown derived their failure criterion mainly from triaxial test data on intact rock specimens. For jointed rock masses they had only triaxial test data from the Panguna andesite. Therefore, the values of *s* for jointed rock masses, have been considered *"very approximate"* as stated by Ward (1991).

[2] σ_c is the compressive strength of intact rock material, JP is the 'jointing parameter' as outlined in Chapter 4.

In this work it has been possible to find another 7 sets of compressive strength data for rock masses used to determine the value of JP for various types of jointing. As discussed in Chapter 4, this is still considered insufficient as a basis for an expression to characterize the strength properties of rock masses. Although relatively good correlations were found between the strength data used, it is probable that the combination of block volume and joint characteristics in JP is relatively rough. With the variability in the rock masses it is hardly possible to find an accurate, 'realistic' and at the same time simple combination of the features and parameters acting. It is, therefore, important to stress that RMi characterizes the *relative* compressive strength of different rock masses.

After introducing it in 1980, Hoek and Brown found from practical applications of their failure criterion that the values of the constant *s* were conservative. Therefore, they adjusted the *s*-values in 1988. A general comparison between *s* and JP is difficult to carry out because different definitions of the two parameters are applied. As seen in Fig. 9-5, the values of *s* (= JP^2), are mainly lower than JP^2 for the 'original' *s*, while they are mostly higher for the 'revised' *s* . Thus, it seems from Fig. 9-5 that there is a fair connection between the 'original' s and JP for small values and between the 'revised' *s* and JP for the higher values.

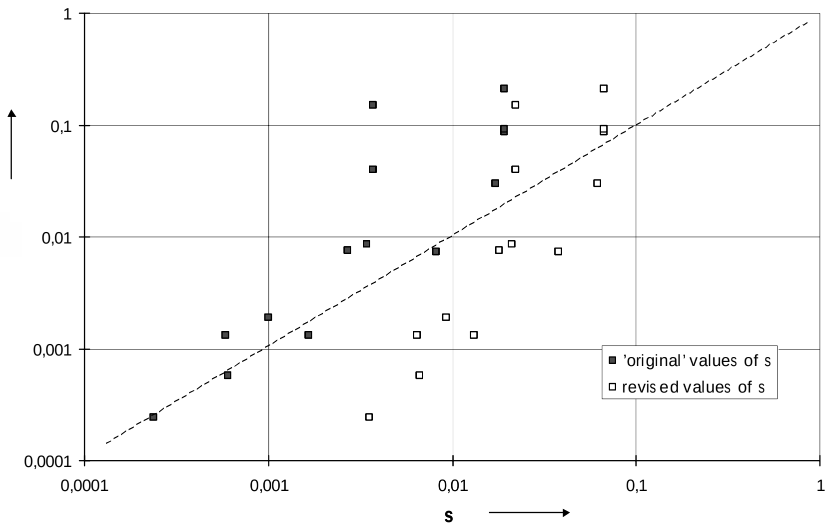

Fig. 9-5 Comparison between the jointing parameter (JP) and the parameter *s* in the Hoek-Brown failure criterion. Values of *s* have been found via the Q-system.

As for the Hoek-Brown failure criterion, also RMi - when applied directly in calculations - is restricted to *continuous* rock masses. In discontinuous rock masses the use of RMi must be adjusted to the local conditions. This has been shown in the application of RMi in design of rock support (Chapter 6) where discontinuous and continuous rock masses have been treated separately in the assessment of stability and rock support.

9.3 ON THE INPUT PARAMETERS TO RMi

Basically, the properties of the *rock material* can be found from laboratory tests. *Joints*, however, have generally so large dimensions that their characteristics can hardly be tested mechanically. An additional difficulty in working out a system for characterizing a rock mass is its three-dimensional structure. Most characterizations are performed as rough, inaccurate one-dimensional measurements of joint spacing or joint frequency based mainly of the dominating joint set. Few rules or guidelines exist how to include the effect of the other joint sets and joints. An important consideration in this work has been, in a simple way, to include the 3-dimensional composition of rock masses. For this the block volume has been selected; in addition, it is possible to include the effect of variations in the joint condition factor (jC) as shown in Chapter 5.

To help the user, several methods have been presented in Appendix 3 on how to compare and select the results from various kinds of jointing descriptions and measurements.

9.3.1 The uniaxial compressive strength of the rock

As the uniaxial compressive strength of rocks is well defined, this measurement should in most cases be easy to apply in the system. This parameter makes it possible also to include clay materials in the characterization by using their unconfined, undrained compression strength. Also clay fillings in faults and weakness zones where the blocks do not have contact, can in this way be characterized by the strength of the clay material. For granular soil materials like silt, sand and gravel the compressive strength is, however, difficult to measure; and has to be roughly estimated where such input is required.

Uniaxial compressive strength test is most frequently used to define rock behaviour. The test is open to misinterpretation (Farmer and Kemeny, 1992). The reason for this lies principally in the structure and breakdown mechanism of the rock. There are also possible sources of error in the sampling and sample preparation.

Appendix 3 shows various other methods for determining the uniaxial compressive strength. For example, the point load strength is a quick and easy method for determining the strength of rocks, and it may sometimes give more reliable results than compression tests on machined cylindrical samples.

The lowest value of σ_c should be applied in RMi which means that for anisotropic rocks the test should be made at approximately 45^o to the schistosity or layering, as shown in Appendix 3, Section 1.

9.3.2 Jointing

9.3.2.1 Joint characteristics

Ideally, all the characteristics (smoothness, waviness, length) included in the joint condition factor jC should be measured accurately. Such measurements of the joints would generally be either extremely time-consuming or in most cases, practically impossible to carry out. Only a few joints in the rock mass can be observed and measured and extrapolations have to be made.

Methods given in Chapter 5 show how to calculate jC, also where the input parameters vary. For rough estimates, where limited information on the joint characteristics exists, a 'common' value jC = 1 - 2 has been recommended. Using this it is possible to give preliminary estimates of RMi, also where input data on joint properties are lacking.

9.3.2.2 Block volume

The intensity of jointing has in most cases the greatest influence on the engineering properties of rock masses. An important feature in the RMi system is the selection of block volume for this parameter. By this it is possible to describe the whole range of degree of jointing from spacing less than 1 cm to several meters.

The measurement of block volume is especially useful where small blocks or irregular jointing occur. Crushed rock masses both in excavations and in drill cores are examples where the use of block size can give a more accurate description than traditional joint measurements.

Not all types of rock masses are, however, made up of separate blocks. As soon as many of the joints are discontinuous, or less than three joint sets occur the joints do not delimit defined blocks. This feature has been dealt with in Chapter 5 and in Appendix 3, Section 3 where guidelines are worked out for how to determine an equivalent block volume. In fact, this is not a feature specific to the measurement of block size. It is apparently "hidden" in jointing measurements like RQD and joint spacing. The presence of discontinuous joints and/or few joint sets has, however, a significant effect on the properties and behaviour of rock masses and should be included in the engineering characterization.

9.4 ON THE VARIATIONS AND UNCERTAINTIES IN ROCK MASSES

> *"When the starting point is least sound, most surprising results may be found."*
> Henrik Ibsen (1867)

The variations in the structure and composition of a rock mass often result in problems and uncertainties when its features or properties are to be described and characterized.
According to Bieniawski et al. (1993) the hardest challenges to the designer are the variability of the rock conditions and the lack of sufficient information when rigorous analyses are being made.

Where the rock mass characterization is carried out *before* construction, uncertainties are introduced from the *interpolations* made between more or less known conditions at the surface and from various forms of *extrapolations* carried out from these (known) conditions to areas with unknown information. Except for wrong interpretations, improved characterization of the rock mass by RMi will generally increase the quality of the geological input data to be applied in evaluation, assessments or calculations. This will in turn lead to better designs.

Where the rock mass characterization is carried out in the tunnel or cavern, the quality of the input data depends mainly on how the description and characterization of the input parameters are performed. In these cases improved methods for characterizations have a direct impact on the engineering quality.

As there often are wide variations in the rock masses and their behaviour, even within limited areas/volumes, it is often wise to use a variation range of the geological parameters used in RMi. The great variations in structure/composition result in that the relative strength properties of rock masses almost always will vary within certain ranges, refer to Chapter 5.

9.5 COMPARISON BETWEEN RMi AND OTHER METHODS USED IN ROCK ENGINEERING

Chapters 6 - 8 show that RMi can be applied in various types of analyses for rock engineering purposes included underground stability and rock support determination and TBM penetration progress. In addition, some of the parameters in RMi can be used individually in classification systems where they may improve the input because they represent reality better and/or they may be found easier or more relevant to use.

9.5.1 The rock quality designation (RQD)

RQD is probably most commonly parameter in drill core logging, as it is rapid and easy to learn. Today, RQD is applied in the main classification systems as an input parameter for the block size or the jointing density. RQD is one-dimensional; therefore it is strongly directional. This was stressed among others by Bjerrum (1965). Therefore, Hudson and Priest (1983) and several other authors recommend carrying out core drillings in three directions to obtain reliable results. This is, however, an expensive solution to obtain information on the jointing.

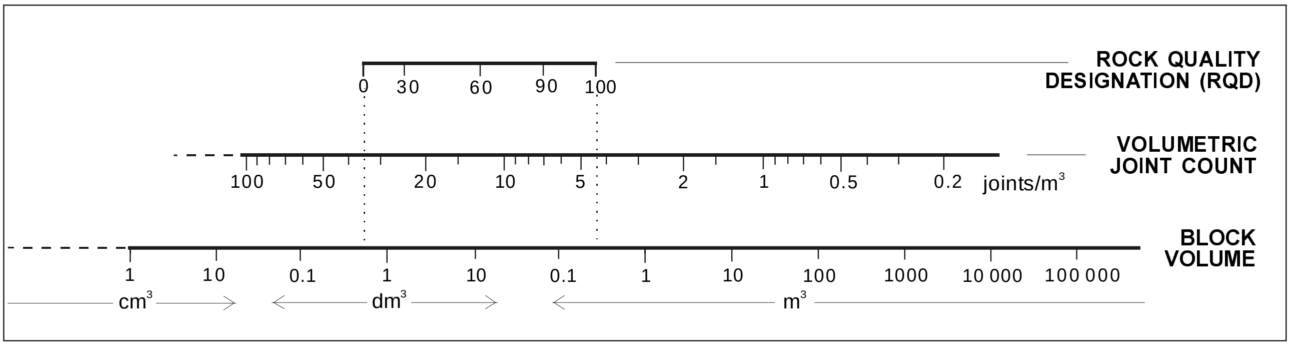

Fig. 9-6 Range of jointing covered by RQD, block volume (Vb), and volumetric joint count (Jv).

Fig. 9-6 shows that RQD only covers a small part of the range of the block sizes in a rock mass. This is further shown in Fig. 4-4 (in Chapter 4) and in Appendix 4. Thus RQD does neither express the variations for a high degree nor for a low degree of jointing. Therefore, several authors have suggested improvements in the registration of RQD, such as:

- Sen and Eissa (1991) have published a method for more accurate determination of the block volume from core drillings and RQD measures. It requires, however, considerable amount of information on jointing to establish the statistical jointing distribution required.
- Barton et al. (1974) have improved the application of RQD in the Q-system by dividing it with a factor (Jn) for the number of joint sets.
- Also Bieniawski (1973) has modified the use of RQD in the RMR system by adding a rating for the spacing of the joints.

The extensive use of RQD comes partly from the fact that it is a simple, cheap, and rapid parameter for characterizing drill cores. Considering the costs of coring a hole, it is, however, remarkable that so little work has been performed on improving core logging. The weighted jointing density method described in Appendix 3, which is fairly rapid and simple, offers an attractive improvement of core characterization.

9.5.2 Rock support design systems

The two most used classification systems - the rock mass rating (RMR) of Bieniawski (1973) and the Q-value of Barton et al. (1974) - both arrive directly at their quality value related to stability and rock support from various parameters in the rock mass.
These empirical systems are models for support practice and not tunnel mechanics or analysis of rock masses. As noted by Dowding et al. (1975), the selection of initial supports is often governed by factors having nothing to do with required capacity, i.e. material availability. Also, there is an understandable tendency by the tunnellers to be safe, which leads to overdesigned supports. Final supports are usually overdesigned again by being conservative and by not often considering the effect of initial support. All of this would be unimportant if the degree of overdesign were known, but it is not (Einstein et al., 1979).

9.5.2.1 Comparison between RMi and the classification systems of RMR and Q

By excluding the parameters related to the location (rock stresses, water pressure and orientation of joints), both classification systems can indicate the general conditions of the rock mass and thus be compared with RMi. The results from an investigation of the connection between RMi - RMR and between RMi - Q are shown in Figs. 9-7 and 9-8. The values have been found using various input data on:

- uniaxial compressive strength of rock material;
- joint set spacings and number of joint sets; and
- joint roughness and alteration.

The corresponding values of RQD, block volume and spacing have been found using equations derived in Appendix 3.

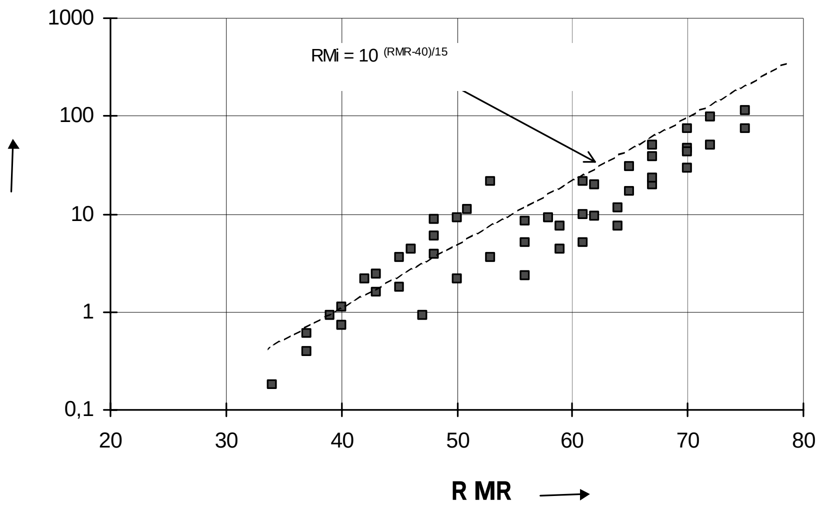

Fig. 9-7 Comparison between RMR and RMi

As shown a general correlation[3] can be expressed as

$$\mathrm{RMi} \approx 10^{(\mathrm{RMR}-40)/15} \qquad \text{eq. (9-1)}^{4}$$

[3] The correlation is best for RMR < approx. 70

[4] Applying this correlation and $V_{el} = 10^{(\mathrm{RMR}-10)/40}$ (Serafim and Pereira, 1983) the deformation modulus for rock masses can be expressed as $V_{el} \approx 5.6\ \mathrm{RMi}^{0.375}$. This equation should, however, be further documented from in situ measurements.

For some conditions there is, however, considerable deviation between the two corresponding values. A main reason may be the different ways the two systems apply jointing intensity (or block size). In the RMR system the jointing is characterized by RQD and by spacing of joints. The insufficient definition of spacing, and in addition the use of RQD causes that the jointing parameter in the RMR system generally is an inaccurate parameter. This is further documented in Appendix 4.

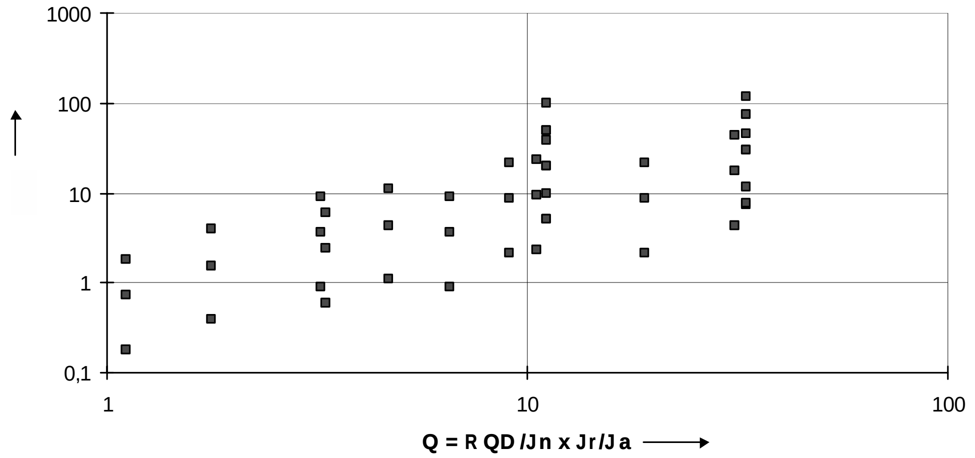

Fig. 9-8 Comparison between values of Q and RMi. The parameters for Jw and SRF have been given value one.

There is poor correlation between values of Q and RMi in Fig. 9-8. The main reason is that the Q-system does not include a strength parameter for the rock. The input of RQD to the value of Q may also increase the inaccuracy of the correlation. In Fig. 9-9 the jointing parameter, JP, has been applied instead of RMi, thus avoiding the rock strength parameter such that the two systems contain the same parameters. For Q > 1 the expression

JP = approx. 0.01 Q

gives as shown a rough correlation. For lower Q-values it does not seem to be any correlation. This is probably caused mainly by RQD's incapability characterizing highly jointed rock (see Appendix 4).

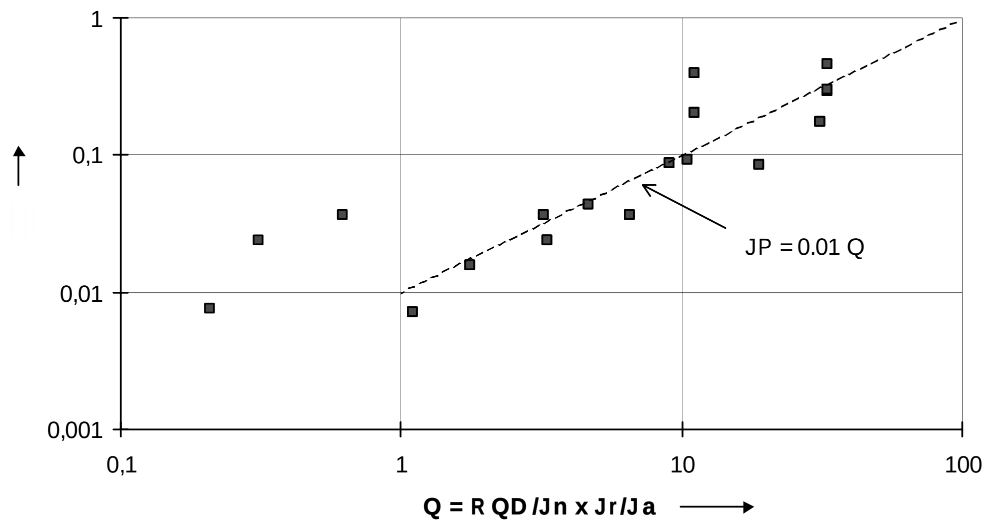

Fig. 9-9 Comparison between values of Q and the jointing parameter, JP. In the Q value the parameters for Jw and SRF have been excluded.

The various parameters used in the two systems and in RMi are shown in Table 9-1. Here, the parameters in the RMi system applied in assessment of rock support as presented in Chapter 6, have been used.

It is clear from this that the RMi-system includes mainly the same input parameters as the Q-system and the RMR system. RMi can, however, more easily be adjusted for local features of importance.

Both the RMR and Q systems "mix" the input parameters into one value which is used to recommend the rock support. They are both fairly simple so that relatively inexperienced people can carry out the collection of input data and perform the support evaluations. RMi, being a stepwise system, requires more experience to be fully utilized. It has a structure which makes it easier to understand the interaction and significance of the various features and parameters used; this makes the use of judgement easier and more attractive.

TABLE 9-1 COMPARISON OF THE RMR AND Q SYSTEMS WITH THE RMi USED FOR ROCK SUPPORT

ROCK MASS PARAMETER	**PARAMETERS REPRESENTED IN**		
	The RMR system	**The Q-system**	**Support applic. of the RMi system**
JOINTING INTENSITY	RQD joint spacing	RQD number of joint sets	Block volume *)
JOINT CHARAC-TERISTICS	joint roughness 2) joint alteration 2) joint filling 2) joint thickness	joint roughness joint alteration joint filling/coating joint thickness	joint roughness *) joint alteration *) joint filling/coating *) joint thickness *) joint length *)
STRENGTH OF ROCK MATERIAL	compressive strength		compressive strength *)
ROCK STRESSES	stress adjustment 1)	rock stresses	rock stresses
SWELLING		swelling pressure	5)
GROUND WATER	leakage and pressure	leakage and pressure	4)
ORIENTATION OF DISCONTINUITIES	strike & dip of joints		strike & dip of joints strike & dip of zones
OTHER FEATURES	blasting damage 1) major faults/fracture 1)	 weakness zones	4) weakness zones
DIMENSION OF EXCAVATION	related to 10 m span	span and/or height	span and/or height
USE OF THE EXCAVATION		excavation support ratio	6)

*) Applied in the <u>general</u> (basic) rock mass characterization (RMi).
1) Parameters used to adjust the basic RMR value for mining purposes.
2) A better division has been presented by Bieniawski, 1989. (See Table 8-6)
4) May be included where it has important influence.
5) The effect from swelling often requires special analysis to be carried out; therefore swelling is not included in the support method of RMi.

6) Support charts for various applications of the excavation remain to be worked out.

Castelli (1992) has shown another way to compare classification systems by finding how many arrangements for all probable combinations they offer. He found that

- the Rock Mass Rating has totally 21,875 combinations, while
- the Q-system has a total of 2,363,904 combinations, or
- the Q system excluding the SRF factor has 147,744 combinations.

As Castelli points out, the number of combinations will in practice be reduced because it is unlikely that some combinations occur simultaneously. For example, Castelli mentions that in the RMR system, RQD < 25% and discontinuity spacing > 2 m is extremely unlikely. In spite of that, each system characterizes a large number of different rock masses. Especially, the Q-system is considerably subdivided. The RMi system, includes a wider variation in jointing by applying block volume and in addition includes joint size and the compressive strength of the rock, incorporates probably a higher number of combinations than both systems.

9.6 THE NEED FOR A 'LANGUAGE' IN ROCK MECHANICS AND ROCK ENGINEERING

Because many engineering decisions are based on a combination of geologic, geotechnical and rock mechanics data, ISRM (1971) finds it important that a more systematic means of combining and correlating this information should be developed.

Similarly, a common deficiency in both geological and geotechnical literature has been the lack of an adequate and generally accepted means of transmitting an overall assessment of the nature of rock masses to those who have not had the opportunity of observing them. A language common to rock mechanics specialists and experts from related fields should, according to ISRM (1980), be available. This has also been mentioned by Matula (1969).

Such a 'language' or guidelines for descriptions using well defined terms will improve the communication between the field geologist and rock engineer (Hoek and Brown, 1980). It will also help in a meaningful interpretation so that field data should be intelligible to other engineers and geologists who may become involved in the project. Deere et al. (1969) mention that a better language will also help in the accumulation of experience associated with various classification systems, when the description of the parameters are quantitative and can be 'translated' from one system to another.

Müller (1982) finds that the geological descriptions as well as the geomechanical testing and presentation of data generally are good. But the transfer to application, the technical interpretation, is missing or is poor. The engineering geologist should act like an interpreter between the geologist and the rock engineer. *"Never should rock mechanics be used without the background of engineering geology. Such a use or misuse would be worse than the use of engineering geology without rock mechanics."*

The following features in this work can possibly improve these draw-backs and problems in communication and exchange of geo-data:

- The defined characterizations of the various rock mass parameters included in the RMi system in Chapter 4 as well as in Appendix 3.

- A list of definitions for common rock mass features in rock engineering, given in Appendix 3 useful for a more concise use of descriptive terms.

- Guidelines on how to measure and combine many of the parameters used and apply them in the characterization as shown in Chapter 5 and Appendix 3.
- The guidelines presented for 'translation' of qualitative descriptions into quantitative numbers in Appendix 3.

The use of RMi as a general, numerical system of rock masses, connected to descriptions will, therefore hopefully, strengthen the communication between those engaged in rock construction, rock engineering and design.

9.7 BENEFITS AND LIMITATIONS IN APPLICATION OF THE RMi SYSTEM

Some of the *benefits* using the RMi system are:

- In the author's opinion RMi will give a significant improvement in the geological data applied in connection with rock constructions:
    - by its more systematic use of the input of rock mass characterization; and
    - by the way its parameters are determined, including the possibilities applying results from different types of measurements and descriptions.
- It can also be used when limited information on the ground conditions is available; for example, in early stages of a project or where rough estimates are sufficient.
- It can easily be used in comparisons and exchange of knowledge between different locations, as well as in general communication.
- It is a stepwise system suited for engineering judgement.
- It is much easier to find the values of s (= JP^2) using the RMi system than the methods outlined by Hoek and Brown (1980) which incorporate the use of classification systems.
- It covers a wide spectrum of rock mass variations and therefore has possibilities for wider application than most other rock mass classification and characterization systems. This has for example:
    - the system developed for assessment of rock support; and
    - the system developed for assessing the boring rate of TBMs.
- The use of parameters in RMi can improve the input in other rock mass classification systems and in the NATM.

It is, however, important to also realize the following *limitations* of the RMi:

- As a result of the often large volumes involved plus the three-dimensional and complex structure of rock masses combined with the inaccessibility for seeing or observing the real conditions, it is not possible to:
    - apply all the various parameters in a rock mass in a simple system;
    - collect exact information on the rock mass structure as measurement and description of rock masses generally is based on extrapolation;
    - obtain/record the exact data on the rock mass conditions even with the most sophisticated investigation program;

The assessments in rock design and engineering must, therefore, often be based on data found from simplified descriptions. This is, however, a limitation valid also for other methods used in the collection of geo-data.

- We have to accept that the data we use in our calculations, evaluations and assessments often have limited accuracy. A part of this stems from the descriptions of rock masses and how their features are combined. The results from design and engineering can never be better than the quality of the geo-data used, however sophisticated the calculation methods and models applied may be.

- Considering the uncertainties connected with rock masses and the simplifications made in the expression of RMi, it should be stressed that it expresses only the index strength of a rock mass.

- RMi basically expresses the general features of rock masses and should not be uncritically applied where more specific analyses need to be carried out.

9.8 SOME CONCLUDING REMARKS

By using mostly standard geological and rock mechanical descriptions and classifications, the RMi system should be relatively easy to adapt and apply. Most users should soon be familiar with finding the value or ratings of the parameters involved. Simple features and expressions have been preferred here rather than more sophisticated and complicated solutions, even if the latter could give more accurate results.

As most of the evaluations, assessments and engineering are based on observations, the results are wholly dependent on the quality of the input data found from visual description or from measurements. The well defined parameters used in RMi and the way they are structured may, as mentioned, improve the quality of such data. Prerequisite for this is, however, that experienced people are responsible for the interpretation and acquisition of the geo-data.

It is not possible to exactly characterize all the varieties of such complex a material as a rock mass is by any simple system. Though RMi offers a stepwise method where variations in the rock mass possibly may be better characterized than in most other systems, the results are generally rough. For practical purposes, however, they should in most cases be sufficient as input in the assessments, keeping in mind that considerable efforts have to be made to obtain better structure and strength information from the rock mass.

RMi is a tool - a help - during the rock engineering design process. It can never replace geological feeling and/or practical experience. Further, it can never cover all of the innumerable cases/types/occurrences of rock masses. Practical judgement always has to be the main factor when assessments and evaluations are made in this field.

At the end of this chapter it is, therefore, appropriate to emphasize the role of engineering judgement. Prerequisite for this is a sound *understanding* of the site conditions and the impact caused by the construction works. Any attempt to replace geology by classifications or numerical values may lead to loss of geological understanding. The aim in the development of RMi has been that its simple structure largely can maintain 'the geological feeling' of the experienced rock engineer and the engineering geologist. This can be achieved, as mentioned earlier, by connecting RMi to an additional description of the rock mass using well defined terms.

9.8.1 Future developments

It has, during development of this work, been important to show how RMi can be used in rock engineering and design in rock support evaluation, and in assessment of TBM penetration rate. A lot of work remains, including the collection of field data on the ground conditions and the experience gained from construction case studies, to refine these methods.

So many aspects are involved in acquisition of geological data and their use in rock engineering, that it has not been possible within this work to fully develop definitions, methods and expressions which cover all possible applications. The expressions, diagrams and tables developed may possibly be refined when more experience and data from constructions combined with rock mass characteristics are available. More accurate expressions, can then be developed.

Some of the most interesting additional utilizations of RMi and/or its parameters include:

- a method to determine the deformation modulus of rock masses;
- input to design of rock blasting and fragmentation;
- input to numerical models; and
- a method to improve the interpretation of refraction seismic results to characterize jointing shown in Appendix 5.

The use of the RMi system by the author in engineering practice for a couple of years has shown promising results as well as interesting possibilities for development in rock mechanics and rock engineering.