Geo-registrations, Rockmass Conditions and Ground Quality

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SUMMARY

Observations of rockmass parameters constitute important input to rock engineering and design. The quality of geo-observations made depends on the ground parameters selected and on the ability of the observer to correctly characterize and appropriately describe those parameters. The paper outlines the most important parameters influencing on the ground quality (i.e. stability) in rock excavations. These have been included in a Geo-registrations form presented. Each of the parameters has been divided into sub-classes, which can easily be marked on the form during the field mapping. In this way an effective means of characterizing rockmasses in the field is created. A corresponding computer spreadsheet makes transfer of the mapped data easy. This Geo-conditions spreadsheet calculates the value (quality) of the ground in three classification systems independently. It also shows how surface observations have been extrapolated to the assumed conditions underground. Thus it is well suited for documentation of the observations made, and can easily be copied into the the engineering geological site investigation report.

Contents

1 INTRODUCTION

Collection of geological data and engineering geological evaluations play an important role of the design and execution of rock excavations. These tasks can be challenging, especially in the planning phase, because of reduced access to the site and the possibility for observations, as well as complicated geology, costly investigations etc. This is why Douglas R. Piteau back in 1970 wrote 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."*
Further, Z.T. Bieniawski stated in 1984 that *"The success of the field investigation will depend on the geologist's ability to recognise and describe in a quantitative manner those factors which the engineer can include in his analysis."*

Later, in 1986 Dr. Evert Hoek made a similar comment on the importance of appropriate collection of geological data for the use in rock design, numerical modelling, as well as in selecting the location of underground excavations, by saying that *"The corner-stone of any practical rock mechanics analysis or rock engineering is the geological data base upon which the definition of rock types, structural discontinuities and material properties is based. Even the most sophisticated analysis can become a meaningless exercise if the geological information upon which it is based is inadequate or inaccurate."*

This paper has been worked out to help the engineering geologist in characterizing the ground conditions. It concentrates on engineering geological observations and description of the rockmass conditions for which it outlines the most important geological parameters responsible for the behaviour (stability) in rock excavations. An improved method to observe and select the input values during mapping is presented.

There is a trend in the field of engineering geology, rock engineering and rock mechanics to increased use of computer programs for calculations, design and problem-solving. However, the fact is that the input to such programs is wholly based on the geological data base of collected geo-parameters, often mainly found from geo-observations.

Appropriate experience and qualifications of the observer are important for quality mapping and site descriptions. He should have education in engineering geology combined with experience in excavation technique, rock support, etc. and knowledge of classification systems, including their background, the parameters involved and not least their limitations.

The following main types of investigations are used for collection of rockmass parameters, of which the items dealt with in this paper are shown in bold letters:

1. ***Existing geological maps and descriptions,*** which form the basis for all the other investigations
2. ***Experience from possible nearby rock constructions***. This may give approximate information on the rockmass qualities and potential excavation problems.
3. ***Aerial photo studies*** can in many areas give a good picture of the outcropping lineaments and geological structures.
4. ***Engineering geological observations*** of outcrops, of cuttings and in underground excavations give generally the most useful and often the best information on rockmass conditions.
5. Seismic refraction is the geophysical method that generally provides the best geo-information for use in rock evaluations and design. It may give indication of rockmass properties. Other types, such as resistivity measurement and IP measurements are gradually taken more into use.
6. Core drillings will give information of the rockmasses below the zone of weathering. The hole may be made long enough to reach down to the (planned) underground excavation. The main geological information is found through the core logging.

7. Laboratory investigations and tests are used to measure the mechanical properties of rocks and soils, in addition to swelling, slaking brittleness, durability etc. In connection with this, thin section studies, x-ray analysis are often performed to give additional information of the mineral composition, texture, etc.
8. Field tests for measurements of stresses, ground water, rockmass deformation modulus, etc. are often conducted in boreholes.
9. Special adits (test tunnels) excavated to investigate the rockmass and ground conditions.

In this paper,
rockmass = the material in which the rock excavation is constructed, i.e. rocks penetrated by joints, and
ground = the rockmass subjected to stresses and ground water.

2 ON COLLECTION OF GEO-DATA

There are many ways and methods for collecting geological information and geo-data from rock surfaces (outcrops, cuttings), drill holes, and underground excavations. Figure 1 shows some them.

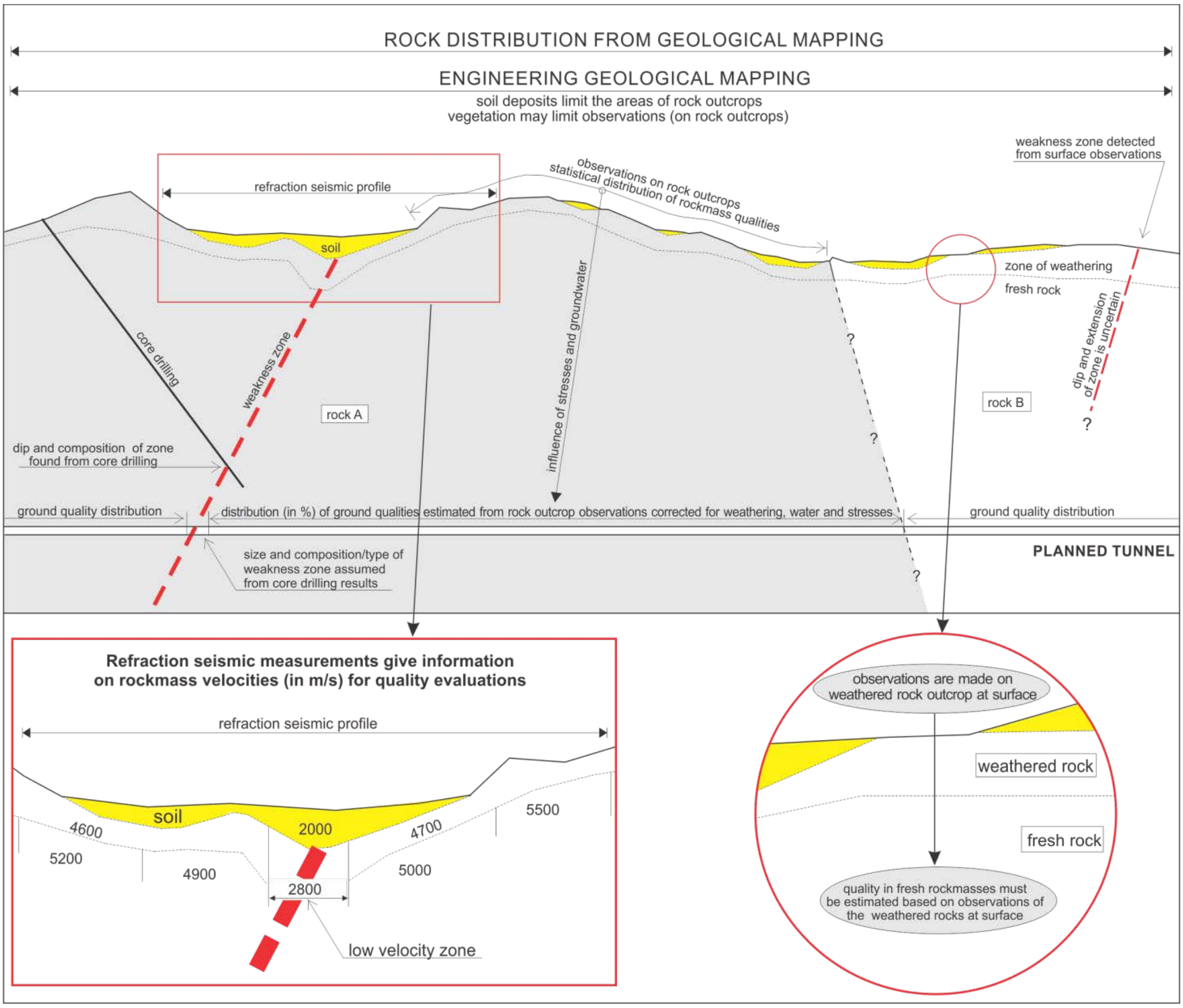


Figure 1: Principles of some types of surface field investigations (including engineering geological observations) related to an underground excavation

There are two main types of applications of the collected geological information:

I. For assessments of the ground conditions in the planned underground excavation (tunnel, cavern, shaft), mainly for evaluation of rock support and excavation works.
II. For making assessment of the stability and corresponding rock support in the excavation during and after the excavation works and for documentation of the ground conditions encountered.

This is further discussed in this paper.

3 INFORMATION ON GEOLOGY AND EARLIER TUNNELLING WORKS

3.1 Existing geological information

Before the investigations for a new project starts, existing geological data should be collected and studied. Conventional approaches to a geological desk study for the feasibility study and early phases of site evaluation typically use the local maps and literature, which commonly exist in many developed areas around the world. These data may include geological maps and papers or reports describing the actual area and the neighbouring areas. The national geological survey will usually have a database showing the existing geological data from different regions. In addition, there will often be some unpublished data. Geologists having worked in the area before may have additional information.

The geological setting of the actual site forms a main issue for the planning of the rock excavation. It is a result of the geological history and geomorphological development and is of special importance where challenging or difficult ground conditions occur.

Before field investigation starts, it is useful to prepare a geological sketch map based on existing geological data and from study of air photographs. On this sketch the distribution of different rock types and soils should be shown, in addition to the main geological structures, such as faults and fracture zones. During field mapping this sketch map will be helpful and time saving.

3.2 Geological mapping

A satisfactory rock engineering evaluation can only be carried out where the geology of the area is known. The preferable scale of an engineering geological map used for rock engineering purposes depends on the type of project and of course on the available topographic map. For designing caverns, geological maps in scale 1:1,000 are often convenient. For tunnels, smaller scales from 1:5,000 to 1:20,000 are often used. Usually geological maps in such scales do not exist beforehand, and it may be necessary to perform additional geological mapping to update existing geological maps to a relevant scale.

A geological map shows the distribution of rocks and soil, and the boundaries between the different rocks where they are reliable and where they are assumed. The orientation of the different rock layers should be measured and shown by means of strike and dip symbols. Important structures such as folds, faults and large fractures must be shown and the dip indicated. Based on the geological map, vertical section(s) along the excavation should show the distribution of rocks and the course of weakness zones[1] and other structures down to the tunnel level. Such sections will always be an extrapolation from surface observations.

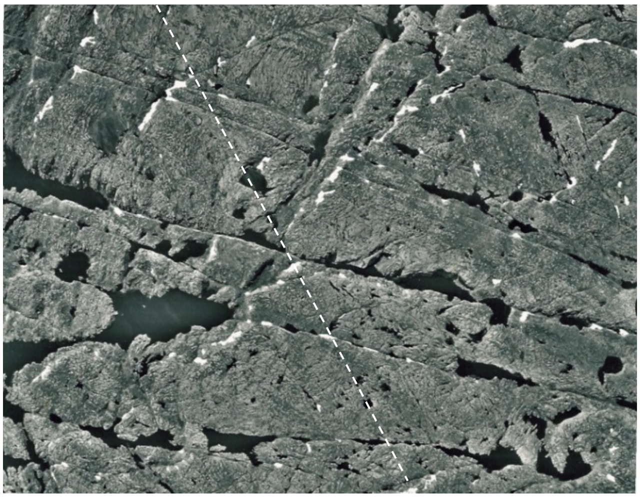
3.3 Information from earlier nearby excavations

Existing rock excavations in the neighbourhood of the planned tunnel, cavern or shaft may provide valuable information of the ground conditions and the excavation technique. Also excavations further off in similar geological conditions can give useful information in the planning stage.

[1] Weakness zone = A part or zone in the ground in which the mechanical properties are significantly lower than those of the surrounding rock mass. Weakness zones can be faults, shears / shear zones, thrust zones, weak mineral layers, etc.

3.4 Studies of aerial photos

An overview of the faults and weakness zones is a provision for adequate understanding of the site conditions. A study of relevant aerial photos may yield valuable information here, especially in areas with no or little soil cover. In areas with exposed rocks at the surface, aerial photographs can clearly show the pattern of faults/weakness zones as shown in Figure 2.



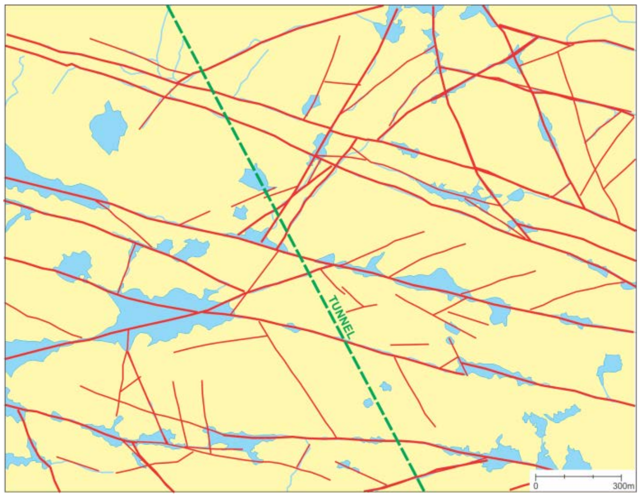


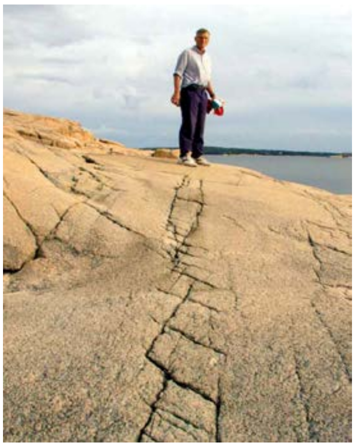
Figure 2: Example of an aerial photo where almost fresh rocks are exposed in the surface. The larger lineaments (mainly weakness zones) are easily seen. Also many smaller lineaments can be observed. In fact, very much tectonic information can be found.

4 GEO-OBSERVATIONS OF ROCK EXPOSURES

4.1 On rock outcrops

Geo-observations can be made at terrain surface, in underground excavations, or on drill cores. However, the occurrence of exposed rock in the surface varies a lot. There are areas where no outcrops can be found and there are others where rocks are exposed all over, see Photos 1 – 5 and Figure 3.

Photo 1: No information can be found where the rock surface is covered by loose deposits and/or vegetation. The forecast of rockmass underground conditions must be based on drillings, geophysical measurements (and on information from nearby underground excavations)



Photos 2 - 4: Three examples of very good exposures of rock in the terrain surface

Photo 5: The best terrain surface observations can generally be performed in excavated cuttings

The rock mass qualities vary usually within the location. Therefore, there may be necessary to divide an area into several sub-areas, so that the rock mass quality in each sub-area is within a limited range.

A verbal description of the conditions should preferably form part of the observations, especially the occurrence and composition/structure of weakness zones. This may be difficult from terrain surface observations without further field investigations, because such zones often form depressions in the surface which are filled with soil. Photographs of different rocks and geological structures will always be a good supplement to the verbal description.

As shown in Figure 3, the quality and accuracy of the description will depend on the exposures and the ability of the observer to correctly select appropriate parameter values. In areas with much soil and few exposures, the exposures will usually consist of the rockmass with best quality, whereas jointed rock and weakness zones will be covered. On natural surfaces the rock exposures will often be weathered and the ground conditions sometimes difficult to observe. The best rock exposures are usually found in road cuttings and quarries where less weathered rock occurs.

Possible features that may reduce the possibilities for good geo-observations are presented in Table 1.

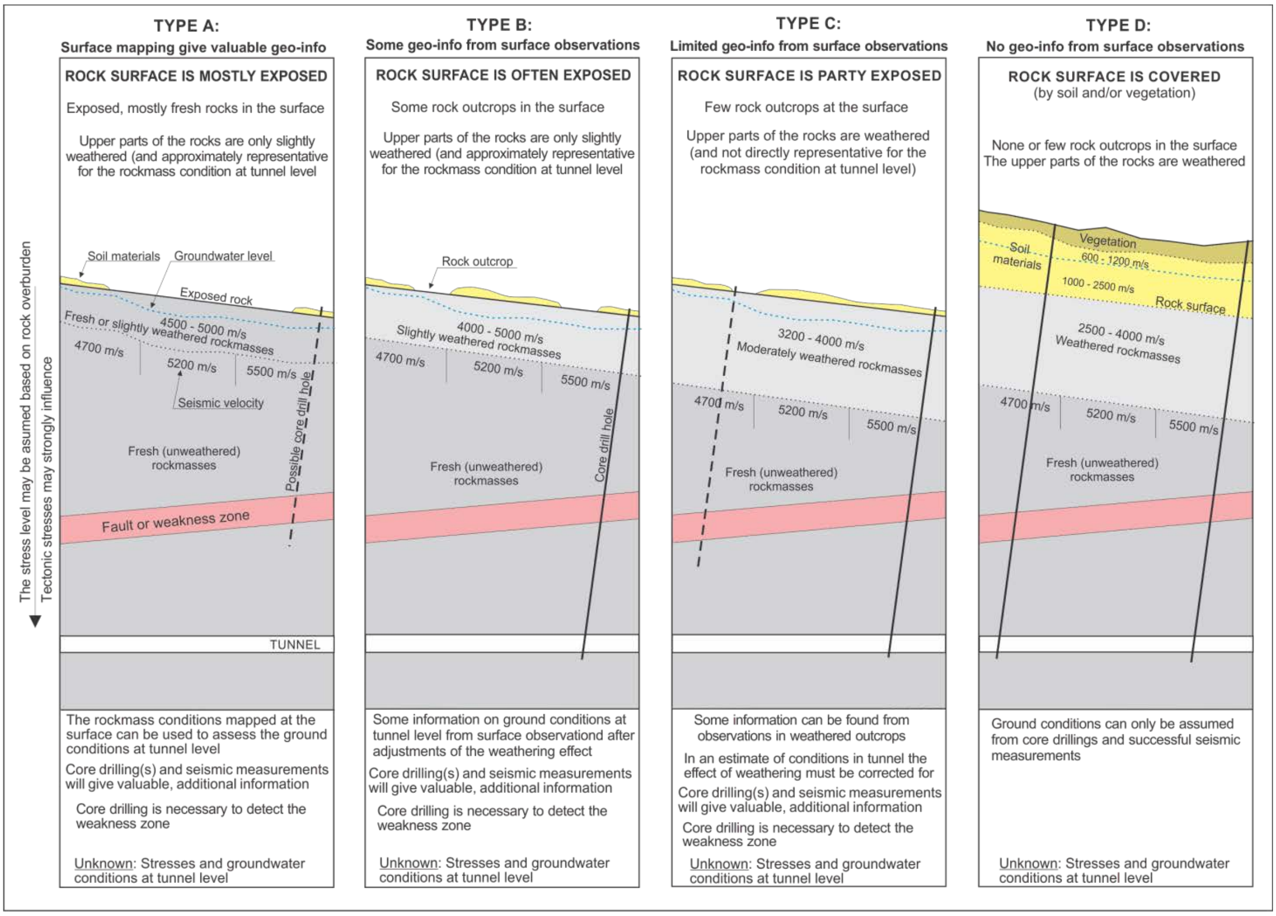


Figure 3: Four different classes of terrain surface conditions with respect to field investigations. Geo-observations provide a main source of information, especially for types A and B

Table 1: Possible features that may hamper geo-observations

Observations or measurements in:	Features that may reduce measurement or interpretation quality	Consequences for the observations
Rock outcrops	Loose material, vegetation, water, snow, or ice, which cover ("hide") the rock surface Weathered rocks occur in and near the surface (but not in the underground excavation).	No or limited area of exposed rocks for observations, hence no engineering geological observations The rock conditions observed are different from the conditions in deeper located rockmasses
Excavated cuttings, trenches, adits, etc.	Weathered rocks occur in the surface (but not deeper into the ground)	The rock conditions observed are different from the conditions in deeper located rockmasses
Core drill holes (core logging). Hammer holes	- Core loss (often caused by poor rockmass) - Drilling problems and/or poor work - Loose, broken rock	- No core → no information - The cores are partly destroyed during drilling - In loose and broken rock, hammer drilling may be difficult to perform
Underground rock excavations	The surface in the tunnel has been covered by mud, shotcrete or other remedial (before geological mapping is performed)	The mud cover hides the rock surface, which reduces possibilities for making good observations

During geo-observations and mapping at the *terrain surface* the following conditions should be considered:

I. The observations cover only the upper 5m to 10m of the rockmasses. The rock materials near the surface are often weathered and there will usually be more joints than at greater depths. Also other rockmass parameters are often different, such as joint roughness and joint separation.

II. Weathering generally penetrates significantly deeper along joints, weakness zones and faults.

III. Water and stresses are not present at the surface, i.e. the Q-values here are not relevant for the conditions in the underground excavation.

4.2 Important rockmass and ground parameters

The aim of engineering geological observations is to describe and quantify the rock mass conditions with relevance to stability, water leakage, drillability etc. To describe the condition and the quality of the rockmass, the occurrence of different rockmass parameters must be determined. In fact, geo-observations often constitute the main contribution in the collection of engineering geological data.

Table 2 presents the main rockmass and ground parameters influencing on the stability in a rock excavation. As shown, most of these parameters are used in the Q-, RMR-, RMi- and GSI-systems. In the Q-, RMR- and RMi-systems, each of the parameters has been classified and given values or ratings. The GSI system is a little different: a diagram is applied to find the GSI value, which may be used in the Hoek-Brown failure criterion and in numerical calculations.

Table 2: Main geological parameters contributing to ground quality and stability. The applications of these parameters in four classification systems are shown.

Ground parameters				Symbol	Use in classification systems:			
	Rockmass parameters				Q	RMR	RMi	GSI
GROUND	ROCKMASS	Rock	Uniaxial compr. strength [3]	σ_c, UCS		x	x	
			Schistosity / anisotropy					(x)
			Weathering [4]					
		Degree of jointing	Rock quality designation	RQD	x	x		x
			Block volume	Vb			x	
			Volumetric joint count	Jv	(x)	(x)	(x)	
			Joint spacing	Sa		x		
		Jointing pattern	Number of joint sets	Jn or Nj	x		x[1]	
			Block shape / blockiness	β				
			Orientation of joint /joint set	Co		x	x	
		Characteristics of main joints or main joint set	Joint roughness: smoothness	Jr: js	x	x	x	x
			Joint roughness: waviness	Jr: jw			x	
			Joint condition	Ja, jA	x	x	x	x
			Joint size (persistence), continuity	jL			x	
			Joint aperture or separation	e		x		
		Weakness zone	Size / thickness of zone	Tz			x	
			Orientation of the zone	Co_w			x	
			Zone type / structure [5]	SRF	x			(x)
		Rockmass	Rockmass structure / type					x
			Interlocking of rockmass	IL			x[2]	x
	Rock stresses		Stresses or Stress level	σ or SL / SRF	x		x[1]	
	Ground water		Water pressure or water Inflow	Jw	x	x	x[1]	
Special minerals and rocks responsible for swelling, durability, slaking, abrasiveness, etc.					(x)[6]			

[1] Used in the RMi support method
[2] Included in the extended RMi system
[3] Can be crudely calculated from simple field test or from rock name
[4] Weathering tends to reduce the strength, therefore, the effect is generally included in the σc
[5] Needs special description
[6] The Q-system includes input of swelling

Where exposed rock can be observed, most of the parameters in Table 2 can be observed and the values of input parameters determined, see Figure 1. Some of the parameters can also be found from observations on drill cores, see Table 15. The parameters for rocks and jointing characteristics can usually be well observed during field mapping, while the parameters for groundwater and stresses in the underground excavation can only be assumed if observations are made at terrain surface.[2]

[2] In addition to the geo-observations, laboratory and field test are required to find values for some of the parameters used in FEM and other calculations, as indicated in Table 15.

In connection with numerical modelling and other rock engineering calculations, there will also be necessary to determine parameters like JRC (joint roughness coefficient), JCS (joint compression strength) and ϕ_r (residual friction angle), rockmass strength and deformation modulus, as well as Hoek-Brown failure criterion parameters (m_i and s). Investigations to measure these are not dealt with in this paper.

The input parameters in Table 2 have been divided into defined classes in the classification systems. This is described in the following sections.

4.3 Rock parameters

4.3.1 Rock strength

Testing of the uniaxial compressive is time-consuming and is also restricted to those relatively hard, unbroken rocks that can be machined into regular specimens. Although this strength parameter is based on laboratory tests, it can be approximated estimated by simple methods. An experienced person can make a rough five-fold classification of rock strength with a hammer or pick, see Table 3.

Rock strength can also be estimated with a Schmidt hammer test with enough reliability to make an adequate strength characterization.

4.3.1.1 Strength assessment from rock name

Probably, the most generally used single describer of rock composition and structure is "rock type". In this term a wide variety of geological factors is embraced, ranging from basic rock origin (igneous, sedimentary and metamorphic) to special properties such as texture and structure, mineral size, composition, anisotropy, degree of weathering or alterations, etc. Results from compressive strength tests are given in many textbooks. Refer to Lama and Vutukuri (1978), Hoek and Brown (1980), etc. A good characterization of the rock material is a prerequisite when rock strength is evaluated from the rock name.

Table 3: Simple field identification of compressive strength of rock and clay (from ISRM, 1978)

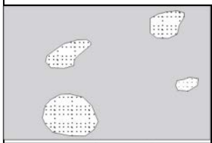
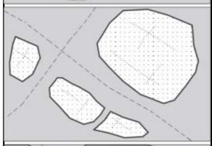
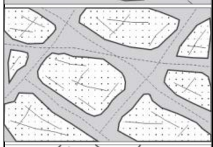
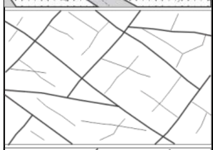
GRADE	TERM	FIELD IDENTIFICATION	Range of σ_c (MPa)
S1	Very soft clay	Easily penetrated several inches by fist.	< 0.025
S2	Soft clay	Easily penetrated several inches by thumb.	0.025 - 0.05
S3	Firm clay	Can be penetrated several inches by thumb with moderate effort.	0.05 - 0.10
S4	Stiff clay	Readily intended by thumb, but penetrated only with great effort.	0.10 - 0.25
S5	Very stiff clay	Readily intended by thumbnail.	0.25 - 0.50
S6	Hard clay	Intended with difficulty by thumbnail.	> 0.50
R0	Extremely weak rock	Intended by thumbnail.	0.25 - 1
R1	Very weak rock	Crumbles under firm blows with point of geological hammer; can be peeled by a pocket knife.	1 - 5
R2	Weak rock	Can be peeled by a pocket knife with difficulty, shallow identi-fications made by firm blow with point of geological hammer.	5 - 25
R3	Medium strong rock	Cannot be scraped or peeled with a pocket knife; specimen can be fractured with single firm blow of geological hammer.	25 - 50
R4	Strong rock	Specimen requires more than one blow of geological hammer to fracture it.	50 - 100
R5	Very strong rock	Specimen requires many blows of geological hammer to fracture it.	100 – 250
R6	Extremely strong rock	Specimen can only be chipped with geological hammer.	> 250

The clays in grade S1 - S6 can be silty clays and combinations of silts and clays with sands, generally slow draining.

4.3.1.2 Influence of weathering and alteration

The degree of weathering is usually estimated from visual observations where only the qualitative information is required. Table 4 shows classification of weathering/alteration similar to that presented by ISRM (1978). A more precise characterization of alteration and weathering can be found from analysis of thin sections in a microscope. When the rock is tested, the strength measured includes the reducing effect from weathering or alteration (as a lower strength).

Table 4: Engineering classification of the weathering of rocks, based on Geoguide 3 (1988)

Grade		Rock characteristics	Material
VI Residual soil		Original rock texture completely destroyed. Can be crumbled by hand into constituent grains.	Soil
	V Completely decomposed	Original rock texture preserved. Can be crumbled by hand into constituent grains. Easily indented by point of geological pick. Slakes when immersed in water. Completely discoloured compared with fresh rock.	Soil, probably with clay properties
	IV Highly decomposed	Can be broken by hand into smaller pieces. Makes a dull sound when stuck by geological pick. Does not slake when immersed in water Completely discoloured compared with fresh rock.	Mixed ground
	III Moderately decomposed	Cannot usually be broken by hand; easily broken by geological hammer. Makes a dull or slight ringing sound when stuck by geological hammer. Completely stained throughout.	
	II Slightly decomposed	Not broken easily by geological hammer. Makes a ringing sound when stuck by geological hammer. Fresh rock colours generally retained but stained near joint surfaces.	Rock mass
	I Fresh	Not broken easily by geological hammer. Makes a ringing sound when stuck by geological hammer. No visible signs of decomposition (i.e. no discolouration).	

Deterioration from weathering and alteration generally affects the walls of the discontinuities more than the interior of the rock (Piteau, 1970, 1973). In rock engineering and construction there is seldom of interest to describe how the process of weathering or alteration has been acting; the main topic is to characterize the result.

4.4 Jointing parameters

4.4.1 Joint sets

Nearly parallel joints make up a joint set. On a certain location there are usually 2 - 3 joint sets. For an underground excavation the number of joint sets to be used in a stability assessment (classification system) should be measured in an area equivalent to the unsupported /instable roof area of one to a few blast rounds (3 to 10m), see Figure 11. This means that for a 10m wide tunnel and with 5m blast round (of unsupported rock), the area is 30 to 100m^2.

The characteristics of the joints in the various sets can vary greatly depending on their mode of origin and the type of rocks in which they occur. Not only the size and average spacing of joints may vary, but also the other jointing parameters. This may cause that one joint set can have a stronger effect on the shear strength characteristics than another set.
Generally one joint set is dominant, being both larger and/or more frequent than joints of other sets in the same locality. This set is often referred to as the main joint set (or by geologists as primary joints). The properties of this set are used in the characterization.

4.4.2 Jointing pattern

The pattern of joints occurs as lines in a surface area where the number of joint sets, the relative differences in spacings, and the angles between them present the main characteristics. The jointing pattern in a rock volume can be expressed as the type and shape of the rock block delineated by the joint planes.

Where relatively regular jointing exists and an appropriate joint survey has been carried out, the pattern may be adequately characterized. In most cases, however, there is not a regular jointing pattern. The following simple equation has been found useful to approximately express the block shape (or pattern) factor:

$\beta \approx 20 + 7\,(L_{max} / L_{min})$ where L_{max} and L_{min} are the longest and shortest dimension of the block.

The block shape factor can be roughly determined after some training from observation in the field or in the underground opening. Normal variations for the various types of blocks are shown in Table 5. The type of block is mainly determined by the difference in dimensions between the block faces. More information can be found in Palmström (1995).[3]

Type of block	Block shape factor	(average)
Cubical (equidimensional) blocks	β = 27 - 32	(30)
Slightly long or flat blocks	β = 32 - 50	(36)
Moderately long or flat blocks	β = 50 - 100	(72)
Very long or flat blocks	β = 100 - 500	(270)
Extremely long or flat blocks	β > 500	(720)

Table 5: The block shape factor for various types of blocks

4.4.3 *Degree of jointing*

The degree of jointing can be defined as the number of joints per unit volume of the rockmass. Common parameters describing the degree of jointing are Rock Quality Designation (RQD), block size (Vb) and volumetric joint count (Jv).

The connections between various measurements of the degree of jointing are shown in Table 6 and in Figure 4. For information, diameters of soil particles are included.

Table 6: Classification of density of joints, volumetric joint count, and block volume, related to particle size of soil (from Palmström, 1995)

DEGREE OF JOINTING (or DENSITY OF JOINTS)	VOLUMETRIC JOINT COUNT TERM	Jv	BLOCK VOLUME TERM	Vb	SOIL PARTICLES *) TERM	VOLUME (V)
massive / no joints ------------	- extremely low	< 0.3	- extremely large	>1000 m^3		
massive / very weakly jointed	- very low	0.3 - 1	- very large	30 - 1000 m^3		
weakly jointed -------------------	- low	1 - 3	- large	1 - 30 m^3		
moderately jointed -------------	- moderately high	3 - 10	- moderate	0.03 - 1 m^3	- blocks	> 0.1 m^3
strongly jointed -----------------	- high	10 - 30	- small	1 - 30 dm^3	- boulder	5 - 100 dm^3
very strongly jointed -----------	- very high	30 - 100	- very small	0.03 - 1 dm^3	- cobbles	0.1 - 5 dm^3
crushed ---------------------------	- extremely high	> 100	- extremely small	< 30 cm^3	- coarse gravel	5 - 100 cm^3

*) $V = 0.58\,d^3$ has been applied for the correlation between particle volume and particle diameter

Several methods have been developed to measure the quantity or density of joints in the rock mass. The selection of the method(s) to be applied at an actual site will normally be a result of the availability to observe the joints in an exposure, the time and cost spent of the investigation, and the experience of the engineering geologist.

As the joint spacings generally vary greatly, there can be significant differences between densities of joints, i.e. the smaller and the larger blocks. Therefore, the characterisation should be given as an interval rather than as a single value.

[3] Block shape or blockiness has earlier been presented by Matula and Holzer (1978)

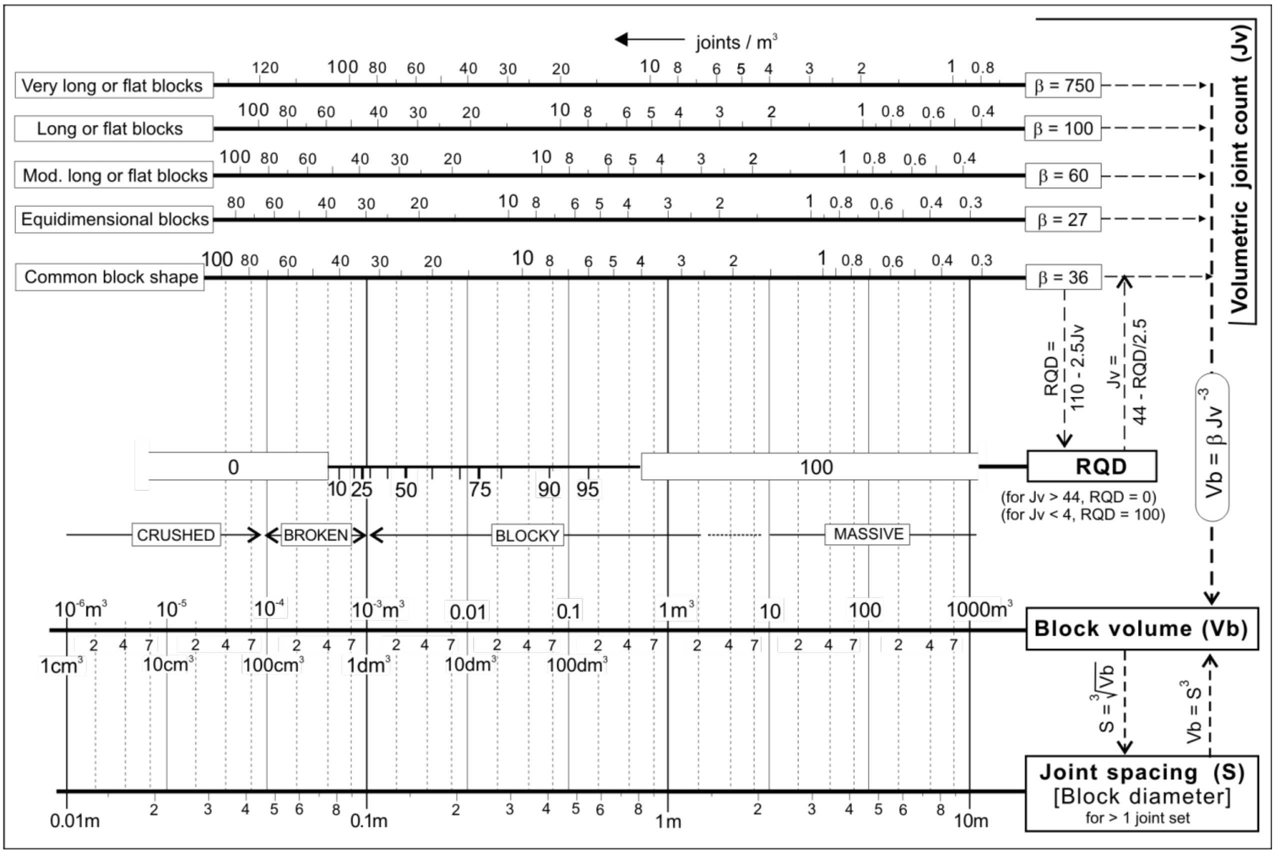


Figure 4: Correlations between various measurements of the degree of jointing (revised from Palmström and Stille, 2010)

4.4.3.1 *The rock quality designation (RQD)*

Rock quality designation probably is the method most commonly used for characterising the degree of jointing in borehole cores. RQD can be regarded as an indirect block size measure, as it is an expression of intact core lengths greater than a threshold value of 0.1m along a borehole or scanline. The classification of RQD is presented in Table 7.

RQD is rapid and easy to learn. Today, RQD is applied in the main classification systems as an input parameter for the jointing density. RQD is one-dimensional; and therefore it has the weakness of being strongly directional. Figure 5 shows that RQD only covers a small part of the range of the block sizes in a rock mass, which means that the RQD does neither express the variations for a high degree, nor a low degree of jointing.

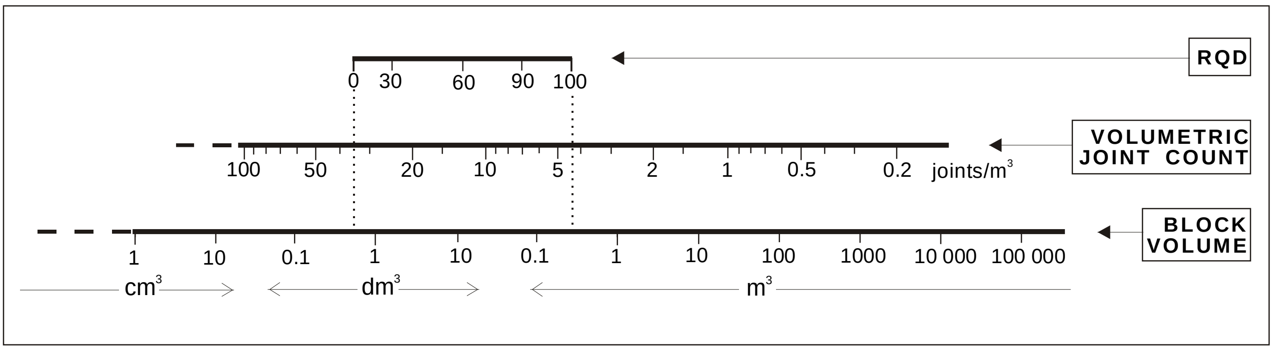


Figure 5: Range of jointing covered by RQD, block volume (Vb), and volumetric joint count (Jv).

TERM	RQD
Very poor	< 25
Poor	25-50
Fair	50-75
Good	75-90
Excellent	90-100

Table 7: Classification of the RQD (from Deere, 1964).

4.4.3.2 The volumetric joint count (Jv)

The volumetric joint count (Jv) is the number of joints intersecting a rock mass volume of $1m^3$. Where the jointing is formed mainly by joints sets, it can be found from the following measurements:

1. Measuring the spacing of each joint set:

   $Jv = \Sigma\, 1/S = 1/S1 + 1/S2 + 1/S3 + ...$

   where S1, S2, S3, etc. are joint spacings for the various joint sets given in metres

2. Where joint sets and additional random joints occur, a 'spacing' of 5m is applied for each random joint seen in 1 m^3 volume:

   $Jv = \Sigma\, (1/S) + Nr/5) = (1/S1 + 1/S2 + 1/S3 + . . .) + Nr/5$

   where Nr = the number of random joints

3. From frequency in drill cores:

   Jv = kl x Nl

   where Nl = the number of joints per metre along the core;
   kl = a correlation factor, which commonly is approximately kl = 2

4. From RQD measurements:

   Jv = 44 - RQD/2.5 (or the older equation Jv = 35 - RQD/3.3)

5. From *weighted joint density* observations

   – in boreholes: $Jv \approx wJd = \Sigma(n_i \times f_i) / L$ (L is measured length along the hole in metres)
   – on surfaces: $Jv \approx wJd = \Sigma(n_i \times f_i) / \sqrt{A}$ (A is size of observation area in m^2)

   Here, f_i is a factor given for the intersection angle between the joint and the plane or borehole with ratings as given in Table 8. n_j is the number of joints observed within each interval. For every joint the angle is estimated and the rating of f_i noted. The wJd is found as the sum of the ratings divided by the interval length or the measurement area.

Classification of the Jv is shown in Table 9.

Table 8: Ratings of the angle factor f_i (from Palmström, 1995)

Angle	Value of f_i	Example
$< 15^o$	6	From 5 m of bore hole cores are found:
$15 - 29^o$	3.5	n_j =9 joints intersect at > 60^o, n_j = 6 joints at 30 - 59^o, n_j = 4 joints at 15 -
$30 - 59^o$	1.5	29^o, and n_j = 2 joints for intersections < 15^o
$> 60^o$	1	This gives wJd = (9 x 1 + 6 x 1.5 + 4 x 3.5 + 2 x 6)/5 = 8.8

Classification	Value (joints/m^3)
Extremely low	Jv < 0.3
Very low	Jv = 0.3 - 1
Low	Jv = 1 - 3
Medium	Jv = 3 - 10
High	Jv = 10 - 30
Very high	Jv = 30 - 60
Extremely high	Jv > 60

Table 9: Classification of the Jv

4.4.3.3 Block size

Block size is formed mainly by the small and moderate joints. The block dimensions are determined by joint spacings and the number of joint sets. Individual or random joints and possible other planes of weakness may further influence on the size and shape of rock blocks.

The block volume (Vb) can be found from different methods applied in the underground opening, in outcrops on the surface, in blasted cuttings, or in drill cores. Direct measurement can be made where the rock masses can be observed. The block volumes will generally vary considerably at each site, and there is generally recommended to record also the variation in volumes in addition to the average volume.

Where less than three joint sets occur, there is often expected that defined blocks will not be found. However, in most cases random joints or other weakness planes will contribute to define blocks. Also, where the jointing is irregular, or many of the joints are discontinuous, the actual size and shape of individual blocks can be difficult to recognise. Sometimes the block size and shape therefore have to be determined from reasonable simplifications. This may also be necessary in order to collect the data within a reasonable amount of work.

The block volume can be found from the joint spacings. With regular jointing the block volume is found from the main 3 sets as

$Vb = S1 \times S2 \times S3$ (measured in m^3)

where S1, S2, S3, etc. are joint spacings for the various joint sets given in metres

Where only 2 joint sets + random joints occur, Vb can be found when random joints calculation purposes are given a fictive spacing of 5m, given as

$Vb = S1 \times S2 \times 5$ (measured in m^3)

Vb can also be found from the volumetric joint count and the block shape factor, β, from:

$Vb = \beta \times Jv^{-3}$ (measured in m^3)

For the frequent (common) value of $\beta = 36$ (see Section 4.2.2.2): $Vb = 36 \times Jv^{-3}$.

4.4.3.4 Joint spacing (Sa)

Joint spacing is the distance between two joints in the same joint set measured at a right angle to the joint planes. In a joint set there is usually some variation in the spacing. During the geo-mapping, the variation in joint spacing for each joint set should be determined. In addition the most common spacing should be noted. Usually this can be done visually. A classification of joint spacing is shown in Table 10.

However, when the recordings are made on drill cores, the spacing is often measured as the average length of core bits.[4] Such spacings or frequencies are not true recordings, as joints of different sets and random joints, which do not necessarily belong to any joint set, are included in the drill cores and hence in the measurement.

Classification	Spacing (S)
Extremely close spacing	< 20mm
Very close	20 - 60mm
Close	60 - 200mm
Moderate	0.2 - 0.6m
Wide	0.6 - 2m
Very wide	2 - 6m
Extremely wide	> 6m

Table.10: Classification of joint spacing (from ISRM, 1978)

[4] Joint or fracture intercept is the appropriate term for measurement of the distance between joints along a line or borehole.

4.5 Parameters for joint characteristics

A joint has two matching surfaces called joint walls. It is composed of several characteristics of which the main are, see Figure 6:

- Roughness, waviness (or planarity) of the joint wall.
- Condition of the joint wall, (alteration of wall rock).
- Presence of possible filling.
- Length and continuity of the joint.
- Joint separation, thickness or aperture.

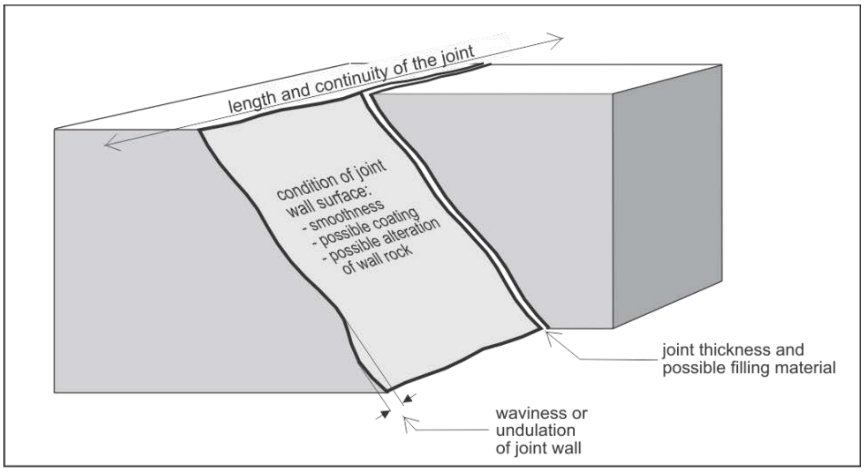


Figure 6: Sketch showing the main features of a joint (from Palmström, 1995).

4.5.1 *Joint roughness*

As shown in Figure 7, the roughness of joint walls is usually characterised in two scales:

1. A large metre-decimetre waviness scale, as undulating to planar
2. A small centimetre-millimetre smoothness scale, as rough to smooth.

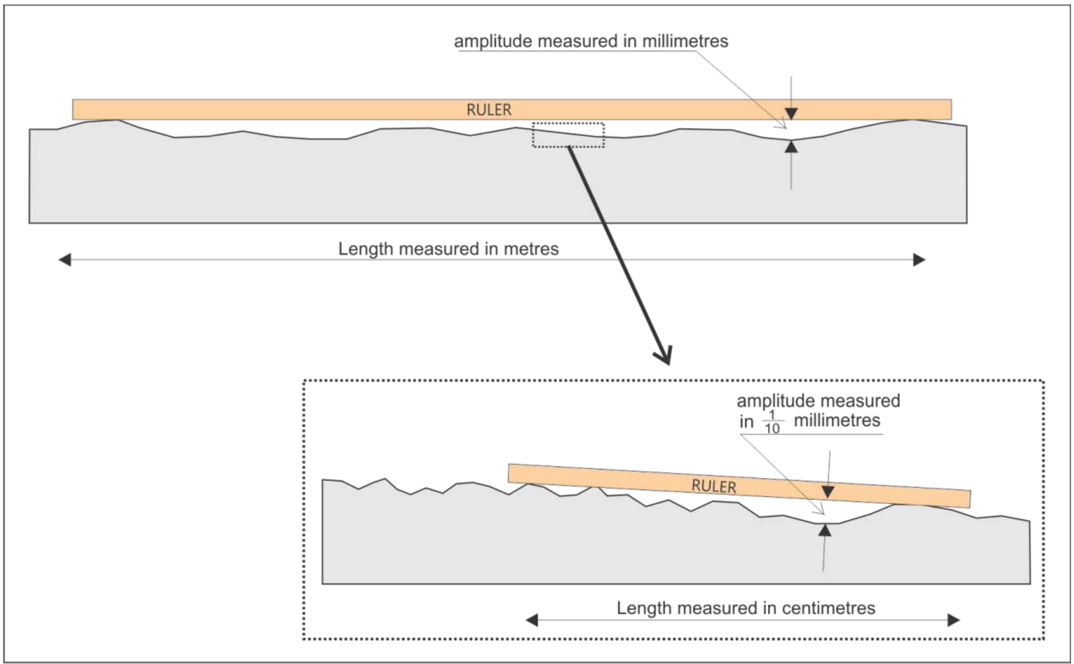


Figure 7: A section of a joint. The joint wall features can be characterised by the large scale waviness and the small scale smoothness (or unevenness). (From Palmström, 1995)

Ideally, the joint waviness should be measured as the ratio between max. amplitude and joint length. As there is seldom possible to observe the whole joint plane, a simplified measurement is often carried out: the so-called waviness factor, representing the ratio between amplitude (A) and a reduced, measured length (L) along the joint plane given as:

$u = A/L$

The longest possible ruler should be applied in measurement of waviness in Figure 7. The classification of waviness is shown in Table 11. The waviness factor is mostly assessed from simple observation of the joint.

Small asperities are designated smoothness or unevenness. Smoothness asperities usually have a base length of some centimetres and amplitude measured in tens of millimetres and are readily apparent on a core-sized exposure of a discontinuity.

Classification used by Milne et al. (1992)		**Classification used in the RMi based on RMR**
Classification	Undulation	
		Discontinuous
		Strongly undulating
Wavy joints	u > 2%	Moderately undulating
Planar to wavy joints	u = 1 - 2%	
		Slightly undulating
Planar joints	u < 1%	Planar

Table 11: Classification of joint plane undulation (jw) based on measurements related to 1 m profile length) (from Milne et al. (1992)

The 'sample length' for smoothness is in the range of a few centimetres. There is a general problem to arrive at a quick, numerical estimate of joint smoothness from measurements or visual observations of the joint wall surface. A possible solution is to simply touch the surface with the finger and compare it with a reference surface of known roughness, for example sand papers of various abrasivenesses (mesh) as indicated in Table 12.

Table 12: Classification and rating of joint smoothness The terms are based on Jr in the Q-system; the description partly on the RMR system (from Palmström, 1995)

TERM	DESCRIPTION
Very rough	Near vertical steps and ridges occur with interlocking effect on the joint surface.
Rough	Some ridges and steps are evident; asperities are clearly visible; joint surface feels very abrasive (rougher than sandpaper grade 30)
Slightly rough	Asperities on the joint surfaces are distinguishable and can be felt (like sandpaper grade 30 - 300).
Smooth	Surface appears smooth and feels smooth to touch (smoother than sandpaper grade 300).
Polished	Visual evidence of polishing exists, as often seen in chlorite and specially talc coatings.
Slickensided	Polished and striated surface that results from shearing along a fault surface or other discontinuity.

4.5.2 Joint condition and infill

Joint infill must be described with reference to thickness and mineral type. Near the surface the infill of soft mineral such as clay may have been washed out. In other cases the joints near the surface may be more weathered than at greater depth. Sometimes there may be difficult to identify the filling minerals visually. Sampling and laboratory tests are then necessary.

The condition of the joint surface (joint wall) can be fresh, weathered, coated, stained, etc. Possible weathering or alteration may strongly affect the condition of the joint and may completely change its behaviour. The main types of joint fillings and their properties are shown in Table 13.

Filling includes materials derived from breakage of the country rock due to movements (as in crushed zones and breccias), in situ weathered materials (i.e. alteration products), infilling materials deposited between the structural planes (such as calcite), and also intruded igneous materials being different from the host rock. A filling can, therefore, consist of several different minerals and materials. The main groups are:

- Hard and resistant minerals (quartz, epidote and serpentine).
- Soft minerals (clay, chlorite, talc and graphite).
- Soluble minerals (calcite, gypsum).
- Swelling minerals (swelling clays (smectites), anhydrite).
- Loose materials (silt, sand and gravel).

Joints, seams and sometimes even minor faults may be healed through precipitation from hydrothermal solutions of quartz, epidote or calcite. This may be the case for layered, igneous and metamorphic rocks in which the layers are strongly welded together.

Large discontinuities, such as shears and seams should be described separately, see Figure 8.

Table 13: Joint condition with description of the filling material (from Palmström and Nilsen, 2000, based partly on Brekke and Howard, 1972).

TYPE OF JOINT	CHARACTERISTICS	TYPE AND PROPERTIES OF MATERIAL
Clean joints Joints without fillings or coatings	Healed or welded joints. The joint plane may be regarded often as a plane of reduced strength.	Discontinuities may be healed through precipitation from solutions of quartz, epidote or calcite. Note: Quartz and calcite may well be present in a joint without healing it.
	Fresh rock walls.	These are joint walls of unweathered or unaltered rock. They may, however, show staining (rust) on the surfaces.
	Altered or weathered rock walls. The degree of weathering is usually estimated from visual observations (see Table 4).	Alteration of the rock material along the joint surface. When weathering or alteration has taken place, it is often more pronounced along the joint surface than in the rock. The wall strength is considerably lower than that of the fresher rock found in the interior of the rock blocks.
Coated joints The joint surfaces have a thin layer or 'paint' with some kind of mineral.	Coating will affect the shear strength of joints especially if they are planar, and have wet coating of chlorite, talc or graphite.	Joint coating, which is not thicker than a few millimetres, can consist of various kinds of minerals, such as chlorite, calcite, epidote, clay, graphite, zeolite.
Filled joints Filling or gouge is thicker than coating	Chlorite, talc, graphite filling.	Very low friction materials, in particular when wet.
	Inactive clay materials filling.	Weak, cohesive materials with low friction.
	Swelling clay filling.	Exhibits very low friction and swelling with loss of strength. Exerts considerable swelling pressure when confined.
	Calcite filling.	May, particularly when being porous or flaky, dissolve during the lifetime of the project, and strongly reduce the shear strength of the joint.
	Gypsum filling.	May behave in the same way as calcite.
	Filling of sandy or silty materials.	Cohesionless, friction materials. A special occurrence is the thick fillings of altered or crushed (sand-like) materials which may run or flow immediately after exposure by excavation.
	Filling of epidote, quartz and other hard materials.	May cause healing or welding of the joint, resulting in increased shear strength.

4.5.3 Joint size (length)

Discontinuous joints terminate in massive rock. Such joints can be foliation partings, and many of the smaller joints (less than 1 metre long), see Photo 2. Continuous joints terminate at other joints.

Persistence implies the size, length or area extent within a joint plane. Joints rarely exceed some hundreds of metres, see Figure 8. The size of a joint may vary within the same joint set. This is specially the case for foliation joints where small joints or partings often occur between longer, continuous joints.

Joint length can be crudely quantified by observing the joint trace lengths on the surface exposures. Often, rock exposures are small compared to the area or length of persistent joints, and in such cases the real persistence can only be guessed. The classification of joint size is presented in Table 14.

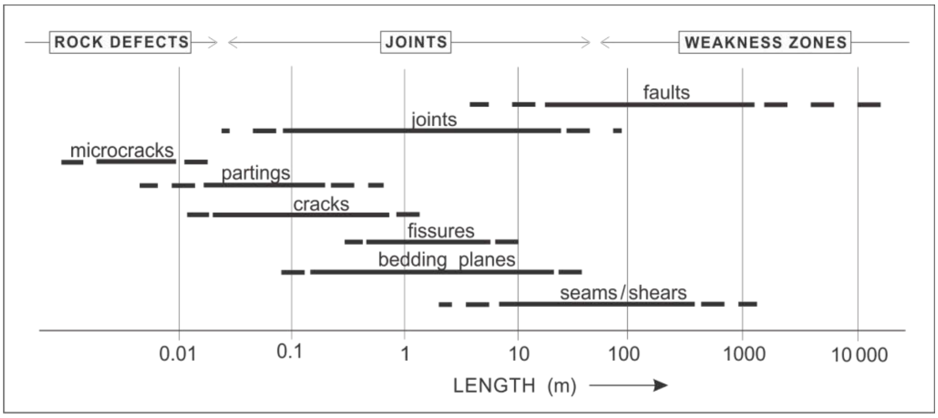


Figure 8: The lengths of various types of discontinuities (after Palmström, 1995)

Persistence	Joint length	Classification
Very low	< 1 m	Very short joint (crack)
Low	1 - 3 m	Short joint
Medium	3 - 10 m	Common or medium joint
High	10 - 20 m	Long joint
Very high	> 20 m	Very long joint

Table 14: Classification of joint persistence (from Bieniawski, 1984) and joint size (length)

4.5.4 Joint separation

Separation is the distance between the joint walls. It varies generally along the joint. Most clean joints (without filling) have very small separation, being tight or very tight. Such joints can be open near the terrain surface where the stresses are low. Thus, separation is generally connected to filled joints. Joints with filling > 25mm can be characterized as a singularity or a major discontinuity (Bieniawski, 1984).

4.6 Parameters for weakness zones and faults

A weakness zone is a zone in which the rock quality is poorer than in the surrounding rock masses. Faults and beds of weak rock may form weakness zones. The weakness zone must be marked on the map by special symbol and orientation; width (size) and characteristic features must be described. The weak zone often forms depression in the surface, and since depressions often are filled with soil, the rock masses in the zone may be difficult to observe at the terrain surface.

The apparent width of the zones depends on erosion, for example by ice movement during the glaciation period. The strike of the zones is usually easy to measure, but estimating the dip angle may be more difficult. A profile across a zone will often be asymmetric, and usually the steepest side represents the dip direction of the zone. In many cases the orientation of single joints within the zone can be measured, but this orientation is not necessarily parallel to the zone itself.

Three main types of zones may be identified:

1. Fracture zones are zones in which the joint spacing is significantly less than in the surrounding rock masses. Often they consist of only one set of parallel joints.
2. Crushed zones are usually faults where the rock has been crushed to small pieces. There are usually two or more joint sets. The crushed zones may be more or less healed by mineralization of e.g. quartz or calcite and may then be classified as breccias.
3. Clay zones along which a chemical alteration may have taken place and the ordinary rock may be more or less altered to clay minerals. There may be different types of clay minerals, and there is important to know if swelling clay (smectite) occurs. Sampling and laboratory testing are therefore often necessary.

Faults are joints where displacements have occurred. Large faults will often occur as crushed zones or clay zones. Old faults may be healed in such a way that they do not represent a weakness zone at all. To make an evaluation of the geological condition, there is important to know the geological history and the displacements that have taken place along the fault. This may be difficult if there are not significant layers to relate the displacement.

Where the zone weakness or fault features can be observed, a good description of the composition and structure should be made, in addition to its size given as thickness. In the terrain surface only a crude assumption can be made based on topography of the outcropping zone.

The Q-system applies the types of zones shown in Table 15. Location refers to the level of the excavation below surface.

Type of zone	Depth of actual location
Multiple, complex weakness zones	- any depth
Single weakness zone with clay	- depth < 50m
	- depth > 50m
Multiple clay-free shear zones	- any depth
Single shear zones	- depth < 50m
	- depth > 50m
Loose, open crushed zones	- any depth
Heavily jointed ("sugar cube") zones	- any depth

Table 15: The different types of weakness zones classified in the Q-system

The width or thickness of the weakness zone is an important feature regarding stability in the excavation. Only the RMi system has input for this parameter. Combined with orientation (related to the tunnel) Figure 9 shows the significant difference for zones across the tunnel (strike/dip = $90^o/90^o$) and zones with an acute strike angle and a gentle dip.

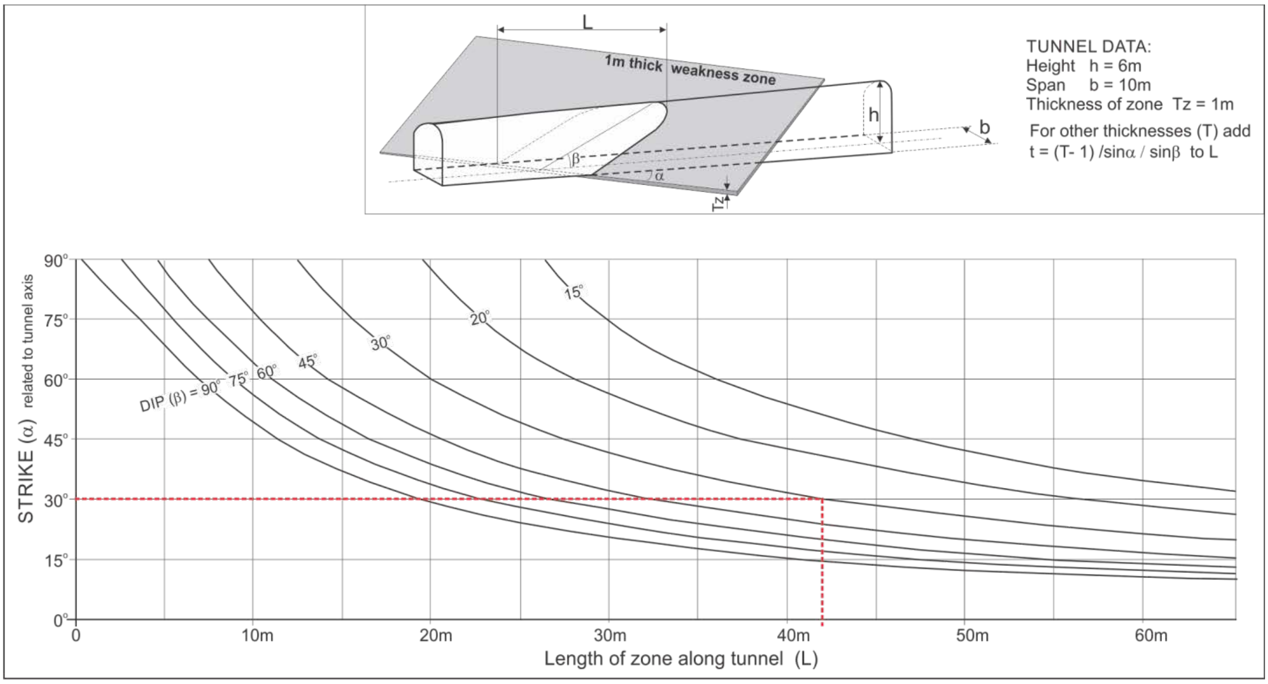


Figure 9: The orientation of a weakness zone highly influences on its appearance in the tunnel. While a 1m thick zone in a 10m span and 6m high tunnel will occur along 1m when the zone has strike/dip = $90^o/90^o$, the zone will appear along 43m when the strike/dip = $30^o/30^o$ as shown with the red, dotted line.

4.7 Parameter for water condition

Except for a few porous rocks (such as some sandstones), the water leakage into tunnels usually occurs along joints and weakness zones. But to predict which zones or joints will conduct water is generally difficult. Many large weakness zones are rather tight because they contain clay mineral filling. However, along the boundaries of a large zone the jointed rocks may be without clay and water inflow may occur.

Water leakage into an underground excavation may lead to problems for the construction as well as for the usage and for the surface environment. An evaluation of the permeability of rockmass is often difficult to make from field observations. Study of the jointing and/or water loss (Lugeon) tests in boreholes may give some indications.

4.8 Parameter for the stress condition

The rock stresses will usually be a function of the depth, but tectonic and residual stresses may disturb this picture. From field observations only, there is difficult to make any exact evaluation of the stress condition. In steep mountain slopes, jointing parallel to the surface (sheeting) and circle-formed marks in the rock surface may be an indication of high stresses, see Photo 6. The Q-system includes a division of different types and ground behaviour influenced by stresses.

Photo 6: Development of sheeting in a massive granitic rock. The power tunnel located 100m from the valley slope suffered from heavy rock bursting

5 A GEO-REGISTRATION FORM FOR IMPROVED FIELD AND TUNNEL MAPPING

A geo-registration form or scheme can be a useful aid in the engineering geological mapping. Such form should be simple and at the same time contain all relevant information needed for the observation results to be used in rock engineering.

Table 1 includes most of the rockmass parameters with influence on rockmass strength and on stability in rock excavations and which should be used in a geo-registration form. Table 16 indicates useful investigations to characterize and/or measure these parameters.

Based on Table 16 the Geo-registration form in Figure 10 has been developed. Each input parameter is divided into classes commonly used in the RMR-, Q- and RMi-classification systems. These are given as ratings (a, b, c etc.), each representing classes in three classification systems, as shown in Table A1. Note that the block shape/blockiness and the rockmass interlocking parameters have not been selected in the form, as they are not directly included in these classification systems.

Where there are many small, rather similar exposures, some of them may be described together on one sheet. For opposite cases, large exposures with considerable variation in rockmass compositions may be divided into several sub-areas of appropriate size using one sheet for each sub-area.

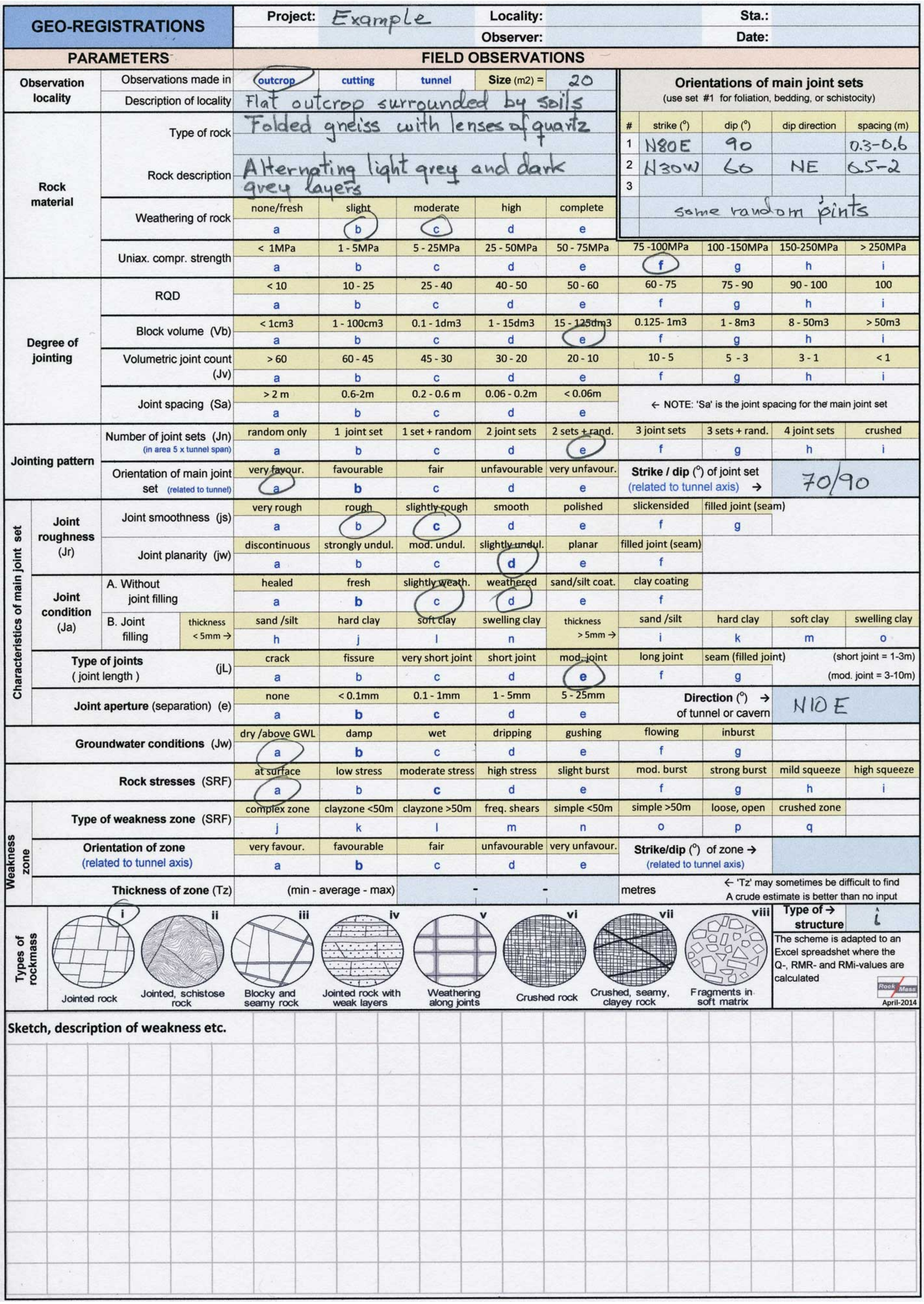
The form for Geo-registrations can be used for registrations at the terrain surface, as well as in the rock excavation. It contains space for information on the observation location in the upper left part. The parameters used in the form are those which commonly have the greatest influence on ground quality and stability conditions in an underground rock excavation (see Table 16). The variations (classes) of each parameter are listed along the rows of yellow cells. This helps to make quick registrations and at the same time prevents the user from forgetting to observe all parameters.

Table 16: The possibilities to observe the parameters in Table 1

Geological Parameter				Symbol	Can be studied or measured from: Observations: in under-ground excavation (at face or later)	Observations: at surface (in outcrop and/or rock cutting)	Core drilling (by core logging)	Refraction seismics (as seismic velocities)	Tests: in lab.	Tests: in field
GROUND	ROCKMASS	Rock(s)	Uniaxial compr. strength	σ_c , UCS	1)	1)	1)		x	
			Weathering 3)		x	x	x		x	
		Degree of jointing	Rock quality designation	RQD	x	x	x			
			Block volume	Vb	x	x	occasionally	4)		
			Volumetric joint count	Jv	x	x	x*			
			Joint spacing	Sa	x	x	uncertain			
		Jointing pattern	Number of joint sets	Jn, Nj	x	x				
			Block shape / blockiness	β	x	x				
			Orientation of joint sets	Co	x	x				
		Character-istics of main joint set	Roughness: smoothness	Jr: js	x	x*	x		(x)	
			Roughness: waviness	Jr: jw	x	x				
			Condition /Alteration	Ja, jA	x	x*	x		(x)	
			Size (persistence)	jL	often	often				
			Aperture / Separation	e	x	2)	x*			
		Weakness zone	Size / thickness of zone	Tz	x	x*	often	x		
			Orientation of zone	Coz	x	x	x*			
			Type / structure	SRF	x	seldom	x*	4)		
		Rockmass features	Interlocking of rockmass	IL	x	(x)				(x)
			Rockmass structure		x	x				
	Water		Water pressure or inflow	Jw, GW	x		x*			x
	Stresses		Stress or stress level	σ or SL / SRF		4)	3)			x
Special minerals and rocks		Special materials		Clay, chlorite, anhydrite, smectite, calcite, some zeolites					x	
		Special properties		Swelling/expending, deformation slaking, solubility, durability, hardness, abrasion, toughness, etc.					x	

(x) Possible, seldom performed
x* Partly/sometimes

1) May roughly be found from simple field test or handbook tables
2) The aperture observed in the surface is generally not representative
3) Borehole is used for stress measurement
4) May be crudely assessed



GEO-REGISTRATIONS | Project: Example | Locality: | Sta.: | Observer: | Date:

PARAMETERS		FIELD OBSERVATIONS									
Observation locality	Observations made in	outcrop	cutting	tunnel	Size (m2) = 20						
	Description of locality	Flat outcrop surrounded by soils									
Rock material	Type of rock	Folded gneiss with lenses of quartz									
	Rock description	Alternating light grey and dark grey layers									
	Weathering of rock	none/fresh a	slight b	moderate c	high d	complete e					
	Uniax. compr. strength	< 1MPa a	1 - 5MPa b	5 - 25MPa c	25 - 50MPa d	50 - 75MPa e	75 -100MPa f	100 -150MPa g	150-250MPa h	> 250MPa i	
Degree of jointing	RQD	< 10 a	10 - 25 b	25 - 40 c	40 - 50 d	50 - 60 e	60 - 75 f	75 - 90 g	90 - 100 h	100 i	
	Block volume (Vb)	< 1cm3 a	1 - 100cm3 b	0.1 - 1dm3 c	1 - 15dm3 d	15 - 125dm3 e	0.125- 1m3 f	1 - 8m3 g	8 - 50m3 h	> 50m3 i	
	Volumetric joint count (Jv)	> 60 a	60 - 45 b	45 - 30 c	30 - 20 d	20 - 10 e	10 - 5 f	5 - 3 g	3 - 1 h	< 1 i	
	Joint spacing (Sa)	> 2 m a	0.6-2m b	0.2 - 0.6 m c	0.06 - 0.2m d	< 0.06m e	← NOTE: 'Sa' is the joint spacing for the main joint set				
Jointing pattern	Number of joint sets (Jn) (in area 5 x tunnel span)	random only a	1 joint set b	1 set + random c	2 joint sets d	2 sets + rand. e	3 joint sets f	3 sets + rand. g	4 joint sets h	crushed i	
	Orientation of main joint set (related to tunnel)	very favour. a	favourable b	fair c	unfavourable d	very unfavour. e	Strike / dip (°) of joint set (related to tunnel axis) →	70/90			
Characteristics of main joint set: Joint roughness (Jr)	Joint smoothness (js)	very rough a	rough b	slightly rough c	smooth d	polished e	slickensided f	filled joint (seam) g			
	Joint planarity (jw)	discontinuous a	strongly undul. b	mod. undul. c	slightly undul. d	planar e	filled joint (seam) f				
Joint condition (Ja)	A. Without joint filling	healed a	fresh b	slightly weath. c	weathered d	sand/silt coat. e	clay coating f				
	B. Joint filling, thickness < 5mm →	sand /silt h	hard clay j	soft clay l	swelling clay n	thickness > 5mm →	sand /silt i	hard clay k	soft clay m	swelling clay o	
Type of joints (joint length) (jL)		crack a	fissure b	very short joint c	short joint d	mod. joint e	long joint f	seam (filled joint) g	(short joint = 1-3m) (mod. joint = 3-10m)		
Joint aperture (separation) (e)		none a	< 0.1mm b	0.1 - 1mm c	1 - 5mm d	5 - 25mm e	Direction (°) → of tunnel or cavern	N10E			
Groundwater conditions (Jw)		dry /above GWL a	damp b	wet c	dripping d	gushing e	flowing f	inburst g			
Rock stresses (SRF)		at surface a	low stress b	moderate stress c	high stress d	slight burst e	mod. burst f	strong burst g	mild squeeze h	high squeeze i	
Weakness zone	Type of weakness zone (SRF)	complex zone j	clayzone <50m k	clayzone >50m l	freq. shears m	simple <50m n	simple >50m o	loose, open p	crushed zone q		
	Orientation of zone (related to tunnel axis)	very favour. a	favourable b	fair c	unfavourable d	very unfavour. e	Strike/dip (°) of zone → (related to tunnel axis)				
	Thickness of zone (Tz)	(min - average - max)	-	-	metres	← 'Tz' may sometimes be difficult to find. A crude estimate is better than no input					

Orientations of main joint sets (use set #1 for foliation, bedding, or schistocity)

#	strike (°)	dip (°)	dip direction	spacing (m)
1	N80E	90		0.3-0.6
2	N30W	60	NE	0.5-2
3				

some random joints

Types of rockmass: i Jointed rock; ii Jointed, schistose rock; iii Blocky and seamy rock; iv Jointed rock with weak layers; v Weathering along joints; vi Crushed rock; vii Crushed, seamy, clayey rock; viii Fragments in soft matrix. Type of → structure: i

The scheme is adapted to an Excel spreadsheet where the Q-, RMR- and RMi-values are calculated. Rock Mass April-2014

Sketch, description of weakness etc.

Figure 10: The Geo-registration form with example of observations made in a rock outcrop. The observed, appropriate ratings of the parameters can in field e.g. be marked with a circle as shown. Variation of a property can be shown with two circles as is shown for joint smoothness. Blue cells are for description or value input. Yellow cells are classification of the selected parameters.

Usually one sheet of the Geo-registration form is used for each location. The size of the exposure used in the observation should be noted, i.e. how many square metres it constitutes. Ideally, it should, as mentioned earlier, be similar to the area to be supported in the tunnel or cavern. Often this size can, as shown in Figure 11, be approximately found from

$A \approx \text{span} \times \text{blast round}$ (in m^2).

For a 10m wide tunnel with 4m long blast rounds, $A = 40m^2$

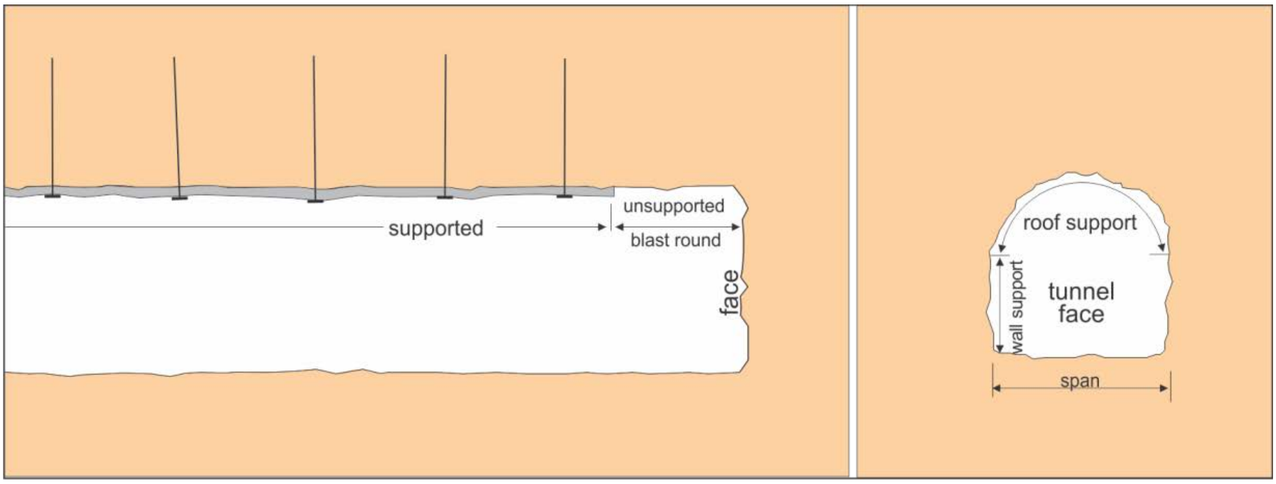


Figure 11: Geo-observation aims at describing the conditions in the area to be supported, such as the unsupported section shown.

In Figure 10 the registrations have been made at the terrain surface in an outcrop of $20m^2$ size with slight to moderate weathering. As shown, the relevant feature(s) observed for each of the input parameters is marked. For some of the parameters there may be a variation in the occurrence. Then more than one feature is marked, e.g. as is shown for 'Joint smoothness'. Additional information, such as a sketch or a description, can be entered.at the bottom of the form. Verbal descriptions of special rockmass features, such as weakness zone and special rocks, will give valuable, additional information to the parameter ratings given.

Eight types of rockmass structures are shown at the left bottom of the form. Input for this is meant as additional information and is not used as input to the calculation.

The geo-registrations form in Figure 10 presents a systematic and rational method for documentation of surface observations and evaluations made when conditions at tunnel level are assumed. It should be pointed out that this geo-observation method does not reduce geological uncertainties, but gives the reader an easier and better understanding of the evaluations made in the forecast of the probable ground conditions along the tunnel.

The Geo-registrations form can be downloaded from www.rockmass.net

6 GROUND CONDITIONS FOUND FROM THE GEO-REGISTRATIONS

6.1 A spreadsheet for documentation and calculations of the ground conditions

A computer spreadsheet attached to the Geo-registrations form has been developed for documentation of the geo-observations and for calculating the ground quality values in three classification systems[5], see Figures 12 and 15.

Figure 12 shows how the documentation of the field data is presented and used in the computer spreadsheet. The field registrations made are shown in the left part of the sheet as grey cells. In the column on the right side, input ratings or values assumed relevant for the conditions in the (planned) tunnel, shaft or cavern are inserted. Where variations (min – max) in a parameter have been found, an evaluation must be made to assess which of them probably occur together in the actual location. If all minimum input ratings are used to calculate the lowest Q-, RMR-, or RMi-value, - and the most favourable ratings are used for the highest value, - unrealistic values may be found. This is because extreme values of all parameters seldom occur together in the same location.

Not all parameters need to be inserted in the spreadsheet for calculations to be made. The spreadsheet automatically applies a common value for a parameter[6] if no input rating or value has been inserted. This may e.g. be the case where a parameter was impossible to be observed or measured. This task is further explained in the computer spreadsheet.

The field observations are given on the left part of the form, while the (assessed or extrapolated) conditions in the excavation are given on the right part.

6.2 Forecast of the conditions in the underground excavation from surface observations

The Geo-registration form in Figure 10 covers observations at the terrain surface or in the rock excavation. Where the observations are made in the excavation where support is to be designed, the geo-registrations (ratings or values) can be used directly as input to rock engineering, calculations and design, see Figure 12.

But for observations made at the terrain surface, the conditions are different from those underground. Except for some long test adits or existing nearby excavations, there is seldom possible during planning of an underground excavation to observe the 'real' ground conditions in the excavation. These have to be predicted or extrapolated using some sort of prescribed assessments, estimates or guess-works. However, such predictions are seldom explained or documented well today in the reports. Generally, the conditions assessed in an underground excavation seem to be found by some sort of diffuse forecast diluted with some personal judgement. To a reviewer or reader such practice is difficult or impossible to follow, and hence a control or verification may be inappropriate.

A core drilling can penetrate into the fresh rocks below the zone of weathering at the surface and thus provide representative information of the conditions here (see Figures 1 and 13). The distribution of the rockmasses along the fresh part of the borehole shows valuable indications on the general ground conditions underground (see Figures 1, 3, 13 and 14), especially if more boreholes are performed. Also refraction seismic velocities below the zone of weathering may yield some added information on the distribution of rockmass qualities.

[5] Three systems have been chosen for comparison. Experience has shown that for some rockmass conditions the classification systems come up with quite different qualities. Bieniawski (1984) suggests that at least two classification systems be use used in the rock engineering and design.

[6] Except for the degree of jointing.

GEO-CONDITIONS	Project: *Example*	Locality:	Sta.:	Date:	Observer:

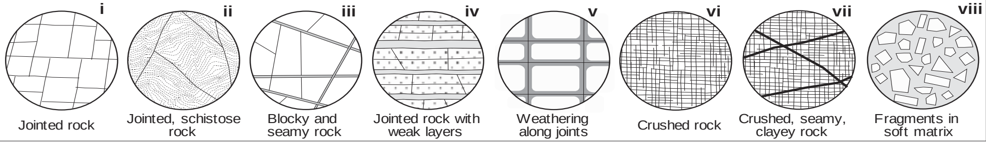
FIELD OBSERVATIONS — **INPUT** 1) to calculations of ground quality (Green cells are for input) — **Some information**

Parameter											Input	Some information
Observation locality	Observations made in:	outcrop	cutting	tunnel	Size (m2) =	20m2						
	Description of locality	At face in the tunnel										
Rock material	Type of rock	Folded gneiss with lenses of quartz										
	Rock description	Alternating light grey and meduim grey layers or lenses									Rock type 2)	gneiss with quartz lenses
	Weathering of rock	none/fresh	slight	moderate	high	complete					Weathering of rock 2)	a
		a	b	c	d	e						
	Uniaxial compr. strength (UCS)	< 1MPa	1 - 5 MPa	5 - 25MPa	25 - 50MPa	50 - 75MPa	75 -100MPa	100 -150MPa	150-250MPa	> 250MPa	UCS = f	Value used = 88MPa
		a	b	c	d	e	f	g	h	i		
Degree of jointing (fill in for RQD and/or Vb and/or Jv) (see note for Sa →)	RQD (Rock Quality Designation)	< 10	10 - 25	25 - 40	40 - 50	50 - 60	60 - 75	75 - 90	90 - 100	100	RQD =	Value used = 90
		a	b	c	d	e	f	g	h	i		
	Block volume (Vb)	< 1cm3	1 - 100cm3	0.1 - 1dm3	1 - 15dm3	15 - 125dm3	0.125- 1m3	1 - 8m3	8 - 50m3	> 50m3	Vb = e	Value used = 0.070m3
		a	b	c	d	e	f	g	h	i		
	Volumetric joint count (joints/m3) (Jv)	> 60	60 - 45	45 - 30	30 - 20	20 - 10	10 - 5	5 - 3	3 - 1	< 1	Jv =	
		a	b	c	d	e	f	g	h	i		
	Joint spacing (Sa)	> 2 m	0.6-2m	0.2 - 0.6 m	0.06 - 0.2m	< 0.06m	← NOTE: 'Sa' is the spacing for the main joint set				Sa =	Value used = 0.55m
		a	b	c	d	e						
Jointing pattern	Number of joint sets (in area ca. 5 x tunnel span) (Jn)	random only	1 joint set	1 set + random	2 joint sets	2 sets + rand.	3 joint sets	3 sets + rand.	4 joint sets	crushed	Jn or Nj = e	
		a	b	c	d	e	f	g	h	i		
	Orientation of *main* joint set related to tunnel axis (Co)	very favour.	favourable	fair	unfavourable	very unfavour.	Strike / dip (°) → of joint set (related to tunnel)		70/90		Co roof = b; Co wall = c	
		a	b	c	d	e						
Characteristics of main joint set: Joint roughness (Jr)	Joint smoothness (js)	very rough	rough	slightly rough	smooth	polished	slickensided	filled joint (seam)			js = c	(Jr = js x jw)
		a	b	c	d	e	f	g				
	Joint planarity (jw)	discontinuous	strongly undul.	mod. undul.	slightly undul.	planar	filled joint (seam)				jw = d	
		a	b	c	d	e	f					
Joint condition (Ja) (fill in for A. or for B.)	A. *Without* joint filling	healed	fresh	slightly weath.	weathered	sand/silt coat.	clay coating				Ja or jA = b	
		a	b	c	d	e	f					
	B. *With* filling — thickness < 5mm →	sand /silt	hard clay	soft clay	swelling clay	thickness > 5mm →	sand /silt	hard clay	soft clay	swelling clay		
		h	j	l	n		i	k	m	o		
Type of joints (joint length) (jL)		crack	fissure	very short joint	short joint	mod. joint	long joint	seam (filled joint)	(short joint = 1-3m) (mod. joint = 3-10m)		jL = e	
		a	b	c	d	e	f	g				
Joint aperture (separation) (e)		none	< 0.1mm	0.1 - 1mm	1 - 5mm	5 - 25mm	Direction (°) → of tunnel or cavern		N10E		e =	Input used = c
		a	b	c	d	e						
Groundwater conditions (Jw)		dry/above GWL	damp	wet	dripping	gushing	flowing	inburst			Jw = c	
		a	b	c	d	e	f	g				
Stress level or stress type (SRF)		at surface	low stress	moderate stress	high stress	slight burst	mod. burst	strong burst	mild squeeze	high squeeze	SRF = c	
		a	b	c	d	e	f	g	h	i		
Weakness zone: Type of weakness zone		complex zone	clayzone <50m	clayzone >50m	freq. shears	simple <50m	simple >50m	loose, open	crushed zone			
		j	k	l	m	n	o	p	q			
Orientation of the zone related to tunnel axis (Coz)		very favour.	favourable	fair	unfavourable	very unfavour.	Strike/dip (°) of zone → (related to tunnel)				Coz roof = ; Coz wall =	
		a	b	c	d	e						
Thickness of the zone (Tz)	(min - average - max)		-	-			← 'Tz' may sometimes be difficult to find (A crude estimate is better than no input)				Tz =	
Description of the zone →												

Orientations of main joint sets (use first line for foliation, bedding, or schistocity)

strike (°)	dip (°)	dip direction	spacing (m)
70	90		0.3-0.6
40	60	right	0.5-2
some random joints			

Types of rockmass structures



Mark structure type → i | ii | iii | iv | v | vi | vii | viii

CALCULATED GROUND QUALITY

Q_{roof} =	17.327	good	Q_{wall} =	86.636
RMR_{1989} =	63	good	Qc =	15.161
Gc_{roof} =	9.605	fair	Gc_{wall} =	48.024
RMi =	9.605	moderate	RMi indicates the rockmass compressive strength (MPa)	

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1) Be aware of the extrapolation from surface observations to input for underground conditions 2) For general information

Figure 12: Copy of the spreadsheet for documentation and calculation of ground quality. Observations made in the tunnel (shown as grey cells on the left part) can be used directly as input in the green-coloured column on the right part of the sheet for calculation of ground quality. The factor Gc (ground condition factor) expresses the ground quality of jointed rocks in the RMi system.

As there is no water leakage (or water pressure) and the stresses are very low at the surface, the parameters for groundwater and the stress conditions may be completely different from those in the underground excavation. The surface observations of groundwater and stresses have been included in the Geo-registrations form and in the Geo-conditions spreadsheet. In this way the value and use of SRF is clearly shown preventing possible rock engineering errors.

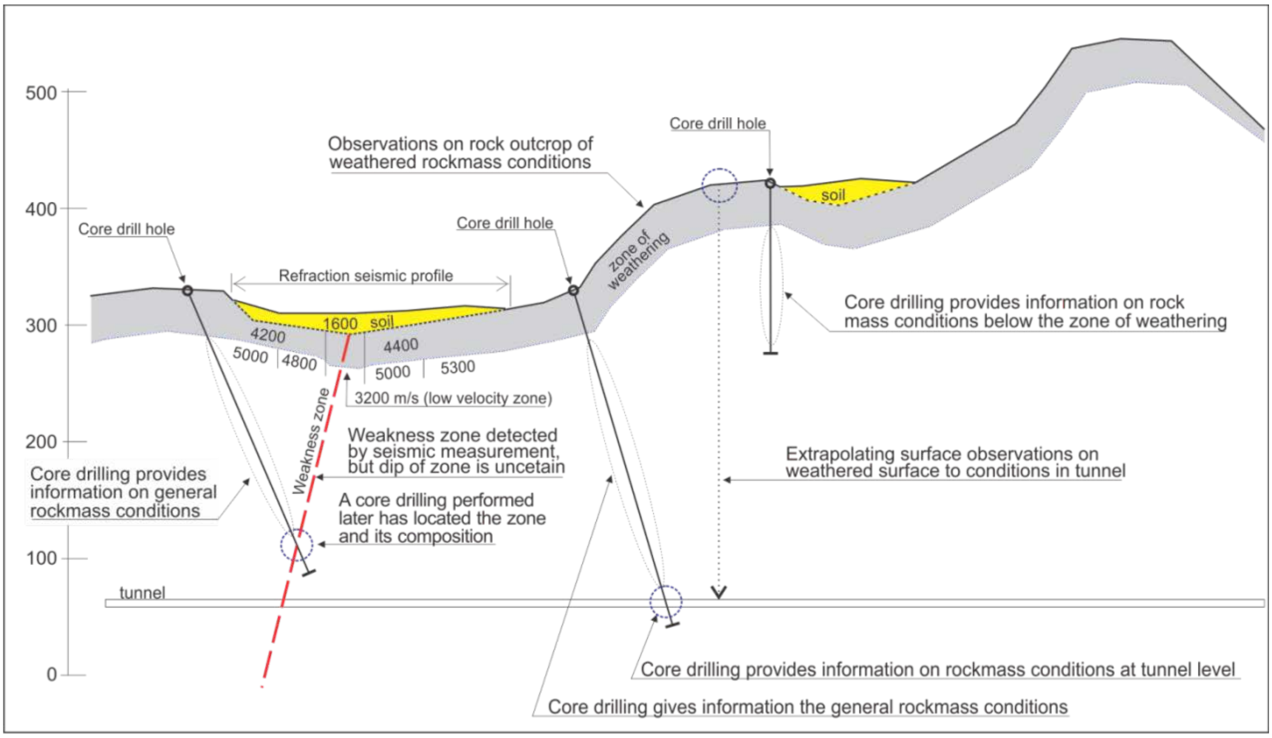


Figure 13: The use of geo-observations, refraction seismic measurements and core drillings to assess the rockmass conditions underground. Study of aerial photos and collection of experience from other, nearby tunnel constructions may provide useful, additional information

The surface geo-observations can be supported by core drillings and/or refraction seismic and/or resistivity measurements, see Figures 13 and 14. When the rockmass and ground conditions found are used to estimate the conditions in the underground excavation often located at a depth several hundred metres below, the challenges are:

1) To characterize and describe the rockmass conditions correctly where the geo-observations are collected.[7]
2) To evaluate the effects or influence of possible weathering at the surface, as well as variations in rockmass composition and structure, such as:
   - The rocks in the tunnel are less weathered and therefore often stronger at tunnel level
   - The block volume observed is assumed to be larger in the tunnel than at the surface.
   - A similar trend is for clean joint surfaces, which are often somewhat smoother at tunnel level
3) Possible occurrence of weakness zone or fault, which requires special attention, description and investigations.
4) The influence of rock stresses in the underground rock excavation. Stress measurements in deep boreholes may provide valuable information, but such measurements are generally difficult to conduct, and may have unreliable results. The stress parameters have therefore to be assumed until more reliable stress measurement can be performed in or near the actual excavation during construction.
5) The influence of groundwater conditions in the rock excavation. Water loss tests in deep boreholes may give indications of this parameter, but mostly this parameter has to be assumed.

[7] Often, the conditions observed cannot alone yield sufficient information on the ground qualities. Therefore, additional field investigations must be carried out. These will often be core drillings and/or geophysical measurements, see Figures 13 and 14.

Figure 14 further shows how refraction seismic measurement and a core drilling can be utilized to collect geo-information, both of a weakness zone and of the rockmasses on both sides of the zone. This borehole investigation is performed in an area with cover of loose materials (soils) similar to the conditions in Photo 1. The figure shows excerpt of core logging presented along the borehole at site. Interpretation of the logging can provide general information of the rockmass conditions and features.

Figure 15 shows the field conditions observed (in the Geo-registrations in Figure 10) and how these are adjusted to the assumed conditions in the underground excavation. The latter are given in the column on the right side of the sheet, as input ratings relevant for the assumed conditions in the (planned) tunnel, shaft or cavern. For example, the block volume in Figure 15 has been assumed larger in the tunnel than observed at the surface.

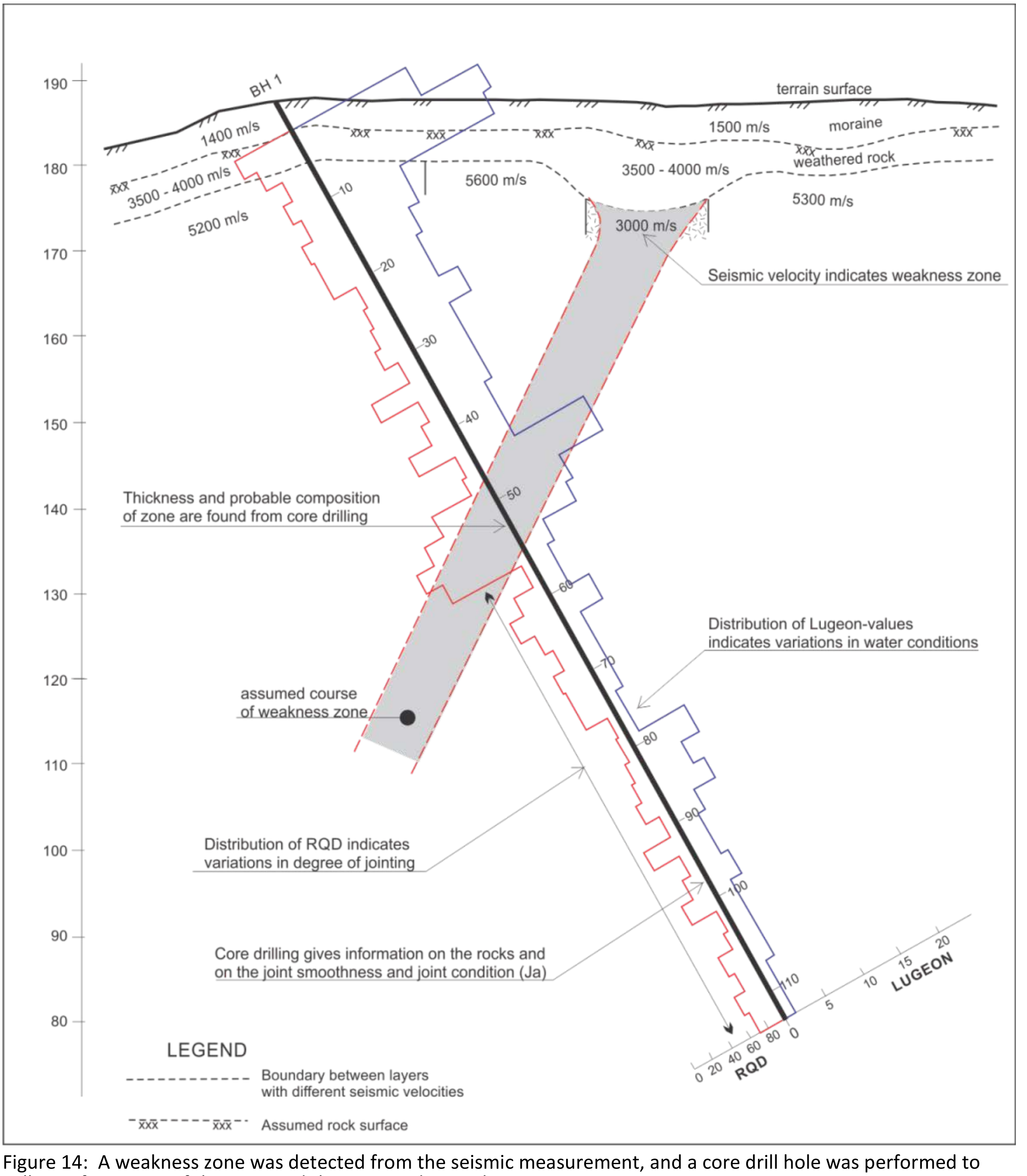


Figure 14: A weakness zone was detected from the seismic measurement, and a core drill hole was performed to collect information of the zone and the surrounding rockmasses.

GEO-CONDITIONS

Project: *Example* | Locality: | Sta.: | Date: | Observer:

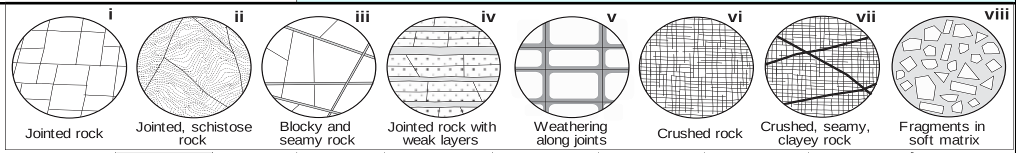
FIELD OBSERVATIONS

Group	Parameter	Symbol	a	b	c	d	e	f	g	h	i	INPUT [1] to calculations of ground quality	Some information
Observation locality	Observations made in:		outcrop	cutting	tunnel	Size (m2) =	20m2					(Green cells are for input)	
	Description of locality		A flat outcrop surrounded by loose deposits										
Rock material	Type of rock		Folded gneiss with lenses of quartz									Rock type [2]	gneiss with quartz lenses
	Rock or rockmass description		Alternating light grey and meduim grey layers or lenses										
	Weathering of rock		none/fresh a	slight b	moderate c	high d	complete e					Weathering of rock [2] a	
	Uniaxial compr. strength	(UCS)	< 1MPa a	1 - 5 MPa b	5 - 25MPa c	25 - 50MPa d	50 - 75MPa e	75 -100MPa f	100 -150MPa g	150-250MPa h	> 250MPa i	UCS = g	Value used = 125MPa
Degree of jointing (fill in for RQD and/or Vb and/or Jv) (see note for Sa →)	RQD (Rock Quality Designation)		< 10 a	10 - 25 b	25 - 40 c	40 - 50 d	50 - 60 e	60 - 75 f	75 - 90 g	90 - 100 h	100 i	RQD =	Value used = 100
	Block volume	(Vb)	< 1cm3 a	1 - 100cm3 b	0.1 - 1dm3 c	1 - 15dm3 d	15 - 125dm3 e	0.125- 1m3 f	1 - 8m3 g	8 - 50m3 h	> 50m3 i	Vb = f	Value used = 0.500m3
	Volumetric joint count (joints/m3)	(Jv)	> 60 a	60 - 45 b	45 - 30 c	30 - 20 d	20 - 10 e	10 - 5 f	5 - 3 g	3 - 1 h	< 1 i	Jv =	
	Joint spacing	(Sa)	> 2 m a	0.6-2m b	0.2 - 0.6 m c	0.06 - 0.2m d	< 0.06m e	← NOTE: 'Sa' is the spacing for the main joint set				Sa =	Value used = 1.06m
Jointing pattern	Number of joint sets (in area ca. 5 x tunnel span)	(Jn)	random only a	1 joint set b	1 set + random c	2 joint sets d	2 sets + rand. e	3 joint sets f	3 sets + rand. g	4 joint sets h	crushed i	Jn or Nj = d	
	Orientation of main joint set related to tunnel axis	(Co)	very favour. a	favourable b	fair c	unfavourable d	very unfavour. e	Strike / dip (°) → of joint set (related to tunnel)	70/90			Co roof = b Co wall = c	
Characteristics of main joint set – Joint roughness (Jr)	Joint smoothness	(js)	very rough a	rough b	slightly rough c	smooth d	polished e	slickensided f	filled joint (seam) g			js = c	(Jr = js x jw)
	Joint planarity	(jw)	discontinuous a	strongly undul. b	mod. undul. c	slightly undul. d	planar e	filled joint (seam) f				jw = d	
Joint condition (Ja) (fill in for A. or for B.)	A. *Without* joint filling		healed a	fresh b	slightly weath. c	weathered d	sand/silt coat. e	clay coating f				Ja or jA = b	
	B. *With* filling	thickness < 5mm →	sand /silt h	hard clay j	soft clay l	swelling clay n	thickness > 5mm →	sand /silt i	hard clay k	soft clay m	swelling clay o		
	Type of joints (joint length)	(jL)	crack a	fissure b	very short joint c	short joint d	mod. joint e	long joint f	seam (filled joint) g	(short joint = 1-3m) (mod. joint = 3-10m)		jL = e	
	Joint aperture (separation)	(e)	none a	< 0.1mm b	0.1 - 1mm c	1 - 5mm d	5 - 25mm e	Direction (°) → of tunnel or cavern		N10E		e = b	
Groundwater conditions		(Jw)	dry above GWL a	damp b	wet c	dripping d	gushing e	flowing f	inburst g			Jw = b	
Stress level or stress type		(SRF)	at surface a	low stress b	moderate stress c	high stress d	slight burst e	mod. burst f	strong burst g	mild squeeze h	high squeeze i	SRF = c	
Weakness zone	Type of weakness zone	(SRF)	complex zone j	clayzone <50m k	clayzone >50m l	freq. shears m	simple <50m n	simple >50m o	loose, open p	crushed zone q			
	Orientation of the zone related to tunnel axis	(Co_z)	very favour. a	favourable b	fair c	unfavourable d	very unfavour. e	Strike/dip (°) of zone → (related to tunnel)				Co_z roof = Co_z wall =	
	Thickness of the zone	(Tz)	(min - average - max)		-		-	← 'Tz' may sometimes be difficult to find (A crude estimate is better than no input)				Tz =	
	Description of the zone →												

Orientations of main joint sets
(use first line for foliation, bedding, or schistocity)

strike (°)	dip (°)	dip direction	spacing (m)
N80E	90		0.3-0.6
N30W	60	NE	0.5-2
some random joints			

Types of rockmass structures



Mark structure type → i | ii | iii | iv | v | vi | vii | viii

CALCULATED GROUND QUALITY

Q_{roof} =	43.581	*very good*	Q_{wall} =	217.906
RMR_{1989} =	77	*good*	Qc =	54.477
Gc_{roof} =	26.295	*good*	Gc_{wall} =	131.475
RMi =	26.295	*high*	RMi indicates the rockmass compressive strength (MPa)	

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[1] Be aware of the extrapolation from surface observations to input for underground conditions [2] For general information

Figure 15: Copy of the spreadsheet for documentation and calculation of ground quality. The field observations in Figure 10 have been inserted, marked as grey cells. Some of the extrapolations from surface data to conditions in the tunnel are shown with red arrows. As no input has been given for the parameters RQD and Sa (caused by e.g. observation difficulties), the spreadsheet automatically calculates the probable values (shown with blue letters), based on other comparable parameters.

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APPENDIX: Classification of the input parameters

The Geo-registrations form (Figure 10) is a documentation of the site conditions. For documentation and use in the report from the investigation, the field registrations can be transferred to a computer spreadsheet in which ground qualities in three classification systems can be calculated independently.[8] This is shown in Figures 12 and 15.

Table A1: The combined input parameters for ground conditions with input values for three classification systems

A. ROCKS			INPUT VALUE TO:		
			RMR	**Q**	**RMi**
A1. Compressive strength (σ_c) of intact rock			A1 =	-	σ_c =
Soil		σ_c < 1 MPa	0	Not included, except in Qc = Q · σ_c /100	Use actual value of σ_c
Rock	a. Very low strength	1 – 5MPa	1		
	b. Low strength	5 – 25MPa	2		
	c. Moderate strength	25 – 50MPa	4		
	d. Medium strength	50 – 100MPa	7		
	e. High strength	100 – 250MPa	12		
	f. Very high strength	> 250MPa	15		

B. DEGREE OF JOINTING		**RMR**	**Q**	**RMi**
B1. Rock quality designation (RQD)		A2 =	RQD =	-
a. Very poor	RQD < 25	5	Use actual RQD value (min RQD = 10)	Not included
b. Poor	25 - 50	8		
c. Fair	50 - 75	13		
d. Good	75 - 90	17		
e. Very good	90 - 100	20		
An approximate correlation between RQD and Jv is: RQD = 110 – 2.5Jv (Jv = jointing parameter)				
B2. Block size		-	-	*Vb* =
Block volume (*Vb*)		Not included	Not included	Use actual value of *Vb* (in m^3)
The block volume can be calculated from the Jv: Vb = $\beta \times Jv^{-3}$ *For cubical block shapes β = 27-32, for slightly long or flat shapes β = 32 - 40, for long or flat shapes β = 40 - 75*				
B3. Joint spacing		A3 = [1)]	-	-
a. Very large spacing	Spacing >2m	20	Not included	Not included
b. Large spacing	0.6 - 2m	15		
c. Moderate spacing	200 - 600mm	10		
d. Small spacing	60 - 200mm	8		
e. Very small spacing	< 60mm	5		
[1)] *Where more than one joint set occurs, the rating for the smallest spacing should be applied*				

C. JOINTING PATTERN	**RMR**	**Q**	**RMi**
C1. Joint set number	-	*Jn* =	*Nj* =
a. No or few joints	Not included	0.75	6
b. 1 joint set		2	3
c. 1 joint set + random joints		3	2
d. 2 joint sets		4	1.5
e. 2 joint sets + random joints		6	1.2
f. 3 joint sets		9	1
g. 3 joint sets + random joints		12	0.85
h. 4 joint sets or more; heavily jointed		15	0.6
i. Crushed, earth-like		20	0.5
C2. Orientation of main joint set	B =	-	*Co* =
a. Very favourable	0	Not included	1
b. Favourable	-2		1
c. Fair	-5		1.5
d. Unfavourable	-10		2
e. Very unfavourable	-12		3

[8] This can be made because the three systems use partly the same input parameters.

D. JOINT CHARACTERISTICS	RMR	Q[1)]	RMi
D1. Joint smoothness (small scale roughness, called 'roughness' in the RMR)	A4c =	(*js* =)	*js* =
a. Very rough	6	2	2
b. Rough or irregular	5	1.5	1.5
c. Slightly rough	3	1.25	1.25
d. Smooth	1	1	1
e. Polished	0	0.75	0.75
f. Slickensided	0	0.5	0.5
D2. Joint undulation or waviness (large scale roughness)	-	(*jw* =)	*jw* =
a. Discontinuous joints	Not included	4	4
b. Strongly undulating		2.5	2.5
c. Moderately undulating		2	2
d. Slightly undulating		1.4	1.4
e. Planar		1	1

1) Joint roughness number Jr = js · jw

Note: Jr = js · jw = 1 for filled joints

D3. Joint alteration or weathering	A4e =	*Ja* =	*jA* =
a. Healed or welded joints	6	0.75	0.75
b. Unweathered, fresh joint walls	6	1	1
c. Slightly weathered joint walls (coloured, d. stained)	5	2	2
d. Altered joint wall (no loose material)	3	4	4
e. Coating of friction materials (silt, sand, etc.)	1	3	3
f. Coating of cohesive materials (clay, chlorite, etc.)	0	4	4

Filled joints *(t = joint thickness)*	A4d =		*Ja* =		*jA* =	
	t < 5mm	t > 5mm	wall contact [1)]	no wall contact [2)]	t < 5mm	t > 5mm
h // i. Friction materials (silt, sand, etc.)	5	2	4	8	4	8
j // k. Hard, cohesive materials (clay, talc, chlorite)	4	2	6	8	6	8
l // m. Soft, cohesive materials (soft clay)	2	0	8	12	8	12
n // o. Swelling clay materials	0	0	10	18	10	18

1) Wall contact before 10cm shear; 2) No contact when sheared;

Note: Q and RMi apply a combination of joint weathering and infilling, while RMR has input of both weathering and infilling

D4. Joint length		A4a =	-	*jL* =
a. Crack [1)] (irregular break)	Length < ~0.3m	8	Not included	5
b. Parting (very short, thin joint)	< 1m	6		3
c. Very short joint	0.3 – 1m			2
d. Short joint	1 – 3m	4		1.5
e. Medium joint	3 – 10m	2		1
f. Long joint	10 – 30m [2)]	1		0.75
g. Seam or filled joint [3)]	> 10m	0		0.5

1) "Crack" has been introduced recently; 2) Length 10 – 20 m is applied in the RMR; 3) Used in cases where most joints in the location are filled

Persistence (continuity) of joints in the RMi system has been replaced by 'Discontinuous joints' in Table D2

D5. Joint separation or aperture (*A*)		A4b =	-	-
a. Closed	None	6	Not included	Partly included in the input for 'Interlocking of structure'
b. Very tight	A < 0.1mm	5		
c. Tight	0.1 – 1mm	4		
d. Open	1 - 5mm	1		
e. Very open	> 5mm	0		

E. INTERLOCKING OF ROCKMASS		RMR	Q	RMi
Compactness of structure		-	-	*IL* =
a. Very tight structure	Undisturbed rockmass	Not included	Not included	1.3
b. Tight structure	Undisturbed rockmass with some joint sets			1
c. Disturbed / open structure	Folded / faulted with angular blocks			0.8
d. Poorly interlocked	Broken rockmasses with angular and rounded blocks			0.5

Note: Interlocking has been introduced in this table, based on its effects used in the GSI system

F. GROUND WATER CONDITIONS			RMR	Q	RMi
Water inflow to tunnel (*q* in litres/min) **or water pressure** (p_w)			A5 =	*Jw* =	*GW* =
a. Dry or damp	*q* = 0	p_w < 1 kg/cm²	15	1	1
b. Wet or small seeps	*q* < 10	p_w = 1 - 2.5 kg/cm²	10	0.66	
c. Dripping	*q* = 10-25	p_w = 2.5 - 10 kg/cm²	7	0.5	2.5
d. Gushing/material outwashing	*q* = 25-125		4	0.3	5
e. Flowing, decaying with time	*q* > 125	p_w > 10 kg/cm²	0	0.15	-
f. Large, continuous inflow			-	0.08	-

NOTE! GW – is related to groundwater's influence on rockmass stability

G. ROCK STRESSES (around tunnel)		RMR	Q	RMi
G1. Stresses below rockmass strength ($\sigma_\theta < \sigma_{cm}$)		-	*SRF* =	*SL* =
a. Very low stress level (as in portals)		Not included	2.5	0.1
b. Low stress level				0.5
c. Medium stress level			1	1
d. High stress level			0.67	1.5
G2. Overstressing; stresses > rockmass strength ($\sigma_\theta > \sigma_{cm}$)		-	*SRF* =	*CF* = RMi / σ_θ
in massive, brittle rocks	e. Moderate slabbing after >1 hr	Not included	25	0.75
	f. Slabbing and rock burst after few minutes		100	0.4
	g. Heavy rock burst		300	0.15
in deformable rocks	h. Mild squeezing		10	0.75
	i. Heavy squeezing		20	0.5

σ_θ = tangential stresses around the opening; σ_{cm} ~ RMi = compressive strength of rockmass

H. WEAKNESS ZONES *)		RMR	Q	RMi
H1. Type of weakness zone		-	*SRF* =	-
a. Multiple weakness zones	any depth	Weakness zones and shears are not explicitly included in RMR	10	(Zone or shear characteristics are included in the other input parameters)
b. Single weakness zone	depth < 50m		5	
c. Single weakness zone	depth > 50m		2.5	
d. Multiple shear zones	any depth		7.5	
e. Single shear zone	depth < 50m		5	
f. Single shear zone	depth > 50m		2.5	
g. Loose, open joints	any depth		5	
h. Heavily jointed ("sugar cube")	any depth		5	
H2. Size of the zone		-	-	*Tz* =
Thickness or width of the zone (*Tz*)		Not included	Not included	Use width of zone in metres
H3. Orientation of zone related to excavation		-	-	*Coz* =
a. Very favourable		Not included	Not included	1
b. Favourable				1
c. Fair				1.5
d. Unfavourable				2
e. Very unfavourable				3

*) *Most weakness zones should be especially evaluated, together with the use of engineering judgement*