Published in ISRM News Journal , 1997, pp. 21- 25

Collection and use of geological data in rock engineering

by Arild Palmström [1]

> *"I see almost no research effort being devoted to the generation of the basic input data which we need for our faster and better models and our improved design techniques. These tools are rapidly reaching the point of being severely data limited."*
> Evert Hoek, in the ISRM News Journal, 1994.

Also several other experts in the field of rock engineering have expressed their concern about the role and use of geological data in rock mechanics and design. About 30 years earlier, Karl Terzaghi wrote *"I am more and more amazed about the blind optimism with which the younger generation invades this field, without paying attention to the inevitable uncertainties in the data on which their theoretical reasoning is based and without making serious attempts to evaluate the resulting errors."*

The main reason for this is the problems involved in the collection of geological data for use in engineering. This was discussed by T.L. Brekke and T.R. Howard in 1972, who concluded that *"Rock masses are so variable in nature that the chance for ever finding a common set of parameters and a common set of constitutive equations valid for all rock masses is quite remote."* Futher, in 1984, Z.T. Bieniawski stated that *"Provision of reliable input data for engineering design of structures in rock is one of the most difficult tasks facing engineering geologists and design engineers."*

The great need for better quality of geological input parameters in rock engineering and design was the main aim for the Ph.D. thesis titled *"RMi - a rock mass characterization system for rock engineering purposes."* which was developed by the author 1991 - 95 at the University of Oslo, Norway.

Construction materials commonly used in civil engineering and mining are mostly characterized by their strength properties which are used in engineering and design. In rock engineering, no such specific strength characterization of the rock mass is in common use. As a concequence of this the Rock Mass index (RMi) has been developed to characterize the strength of the rock mass. An important aim has been to use geological parameters in the RMi which have the greatest significance on the behaviour of the rock mass.
As testing of in-situ rock masses on an appropriate scale is not practical, the collection of geological input data must be based mainly on field observations. A prereqiusite is, however, that such observations and measurements are well defined and that the actual parameters are easily recognisable. The RMi is based on the reduction in compressive strength of intact rock (σ_c) caused by the joints. It is expressed as

$$\text{RMi} = \sigma_c \times \text{JP}$$

where JP = the jointing parameter, expresses the resulting effect of the joints in a volume of rock.

As shown in Figure 1 the following features of joints are involved in the JP:

- The block volume (Vb) measured in m^3
- The joint characteristics consisting of:
  - ∗ the joint roughness factor (jR), (similar to Jr in the Q system);
  - ∗ the joint alteration factor (jA), (similar to Ja in the Q system); and
  - ∗ the joint size and continuity factor (jL).

  These factors, which have been given ratings as shown in Table 1, are combined to form the joint condition factor $jC = jL \times jR/jA$

The value of the JP has been roughly determined from large scale tests. Such tests are few and results from only 8 tests were found, see Table 2. In each of these the parameters included in the RMi have been quantified:

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- σ_c - by the uniaxial compressive strength of intact rock (in MPa);
- Vb - by the average volume of the rock blocks (in m^3); and
- jC - found from observed ratings of jR, jA and jL.

From these data and the measured uniaxial compressive strength of the rock mass (= RMi) the value of JP have been calculated. The values of JP, jC, and Vb have been plotted in Fig. 2. Using the inclined lines for jC, the connection between these parameters can be expressed as

$$JP = 0.2\sqrt{jC} \times Vb^{0.37\,jC^{-0.2}}$$

From this equation the uniaxial compressive strength of a rock mass can be found from

$$\text{RMi} = \sigma_c \times \text{JP} = \sigma_c \times 0.2\sqrt{jC} \times Vb^{0.37\,jC^{-0.2}}$$

As mentioned earlier, this attempt to directly express the compressive strength of rock masses is based on a limited number of large scale tests as well as several simplifications. Therefore, RMi gives only an approximate value. Additional test results of other large scale samples which can be used to improve the quality of RMi are of great interest.

Table 1 Ratings of the factors represented in the joint condition factor (jC)

Ratings of the joint wall smoothness factor (js)

Type	Description	Rating of *js* *)
Very rough	Near vertical steps and ridges occur with interlocking effect on the joint walls.	3
Rough	Some rigde and side-angle steps are evident; asperities are clearly visible; joint feel very abbrasive (like sandpaper grade approx. < 30).	2
Slightly rough	Asperities on the joint surfaces are distinguishable and can be felt (like sandpaper grade approx. 30 - 300).	1,5
Smooth	Joint surfaces appear smooth and feels so to the touch (smoother than sandpaper grade approx. 300).	1
Polished	Visual evidence of polishing exists, or very smooth surface as is often seen in coatings of clay, chlorite, and specifically talc.	0,75
Slickensided	Polished and often surface striated joint surfaces that result from friction along the surfaces of a fault or other movement surfaces.	0.6 - 1.5

*) For filled joints *js* = 1

Ratings of the joint waviness factor (jw)

Type	Undulation (u = amplitude / measured length (1 m))	Rating of *jw*
Interlocking	Large scale interlocking	3
Stepped		2,5
Large undulations	Wavy joint u > 3%	2
Small undulations	Wavy joint u = 0.3 - 3%	1,5
Planar	u > 0.3%	1

Ratings of the joint alteration factor (jA)

CONTACT BETWEEN THE TWO JOINT WALLS		
Joint wall character	**Description**	**Rating of *jA***
CLEAN JOINTS:		
Healed or welded joints	Non-softening, impermeable filling (quartz, epidote, etc.)	0,75
Fresh joint walls	No coating or filling in joint, except from staining (rust)	1
Altered joint walls		
1 grade higher	One grade higher alteration than the rock in the block	2
2 grades higher	Two grades higher alteration than the rock in the block	4
COATINGS OR THIN FILLING OF:		
Friction materials	Materials of sand, silt calcite, etc. without content of clay	3
Cohesive materials	Materials of clay, chlorite, talc, etc.	4

FILLED JOINTS WITH PARTLY OR NO JOINT WALL CONTACT		Partly wall contact	No wall contact
Type of filling	Description	Thin filling (approx. < 5 mm) Rating of *jA*	Thick filling or gouge Rating of *jA*
Friction materials	Sand, silt calcite, etc. without content of clay	4	8
Hard cohesive materials	Compacted filling of clay, chlorite, talc, etc.	6	10
Soft cohesive materials	Medium to low overconsolidated clay, chlorite, talc, etc.	8	12
Swelling clay materials	Filling material exhibits swelling properties	8 - 12	12 - 20

Ratings of the joint size and continuity factor (jL)

Joint length	Term	Type	Continuous joints*) Rating of *jL*	Discontinuous joints Rating of *jL*
< 0.5 m	Very short	Bedding or foliation partings	3	6
0.1 - 1 m	Short or small	Joint	2	4
1 - 10 m	Medium	Joint	1	2
10 - 30 m	Long or large	Joint	0,75	1,5
> 30 m	Very long or large	(Filled) joint, seam or shear **)	0,5	1

**) Often a singlularity and should in these cases be treated separately

*) Discontinuous joints end i massive rock

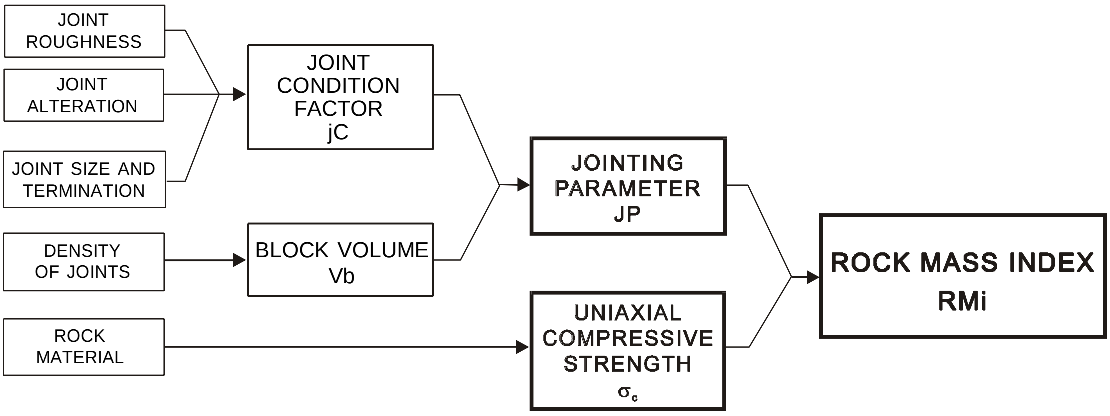

Figure 1 The connection between the parameters applied in the RMi.

Table 2 The results from large scale tests on rock masses

Sample no	Location	Rock type	s_c MPa	jC	Vb	JP
1	Panguna, New Guinea	Andesite	265	4 - 6	2 - 6 cm^3	0.014
2	Stripa, Sweden	Granitic rock	200	1.5 - 2.5	5 - 15 dm^3	0.04
3	Laisvall mine, Sweden	Sandstone	210	0.75 -1	0.1 - 0.3 m^3	0.095
4	Långsele mine, Sweden	Grey schist, greenstone	110 - 160	0.2 - 0.3	8 - 20 dm^3	0.01
5 a	Thüringer wald, Germany	Clay-schist	55	1.5 - 2	5 - 10 dm^3	0.055 *)
5 b	" "	"	100	2 - 2.5	5 - 10 dm^3	0.08 **)
6	Hessen, Germany	Sandstone/claystone	10.5/4.8	5 - 10 (?)	1 - 5 dm^3	0.17
7	Hagen, Germany	Siltstone	65	3.5 - 4.5	5 - 10 dm^3	0.10

*) Tests parallel to schistosity **) Tests normal to schistosity

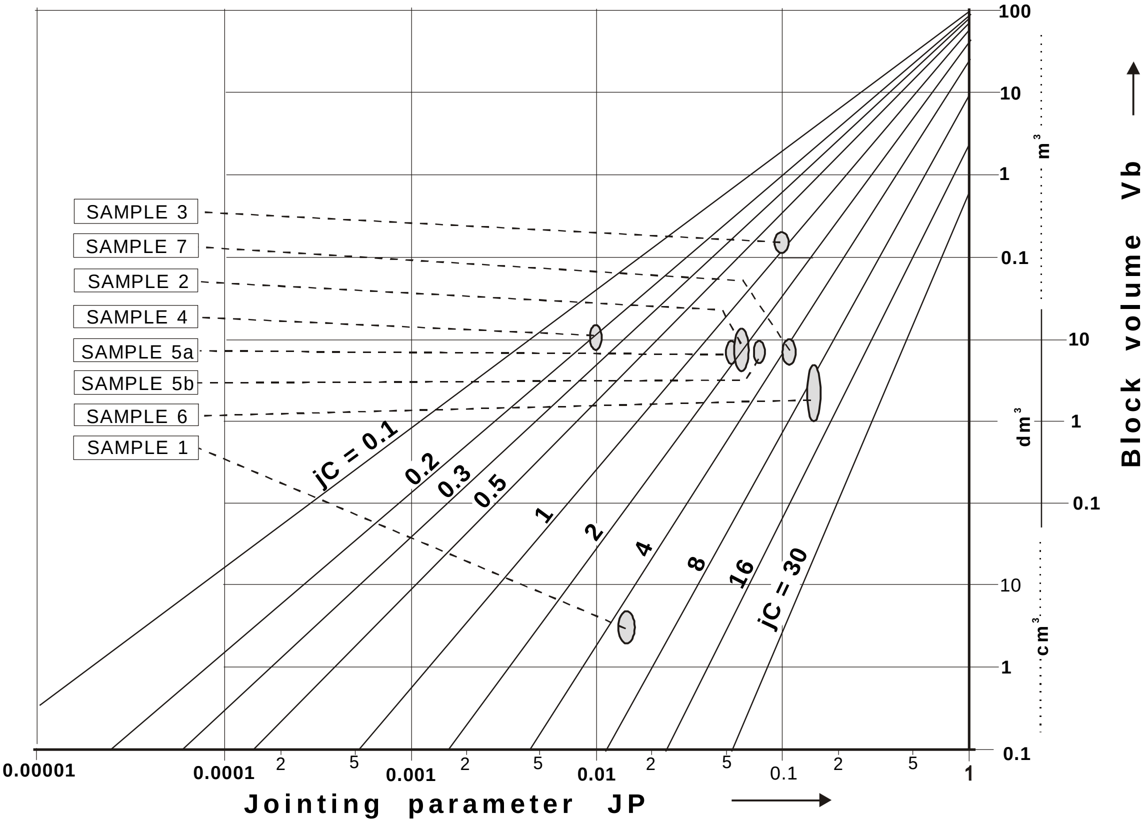

Figure 2 The connection between JP, jC and Vb from test results of 7 large scale tests and 1 back analysis. (The maximum value for JP = 1)

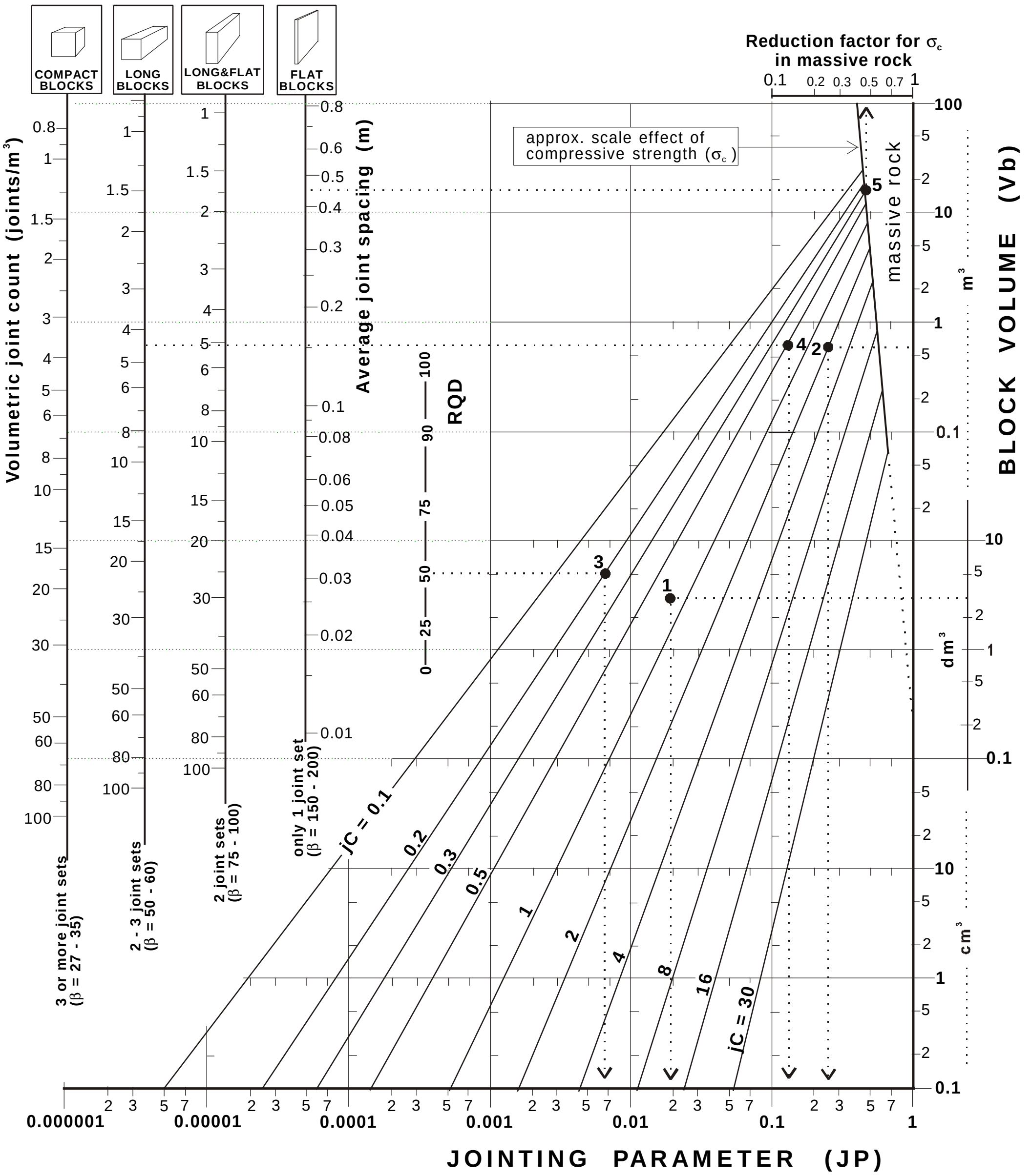

Figure 3 The jointing parameter (JP) found from the joint condition factor (jC) and various measurements of jointing intensity (Vb, Jv, RQD). The determination of JP from Vb (or RQD or Jv) in the examples are indicated (from Palmström, 1995). Examples shown in in this figure:

1: With a block volume Vb = 0.003 m^3 (= 3 dm^3) and a joint condition factor jC = 0.75 the value of the jointing parameter is JP = 0.02

2: Vb = 0.6 m^3 and jC = 2 give JP = 0.25

3: RQD = 50 and jC = 0.2 give JP = 0.007

4: For 2 to 3 joint sets with a volumetric joint count Jv = 4.5 and jC = 0.5, a value of JP = 0.12 is found.

5: One joint set with spacing S = 0.45 m has jC = 8. For this massive rock it is seen that the value of JP is replaced by the scale factor for compressive strength f_s = 0.45. For a rock with compressive strength s_c = 130 MPa the value of RMi = 0.45 ×130 = 59.6

Figure 3 shows how JP can be found from various types of jointing measurements.

As seen from Table 1 some of the factors applied in the RMi are almost the same as in the Q system. The greatest difference between the RMi and other classification systems is the application of block volume in the RMi, instead of RQD and joint spacings. The best measurement of the block volume is achieved if it is measured directly in the field. Palmström (1995, 1996) has shown how the block volume can be found also from other measurements of jointing.

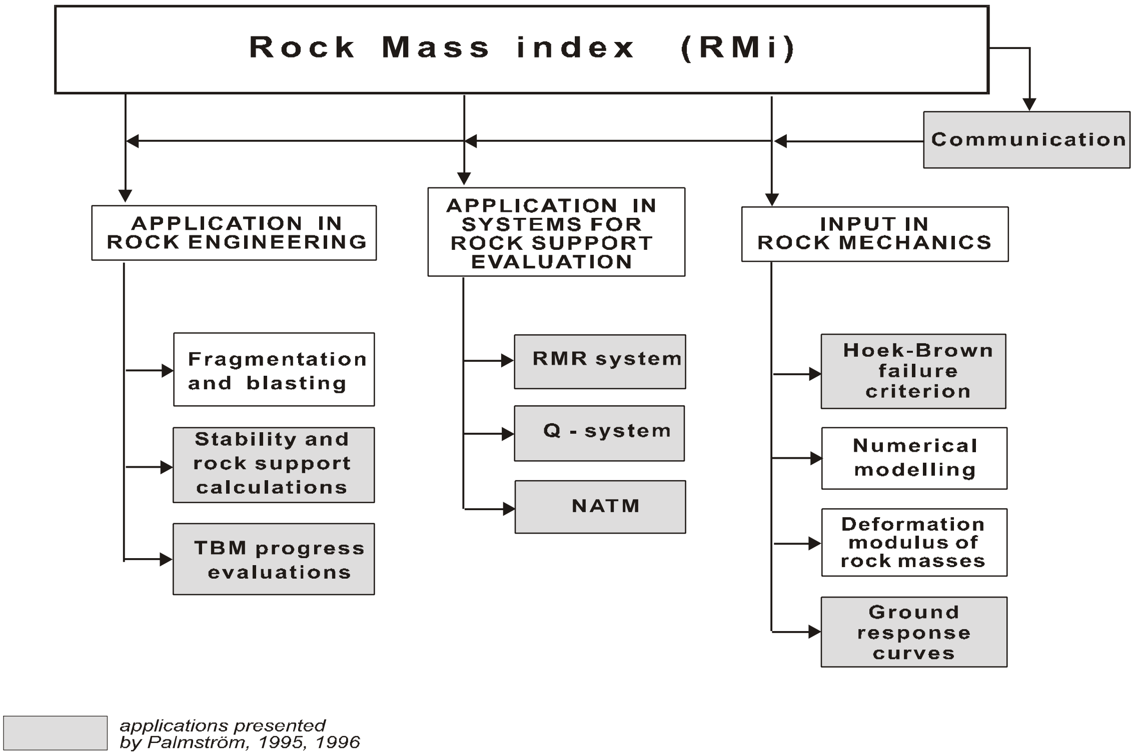

Figure 4 Some applications of the RMi in rock engineering.

Possible applications of RMi in rock engineering are shown in Figure 4. Some published papers presenting a more detailed description of the RMi are given in the reference list.

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