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Oskarshamn site investigation

Rock mechanics characterisation of borehole KLX01, KLX03, KLX04 and KAV04

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December 2006

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Abstract

The report illustrates the rock mechanics characterisation of the rock mass along borehole KLX01, KLX03, KLX04, and KAV04 and Laxemar and Ävrö. The characterisation is performed by means of the two independent empirical systems Q and RMR. The systems are applied to the geomechanical data provided in digital format by SICADA according to SKB's Methodology for the "characterisation" of the rock mass.

The values of Q and RMR are calculated for borehole sections of 5 m length. Moreover, average values are also provided for the rock mass in the Rock Units (volumes with homogeneous mixture of rock types) and Deformation Zones (volumes with high frequency either of the open or of the sealed fractures). Rock units and deformation zones are provided by the geological "single-hole interpretation" of the boreholes.

From the values of Q and RMR, the equivalent deformation modulus of the rock mass is obtained. The two methods provide results very similar to each other. As there is a complete set of relations that correlate RMR to the Poisson's ratio, uniaxial compressive strength, equivalent friction angle and cohesion of the rock mass, it was decided to obtain all the other mechanical properties of the rock mass from the values of RMR trough its relation with the Geological Strength Index (GSI).

The average deformation modulus of boreholes KLX01, KLX04 and KAV04 for the competent rock mass ranges between 36 and 44 GPa compared to boreholes KLX03 for which the average deformation modulus is 64 GPa. The average deformation modulus of the Deformation zones shows a similar pattern with an average deformation modulus for boreholes KLX01, KLX03 and KAV04 of about 22 GPa whereas for KLX03 it is about 42 GPa.

The equivalent cohesion and friction angle of the competent rock mass in the boreholes varies, on average, between 17 and 21 MPa, and between 41° and 44°, respectively, for confinement stresses between 10 and 30 MPa. The apparent uniaxial compressive strength of the rock mass can be determined from the friction angle and cohesion and spans between 56 MPa for the deformation zones and 100 MPa for the competent rock mass.

Based on the range of expected values of the parameters for each 5 m section of borehole, and based on the number of available values for each parameter, the uncertainty of the mechanical properties of the rock mass were estimated. The estimation was performed separately on the properties of the competent rock mass and of the deformation zones.

The uncertainty of the average deformation modulus is about ± 5% for the competent rock mass whereas the uncertainty for the deformation zones shows a larger range of about ± 30%. According to the results, the uncertainty on the deformation modulus determined with Q is slightly lower than that determined by RMR.

Sammanfattning

I denna rapport beskrivs den empiriska karakteriseringen av bergmassan längs borrhålen KLX01, KLX03, KLX04 från Laxemar och KAV04 från Ävrö. Karakteriseringen baserades på de två oberoende system RMR och Q. Systemen tillämpas på geomekanisk data i digitalformat från databasen SICADA enligt SKB:s metodologi för ”karakterisering” av bergmassan.

Q- och RMR-värdena beräknades för 5 m långa borrhålsavsnitt. Medelvärden för de intakta bergenheterna och deformationszonerna i den geologiska enhålstolkningen redovisas dessutom. Bergkvaliteten i den kompetenta bergmassan (utanför deformationszonerna) studerades separat.

Från Q- och RMR-värdena kunde man beräkna den ekvivalenta deformationsmodulen för bergmassan. De två metoderna ger mycket samstämmiga resultat. Dock valdes RMR för att uppskatta de andra mekaniska egenskaperna därför att det finns ett brett utbud av formler som relaterar till RMR i litteraturen för bergmassans Poissontal, enaxiella tryckhållfasthet, friktionsvinkel och kohesion.

Deformationsmodulen hos den kompetenta bergmassan i borrhål KLX01, KLX02 och KAV04 varierade mellan 36 och 44 GPa jämfört med borrhål KLX03 där deformationsmodulen är 64 GPa. Bergmassan i deformationszonerna uppvisar ett liknande mönster med en deformationsmodul för KLX01, KLX03 och KAV04 som är ungefär 22 GPa medan den är 42 GPa för KLX03.

Bergmassans ekvivalenta kohesion och friktionsvinkel varierade mellan 17 och 21 MPa respektive mellan 41° och 44°, för ett celltryck mellan 10 och 30 MPa. Från friktionsvinkeln och kohesionen kan den enaxliga tryckhållfastheten tas fram. Denna varierar mellan 56 MPa för deformationszonerna till 100 MPa för den kompetenta bergmassan.

Osäkerheten hos de mekaniska parametrarna uppskattades med avseende på den förväntade variationen hos parametrarna för var 5 m i borrhålen och antalet tillgängliga mätningar för respektive parameter. Detta gjordes separat för varje egenskap uppdelat mellan den kompetenta bergmassan och deformationszonerna.

Osäkerheten för medelvärdet hos deformationsmodulen hos den kompetenta bergmassan är ungefär ± 5 % dock är osäkerheten för deformationszonerna mycket högre, ungefär ± 30 %. Osäkerheten för deformationsmodulen som bestämts med Q är något lägre än för RMR.

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1 Introduction

1.1 Background

The analysed boreholes are located in the Laxemar area on the mainland (KLX01, KLX03, and KLX04) and on the island of Ävrö (KAV04) (Figure 1-1). All but one of the boreholes are sub-vertical where KLX03 is drilled with an inclination of 75°. The boreholes reach the depth of about 1,000 m except KLX01 which reaches down to about 1,078 m, (Table 1-1). BIPS images are also available for the boreholes.

Table 1-1. Borehole information.

Borehole	Bearing angle	Inclination	Borehole length
KLX01	347°	85°	0–1,078 m
KLX03	199°	75°	101–1,000 m
KLX04	002°	85°	100–993 m
KAV04	077°	85°	100–1,004 m

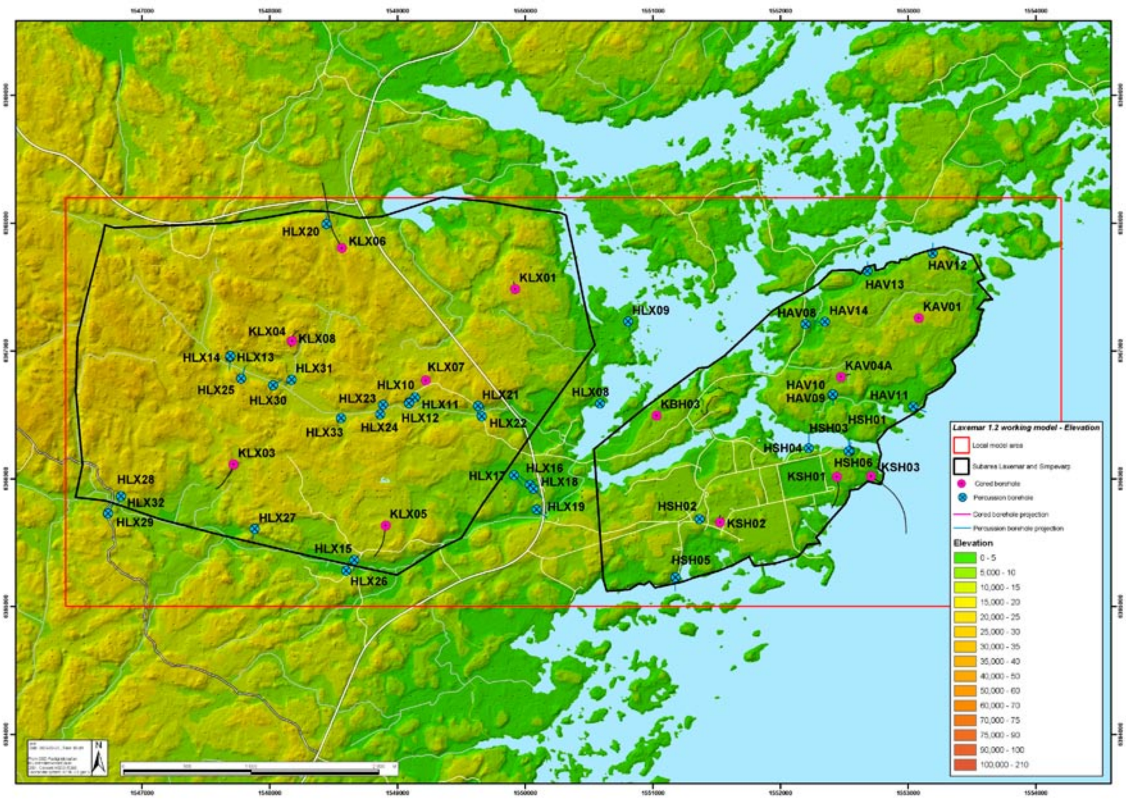

Figure 1-1. Overview of the Laxemar (on the mainland) and Simpevarp-Ävrö Site with indication of the boreholes in this report: KLX01, KLX03, KLX04, and KAV04.

1.2 Objectives

The objectives of this study on borehole KLX01, KLX03, KLX04 and KAV04 are as follows:

- Evaluate the rock mass quality along the boreholes by means of the empirical systems RMR and Q.
- Quantitatively characterise the rock mass by determining its deformation modulus, Poisson's ratio, uniaxial compressive strength, cohesion and friction angle.
- Give summarising properties for the pseudo-homogeneous rock units identified in the geological single-hole interpretation.
- Discuss the results of the characterisation and list the main conclusion of the work.

1.3 Scope

The characterization of the rock mass along the borehole is performed mainly based on data obtained directly from the borehole and contained in the geological single-hole interpretation /Carlsten et al. 2006abc/. This enables for a rock quality determination that applies locally along each borehole. When comparing the results for different depths, the spatial variation along the boreholes can be highlighted.

This Rock Mechanics report is structured as follows:

- Summary of the BOREMAP data on rock types and fractures. The fracture sets occurring along the borehole are illustrated together with their frequency and spacing.
- Summary of the mechanical properties of the common rock types and rock fractures at the site (see also appendices).
- Application of the RMR and Q empirical systems for determination of the rock quality along the four boreholes (see also appendices). The determination of the input parameters is illustrated as well as some spatial variation, scale effect and uncertainty.
- Determination of the continuum equivalent mechanical properties of the rock mass based on empirical relations with RMR and Q. The deformation modulus, Poisson's ratio, uniaxial compressive strength, cohesion and friction angle of the rock mass are determined and shown as a function of depth. The uncertainties of the deformation modulus determination are also treated (see also appendices).
- Discussion of the results.
- Recommendations on the data acquisition, processing and storage in SICADA.
- Appendices.

2 Boremap data

The analysed boreholes (KLX01, KLX03, KLX04, and KAV04) were mapped by examining the core and the BIPS pictures taken on its wall /Ehrenborg and Dahlin 2005abc/. For borehole KLX01, no Boremap mapping was carried out. The geological parameters obtained and stored in SKB's geological database SICADA were:

- Frequency of the fractures.
- RQD evaluated on core lengths of 1m.
- Rock types, rock alteration and structural features.

Each fracture observed along the borehole was classified among "open" and "closed" ("sealed"). The rock mechanics characterisation in this report is based on the properties of the "open" and "partly open" fractures. The following geological features of the fractures were observed:

- Depth of occurrence.
- Mineralization or infilling.
- Roughness and surface features.
- Alteration conditions
- Orientation (strike and dip) (except for borehole KLX01).
- Width and aperture.

A direct estimation of the Q-parameter Joint Alteration Number (Ja) was performed by the geologists for all boreholes except KLX01. The information listed above is contained in the geological and rock mechanics digital database SICADA by SKB.

For the rock mechanics evaluation of the geological information, some more parameters were determined:

- Bias correction of the orientation and spacing of the fractures by Terzaghi's weighting.
- Assignation of each fracture to a fracture or to a group of random fractures.

The fracture sets are identified according to the DFN model in preparation for Laxemar version 1.2 / Hermansson et al. 2005/. In the following sections, the stereonet plots of the poles of the open fractures are presented where the fracture set names are indicated. Once the fracture sets were identified in each rock unit along the borehole, the mean orientation of each set and its Fisher's constant were determined, except for borehole KLX01 (see appendices for the different boreholes). Based on the concentrations of orientation poles shown in the stereonet plots, the fractures were assigned to the various fracture sets. In this way, not only the number of fractures for each occurring set could be calculated, but also the frequency and spacing of each fracture set were determined on average every 5 m of core length. For the fracture spacing, the Terzaghi's correction was applied for taking into account the linear sampling of the fractures applied by the borehole.

The plot with depth of the total fracture frequency, the frequency of the sub-horizontal fractures, the Rock Quality Designation (RQD), and the number of fracture sets contemporarily occurring every 5 m section of borehole are shown for each borehole. The total frequency of the fractures gives an idea of the degree of fracturing of the core. RQD give the sum of the length of core pieces longer than 100 mm every meter of borehole core also indicating the degree of fracturing of the rock mass. Sometimes, for measuring the entity of the bias due to the borehole sampling, it is interesting to observe the fraction of sub-horizontal fractures compared to the total number of fractures. Finally, by counting the number of fracture sets occurring in each 5 m section of core, the plot of the number of fracture sets contemporarily occurring in the borehole can be obtained.

Based on the DFN model, the fracture length rating for RMR was assigned as for fracture lengths between 1 and 3 m.

2.1 KLX01

The orientation of the fractures along this borehole was not measured because the core was not oriented and no BIPS-pictures are available. The number of fracture sets was estimated based on the RDQ values and the results of the characterization of borehole KLX02 reported in the Site Descriptive Model of Simpevarp, version 1.2 /SKB 2005/.

The variation of the total fracture frequency, estimated fracture spacing and RQD along the borehole is shown in Figure 2-1. Down to depth of 580 m the fracture frequency generally vary between 2 and 4 fractures/m. At 580–640 m depth, twice the fracture frequency is found. A RQD of about 70 is found as two troughs at 170 and 910 m depth. Marked peaks of the total spacing are observed at about 800 and 980 m. These two depths also correspond to two less defined decreases in the fracture frequency indicating not only lower frequency but also larger sections of intact core pieces. A high peak in the fracture frequency below 1,000 m can be seen as decreases in both total spacing and RQD. At this depth the lowest values of RQD (40) along the total length of the borehole are found.

2.2 KLX03

In Figure 2-2, the stereonet plot of the poles of the fracture planes for borehole KLX03 is shown. The fractures are subdivided into fracture sets according to the DFN Model for Laxemar version 1.2 /Hermansson et al. 2005/. The fractures intersected by this borehole seem to be prevalently sub-horizontal.

In fact, there are large similarities between the plot of the total frequency and that of the frequency of the sub-horizontal fractures in Figure 2-3. A peak in both the total frequency and the frequency of the sub-horizontal fractures can be seen at depth of 720–800 m. A response to this

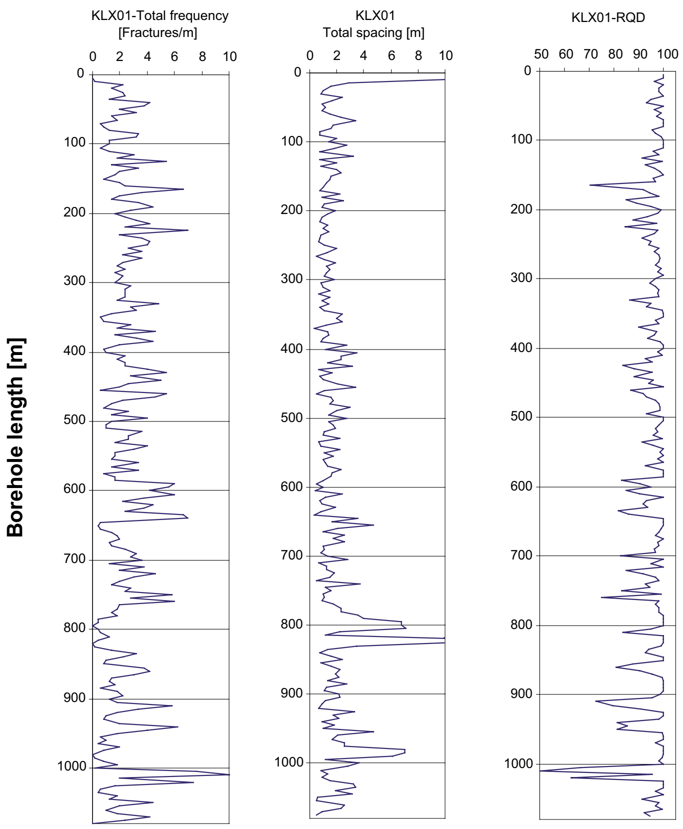

Figure 2-1. Variation of the total fracture frequency, estimated spacing between fractures and RQD with depth for borehole KLX01. Due to lack of fracture orientation information, no Terzaghi's correction has been applied when calculating the spacing. The values of the fracture frequency and spacing are averaged for each 5 m length of borehole.

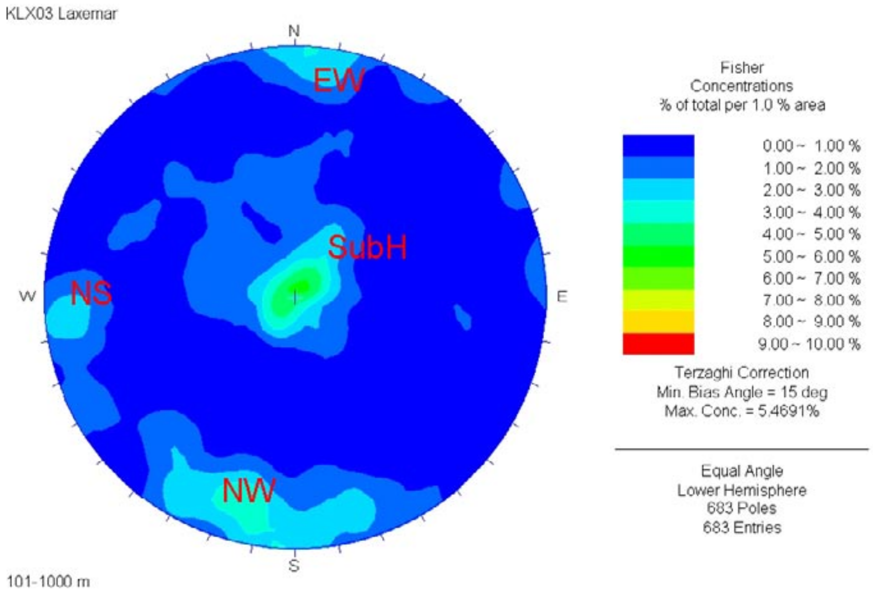

Figure 2-2. *Equiangular pole plot of the fractures logged along borehole KLX03 and indication of the main fracture sets.*

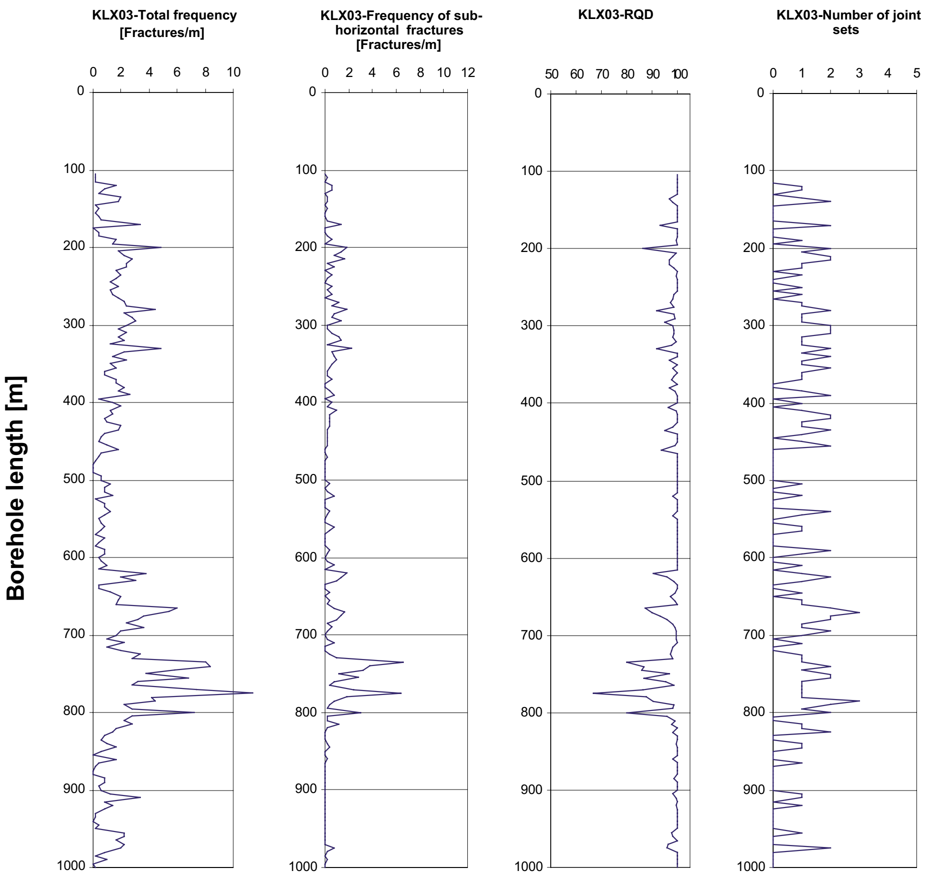

Figure 2-3. *Variation of the total fracture frequency, frequency of the sub-horizontal fractures, RQD and number of joint sets with depth for borehole KLX03. The values are averaged for each 5 m length of borehole.*

increase in fractures in decreasing RQD is striking. A steady increase of the fracture frequency starts at about 620 m and culminates in the high fracture frequency at the 720–800 m interval. The number of fracture sets occurring at the same time does not exceed 3 in this borehole. Generally the number of joint sets range from 1 to 2. An increase to 2–3 sets can be noticed over the same intervals with increased fracture frequency.

2.3 KLX04

The characterization of this borehole was carried out before the actual version of Site Descriptive Model for Simpevarp version 1.2 /SKB 2005/ was completed. Thus, the fracture sets identified by the Model for Simpevarp 1.1 /SKB 2004/ were adopted.

Borehole KLX04 shows a predominance of sub-horizontal fractures (Figure 2-4). The fracture set oriented EW is rather well defined as shown in the stereonet plot. Fracture sets with the orientation NS and NE do not appear in the stereonet plot due to the small number of fractures in each set compared to the total amount of 2,009 entries for this borehole. The fracture set oriented NS contains 25 entries and the fracture set NE contains 37 entries (only fracture sets containing > 40 entries are shown).

About 50% of the fractures in the entire borehole are sub-horizontal, hence the similarity between the total fracture frequency and the frequency for sub-horizontal fractures. A pronounced peak can be seen in the frequency values, and a matching trough in the RQD values starting at about 870 m and continuing with depth. Although this section represents parts with short core pieces, the lowest RQD is found at 350 m depth in a much localized trough. In a section between 500 and 700 m, several troughs can be found in the RQD plot. This section also shows a higher number of fracture sets.

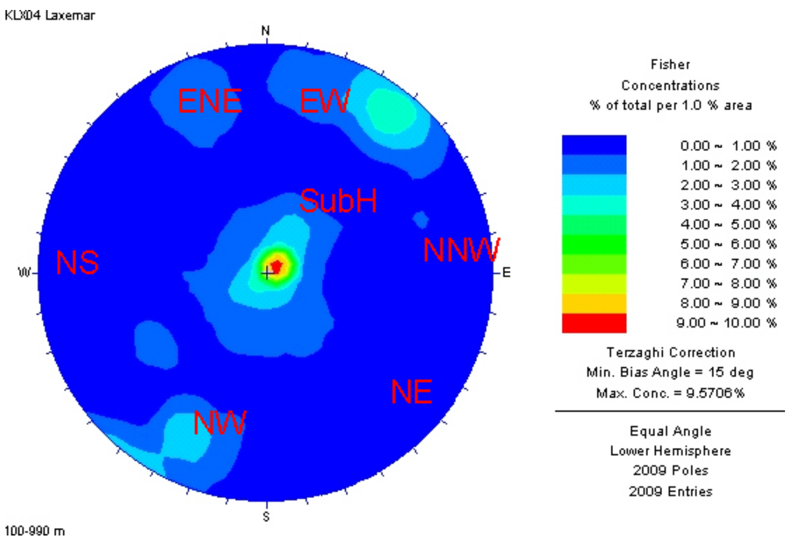

Figure 2-4. *Equiangular pole plot of the fractures logged along borehole KLX04 and indication of the main fracture sets.*

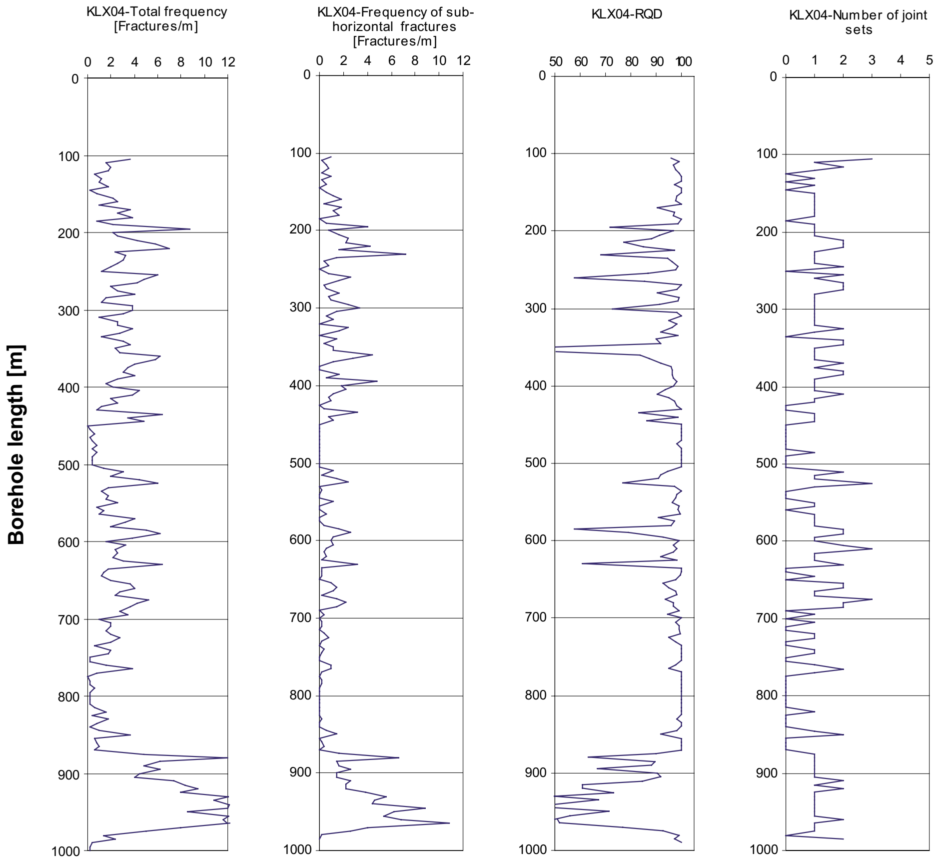

Figure 2-5. Variation of the total fracture frequency, frequency of the sub-horizontal fractures, RQD and number of joint sets with depth for borehole KLX04. The values are averaged for each 5 m length of borehole.

2.4 KAV04

Similarly to borehole KLX04, the characterization of KAV04 hole was made before the completion of the Site Descriptive Model for Simpevarp version 1.2 /SKB 2005/. Also here the fracture sets identified by the Model for Simpevarp 1.1 /SKB 2004/ are used.

In this borehole, three fracture sets dominate the scene (fracture set EW, NNW and NE) (Figure 2-6). Together they only make up 26% percent of the total number of fractures which implies that a large amount of the fractures in this borehole are random.

Contrary to many boreholes a general similarity between the total fracture frequency and sub-horizontal cannot be seen in this borehole (Figure 2-7). At about 700 m the frequency of the sub-horizontal fractures increases drastically compared to shallower levels in the borehole. This increase is mirrored quite consistently in the variation of RQD. This behaviour is quite steady for a 200 m deep section from 700 to 900 m. The continuous low RQD further down the hole is probably an effect of the high total fracture frequency. Three sections of lower fracture frequency, a low number of joint sets and a high RQD are identified at depth of 300, 440 and in a section between 630 and 680 m.

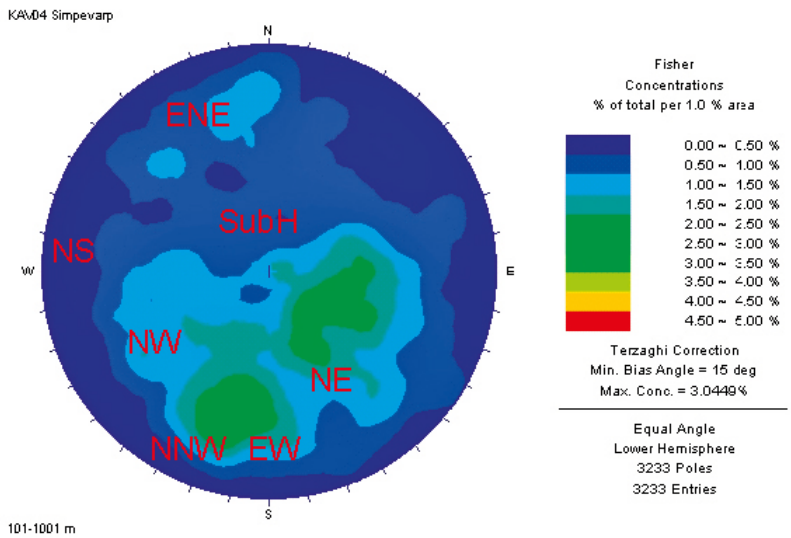

Figure 2-6. *Equiangle pole plot of the fractures logged along borehole KAV04 and indication of the main fracture sets.*

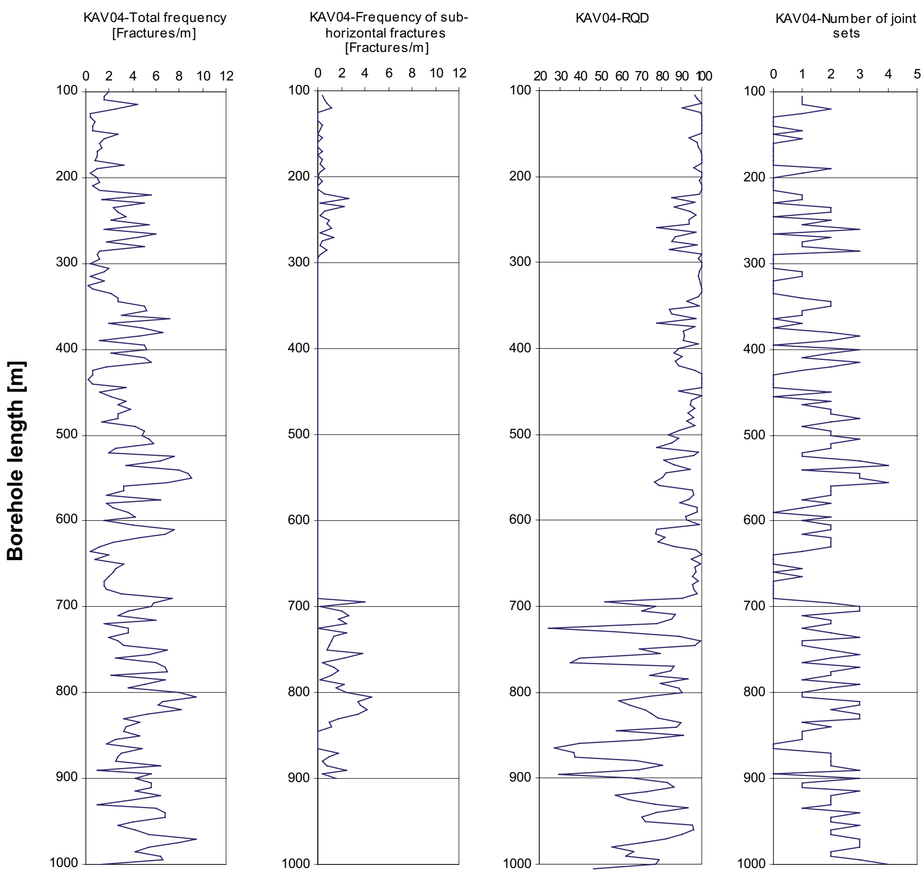

Figure 2-7. *Variation of the total fracture frequency, frequency of the sub-horizontal fractures, RQD and number of joint sets with depth for borehole KAV04. The values are averaged for each 5 m length of borehole.*

3 Mechanical properties of intact rock and rock fractures

The mechanical properties of the intact rock of samples from borehole KSH01A, KSH02, KLX02 and KLX04 are summarized in /Lanaro et al. 2006/. The mechanical properties of the natural fractures are usually not a direct input parameter of the empirical methods. Table 3-1 shows an overview of the available test results on intact rock. Table 3-2 contains the Hoek & Brown's parameters obtained for the intact rock from the uniaxial and triaxial laboratory results.

Table 3-1. Summary of the results of uniaxial compressive tests performed on intact rock samples from borehole KSH01A, KSH02, KLX02 and KLX04 /Lanaro et al. 2006/.

Borehole	Rock type	Indirect tensile tests	Uniaxial tests	Triaxial tests
KSH01A	Quartz monzonite to monzodiorite	20 (2*)	10	8 (3*, 1**)
	Fine-grained dioritoid	20 (6*)	10 (4*)	4 (1*)
KSH02	Fine-grained dioritoid	12 (2*)	5 (1*)	5 (2*)
KLX02	Granite to quartz monzodiorite	30	15	–
KLX04	Granite to quartz monzodiorite	30	15	14

* Samples with sealed fractures.
** Samples with intrusion of fine to medium grained granite.

Table 3-2. Parameters for the Hoek & Brown's Criterion (uniaxial compressive strength UCS and mi) based on the results of uniaxial and triaxial tests performed on intact rock sampled from borehole KSH01A, KSH02, KLX02 and KLX04 /Lanaro et al. 2006/.

Rock type	Number of samples	Minimum		Mean		Maximum	
		USC [MPa]	mi	UCS [MPa]	mi	UCS [MPa]	mi
Fine-grained dioritoid	16	118.5	15.0	207.3	13.7	296.1	13.2
Quartz monzonite to monzodiorite	16	123.4	32.6	160.1	30.6	196.8	29.3
Granite to quartz monzodiorite	44	152.0	16.6	192	18.9	235.0	19.7

4 Characterisation of the rock mass along the boreholes

According to the methodology for rock mass characterisation /Andersson et al. 2002, Röshoff et al. 2002/, two empirical classification systems should be used for the purpose of determination of the mechanical property of the rock mass: the Rock Mass Rating, RMR, and the Rock Quality Index, Q. These classification systems are applied here for the "characterisation" of the rock mass, in contraposition to their general use for "design" of underground excavations. This implies that constrains due to the shape, orientation, function and safety of a potential excavation are not of concern.

4.1 Equations for RMR and Q

The very well known relations for the Rock Mass Rating (RMR) /Bieniawski 1989/ and Rock Quality Index (Q) /Barton 2002/ are reported here for convenience of the reader. The basic equation for RMR /Bieniawski 1989/ is:

$$RMR = RMR_{strength} + RMR_{RQD} + RMR_{spacing} + RMR_{conditions} + \\ + RMR_{water} + RMR_{orientation} \tag{1}$$

where the subscripts strength, RQD, spacing, conditions, water, orientation refer to the strength of the intact rock, to the Rock Quality Designation, to the conditions and spacing of the fracture, to the groundwater conditions and the orientation of the fracture sets with respect to the hypothetical tunnel orientation, respectively. In the source, each rating is provided with a description and a table.

The basic equation for Q /Barton 2002/ is:

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF} \tag{2}$$

where, besides RQD, J_n depends on the number of fracture sets, J_r and J_a on the roughness and alteration of the fractures, J_w on the groundwater conditions and the Stress Reduction Factor (SRF), takes into account the stresses in the rock mass. Also these parameters are described and tabulated in the source.

Table 4-1. Rock mass classification based on RMR and Q.

RMR rating	100–81	80–61	60–41	40–21	20–0
Rock class	I	II	III	IV	V
Classification	Very good	Good	Fair	Poor	Very poor
Q number	> 40	10–40	4–10	1–4	0.1–1
Classification	Very good	Good	Fair	Poor	Very poor

4.2 The relation between RQD and J_n at Laxemar

J_n is an essential parameter used for the rock mechanics characterisation system Q /Barton 2002/. For the drill-core from KLX01, this parameter must be estimated as we do not have any information about the orientation of the fractures in this borehole. The J_n parameter accounts for the number of joint sets (9 for 3 sets, 4 for 2 sets, etc.) in the same domain /Barton 2002/, in this report 5 m. In the case of KLX01 we have to use other parameters for estimating the J_n parameter for Q.

Another parameter based on the frequency of fractures is the RQD parameter, which is the percentage of complete drill-core pieces longer than 100 mm that occur per meter in a selected domain /Barton 2002/, in this report 5 m.

With data from an orientated drill-core from the same sampling area (KLX02) the relation between these two parameters is used to estimate J_n. The ratio RQD/J_n is a parameter providing information of the relative rock block size /Barton 2002/.

For this evaluation, the fracture information from drill-core KLX02 is divided into competent rock and fractured rock due to the assumption that the fractured rock generally represents sections with more fracture sets.

When making a statistical analysis of the different parameters, the minimum mean, mode and maximum values are calculated over a drill-core domain. The different characteristics of the RQD and J_n were calculated separately but the analysis was made plotting them to represent different case scenarios. Here the "worst case scenario" is where the minimum value of RDQ is plotted against the maximum value of J_n. The maximum value of RDQ is plotted against the minimum value of J_n to represent the "best case scenario". The results of this investigation are presented in Figure 4-1 where the mean RQD and the mean J_n values from KLX02 are plotted in an x-y-plot.

The result from the worst case scenario can be seen as the upper limit (green) in the plot. These results are obtained from a plot of the maximum J_n versus the minimum RQD and are assumed so that the J_n number is 12 for RQD > 52 and 15 for RQD < 52 for competent rock. In the diagram of the mean RQD in relation to the mean J_n for drill-core KLX02 (Figure 4-1), the trend line of the data indicates the relation between mean RDQ and mean J_n according to the equation:

$$J_n = -0.1944\, RQD + 22$$

This relation is used to calculate the mean J_n from the mean RQD for drill-core KLX01.

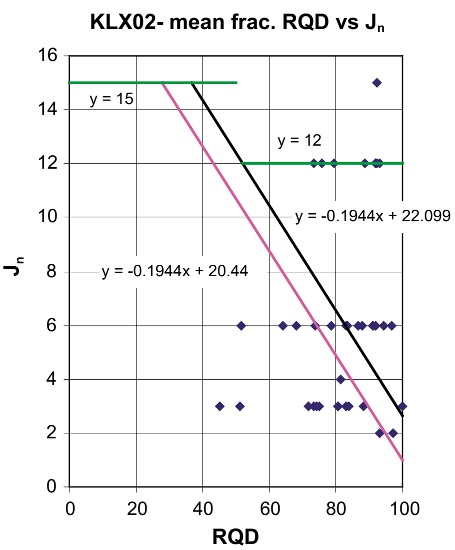

Figure 4-1. *The mean RQD and the mean J_n values from KLX02 and their relation.*

Table 4-2. Distribution of the minimum J_n when RQD is 100 for KLX02.

J_n	%
0.5	1.6
1	43.1
2	11.4
3	31.7
4	1.6
6	9.8
9	0.8

The best case scenario is described by the lower trend line (red). The lower boundary for minimum J_n is set to 1, which occurs when the maximum RQD is 100. This assumption is made according to the distribution of J_n when RQD is 100 in borehole KLX02 (Table 4-2).

The trend line for the best case scenario follows the same trend as the trend line for the mean RQD and mean J_n but with a shift to lower values. This trend line also experiences a cut-off limit when it crosses the trend line for worst case scenario at RQD < 43.4 where the J_n value is 15.

When generating J_n values for borehole KLX01, the maximum RQD values for the 5 m long drill-core sections in KLX01 are used for obtaining the minimum J_n values according to the best case scenario. On the other hand, the minimum RQD values are used to generate maximum J_n values according to the worst case scenario. Finally, the mean RQD values are used to generate the mean J_n values.

4.3 Single-hole interpretation

The "single-hole interpretation" provides the partitioning of the boreholes into Rock Units (pseudo-homogeneous rock volumes with a predominant rock type or particular mixture of them) and Deformation Zones (zone of higher fracture frequency and alteration often observed as seismic and radar reflectors), /Ehrenborg and Dahlin 2005abc/. The Boremap mapping of the borehole walls represent one of the major data sources. For Rock Mechanics purposes, the partitioning according to rock type groups was adopted to investigate the possible correlation of the rock type with the quality of the rock mass. The fractured zones were accurately checked and only the ones that would correspond to considerably reduced rock mass quality were considered as separated objects in the Rock Mechanics analysis.

4.4 KLX01

4.4.1 Single-hole interpretation

The geological single-hole interpretation provides a partitioning of borehole KLX01 into pseudo-homogeneous sections that apply also for the rock mechanics analysis /Carlsten et al. 2006a/. Three different rock type groups are recognised together with one fractured/deformation zone. In Table 4-3, the rock units, rock type groups and the decision process for the choice of the fractured zones for Rock Mechanics are reported.

- RU1: totally dominated by granite to quartz monzodiorite, generally porhyritic Ävrö granite with subordinate sections of fine-grained mafic rock (fine grained diorite to gabbro).
- RU2: dominated by granite to quartz monzodiorite, generally porhyritic Ävrö granite with subordinate sections of fine- to medium-grained granite and fine-grained diorite to gabbro.
- RU3: totally dominated by granite to quartz monzodiorite, generally porhyritic Ävrö granite with some sections shorter than 35 m of fine-grained mafic rock (fine grained diorite to gabbro) and scattered sections of fine- to medium-grained granite.

Table 4-3. Partitioning of borehole KLX01: rock units, rock types and deformation zones /Carlsten et al. 2006a/.

Depth [m]	Rock Unit	Depth [m]	Deformation Zones
0–585	RU1		
585–640	RU2		
640–1,078	RU3	1,000–1,020	DZ1

4.4.2 Characterisation with RMR

For each 5 m sections of borehole, the geomechanical parameters from borehole logging were scrutinized (Figure 4-2 and Appendix 1). The minimum, average, most frequent and maximum ratings for RMR were determined for each borehole section. The plots in Figure 4-2 are obtained for the RQD, fracture conditions, spacing rating that result into the RMR ranges on the right, respectively.

RMR seems to be rather constant along the entire hole. A slight decrease can be noticed as a trough just below 1,000 m. The ratings for tunnel orientation and water pressure were assumed for "fair conditions" and for a "completely dry" borehole, as prescribed for rock mass characterisation.

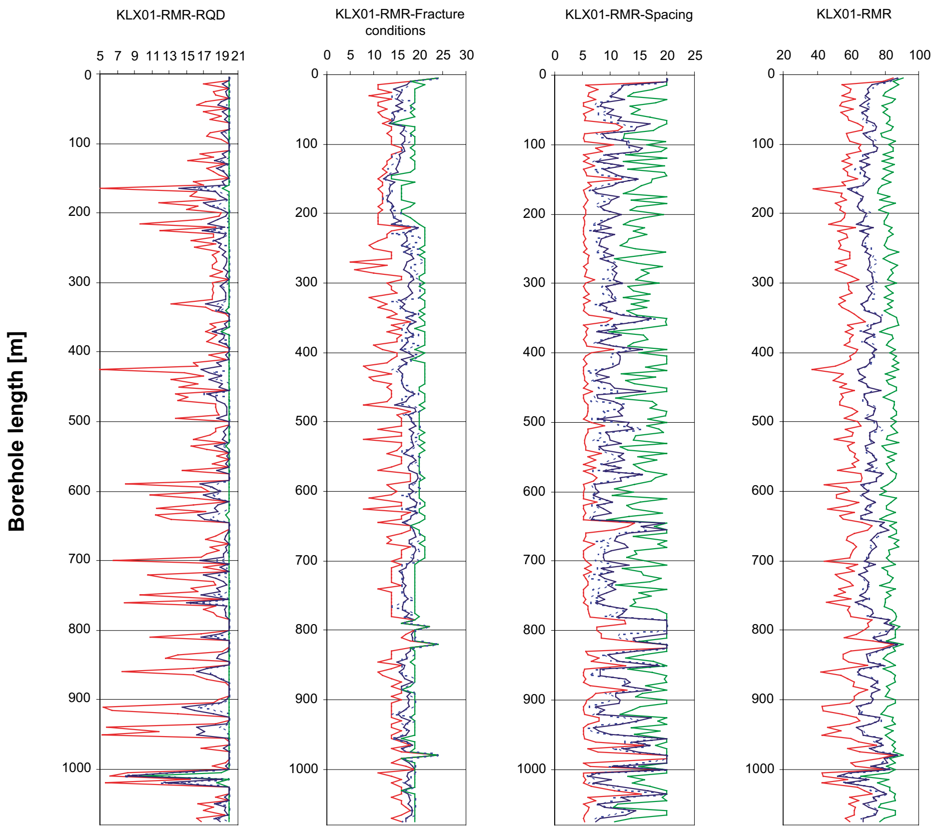

Figure 4-2. Ratings for RMR characterisation and resulting RMR values for borehole KLX01. The ratings for RQD, fracture conditions, fracture spacing are plotted with depth together with RMR. The lines in red, blue, dashed blue and green represent the minimum, average, and most frequent and maximum values observed in every core section of 5 m, respectively.

The RMR values were also summarised for each rock type group, for competent rock, fractures zones and for the whole borehole as shown in Appendix 1. In summary:

1) The poorest rock in the borehole is classified as "fair rock" (RMR = 52).
2) The fractured rock in the deformation zones show an average RMR of about 60, which means a rock mass at the upper range of the "fair rock" class.
3) The competent rock has a mean RMR of 72 that places it in the middle of the range of "good rock" (RMR between 61 and 80).
4) The best rock quality observed in the borehole reaches an RMR of 88 ("very good rock").

Rock Unit 1 and 3 exhibits a higher average RMR (RMR = 71 and 73 resp.) than Rock Unit 2, (RMR = 69).

4.4.3 Characterisation with Q

The input numbers for the Q system and the resultant Rock Quality Index for 5 m are plotted in Figure 4-3. As for RMR, the Q numbers are obtained through the choice of minimum, average, most frequent and maximum values of the geomechanical parameters logged along the borehole. The fracture set (for the special case of KLX01 see Section 4.2), roughness and alteration numbers are obtained for each borehole section of 5 m (see also Appendix 1). SRF is assigned to the fractured zones based on considerations about their width, depth, degree of fracturing and alteration, but also based on the ratio between the uniaxial compressive strength of the intact rock and the major rock stress. The fractured zones listed in Table 4-3 were assigned an SRF of 2.5. The Q parameter for water was assumed equal to 1 (dry borehole) as it is usually done for rock mass characterisation.

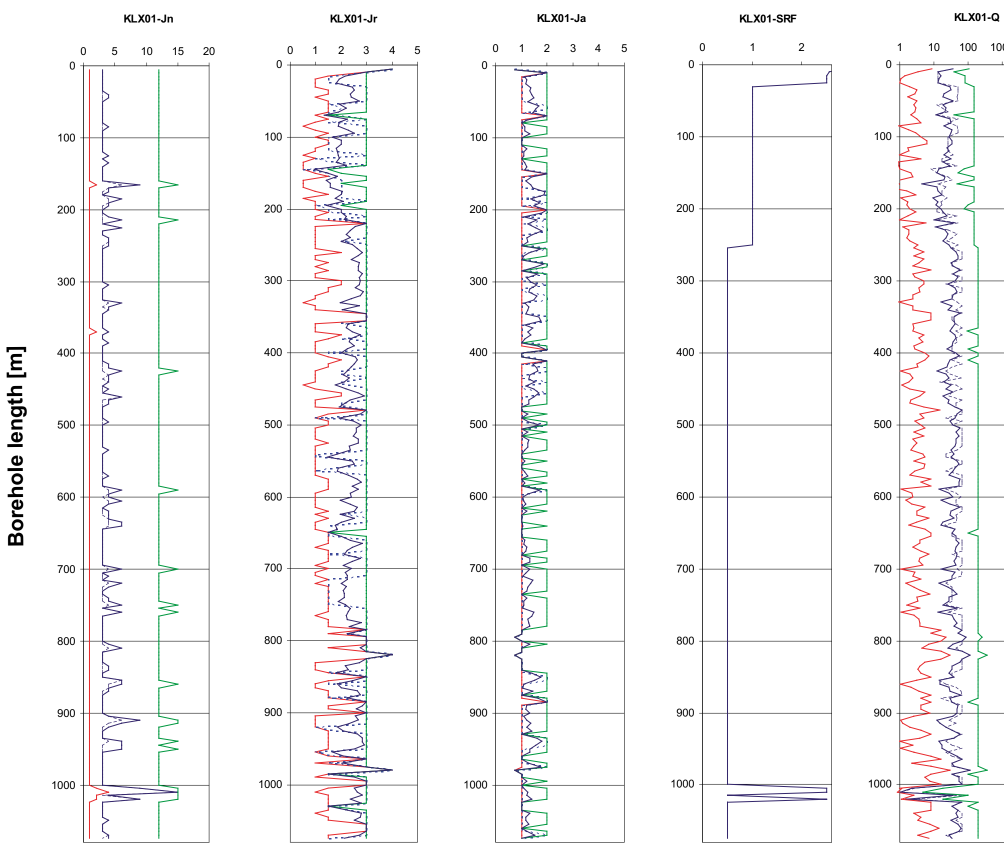

Figure 4-3. Numbers for Q characterisation and resulting Q values for borehole KLX01. The number for fracture set number, fracture roughness, fracture alteration and SRF are plotted with depth together with Q. The lines in red, blue, dashed blue and green represent the minimum, average, and most frequent and maximum values observed in every core section of 5 m, respectively.

The distinct depression in the plot of Q reflecting poorer rock just below 1,000 m depth can be found here as well as in the RMR values. However, according to the Q system, the rock along borehole KLX01 can be classified as “good rock” as the average Q is larger than 10 and the most frequent value is 33. Rock Unit 3 have higher Q than the other two rock units (Q value 40) whereas Rock Unit 1 and 2 have lower Q values (31 and 28, respectively).

Q values can be summarised as follows:

1) The poorest rock occurs in the deformation zone and has Q 0.7 (“very poor rock”).
2) The rock in the deformation zone has an average of 11 classed as “fair rock” and frequent Q of 2 that indicate a “poor rock” class.
3) The competent rock has average and frequent Q of 35 and 33, respectively, thus belonging to the class of “good rock”.
4) The best rock within the competent rock has a Q of 117, which means “very good rock”.

4.5 KLX03

4.5.1 Single-hole interpretation

The Rock Units and Deformation Zones observed by the single-hole interpretation of the core and borehole pictures are summarized in Table 4-4 /Carlsten et al. 2006b/. The rock units are characterised by the following rock types:

- RU1: Totally dominated by Ävrö granite (granite to quartz monzodiorite, generally porphyritic). Subordinate rock types comprise fine- to medium-grained granite, fine-grained diorite to gabbro (fine-grained mafic rock), fine-grained dioritoid (fine-grained intermediate rock), quartz monzodiorite (quartz monzonite to monzodiorite), diorite to gabbro and pegmatite.
- RU2: Totally dominated by Ävrö granite (granite to quartz monzodiorite, generally porphyritic). Subordinate rock types are dominated by diorite to gabbro (ca 8 m long sections). Furthermore, sections of fine- to medium-grained granite, quartz monzodiorite (quartz monzonite to monzodiorite), fine-grained dioritoid (fine-grained intermediate rock) and fine-grained diorite to gabbro (fine-grained mafic rock) occur.
- RU3: Totally dominated by quartz monzodiorite (quartz monzonite to monzodiorite). Subordinate rock types comprise ca 17 m long sections of fine-grained diorite to gabbro (fine-grained mafic rock). Furthermore, subordinate rock types comprise Ävrö granite (granite to quartz monzodiorite, generally porphyritic), fine- to medium-grained granite, pegmatite and fine-grained dioritoid (fine-grained intermediate rock).
- RU4: Totally dominated by quartz monzodiorite (quartz monzonite to monzodiorite). Subordinate rock types comprise fine- to medium-grained granite, pegmatite, fine-grained dioritoid (fine-grained intermediate rock) and medium- to coarse-grained granite.

The deformation zones are described as follows:

- DZ1: Sealed, hydrothermally altered fracture zone with relatively low frequency of open fractures. Scattered narrow sections are strongly foliated (low grade ductile shear zones) and overprinted by the hydrothermal alteration and the sealed fracture network.

Table 4-4. Partitioning of borehole KLX03: Rock units and Deformation zones /Carlsten et al. 2006b/.

Depth [m]	Rock Unit	Depth [m]	Deformation Zone
101–426	RU1		
426–620	RU2		
620–798	RU3	722–814	DZ1
798–1,000	RU4		

4.5.2 Characterisation with RMR

For each 5 m section of borehole, the geomechanical parameters from borehole logging were scrutinized. The minimum, average, most frequent and maximum rating for RMR was determined for each borehole section, sometimes through averaging processes (Appendix 2). The plots in Figure 4-4 show the RQD, fracture condition, spacing rating that results into the RMR ranges for rock mass characterisation on the right.

The RMR for the whole borehole ranges between 62 and 84, with in general a difference of about 10 between the competent rock and the deformation zones can be observed. More in detail:

1) The poorest rock in the deformation zones has a minimum RMR of 62 ("good rock").
2) The average RMR in the deformation zone is 74, placing it in the middle range of the "good rock" class.
3) The average rock quality in the competent rock mass is 83, thus in "very good rock".
4) The maximum RMR in the competent rock is 85, in the "very good rock".

Although the deformation zone displays lower RMR values than the competent rock the minimum value for rock quality never decreases below "good rock" in the entire borehole. The average values for the four different rock units are all in the "very good rock" class (ranging between 81 and 100) whereas it is only Rock Unit 3 that shows a RMR value within the "good rock" class (RMR value of 77).

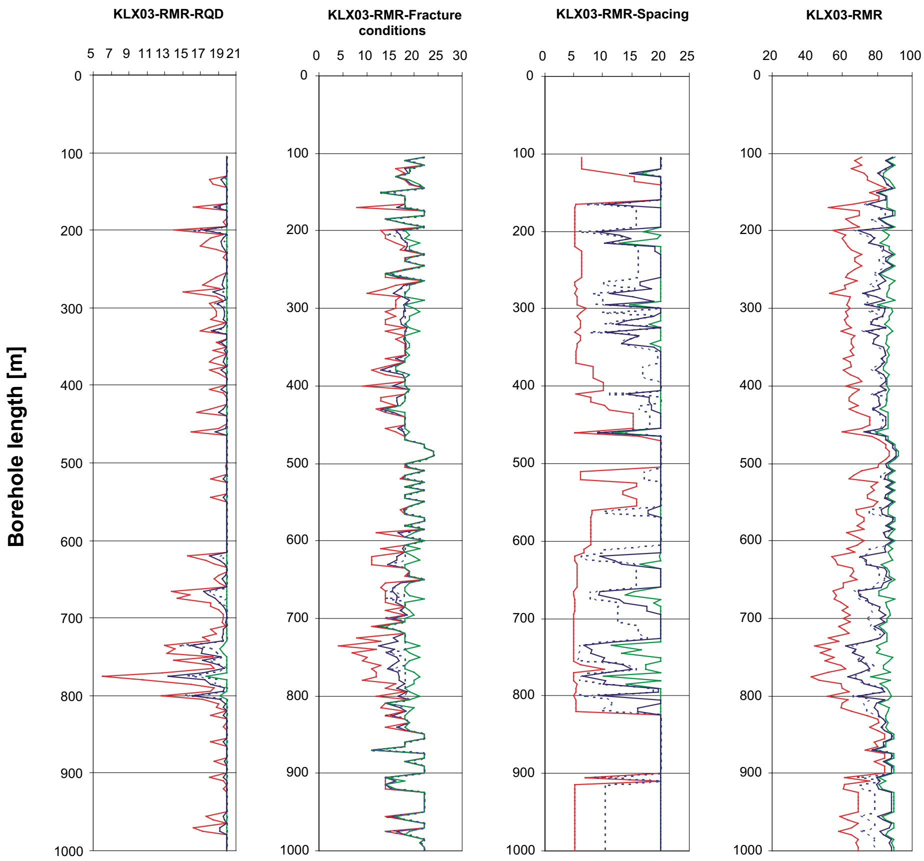

Figure 4-4. Ratings for RMR characterisation and resulting RMR values for borehole KLX03. The ratings for RQD, fracture conditions, fracture spacing are plotted with depth together with RMR. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed in every core section of 5 m, respectively.

4.5.3 Characterisation with Q

The input numbers for the Q system and the resultant Rock Quality Index for 5 m are plotted in Figure 4-5, respectively. As for RMR, the Q numbers are obtained through the choice of minimum, average, most frequent and maximum values of the geomechanical parameters logged along the borehole (Appendix 2). SRF is assigned to the fractured zones based on consideration about their width, depth, degree of fracturing and alteration, but also based on the ratio between the uniaxial compressive strength of the intact rock and the major rock stress. The fractured zones were assigned an SRF of 2.5. The Q number for water was assumed equal to 1 (dry borehole) as it is usually done for rock mass characterisation.

Similarly to the RMR values, Q shows that the rock quality in the borehole is generally very good with Rock Unit 3 in the "good rock" range (Q value of 32).

The rock mass can be classified for the purposes of characterisation as follows:

1) The poorest rock in the deformation zones has a minimum Q of 4 that corresponds to "fair rock".
2) The deformation zones have an average and frequent value of Q of 14 and 13, respectively, both values being in the category of "good rock".
3) The average and frequent Q values for the competent rock are in the range of "very good rock", respectively being 99 and 44.
4) The best rock section in the competent rock classes as "very good rock" according to Q (maximum value 704).

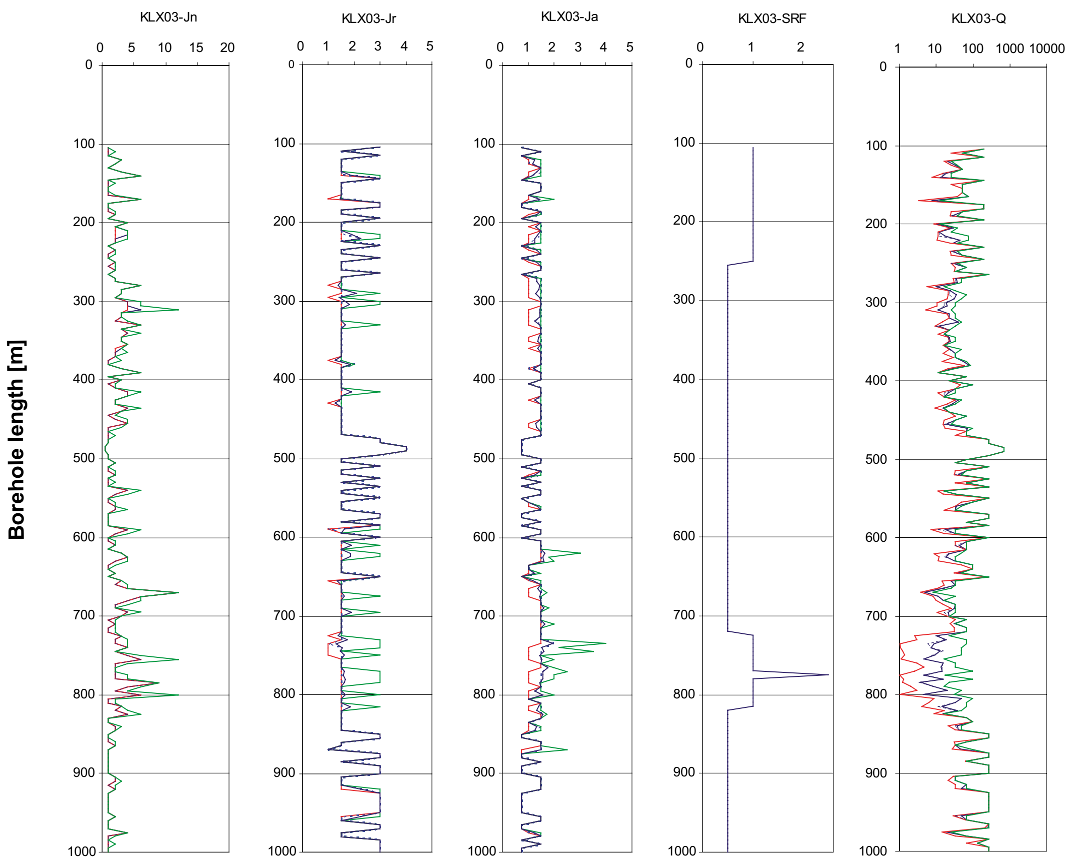

Figure 4-5. *Numbers for Q characterisation and resulting Q values for borehole KLX03. The number for fracture set number, fracture roughness; fracture alteration and SRF are plotted with depth together with Q. The lines in red, blue, dashed blue and green represent the minimum, average, and most frequent and maximum values observed in every core section of 5 m, respectively.*

4.6 KLX04

4.6.1 Single-hole interpretation

Table 4-5 contains the list of the Rock Units and Deformation Zones identified along borehole KLX04 /Carlsten et al. 2006c/. The rock units are shortly described as:

- RU1: Totally dominated by Ävrö granite. Subordinate rock types comprise scattered ca 4 m long sections of fine-grained diorite to gabbro, and scattered minor sections of fine- to medium-grained granite, fine-grained dioritoid and some pegmatite. The section 787–790 m is foliated.
- RU2: Mixture of Ävrö granite and quartz monzodiorite. Subordinate rock types comprise ca 17 m long sections of medium- to coarse-grained granite, fine-grained dioritoid, fine- to medium-grained granite, diorite to gabbro and fine-grained diorite to gabbro. Scattered up to 5 m long sections are foliated.
- RU3: Dominated by quartz monzodiorite with a ca 17 m long section (705–722 m) of fine- to medium-grained granite. Subordinate rock types Ävrö granite, pegmatite and fine- to medium-grained granite. A major part of this unit is foliated.

Six possible deformation zones have been identified in KLX04:

- DZ1: Strongly brecciated. Crush and chlorite-healed fractures.
- DZ2: One meter of crushed rock including severe alteration. Reactivated zone.
- DZ3: Zone centre at 296–297 m.
- DZ4: Brecciated, strongly altered rock.
- DZ5: Brittle deformation with brecciation (sealed network).
- DZ6: Repeated crush and sealed network. Alteration in upper part, but missing in the central part. Zone centre with strong inhomogeneous brittle deformation.

4.6.2 Characterisation with RMR

In Appendix 3, the minimum, average, most frequent and maximum rating for RMR are reported for each borehole section of 5 m. The plots in Figure 4-6 show RQD, fracture condition, spacing rating that results into the RMR ranges, respectively. The ratings for tunnel orientation and water pressure were assumed for “fair conditions” and for a “completely dry” borehole, as prescribed for rock mass characterisation.

Table 4-5. Partitioning of borehole KLX04: rock units, rock types and fractured deformation zones /Carlsten et al. 2006c/.

Depth [m]	Rock Unit	Depth [m]	Deformation Zone
100–385	RU1	227–230	DZ1
		254–258	DZ2
		295–298	DZ3
		325–326	DZ4
		346–355	DZ5
385–555	RU2		
555–680	RU1		
680–728	RU3		
728–992	RU1	875–973	DZ6

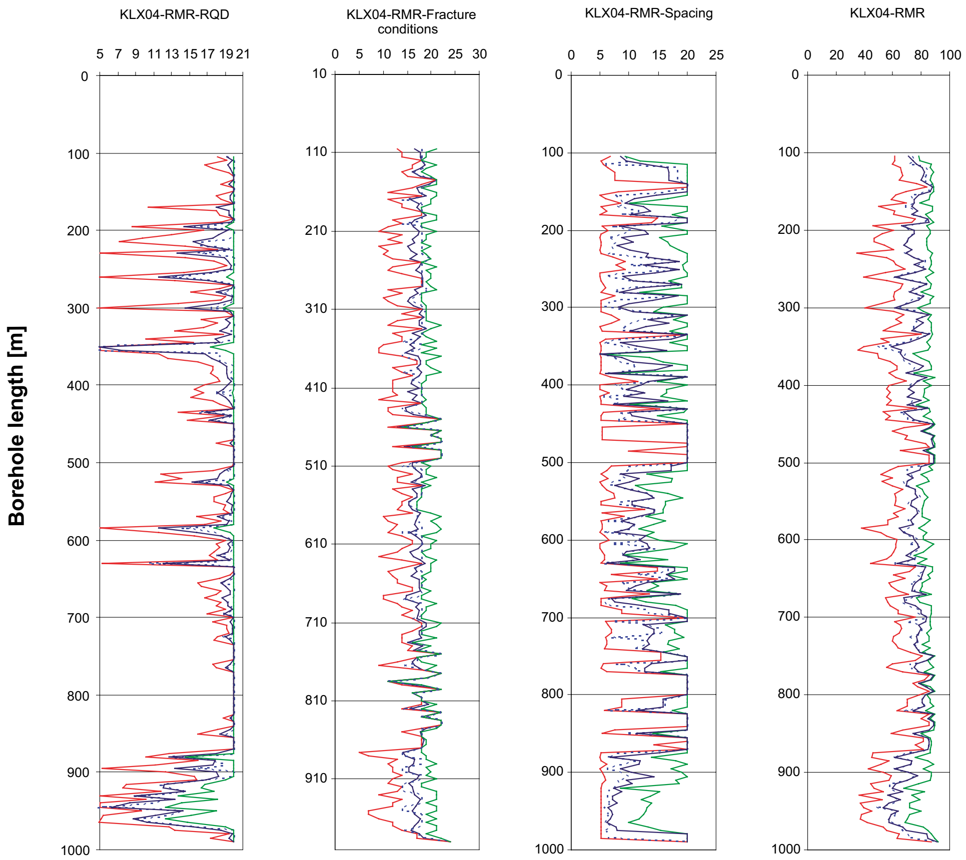

Figure 4-6. Ratings for RMR characterisation and resulting RMR values for borehole KLX04. The ratings for RQD, fracture conditions, fracture spacing are plotted with depth together with RMR. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed in every core section of 5 m, respectively.

The average RMR values found for the different rock units in the borehole range between 61 and 87, from "good" to "very good rock". The rock mass quality in Rock Unit 2 and 3 is generally higher (average RMR 79 for both) than for Rock Unit 1 (RMR 75) dominating the length of the borehole. At depth below 873 m Deformation Zone 6 causes the rock quality to decrease to 53, which indicate "fair rock".

The quality of the competent versus fractured rock can be summarised as follows:

1) The poorest rock quality observed in the borehole is RMR = 53 ("fair rock").
2) The average RMR in the deformation zones is 64 ("good rock").
3) The average RMR for the competent rock is 78 ("good rock").
4) The maximum rock mass quality in the competent rock was RMR = 90, which means "very good rock".

4.6.3 Characterisation with Q

The input numbers for the Q system and the resultant Rock Quality Index for 5 m are plotted in Figure 4-7. Here, the Q numbers are obtained through the choice of minimum, average, most frequent and maximum values of the geomechanical parameters logged along the borehole. The fracture set, roughness and alteration numbers are obtained for each borehole section of 5 m (see also Appendix 3). SRF was assigned for "characterisation" the same way as for the other boreholes.

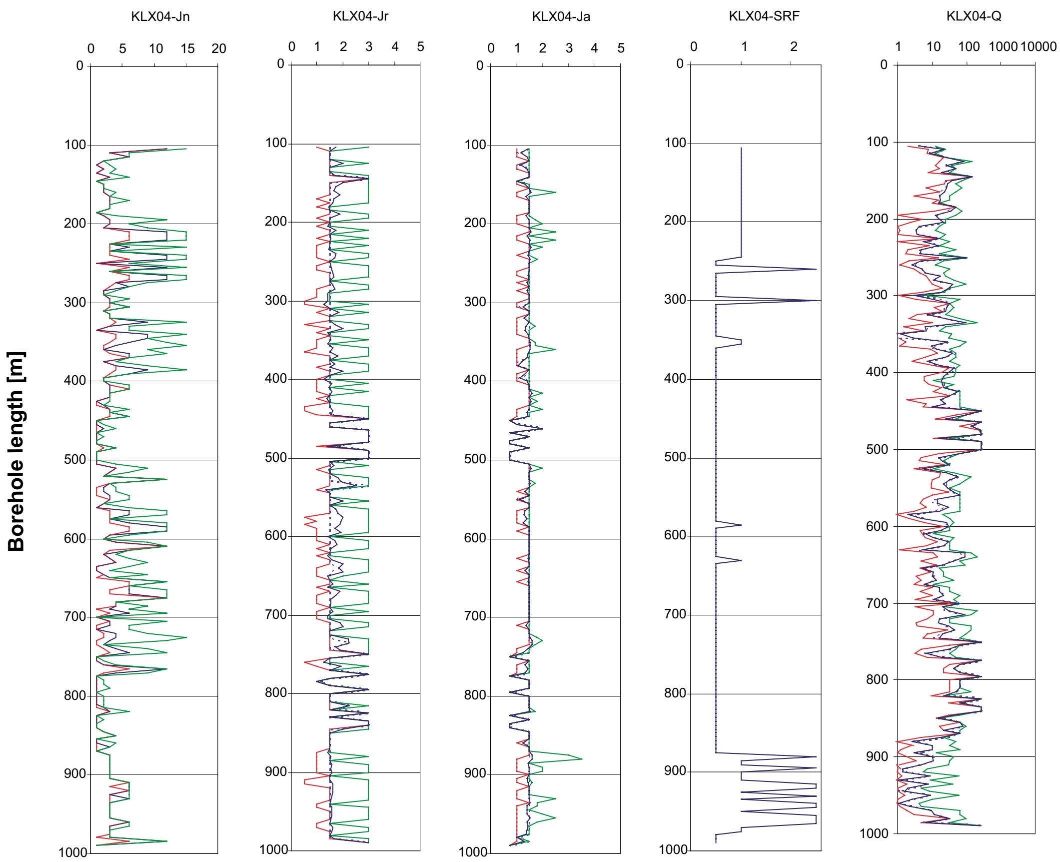

Figure 4-7. *Numbers for Q characterisation and resulting Q values for borehole KLX04. The number for fracture set number, fracture roughness; fracture alteration and SRF are plotted with depth together with Q. The lines in red, blue, dashed blue and green represent the minimum, average, and most frequent and maximum values observed in every core section of 5 m, respectively.*

The characterisation with Q shows that the Deformation Zones 2, 3 and 5 present poor rock mass quality. All these zones can be found in Rock Unit 1. The average value of Q in Rock Unit 1 is about 37 ("good rock"). However, the same section also shows a minimum Q of 1 that corresponds to "poor to very poor rock". The differences between competent and fractured rock can be summarised as:

1) The poorest rock quality in the deformation zones is Q = 1 ("poor to very poor rock").
2) An average Q of 5 is observed in the deformation zones ("fair rock").
3) The competent rock has an average Q of 52 that indicates "very good rock".
4) The maximum observed Q value belongs to the competent rock and is 264 ("very good rock").

4.7 KAV04

4.7.1 Single-hole interpretation

In borehole KAV04, the following Rock units were recognised /Carlsten et al. 2006a/:

- RU1: Dominated by granite to quartz monzodiorite, generally porphyritic (Ävrö granite). Subordinate rock types include fine-grained dioritoid, fine- to medium-grained granite, pegmatite and a few sections of medium- to coarse-grained granite. The Ävrö granite is vuggy in character in the section between 256 and 257.5 m. Scattered sections are foliated.

- RU2: Mixture of granite to quartz monzodiorite, generally porphyritic (Ävrö granite) and quartz monzodiorite. Subordinate rock types include sections shorter than 30 m of fine-grained dioritoid, fine- to medium-grained granite, pegmatite, fine-grained mafic rock (fine-grained diorite to gabbro) and diorite to gabbro. Scattered sections are foliated.
- RU3: Mixture of granite to quartz monzodiorite, generally porphyritic (Ävrö granite) and fine- to medium-grained granite. Quartz monzodiorite occurs in sections shorter than 20 m. Subordinate rock types include fine-grained dioritoid (fine-grained, intermediate, magmatic rock), pegmatite, medium- to coarse-grained granite and fine- to medium-grained granite (in remaining rock types). Scattered sections are foliated and these often correlate with sections of fine- to medium-grained granite.
- RU4: Mixture of granite to quartz monzodiorite, generally porphyritic (Ävrö granite) and fine- to medium-grained granite. Subordinate rock types include medium- to coarse-grained granite, fine- to medium-grained granite (in remaining rock types), pegmatite and certain sections of fine-grained dioritoid (fine-grained, intermediate, magmatic rock). Foliated sections correlate with sections of fine- to medium-grained granite. This rock unit is characterized by an inhomogeneous brittle overprinting.
- RU5: Totally dominated by fine-grained dioritoid (fine-grained, intermediate, magmatic rock). Subordinate rock types include fine- to medium-grained granite and pegmatite. This rock unit is characterized by an inhomogeneous brittle overprinting.
- RU6: Inhomogeneous mixture of granite to quartz monzodiorite, generally porphyritic (Ävrö granite), quartz monzodiorite, fine-grained dioritoid (fine-grained, intermediate, magmatic rock), fine- to medium-grained granite and fine-grained mafic rock (fine-grained diorite to gabbro). This rock unit is characterized by an inhomogeneous brittle overprinting.

One deformation zone was identified by the single-hole interpretation:

- DZ1: is characterized by an inhomogeneous brittle-cataclastic deformation.

4.7.2 Characterisation with RMR

For each 5 m section of borehole, the geomechanical parameters from borehole logging were scrutinized to determine the minimum, average, most frequent and maximum rating for RMR (Appendix 4). The plots in Figure 4-8 are obtained for the RQD, fracture condition, spacing rating that results into the RMR ranges shown in the right hand plot. The ratings for tunnel orientation and water pressure were assumed for “fair conditions” and for a “completely dry” borehole, as prescribed for rock mass characterisation.

Table 4-6. Partitioning of borehole KAV04: rock units, rock types and fractured deformation zones /Carlsten et al. 2006a/.

Depth [m]	Rock Unit	Depth [m]	Deformation Zone
100–89	RU1		
289–607	RU2		
607–690	RU3		
690–863	RU4	840–900	DZ1
863–948	RU5		
948–1,004	RU6		

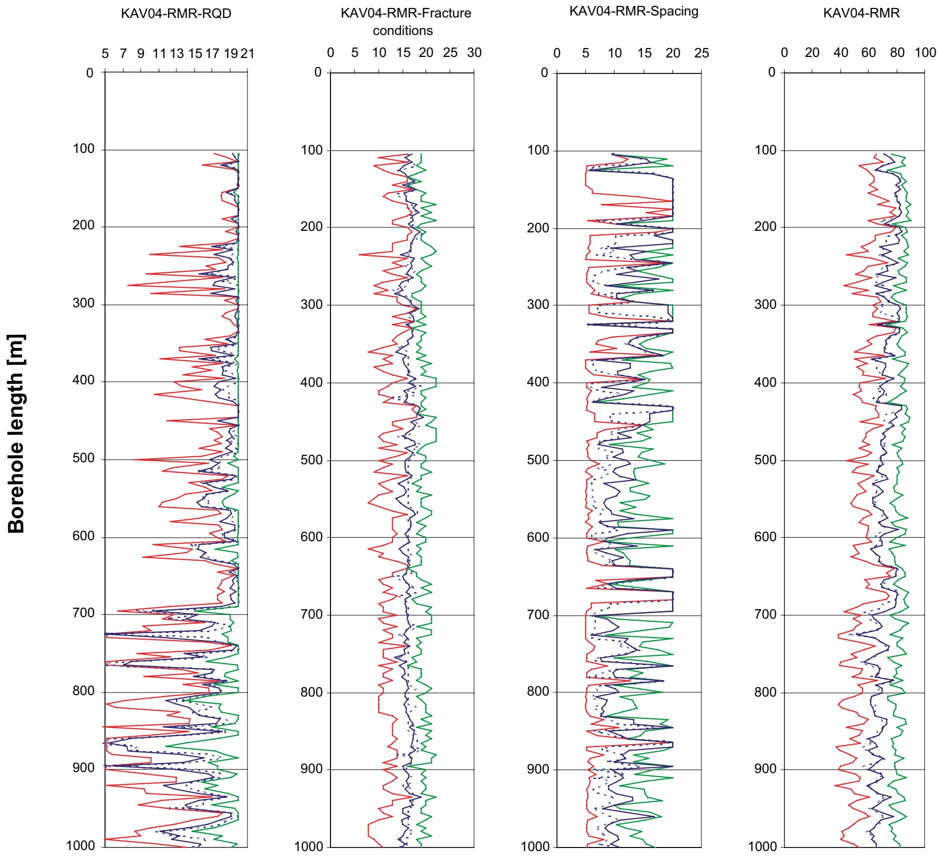

Figure 4-8. *Ratings for RMR characterisation and resulting RMR values for borehole KAV04. The ratings for RQD, fracture conditions, fracture spacing are plotted with depth together with RMR. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed in every core section of 5 m, respectively.*

The different rock units have similar rock mass quality with an average RMR within the "good rock" class, around 71. A slight lowering of rock mass quality downwards in the borehole can possibly be discerned. More in detail:

1) The deformation zones show a minimum RMR of about 60 ("fair rock").
2) On average, the RMR in the deformation zones is rather high (65, "good rock").
3) The competent rock exhibit an average RMR of 72 (also "good rock").
4) The rock mass quality is topped by the competent rock that has a maximum RMR of 84 ("very good rock").

4.7.3 Characterisation with Q

The input Q numbers are obtained through the choice of minimum, average, most frequent and maximum values of the geomechanical parameters logged along the borehole (see also Appendix 4). The Q numbers and the resultant Rock Quality Index for 5 m borehole sections are plotted in Figure 4-9. SRF and water factor are assigned according to the procedure for rock mass characterisation.

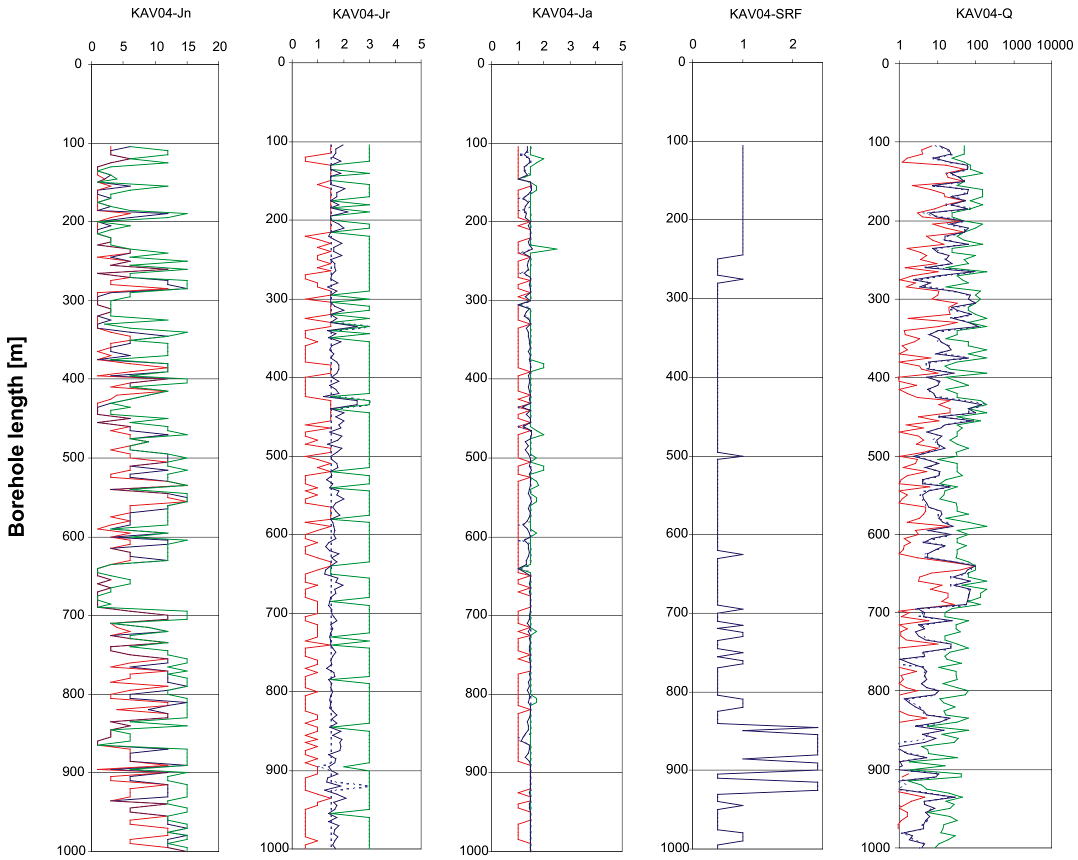

Figure 4-9. *Numbers for Q characterisation and resulting Q values for borehole KAV04. The number for fracture set number, fracture roughness; fracture alteration and SRF are plotted with depth together with Q. The lines in red, blue, dashed blue and green represent the minimum, average, and most frequent and maximum values observed in every core section of 5 m, respectively.*

Down to 700 m depth the Q values indicate a "good" to "very good rock" quality (Q values from 25 to 46). At 700 m and below the rock quality decreases to values showing fair to poor rock quality (Q values between 2 and 7). The quality of the competent and fractured rock can be listed as:

1) The worse rock in the fractured rock has a Q value of 0.5 ("very poor rock").
2) The average quality in the deformation zones is Q = 3.8 ("poor rock").
3) The average quality in the competent rock is Q = 23 ("good rock").
4) The best quality rock is in the competent rock and has a maximum Q value of 141 ("very good rock").

4.8 Evaluation of the uncertainties

4.8.1 Background

The empirical classification systems for characterisation of the rock mass are affected by the uncertainties on the geological and rock mechanical data and intrinsic uncertainties due to the structure of the empirical systems themselves. The uncertainty on a single parameter can vary widely depending on the acquisition technique, subjective interpretation or size of the sample population. But uncertainty can also derive from the way the values of the indexes and ratings are combined with each other. Different operators may obtain and combine the ratings and indices in slightly different ways. The values of Q or RMR for a certain section of borehole may result from the combination of the possible ratings that range from a minimum to maximum value in a certain rock mass volume.

In this report, it was decided to correlate the uncertainty of Q and RMR to the range of their possible values derived from the width of the interval between the minimum and maximum occurring value of each index or rating for each core section. The range of the possible minimum and maximum values of RMR and Q is obtained by combining the ratings and indices in the most unfavourable and favourable way, respectively.

The spatial variability of the geological parameters adds more variability to the indices and ratings and this also mirrors onto the uncertainty on the mean value. For removing the spatial variability, the differences between maximum possible and mean value and minimum possible and mean value are evaluated for each 5 m borehole section and normalised by the mean value. Each obtained value is considered as a sample from a statistical population of variation intervals. The concept of "confidence interval of a population mean" can then be applied to quantify the uncertainty. According to the "Central Limit Theorem" /Peebles 1993/, the 95% confidence interval of the mean Δconf mean is obtained as:

$$\Delta_{conf\ mean} = \pm \frac{1.96\ \sigma}{\sqrt{n}} \qquad (3)$$

where σ is the standard deviation of the population and n is the number of values of the each sample. In practice, two confidence intervals are determined by the proposed technique, one related to the maximum value of RMR and Q, and the other related to the minimum value:

$$\Delta P_{+conf\ mean} = \frac{P_{MAX} - P_{MEAN}}{\sqrt{n}}$$
$$\Delta P_{-conf\ mean} = \frac{P_{MEAN} - P_{MIN}}{\sqrt{n}} \qquad (4)$$

where P is the rating, either RMR or Q, with its possible maximum and minimum values and mean value, respectively. This technique also applies to the rock mechanical parameters derived from the empirical systems (in Chapter 5) such as: deformation modulus, Poisson's ratio, uniaxial compressive strength, friction angle and cohesion of the rock mass.

4.8.2 Uncertainty of RMR and Q

In Table 4-7, the confidence of the RMR mean value is summarised for the competent and fractured rock in borehole KLX01, KLX03, KLX04 and KAV04. The uncertainty on the mean value is larger for the fractured/deformation zones than for the competent rock. This is due to the local variability of the geological features that can give rise to different interpretations and resulting RMR. In Table 4-8, the confidence of the Q mean value is also summarised for the competent and fractured rock in the four boreholes. The confidence of RMR is generally better than that of Q due to the wide range of variation of the Q values (that usually vary over several orders of magnitude). However, this kind of variations is compatible with the use of Q for design applications.

Table 4-7. Uncertainty of the mean values of RMR for boreholes KLX01, KLX03, KLX04 and KAV04 with borehole sections of 5 m.

	Competent rock		Fractured rock	
	Lower uncertainty on the mean	Upper uncertainty on the mean	Lower uncertainty on the mean	Upper uncertainty on the mean
KLX01	–1%	+1%	–11%	+14%
KLX03	–1%	0%	–6%	+4%
KLX04	–1%	+1%	–6%	+5%
KAV04	–2%	+1%	–8%	+7%

Table 4-8. Uncertainty of the mean values of Q for boreholes KLX01, KLX03, KLX04 and KAV04 with borehole sections of 5 m.

	Competent rock		Fractured rock	
	Lower uncertainty on the mean	Upper uncertainty on the mean	Lower uncertainty on the mean	Upper uncertainty on the mean
KLX01	–6%	+35%	–44%	+321%
KLX03	–2%	+2%	–19%	+74%
KLX04	–4%	+11%	–16%	+114%
KAV04	–5%	+25%	–27%	+117%

5 Mechanical properties of the rock mass

5.1 Deformation modulus of the rock mass

By means of empirical formulas, it is possible to obtain an estimation of the equivalent deformation modulus of the rock mass. According to /Serafim and Pereira 1983/ the deformation modulus of the rock mass is given by:

$$E_m = 10^{\frac{RMR-10}{40}} \qquad (5)$$

and according to /Barton 2002/:

$$E_m \approx 10\ Q_c^{1/3}\ \text{(GPa)} \qquad (6)$$

In this report, the determination of the deformation modulus is made for core sections of 5 m (see Appendix 1 to 5). The figures in the following sections report the variation of the deformation modulus with a continuous blue line, while the maximum possible and minimum values are respectively plotted in red and green. These two values are used in Section 5.1.5 for the evaluation of the uncertainties according to Section 4.8.1. In the following sections, reference to the minimum and maximum deformation modulus are done when addressing the peaks and troughs of the blue continuous curve, which represent the expected average value of the deformation modulus at each depth. In all the figures, the dotted line represent the expected more frequent values.

5.1.1 KLX01

In Figure 5-1, the plots of the minimum, average, most probable and maximum expected deformation modulus of the rock mass are given for borehole KLX01. Comparing the mean values obtained independently by means of RMR and Q, a rather good agreement can be observed in the borehole. Larger differences are found above 50 m depth. This is an exception to the behaviour in the rest of the borehole. On average, the deformation modulus of the competent rock is 36 GPa, when obtained from RMR, and 37 GPa when obtained from Q. The values are similar to each other when the deformation zones are concerned: the deformation modulus from RMR is 19 GPa while the deformation modulus from Q is 20 GPa, on average, respectively. The minimum obtained deformation modulus is in the more fractured rock of the deformation zones and is 11 GPa, according to RMR and Q. The maximum value of the deformation modulus coincides in both cases because a threshold of 75 GPa was adopted to limit upward the range of variation of the results of Equations (5) and (6). This value corresponds to the Young's modulus of the intact rock samples in laboratory.

5.1.2 KLX03

In Figure 5-2, the plots of the minimum, average, most probable and maximum expected deformation modulus are given for borehole KLX03. For this borehole a comparison between the mean values obtained independently by means of RMR and Q, a rather good agreement can be observed in the lower part of the borehole (from about 850 m depth). Larger differences are found for the depths between about 300 and 470 m and about 780 m and 860 m. In general, Q gives deformation moduli lower and more varying than RMR. On average, the deformation modulus of the competent rock is 67 GPa, when obtained from RMR, and 49 when obtained from Q.

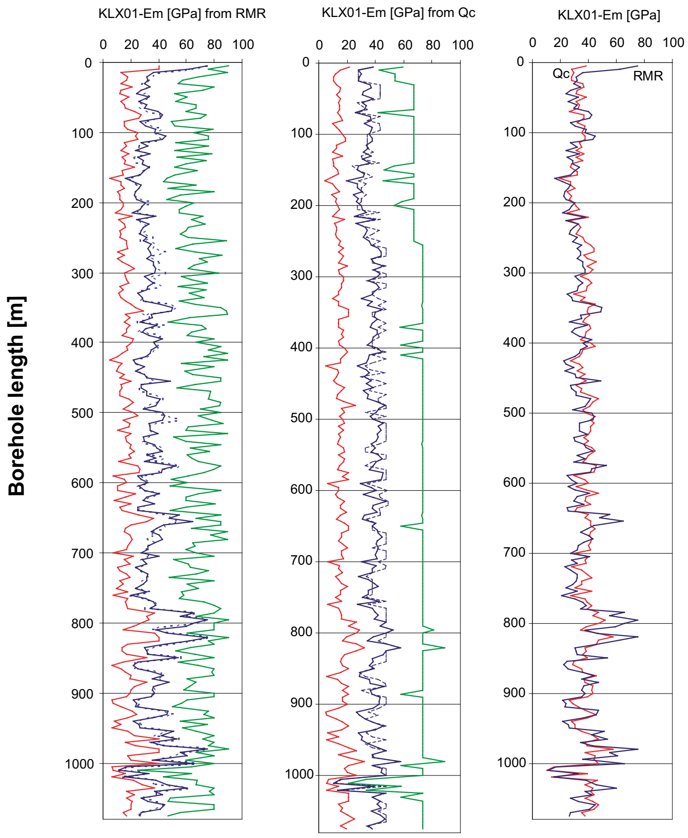

Figure 5-1. *Deformation modulus of the rock mass derived from RMR and Q values for each core section of 5 m for borehole KLX01. A comparison of the mean values along the borehole is given in the graph on the right.*

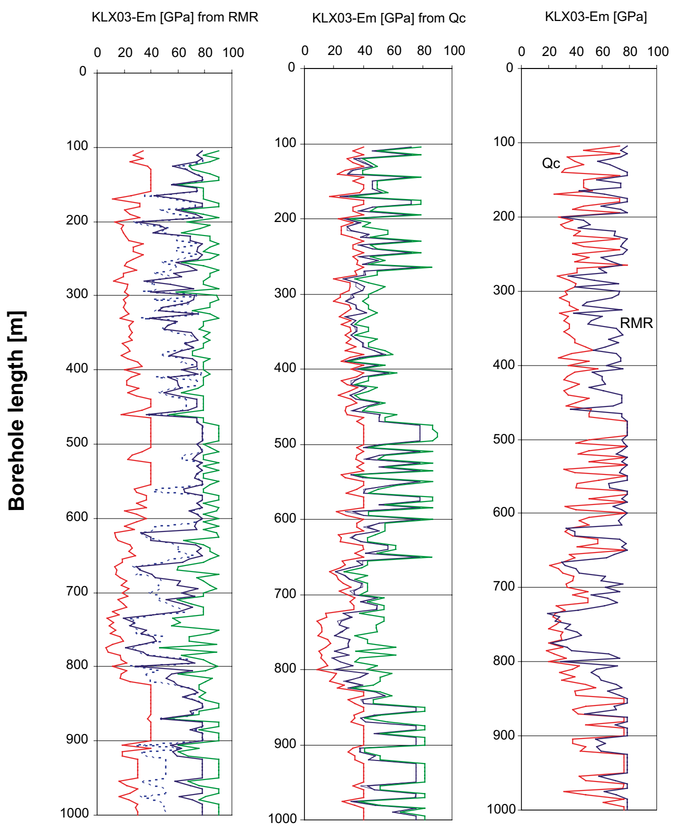

Figure 5-2. *Deformation modulus of the rock mass derived from RMR and Q values for each core section of 5 m for borehole KLX03. A comparison of the mean values along the borehole is given in the graph on the right.*

The values have a similar range when the deformation zones are concerned, even though they are generally lower: the average deformation modulus from RMR is 42 GPa while the deformation modulus from Q is 28 GPa, respectively. Both the empirical Equations (5) and (6) provide minimum values of the deformation modulus between 20 and 19 GPa in the deformation zones, thus showing a rather good agreement between the two independent methods.

5.1.3 KLX04

In Figure 5-3, the plots of the minimum, average, most probable and maximum expected deformation modulus are given for borehole KLX04. Comparing the mean values of the elastic modulus derived from RMR or Q, a rather good agreement can be observed in the whole borehole. On average, the deformation modulus of the competent rock is 52 GPa, when obtained from RMR, and 40 when obtained from Q. The values are much closer to each other when the deformation zones are concerned: the average deformation modulus from RMR is 24 GPa while the deformation modulus from Q is 20 GPa, respectively. The minimum obtained deformation modulus in the more fractured rock of the deformation zones is between 12 and 13 GPa according to RMR and Q, respectively. The good agreement between the two empirical methods is clearly shown in Figure 5-3.

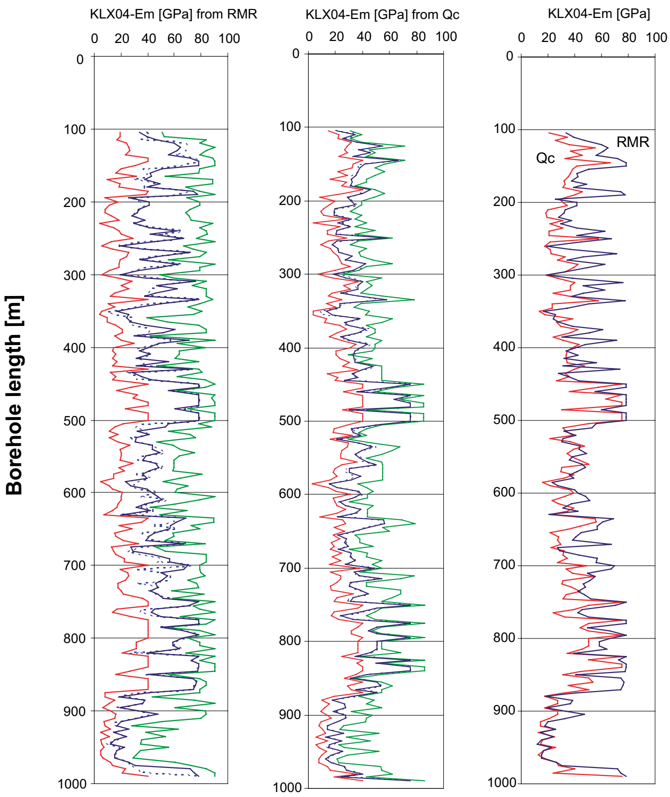

Figure 5-3. *Deformation modulus of the rock mass derived from RMR and Q values for each core section of 5 m for borehole KLX04. A comparison of the mean values along the borehole is given in the graph on the right.*

5.1.4 KAV04

In Figure 5-4, the plots of the minimum, average, most probable and maximum expected deformation modulus are given for borehole KAV04. When comparing the two empirical systems a good agreement between them can be noticed. For the competent rock, the average deformation modulus predicted is 52 and 30 GPa for RMR and Q, respectively. The correspondent value for the deformation zones is 24 and 18 GPa, the first value being obtained by means of RMR. The minimum value observed in the deformation zones is very similar for the two methods and is between 11 and 12 GPa. In Figure 5-1 a general trend of the deformation modulus in the borehole manifested as a lowering of the average deformation modulus with depth from about 48 GPa close to the surface to 23 GPa at depth around 900 m.
The maximum calculated value is affected by the truncation at 75 GPa imposed to all the empirically calculated values.

5.1.5 Uncertainties

Based on the technique presented in Section 4.8.1, the uncertainties on the deformation modulus could be evaluated for the two empirical methods. The uncertainty determination is shown in Table 5-1 and Table 5-2. According to RMR and Equation (5), it can be noticed that the uncertainty estimated for the deformation modulus the deformation zones is almost three times the uncertainty in competent rock mass. This is due, firstly, to less variation of the geomechanical parameters in the competent rock mass than in the deformation zones. Secondly, to the fact that the estimation of the mean deformation modulus of the rock mass in the competent rock is made based on a much larger number of values than for the deformation zones which

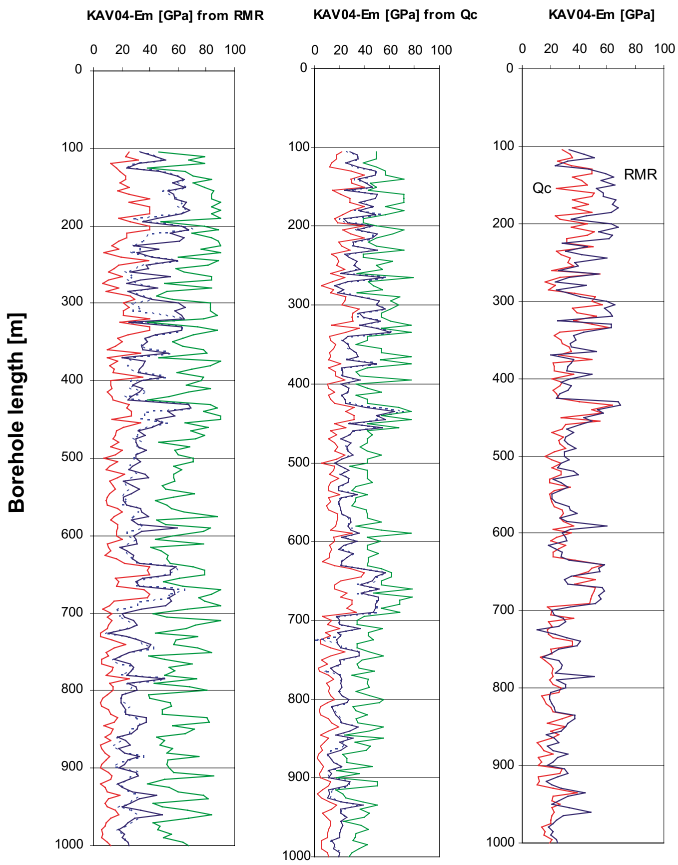

Figure 5-4. Deformation modulus of the rock mass derived from RMR and Q values for each core section of 5 m for borehole KAV04. A comparison of the mean values along the borehole is given in the graph on the right.

Table 5-1. Uncertainty of the mean values of the deformation modulus Em from RMR for borehole KLX01, KLX03, KLX04, and KAV04 and borehole sections of 5 m.

	Competent rock		Fractured rock	
	Lower uncertainty on the mean	Upper uncertainty on the mean	Lower uncertainty on the mean	Upper uncertainty on the mean
KLX01	–3%	+7%	–26%	+86%
KLX03	–5%	+2%	–15%	+22%
KLX04	–5%	+4%	–13%	+31%
KAV04	–4%	+7%	–19%	+40%

Table 5-2. Uncertainty of the mean values of the deformation modulus Em from Qc for borehole KLX01, KLX03, KLX04, and KAV04 and borehole sections of 5 m.

	Competent rock		Fractured rock	
	Lower uncertainty on the mean	Upper uncertainty on the mean	Lower uncertainty on the mean	Upper uncertainty on the mean
KLX01	–4%	+6%	–28%	+52%
KLX03	–2%	+1%	–12%	+17%
KLX04	–3%	+3%	–10%	+18%
KAV04	–3%	+5%	–19%	+25%

greatly diminishes the uncertainties. The uncertainty on the mean value for competent rock might, in this case, range from –5% to +7%. For example, if an average deformation modulus of 52 GPa is calculated, the actual range of variation of the mean value might be between 51.2 GPa and 55.0 GPa for the competent rock mass. For the deformation modulus obtained from Q this range could be slightly smaller, between 51.2 GPa and 54.1 GPa.

RMR was chosen as main parameter for the determination of the rock mass mechanical properties because it is provided with a set of formulas that quantify the rock mass as a continuum, isotropic elastic medium. These parameters are often required for continuum numerical modelling.

5.2 Poisson's ratio of the rock mass

The Poisson's ratio of the rock mass is often determined as a fraction of that of the intact rock. This fraction is determined by the ratio between the deformation modulus of the rock mass and that of the intact rock. Since there are two available values of the deformation modulus, the Poisson's ratio from derived from Q and RMR can be determined. In the appendices, however, only the value from RMR is reported since a good agreement between the two methods was observed in Section 5.1. The uncertainty on the Poisson's ratio can easily be obtained from that of the deformation modulus of the rock mass in Section 5.1.5.

5.2.1 KLX01

Figure 5-5 shows the variation of the Poisson's ratio determined by means of RMR along borehole KLX01. The average Poisson's ratio for the Rock units varies between 0.06 and 0.12. For the competent rock, the average Poisson's ratio is 0.12 with maximum values of 0.24. For the rock in the deformation zones (more fractured rock), the estimated average Poisson's ratio is 0.06 while the minimum expected value is 0.04.

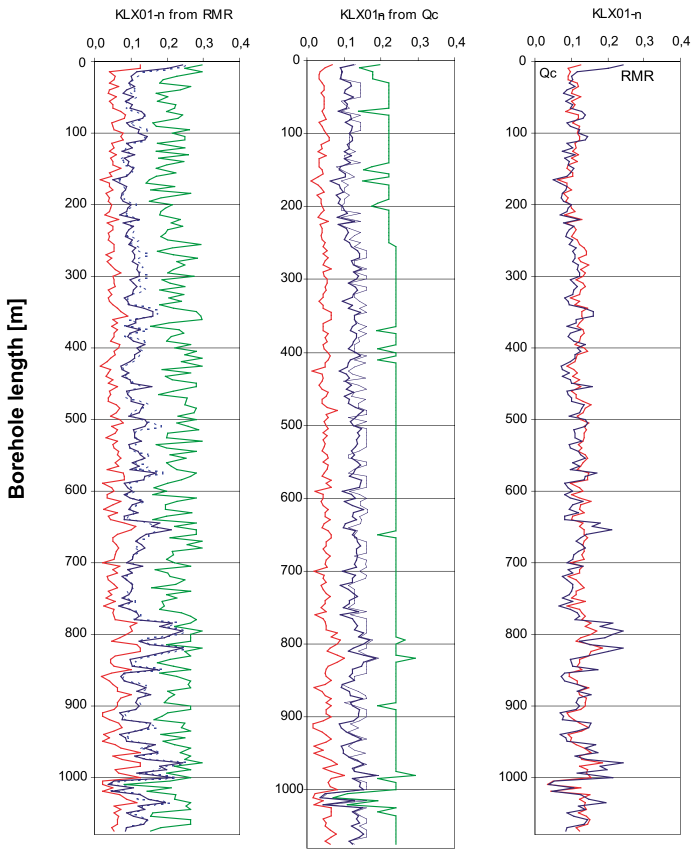

__Figure 5-5.__ Poisson's ratio derived from RMR and Q values for each core section of 5 m for borehole KLX01. A comparison of the mean values along the borehole is given in the graph on the right.

5.2.2 KLX03

For borehole KLX03, the average Poisson's ratio can be estimated about 0.20 and 0.14 for the competent and fractured rock, respectively. The maximum and minimum values of the Poisson's ratio along the borehole are 0.21 and 0.07, respectively (Figure 5-6).

5.2.3 KLX04

In Figure 5-7, the variation of the Poisson's ratio with depth for borehole KLX04 is shown. In this borehole, the competent rock shows an average and maximum value of respectively 0.14 and 0.23. The rock in the deformation zones (more fractured rock), has an average Poisson's ratio of 0.06 and a minimum value of 0.03. The Rock units present average values varying between 0.03 and 0.23.

5.2.4 KAV04

Borehole KAV04 presents Poisson's ratio values between 0.02 and 0.29 (Figure 5-8). The average Poisson's ratio in the competent rock and deformation zones is 0.11 and 0.08, respectively. The average for the Rock units varies between 0.03 and 0.20.

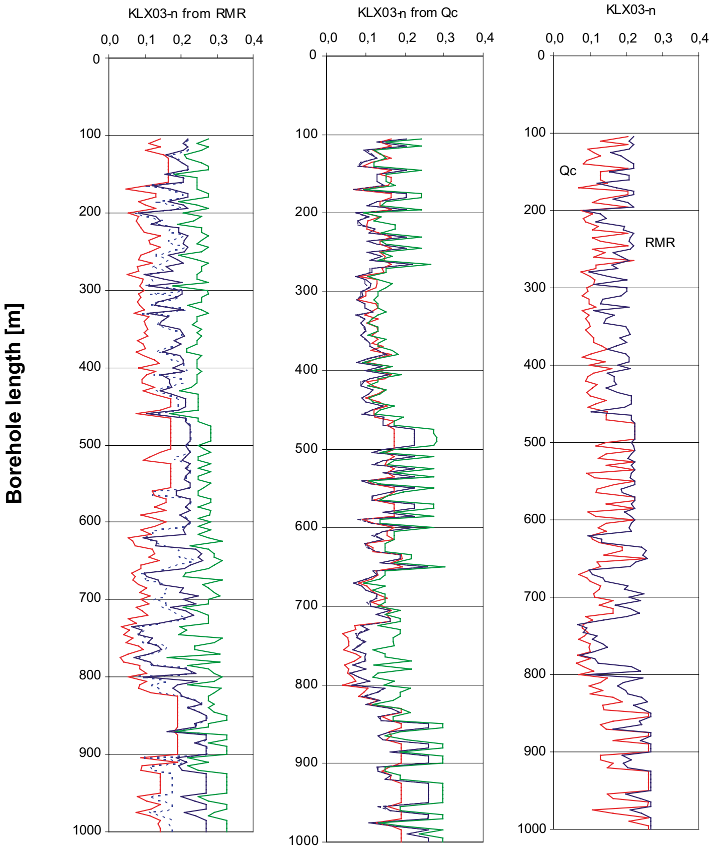

Figure 5-6. *Poisson's ratio derived from RMR and Q values for each core section of 5 m for borehole KLX03. A comparison of the mean values along the borehole is given in the graph on the right.*

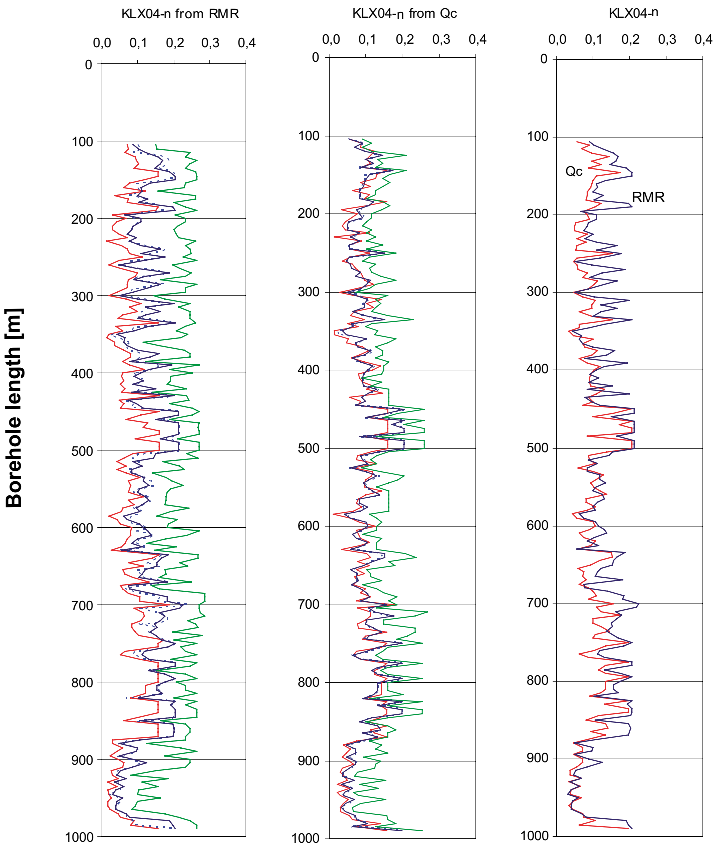

Figure 5-7. *Poisson's ratio derived from RMR and Q values for each core section of 5 m for borehole KLX04. A comparison of the mean values along the borehole is given in the graph on the right.*

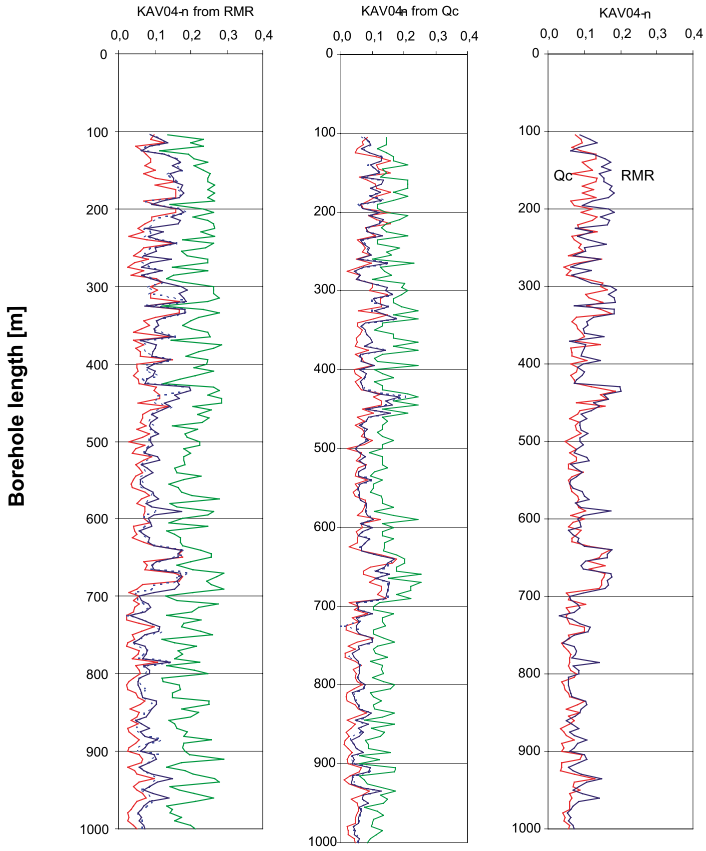

Figure 5-8. Poisson's ratio derived from RMR and Q values for each core section of 5 m for borehole KAV04. A comparison of the mean values along the borehole is given in the graph on the right.

5.3 Uniaxial compressive strength of the rock mass

The equivalent uniaxial compressive strength of the rock mass takes into account the strength of the intact rock and the negative contribution of the rock fractures. Thus, it is not the same thing as the uniaxial compressive strength given in Section 3. The uniaxial compressive strength of the rock mass (UCS) is here determined in two ways:

- by means of the relations between GSI /Hoek et al. 2002/, RMR and the Hoek & Brown's Criterion, where the exponent "a" is assumed to be 0.5. This Criterion is curvilinear and tends to rapidly decrease towards $UCS_{H\&B}$ for low confinement stresses.
- by means of the friction angle and cohesion of the rock mass. These parameters can be obtained by linear interpolation of the Hoek & Brown's Criterion, thus linearly decrease toward $UCS_{M\text{-}C}$ for low confinement stresses. For Simpevarp and Laxemar, it can be observed that $UCS_{M\text{-}C}$ is often about two times $UCS_{H\&B}$.

The values obtained from the Hoek & Brown Criterion for the five boreholes are tabulated and plotted in the Appendices 1 to 4. The values of $UCS_{M\text{-}C}$ can easily be obtained from the following equation /Hoek et al. 2002/:

$$UCS_{M\text{-}C} = \frac{2\,c'\cos\phi'}{1-\sin\phi'} \qquad (7)$$

where c' and φ' are the cohesion and friction angle resulting from the linear fit of the Hoek & Brown's Criterion for a certain confine stress interval. Typically in this report, the confinement stress interval considered to calculate c' and φ' is between 10 and 30 MPa, as it will be presented in Section 5.4.

The values of the Q-parameter Qc are also reported for comparison. These values are however not commented here because they have no clear physical definition.

5.3.1 KLX01

The variation of the rock mass compressive strength calculated from RMR and Qc for KLX01 is shown in Figure 5-9. The uniaxial compressive strength from RMR in the Rock units varies between 14 and 29 MPa. The competent rock mass exhibits an average UCS of 26 MPa while the fractured rock mass in the deformation zones has an average UCS according to Hoek & Brown of 14 MPa. The UCS along the borehole varies between 9 and 62 MPa.

When Equation (7) is used, the apparent UCS of the rock mass from the Mohr-Coulomb envelope results in 80 MPa for the competent rock mass and 64 MPa for the deformation zones, respectively.

5.3.2 KLX03

Figure 5-10 shows the variation of the rock mass compressive strength from RMR and Q in borehole KLX03. The average UCS from RMR ranges between 34 and 66 MPa for the three rock units. For the whole borehole, instead, a variation of UCS between 16 and 88 MPa can be observed. The competent rock exhibits an average value of 57 MPa and the deformation zones an average UCS of 34 MPa, respectively.

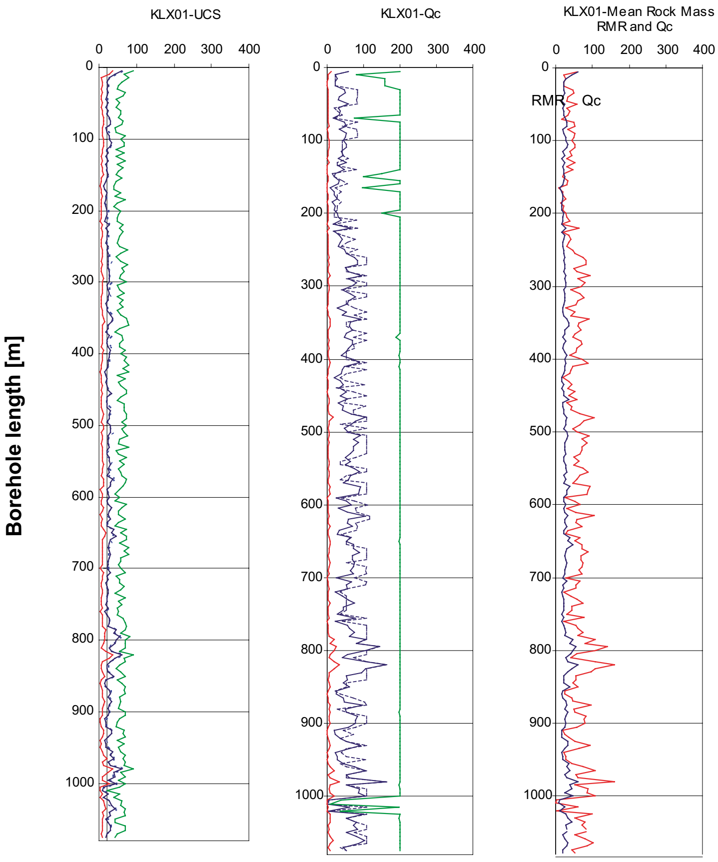

Figure 5-9. *Variation of the rock mass compressive strength from RMR and Q for borehole KLX01.*

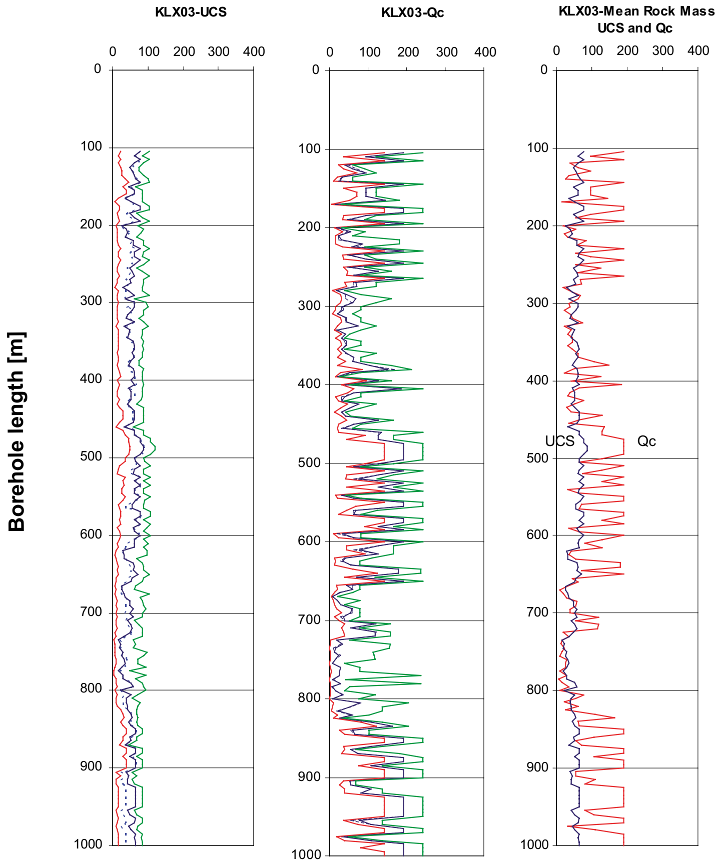

Figure 5-10. Variation of the rock mass compressive strength from RMR and Q for borehole KLX03.

According to Equation (7), the apparent UCS of the rock mass along borehole KLX03 for the Mohr-Coulomb envelope results in 100 MPa for the competent rock mass and 81 MPa for the deformation zones, respectively.

5.3.3 KLX04

The rock mass compressive strength from RMR and Q is plotted versus depth in Figure 5-11. From RMR, the average UCS of the Rock units varies between 17 and 71 MPa. On average, for the competent rock mass and deformation zones, UCS varies between 46 and 21 MPa, respectively. The range of values for borehole KLX04 is between 11 and 89 MPa.

Equation (7) gives different values of the apparent UCS of the rock mass from the Mohr-Coulomb envelope that results in 86 MPa for the competent rock mass and 60 MPa for the deformation zones, respectively.

5.3.4 KAV04

The variation of the rock mass compressive strength from RMR and Qc along borehole KAV04 can be seen in Figure 5-12. The average UCS in the six rock units ranges between 22 and 41 MPa. For the whole borehole, the maximum and minimum observed values of UCS are respectively 110 and 3 MPa. The competent rock shows an average UCS of 32 MPa, which is 9 MPa larger than the average UCS of the deformation zones.

Equation (7) gives the apparent UCS of the rock mass from the Mohr-Coulomb envelope that, for borehole KAV04, is on average 74 MPa for the competent rock mass and 56 MPa for the deformation zones, respectively.

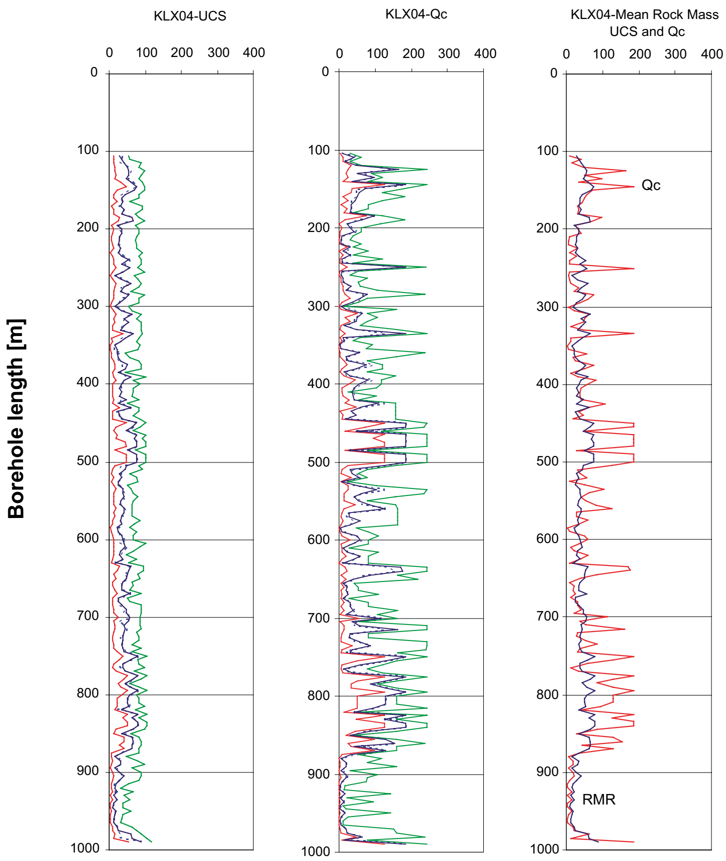

Figure 5-11. Variation of the rock mass compressive strength from RMR and Q for borehole KLX04.

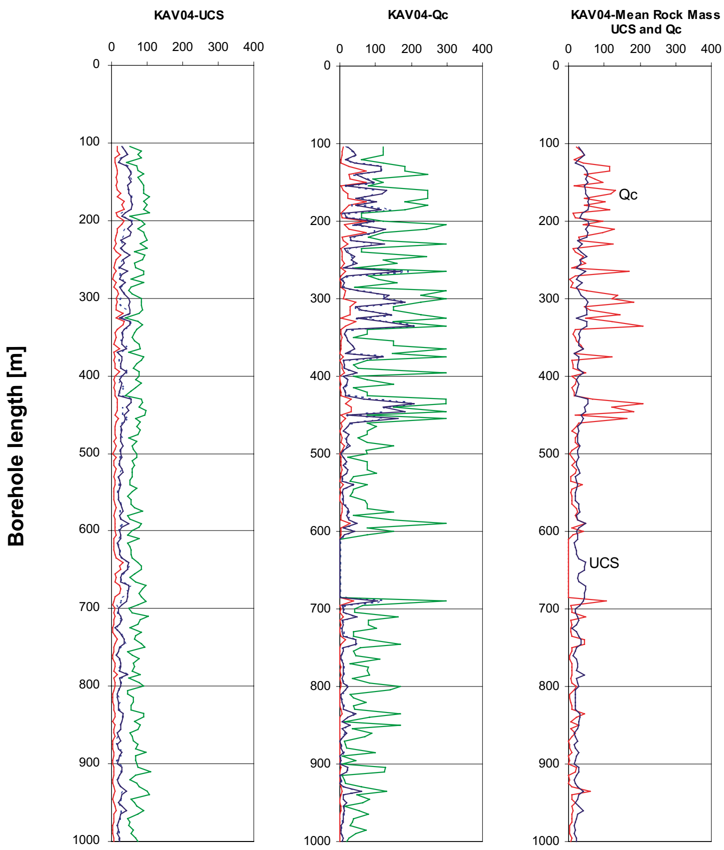

Figure 5-12. Variation of the rock mass compressive strength from RMR and Q for borehole KAV04.

5.3.5 Uncertainties

Table 5-3 summarises the uncertainty of the mean uniaxial compressive strength reported in the former sections. It can be seen that the uncertainty for the competent rock in the rock units ranges between –4% and 23%, where we can find this large range in borehole KLX01, while the uncertainty for the deformation zones ranges between –33% and 113%, also in borehole KLX01. These extreme values are due to the small number of values (4) available for the deformation zone.

5.4 Cohesion and friction angle of the rock mass

Based on the Hoek & Brown's Criterion /Hoek et al. 2002/, the approximated Mohr-Coulomb's parameters (cohesion and friction angle) can be obtained when a certain confinement stress range is specified. In this report, the range of the confinement stress is specified between 10 and 30 MPa. The values of the cohesion and friction angle for the rock units, the deformation zones and at different depths are tabulated and plotted in Appendix 1 to 5.

5.4.1 KLX01

The plot of the cohesion and friction angle for borehole KLX01 is shown in Figure 5-13.

The average cohesion in the rock units ranges between 15 and 18 MPa, while that of the deformation zones and competent rock between 15 and 17 MPa. For the whole borehole, the cohesion spans between 14 and 23 MPa.

For the same range of confinement stress (10 to 30 MPa), the friction angle along the borehole ranges between 38° and 48°. The three rock units have an average friction angle varying between 40° and 44°. A similar difference can be observed between the average friction angle of the competent rock and that of the deformation zones, which are respectively 43° and 40°.

5.4.2 KLX03

Figure 5-14 show the plots of the cohesion and friction angle calculated for a confinement stress between 10 and 30 MPa along borehole KLX03.

The cohesion of the rock mass in the deformation zones is 18 MPa and it is 21 MPa for the competent rock mass. The average cohesion for the four Rock units varies between 18 and 22 MPa. For the whole borehole, the cohesion spans between 15 and 25 MPa.

The friction angle of the rock mass varies between 40° and 48° for the whole borehole. The average values are instead 43° and 45° for the deformation zones and competent rock, respectively.

Table 5-3. Uncertainty of the mean values of the Uniaxial Compressive Strength (UCS) of the rock mass derived from RMR and the secant Mohr-Coulomb's Criterion for borehole KLX01, KLX03, KLX04, and KAV04 and borehole sections of 5 m.

	Competent rock		Fractured rock	
	Lower uncertainty on the mean	Upper uncertainty on the mean	Lower uncertainty on the mean	Upper uncertainty on the mean
KLX01	–4%	+23%	–33%	+113%
KLX03	–5%	+4%	–17%	+35%
KLX04	–5%	+7%	–14%	+41%
KAV04	–5%	+11%	–22%	+63%

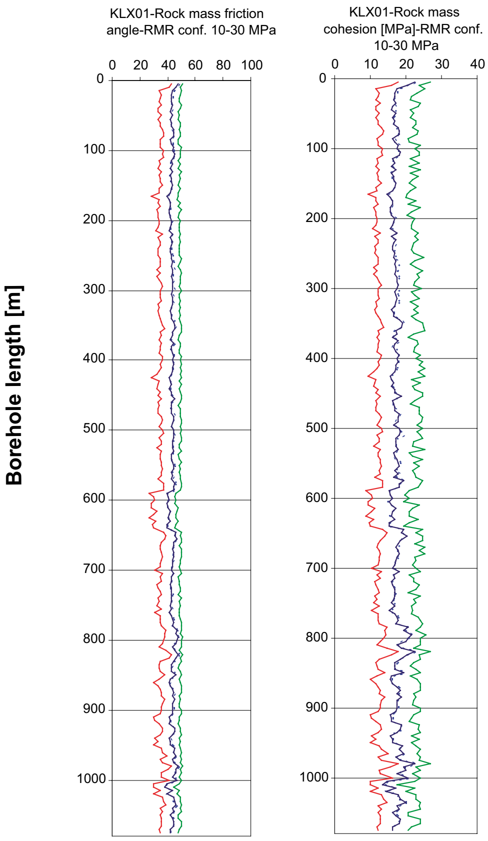

Figure 5-13. Variation of the rock mass friction angle and cohesion from RMR under stress confinement between 10 and 30 MPa for borehole KLX01.

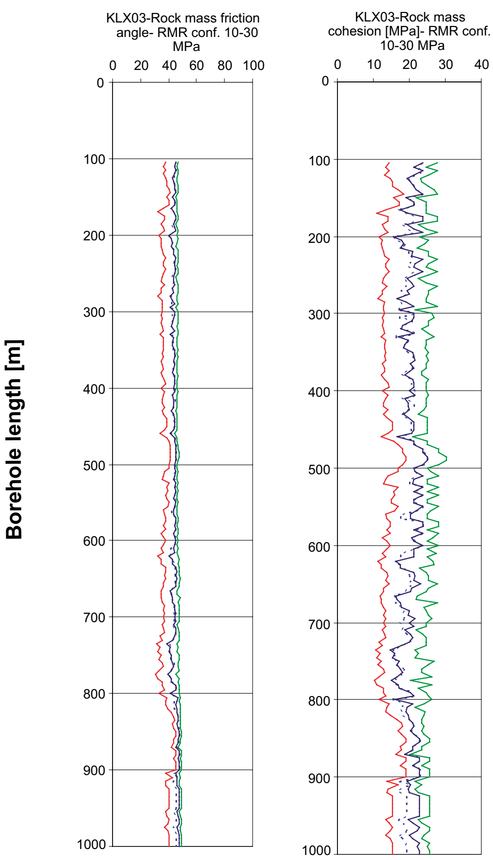

Figure 5-14. Variation of the rock mass friction angle and cohesion from RMR under stress confinement between 10 and 30 MPa for borehole KLX03.

5.4.3 KLX04

For KLX04, the cohesion and friction angle obtained by the empirical methods plot as in Figure 5-15. These values are determined for a confinement stress between 10 and 30 MPa.

The average cohesion of the three rock units ranges between 14 and 23 MPa. That of the competent rock mass and deformation zones ranges between 14 MPa and 19 MPa. For the whole borehole, cohesion values are observed within the interval 13 to 25 MPa.

The rock units have an average friction angles in the range between 38° and 44°. Along the borehole, the friction angle varies between 35° and 45°. The average values for the competent rock and deformation zones are instead 42° and 38°, respectively.

5.4.4 KAV04

Figure 5-16 show the plots of the cohesion and friction angle along borehole KAV04. These values are obtained by interpolating the Hoek & Brown's Criterion between the stresses of 10 and 30 MPa.

On average, the cohesion of the rock mass should vary between 12 and 21 MPa, with an average value for the rock mass in the deformation zones of 14 MPa, and an average value for the competent rock of 17 MPa. Also the five Rock units seem to have very similar average cohesion, which ranges between 14 and 18 MPa.

The friction angle varies between 34° and 45° for the whole borehole. The average friction angle of the five rock units ranges instead between 36° and 42°. The competent rock has an average friction angle (41°) larger than the average friction angle of the deformation zones (37°).

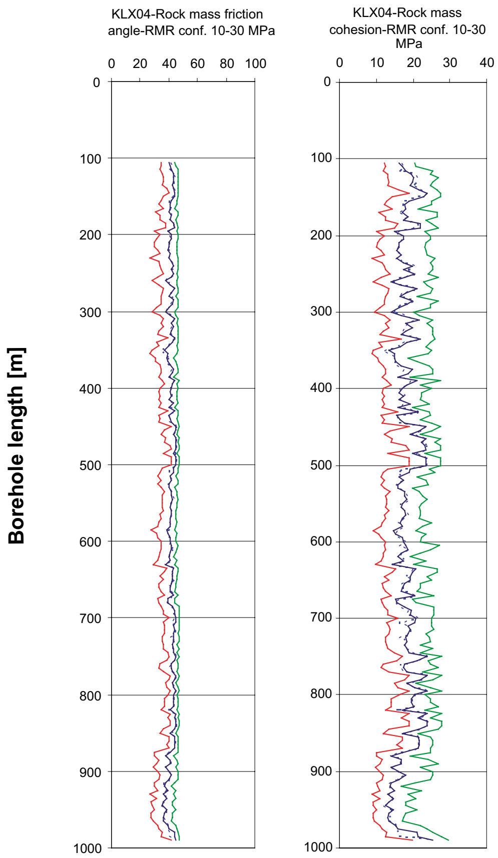

Figure 5-15. Variation of the rock mass friction angle and cohesion from RMR under stress confinement between 10 and 30 MPa for borehole KLX04.

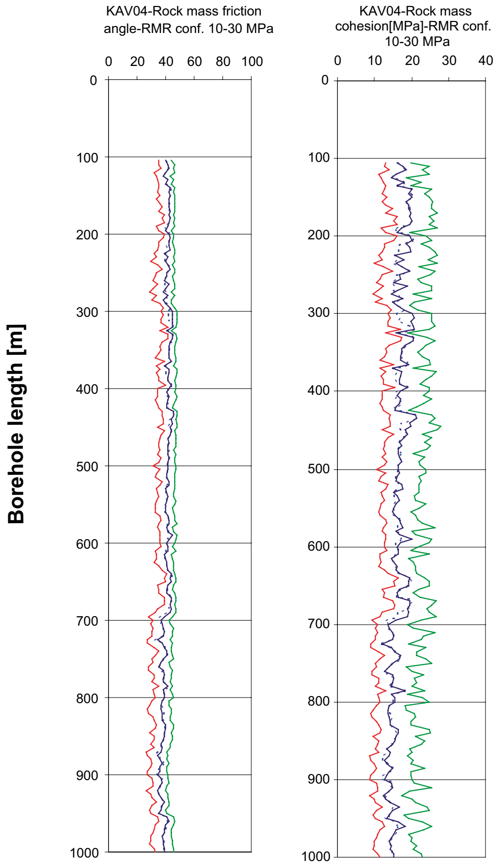

__Figure 5-16.__ Variation of the rock mass friction angle and cohesion from RMR under stress confinement between 10 and 30 MPa for borehole KAV04.

5.4.5 Uncertainties

The uncertainties of the average cohesion reported in the former sections are reported in Table 5-4. Borehole KLX01 seems to have higher uncertainties than the other boreholes. In general, for the competent rock, the uncertainty on the cohesion varies between –2% and +3%. The range of uncertainty of the average cohesion of the deformation zones is at most –15% to +19%. This large range is specific for KLX01 whereas the other three boreholes display a range of at most –9% to +14%.

The uncertainty on the friction angle shows a similar pattern as for the cohesion, with KLX01 showing an uncertainty span larger than the other three boreholes. For the deformation zones in KLX01 the range of uncertainty is between –11% and +9% whereas for the other boreholes ranges between –6% and +4. The uncertainty of the mean friction angle for the competent rock in the rock units does not exceed the range ± 1%.

Table 5-4. Uncertainty of the mean values of the rock mass cohesion (confinement stress 10–30 MPa) for borehole KLX01, KLX03, KLX04, and KAV04 and borehole sections of 5 m.

	Competent rock		Fractured rock	
	Lower uncertainty on the mean	Upper uncertainty on the mean	Lower uncertainty on the mean	Upper uncertainty on the mean
KLX01	–2%	+2%	–15%	+19%
KLX03	–2%	+2%	–7%	+9%
KLX04	–2%	+2%	–6%	+9%
KAV04	–2%	+3%	–9%	+14%

Table 5-5. Uncertainty of the mean values of the rock mass friction angle (confinement stress 10–30 MPa) for borehole KLX01, KLX03, KLX04, and KAV04 and borehole sections of 5 m.

	Competent rock		Fractured rock	
	Lower uncertainty on the mean	Upper uncertainty on the mean	Lower uncertainty on the mean	Upper uncertainty on the mean
KLX01	–1%	+1%	–11%	+9%
KLX03	–1%	0%	–4%	+2%
KLX04	–1%	+1%	–4%	+3%
KAV04	–1%	+1%	–6%	+4%

6 Discussion and conclusions

When comparing the plots with depth of RMR and Q for different boreholes, the following observations can be made:

- All the rock mass quality values and the mechanical properties of the rock mass in this report represent the rock mass as a continuum, homogeneous and isotropic medium. Anisotropy is not considered here, since all boreholes are sub-parallel, thus, strictly, give only information in the vertical direction.
- Borehole KLX03 shows rather high and uniform values of RMR and Q with depth. In borehole KLX04, were the deformation zones are frequent but not very extensive, the RMR rating indicate a good rock class of the Deformation zones whereas the Q system indicate poor rock.
- In general, the competent rock in KLX03, that belongs to the Laxemar Area, exhibits the best (RMR = 83, Q = 99) quality among all boreholes (RMR around 75, Q around 50).
- The deformation zones present an average RMR as low as 71 and Q of about 21, with extreme values of RMR and Q of 51 and 0.7, respectively.
- The uncertainties of the average RMR generally vary between ± 1% for the competent rock mass and ± 7% for the deformation zones. The correspondent uncertainty of the Q values are higher, respectively ± 11% and ± 91%, probably due to the fact that Q usually ranges several orders of magnitude for the same rock mass.
- The average deformation modulus of the boreholes KLX01, KLX04 and KAV04 for the competent rock mass ranges between 36 and 44 GPa compared to boreholes KLX03 for which the average deformation modulus is 64 GPa. The average deformation modulus of the deformation zones shows a similar pattern with an average deformation modulus for boreholes KLX01, KLX04 and KAV04 of about 22 GPa whereas for KLX03 it is about 42 GPa.
- Independently on the method adopted, the uncertainty of the average deformation modulus seems to be about ± 5% for the competent rock mass whereas the uncertainty for the deformation zones shows a larger range of about ± 30%. According to the results, the uncertainty on the deformation modulus determined with Q is slightly lower than that determined by RMR.
- RMR was chosen as a main empirical method, despite what just said about the uncertainty of the deformation modulus, because RMR is provided with a more complete set of empirical relations to estimate the mechanical properties of the rock mass seen as a continuous isotropic and elastic medium (e.g. parameters of the Hoek & Brown's and Coulomb's Criterium).
- According to the Hoek & Brown's Criterion, the average uniaxial compressive strength of the rock mass ranges between 26 and 55 MPa for the four boreholes, with the highest values to be assigned to KLX03. In the deformation zones, the average strength drops to 14 to 34 MPa.
- By extrapolating the Mohr-Coulomb's Criterion outside the range 10 to 30 MPa confining pressure, the uniaxial compressive strength can also be determined. The values so obtained are much higher that those from the Hoek & Brown's Criterion. This is due to the curvilinearity of the Hoek & Brown's Criterion that must provide lower UCS values. The average UCS_{M-C} for the four boreholes in this report varies between 74 and 100 MPa for the competent rock mass, while it varies between 56 and 81 MPa for the deformation zones.
- The uncertainty of the average uniaxial compressive strength is about ± 8% for the competent rock mass and about ± 42% for the Deformation zones, respectively.

- The equivalent cohesion of the competent rock mass in the boreholes varies, on average, between 17 and 21 MPa, for confinement stresses between 10 and 30 MPa. For the deformation zones, the variation is between 14 and 18 MPa.
- The uncertainty of the average cohesion reported in Section 5.4.5 is about ± 2% for the competent rock mass and about ± 10% for the deformation zones, respectively.
- The equivalent friction angle of the rock mass in each borehole ranges between 41° and 45°, for the competent rock mass, and between 37° and 43°, for the deformation zones, respectively. The friction angle is also estimated for confinement stresses between 10 and 30 MPa.
- The uncertainty of the equivalent average friction angle is around ± 1% for the competent rock mass, and about four times as large for the deformation zones except for borehole KLX01 which displays an uncertainty for the deformation zone of about ± 10%.
- Generally the uncertainty of the Q values is larger than that for RMR due to the logarithmic nature of the Q system.

The values of Q can be plotted against the values of RMR to derive a site-specific correlation equation. In Figure 6-1, these correlations are plotted together with some of the relations reported in the literature. In the literature, the relations reported apply for the "design" of the rock mass, where the effect of the boundary conditions is regarded. For "characterisation", as in this report, the effect of the boundary conditions are disregarded and will be added to the parameters in the Modelling Phase of the Site Descriptive Modelling Project for Laxemar version 1.2. The relations between RMR and Q obtained for the five boreholes available at Laxemar (included KLX02) can be summarised as follows:

KLX01: $RMR = 6.33 \cdot \ln(Q) + 50$ (8)

KLX03: $RMR = 3.75 \cdot \ln(Q) + 68$ (9)

KLX04: $RMR = 5.15 \cdot \ln(Q) + 61$ (10)

KLX02: $RMR = 4.20 \cdot \ln(Q) + 62$ (11)

KAV04: $RMR = 4.26 \cdot \ln(Q) + 61$ (12)

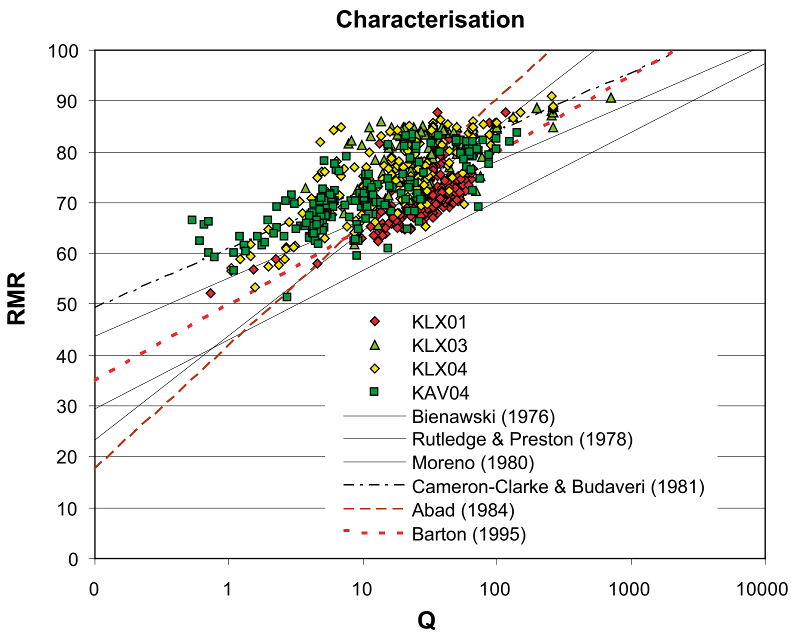

Figure 6-1. *Correlation between RMR and Q for the characterisation of the rock mass along borehole KLX01, KLX03, KLX04 and KAV04 (core sections of 5 m). The characterisation results are compared with some design relations from the literature.*

The lack of information on the orientation of the fractures for borehole KLX01 introduced the use of information from KLX02 into this report. The RQD values and the results of the characterization of borehole KLX02 were used to estimate the parameters for the characterization of KLX01 and the background for this method can be found in Section 4.2.

The relations between RMR and Q obtained for borehole KLX02 has been presented here as well as in the Site Descriptive Model of Simpevarp, version 1.2. It can be seen that this borehole has a lower inclination of the relation between Q and RMR from ranging between about 4 and 5 for the other boreholes compared to about 6.5 for KLX01. It also decreases the RMR response to low Q values (50 for KLX01) compared to the other boreholes (in the range of 60 to 68).

The use of information from other boreholes than KLX02 would reduce the uncertainty of the parameters calculated for KLX01. However, the large uncertainty of the parameters for the deformation zones in KLX01 is probably not a result of this fact but it is rather due to the small amount of values on which the calculations are based.

The data contained in the appendices are delivered and inputted into SKB's database SICADA to complete the single-hole interpretation. The appendices also contain data that quantify the confidence level of the obtained results. The confidence ranges (minimum possible and maximum possible) given are a measure of the spatial variability and uncertainty of the results in each rock unit, rock type group, deformation zone and for the whole borehole.

7 Data delivery to SICADA

The results of the rock mass characterisation are delivered to SKB's database SICADA. The characterisation of the rock mass by means of the RMR and Q systems for rock mechanics purposes is assigned to the activity group "Rock Mechanics". For each borehole, data are given for the pseudo-homogenous sections (rock units) of drill-core/borehole and the deformation zones identified by the geological "single-hole" interpretation. For each rock unit or deformation zone, six values of RMR and Q resulting from the characterisation are delivered to the database: the minimum RMR and Q, average RMR/most frequent Q, and the maximum RMR and Q, respectively. Among the rock mechanics properties, the uniaxial compressive strength of the intact rock (UCS) and the deformation modulus (Em) of the rock mass are also delivered to SICADA. For the deformation modulus, two sets of values are given for each rock unit and deformation zone, one value obtained by means of RMR and one for Q, respectively, each of which consisting of minimum, average and maximum deformation modulus of the rock mass. Before storage into the database, quality assessment routines are performed on the methods and delivered data.

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Appendix 1: KLX01

Characterisation of the rock mass

1.1 Fracture orientation

The orientation of the fractures along this borehole was not measured. The number of fracture sets was estimated based on the RQD values and the results of the characterization of borehole KLX02 included in the Site Descriptive Model of Simpevarp, version 1.2 (see Section 4.2 in this report).

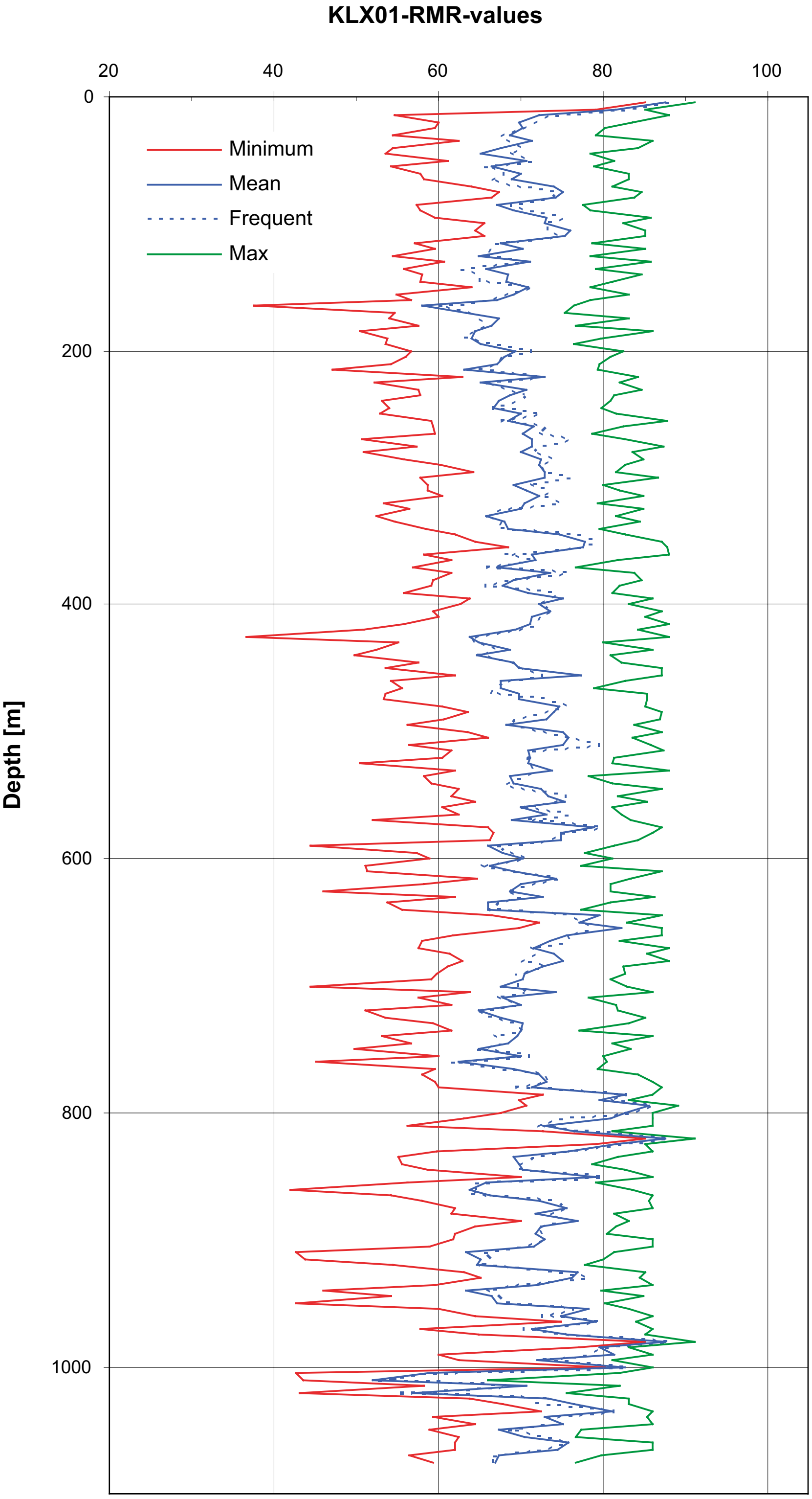
1.2 RMR

RMR values along borehole KLX01 (core sections of 5 m).

Rock unit depth [m]	Minimum RMR	Average RMR	Frequent RMR	Maximum RMR	Standard deviation	Min possible RMR	Max possible RMR
0–585	58.0	70.5	70.3	87.7	4.0	36.7	91.1
585–640	66.0	68.9	68.7	74.4	2.8	44.4	87.1
640–1,000	62.5	73.2	72.3	87.7	6.0	42.0	91.1
DZ, 1,000–1,020*	52.1	59.7	57.9	70.8	7.9	42.6	82.1
1,020–1,078	67.0	72.9	73.3	81.2	4.5	56.5	86.1
RU3, 640–1,078	52.1	72.6	72.2	87.7	6.5	42.0	91.1
Competent rock	58.0	71.5	70.9	87.7	5.0	36.7	91.1
Fractured rock	52.1	59.7	57.9	70.8	7.9	42.6	82.1
Whole borehole	52.1	71.3	70.8	87.7	5.2	36.7	91.1

* Location of the potential deformation zones identified in borehole KLX01.

Variation of RMR with depth for borehole KLX01. The values are given every 5 m.



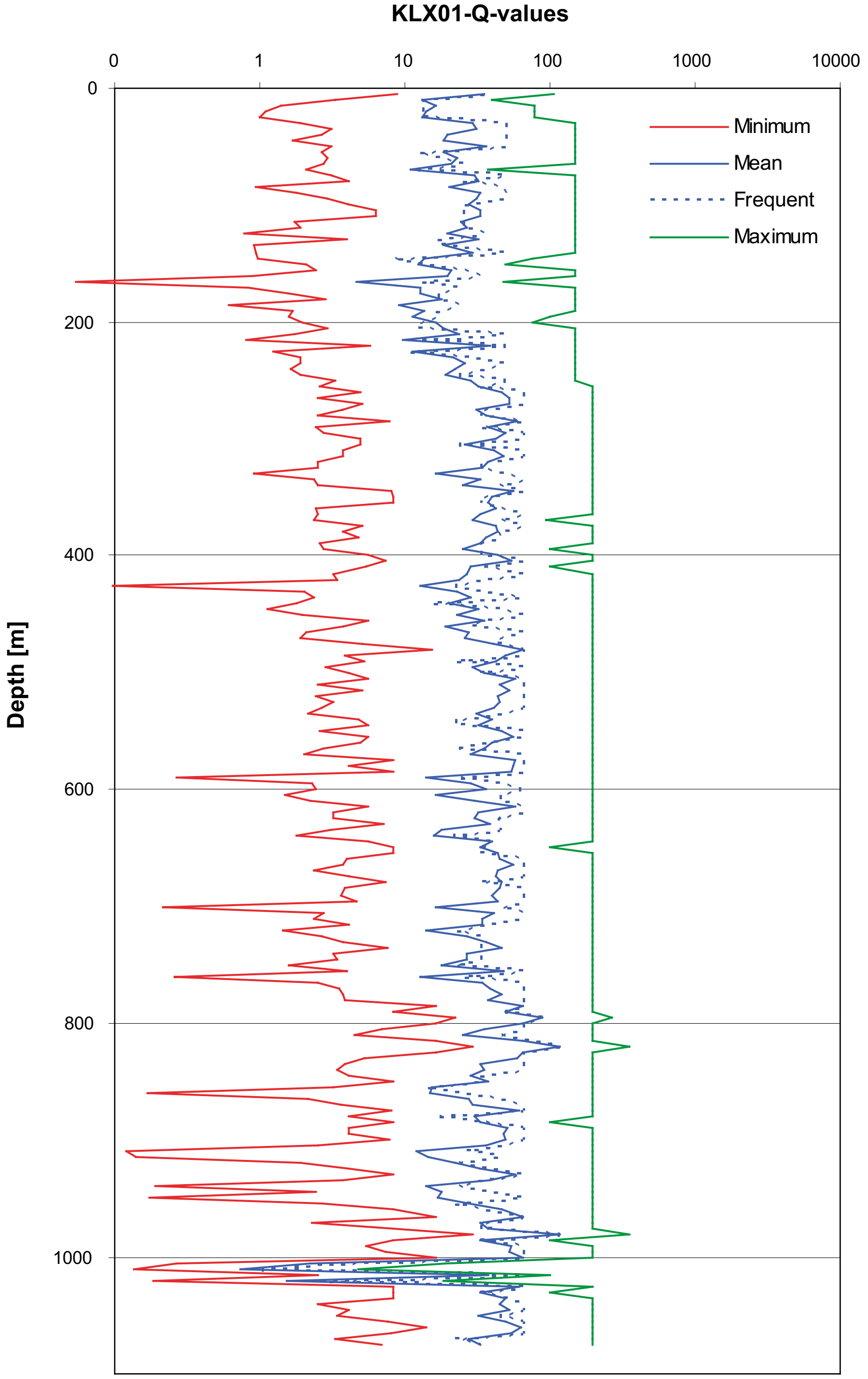
1.3 Q

Q values along borehole KLX01 (core sections of 5 m).

Rock unit depth [m]	Minimum Q	Average Q	Frequent Q	Maximum Q	Standard deviation	Min possible Q	Max possible Q
0–585	4.6	31.1	30.8	64.9	13.2	0.1	198.0
585–640	14.1	28.8	29.8	58.0	12.9	0.3	198.0
640–1,000	11.9	40.9	37.7	117.3	20.4	0.1	352.0
DZ, 1,000–1,020*	0.7	10.5	1.9	37.4	18.0	0.1	99.0
1,020–1,078	27.2	45.5	49.5	64.0	12.6	2.5	198.0
RU3, 640–1,078	0.7	40.1	37.7	117.3	20.5	0.1	352.0
Competent rock	4.6	35.1	33.2	117.3	16.8	0.1	352.0
Fractured rock	0.7	10.5	1.9	37.4	18.0	0.1	99.0
Whole borehole	0.7	34.6	33.1	117.3	17.1	0.1	352.0

* Location of the potential deformation zones identified in borehole KLX01.

Variation of Q with depth for borehole KLX01. The values are given every 5 m.



Rock mass properties

1.4 Deformation modulus

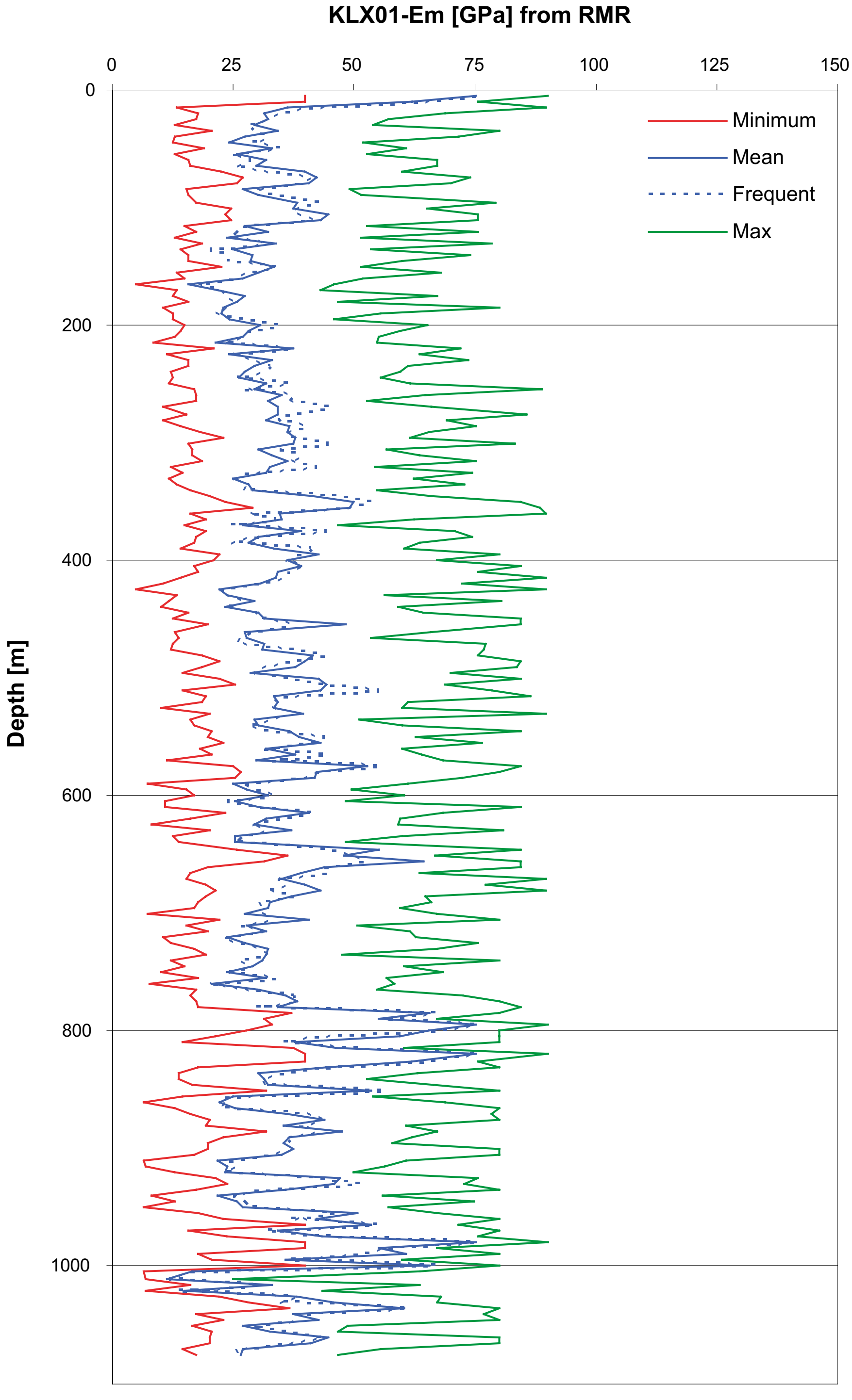
1.4.1 RMR

Deformation modulus Em derived from RMR along for borehole KLX01 (core sections of 5 m).

Rock unit depth [m]	Minimum Em [GPa]	Average Em [GPa]	Frequent Em [GPa]	Maximum Em [GPa]	Standard deviation Em [GPa]	Min possible Em [GPa]	Max possible Em [GPa]
0–585	15.9	33.4	32.1	75.0	8.2	4.7	90.0
585–640	25.1	30.0	29.4	40.6	5.1	7.3	84.6
640–1,000	20.5	40.1	36.1	75.0	14.0	6.3	90.0
DZ,1,000– 1,020*	11.3	19.0	15.8	33.0	9.6	6.6	63.6
1,020–1,078	26.6	38.5	38.3	60.3	10.1	14.6	79.9
RU3, 640–1,078	11.3	38.9	36.0	75.0	14.0	6.3	90.0
Competent rock	15.9	35.8	33.2	75.0	11.0	4.7	90.0
Fractured rock	11.3	19.0	15.8	33.0	9.6	6.6	63.6
Whole borehole	11.3	35.5	33.0	75.0	11.2	4.7	90.0

* Location of the potential deformation zones identified in borehole KLX01. The maximum mean Em and the maximum confidence Em have a physical threshold in the Young's modulus of the intact rock, which is 75 and 90 GPa, respectively.

Variation of the deformation modulus of the rock mass obtained from RMR with depth for borehole KLX01. The values are given every 5 m.



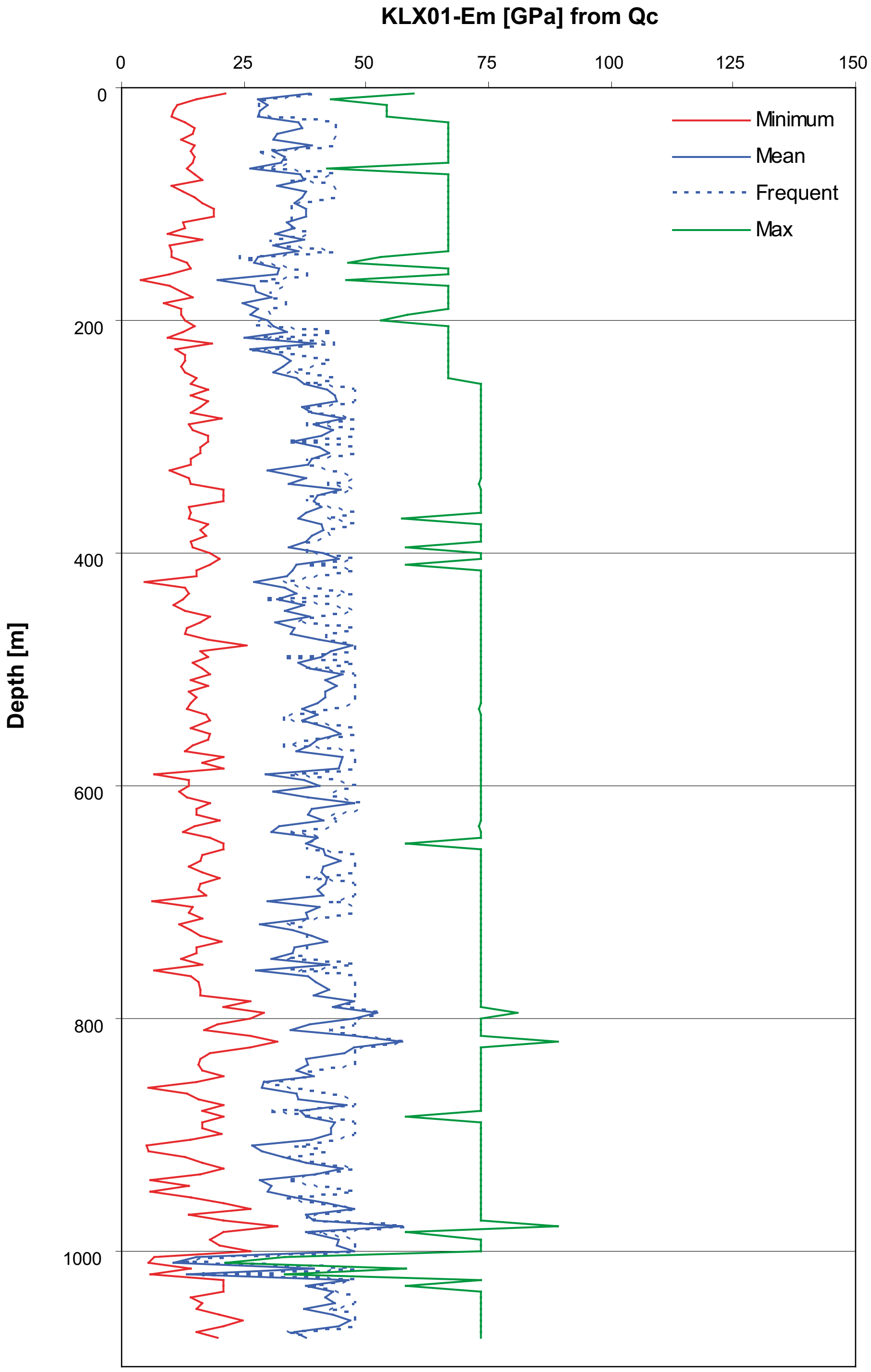
1.4.2 Q

Deformation modulus Em derived from Q along borehole KLX01 (core sections of 5 m).

Rock unit depth [m]	Minimum Em [GPa]	Average Em [GPa]	Frequent Em [GPa]	Maximum Em [GPa]	Standard deviation Em [GPa]	Min possible Em [GPa]	Max possible Em [GPa]
0–585	19.5	36.1	36.7	47.1	5.5	3.9	73.4
585–640	29.6	36.8	37.9	47.3	5.4	6.6	73.4
640–1,000	26.8	39.4	39.3	57.4	6.4	5.1	89.0
DZ, 1,000–1,020*	10.6	38.7	39.3	57.4	7.8	5.1	89.0
1,020–1,078	35.2	41.5	43.0	46.9	4.0	14.1	73.4
RU3, 640–1,078	10.6	19.6	14.4	39.2	13.2	5.3	58.3
Competent rock	19.5	37.5	37.7	57.4	6.0	3.9	89.0
Fractured rock	10.6	19.6	14.4	39.2	13.2	5.3	58.3
Whole borehole	10.6	37.2	37.7	57.4	6.6	3.9	89.0

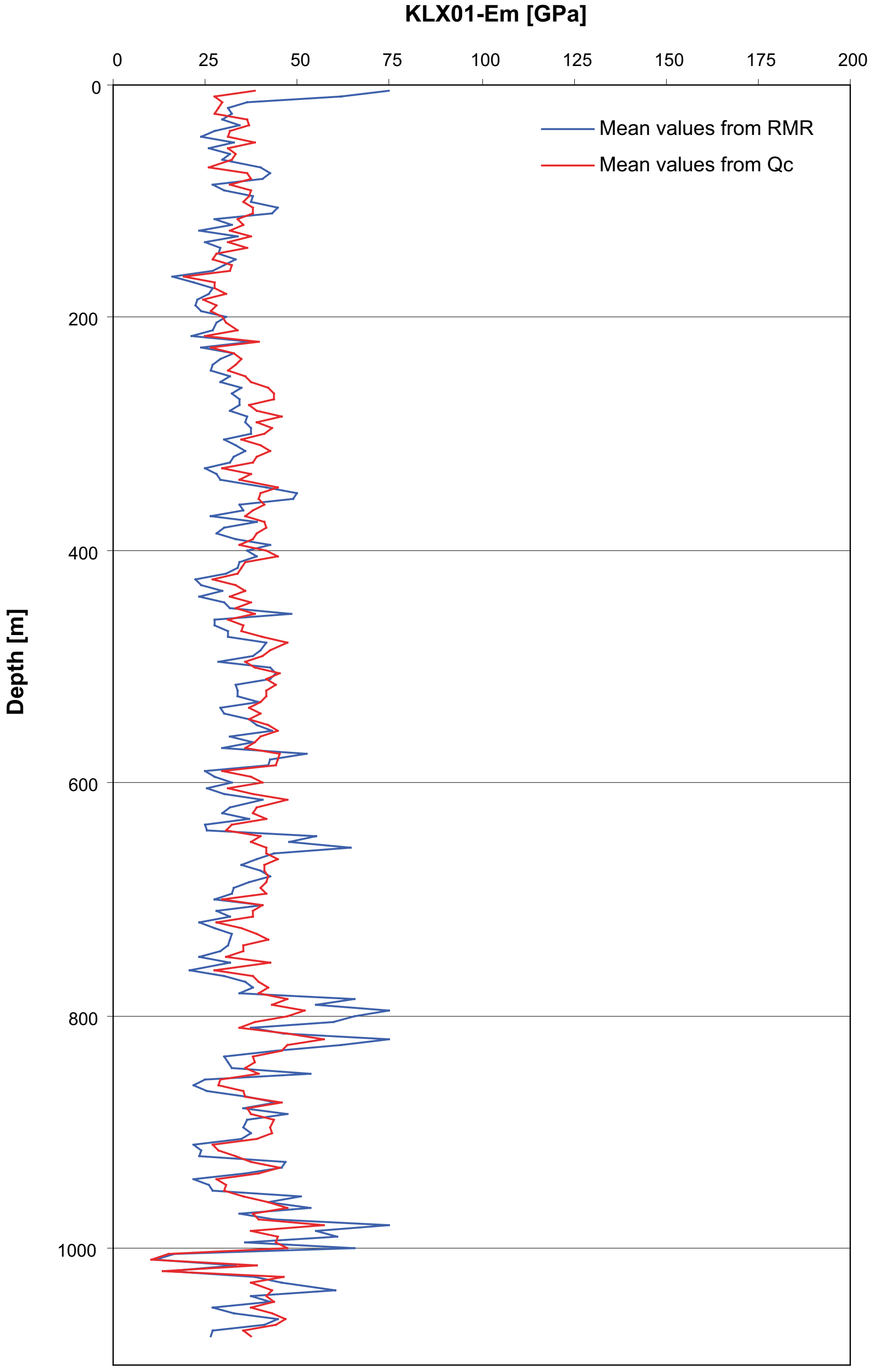
* Location of the potential deformation zones identified in Borehole KLX01. The maximum mean Em and the maximum confidence Em have a physical threshold in the Young’s modulus of the intact rock, which is 75 and 90 GPa, respectively.

Variation of the deformation modulus of the rock mass obtained from Qc with depth for borehole KLX01. The values are given every 5 m.



1.4.3 Comparison

Comparison between the mean values of the deformation modulus Em obtained from RMR and Qc for different depths for borehole KLX01.



1.5 Poisson's ratio

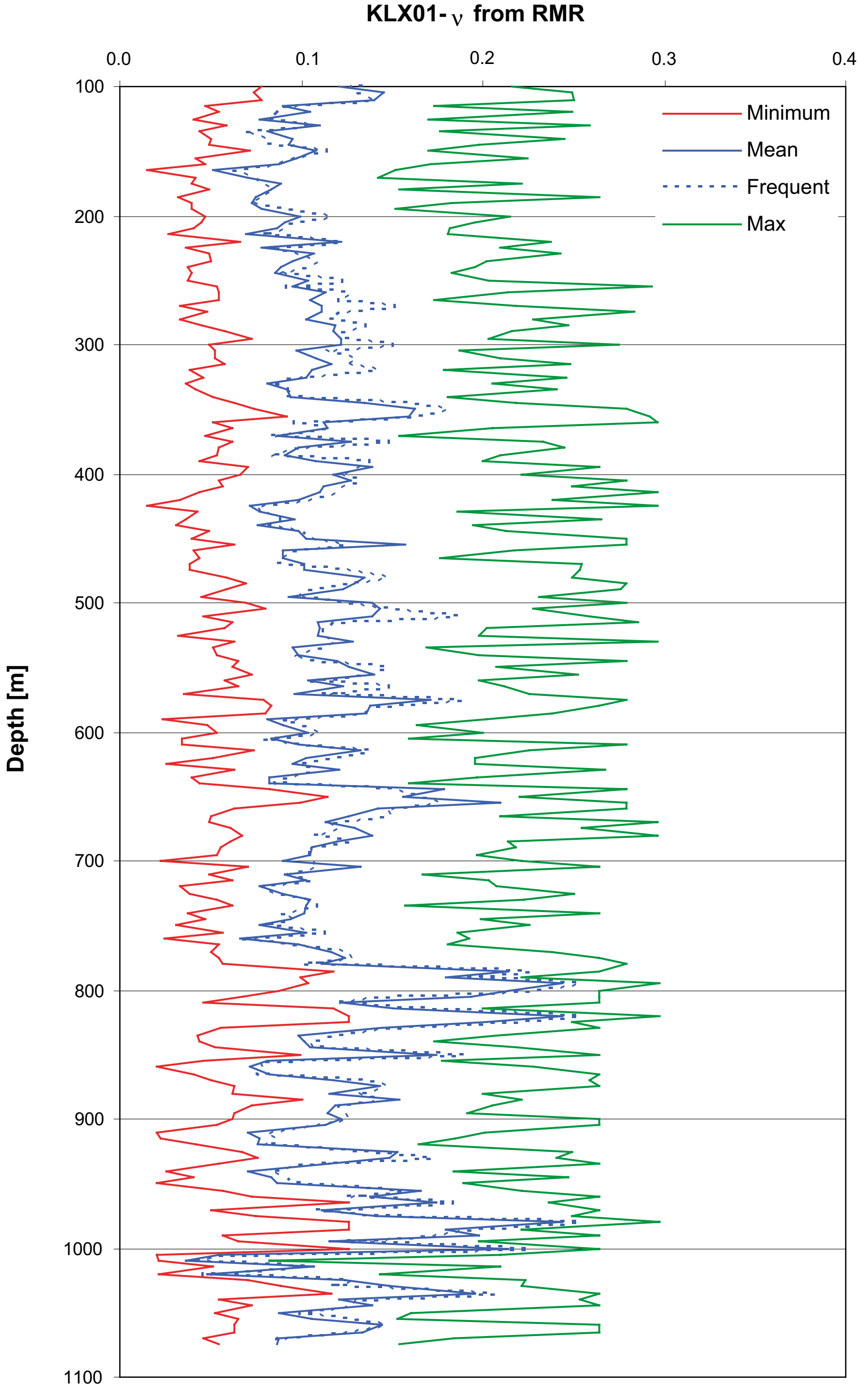
1.5.1 RMR

Summary of Poisson's ratio (ν) derived from RMR for borehole KLX01 (core sections of 5 m, Hoek & Brown's a = 0.5).

Rock unit depth [m]	Minimum ν [–]	Average ν [–]	Frequent ν [–]	Maximum ν [–]	Standard deviation ν [–]	Min possible ν [–]	Max possible ν [–]
0–585	0.05	0.11	0.10	0.24	0.03	0.01	0.30
585–640	0.08	0.10	0.10	0.13	0.02	0.02	0.28
640–1,000	0.07	0.13	0.12	0.24	0.05	0.02	0.30
DZ, 1,000–1,020*	0.04	0.06	0.05	0.11	0.03	0.02	0.21
1,020–1,078	0.09	0.13	0.12	0.20	0.03	0.05	0.26
RU3, 640–1,078	0.04	0.13	0.12	0.24	0.05	0.02	0.30
Competent rock	0.05	0.12	0.11	0.24	0.04	0.01	0.30
Fractured rock	0.04	0.06	0.05	0.11	0.03	0.02	0.21
Whole borehole	0.04	0.12	0.11	0.24	0.04	0.01	0.30

* Location of the potential deformation zones identified in Borehole KLX01.

Variation of Poisson's ratio (ν) with depth for borehole KLX01 (Hoek & Brown's a = 0.5). The values are given every 5 m.



1.6 Uniaxial compressive strength

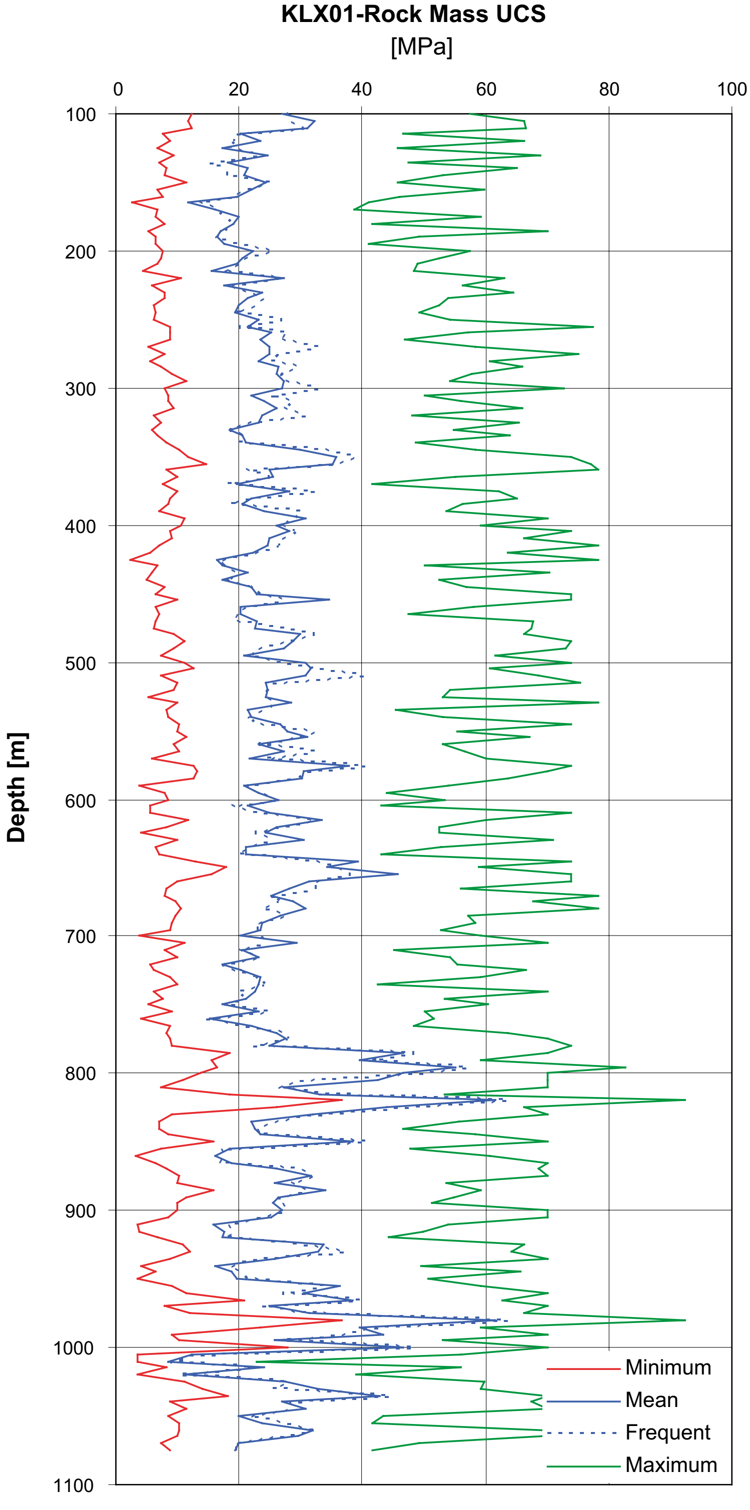
1.6.1 RMR

Summary of the uniaxial compressive strength of the rock mass derived from RMR and Hoek & Brown's Criterion for borehole KLX01 (core sections of 5 m, Hoek & Brown's a = 0.5).

Rock unit depth [m]	Minimum UCS [MPa]	Average UCS [MPa]	Frequent UCS [MPa]	Maximum UCS [MPa]	Standard deviation UCS [MPa]	Min possible UCS [MPa]	Max possible UCS [MPa]
0–585	11.8	24.4	23.4	61.6	6.1	2.5	92.4
585–640	21.0	24.9	24.4	33.4	4.1	3.8	74.0
640–1,000	15.2	29.2	26.2	61.6	10.5	3.3	92.4
DZ, 1,000–1,020*	8.5	14.0	11.8	24.0	6.9	3.4	56.1
1,020–1,078	19.5	27.8	27.7	42.9	7.1	7.4	70.0
RU3, 640–1,078	8.5	28.3	26.1	61.6	10.4	3.3	92.4
Competent rock	11.8	26.2	24.4	61.6	8.1	2.5	92.4
Fractured rock	8.5	14.0	11.8	24.0	6.9	3.4	56.1
Whole borehole	8.5	26.0	24.3	61.6	8.3	2.5	92.4

* Location of the potential deformation zones identified in Borehole KLX01.

Variation of the uniaxial compressive strength of the rock mass with depth for borehole KLX01 (Hoek & Brown's a = 0.5). The values are given every 5 m.



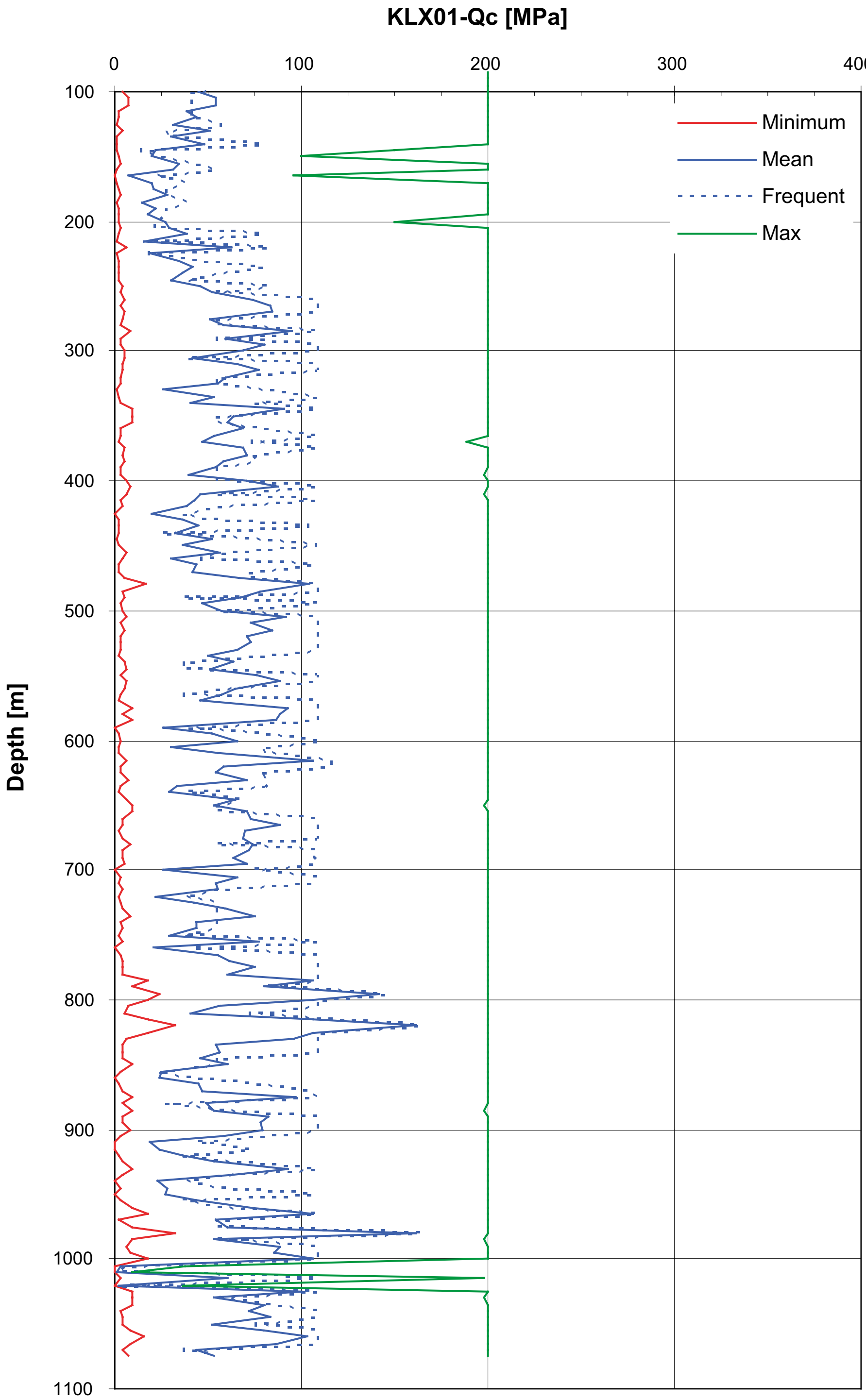
1.6.2 Q

Summary of Qc derived from Q for borehole KLX01 (core sections of 5 m).

Rock unit depth [m]	Minimum Qc	Average Qc	Frequent Qc	Maximum Qc	Standard deviation	Min possible Qc	Max possible Qc
0–585	7.4	50.1	49.6	104.6	21.3	0.1	200.0
585–640	25.9	52.8	54.6	106.1	23.6	0.3	200.0
640–1,000	19.2	65.1	60.7	161.0	30.2	0.1	200.0
DZ, 1,000–1,020*	1.2	16.9	3.0	60.2	28.9	0.2	198.0
1,020–1,078	43.7	73.3	79.7	103.1	20.2	2.8	200.0
RU3, 640–1,078	1.2	63.9	60.7	161.0	30.7	0.1	200.0
Competent rock	7.4	56.6	53.7	161.0	25.8	0.1	200.0
Fractured rock	1.2	16.9	3.0	60.2	28.9	0.2	198.0
Whole borehole	1.2	55.8	53.7	161.0	26.4	0.1	200.0

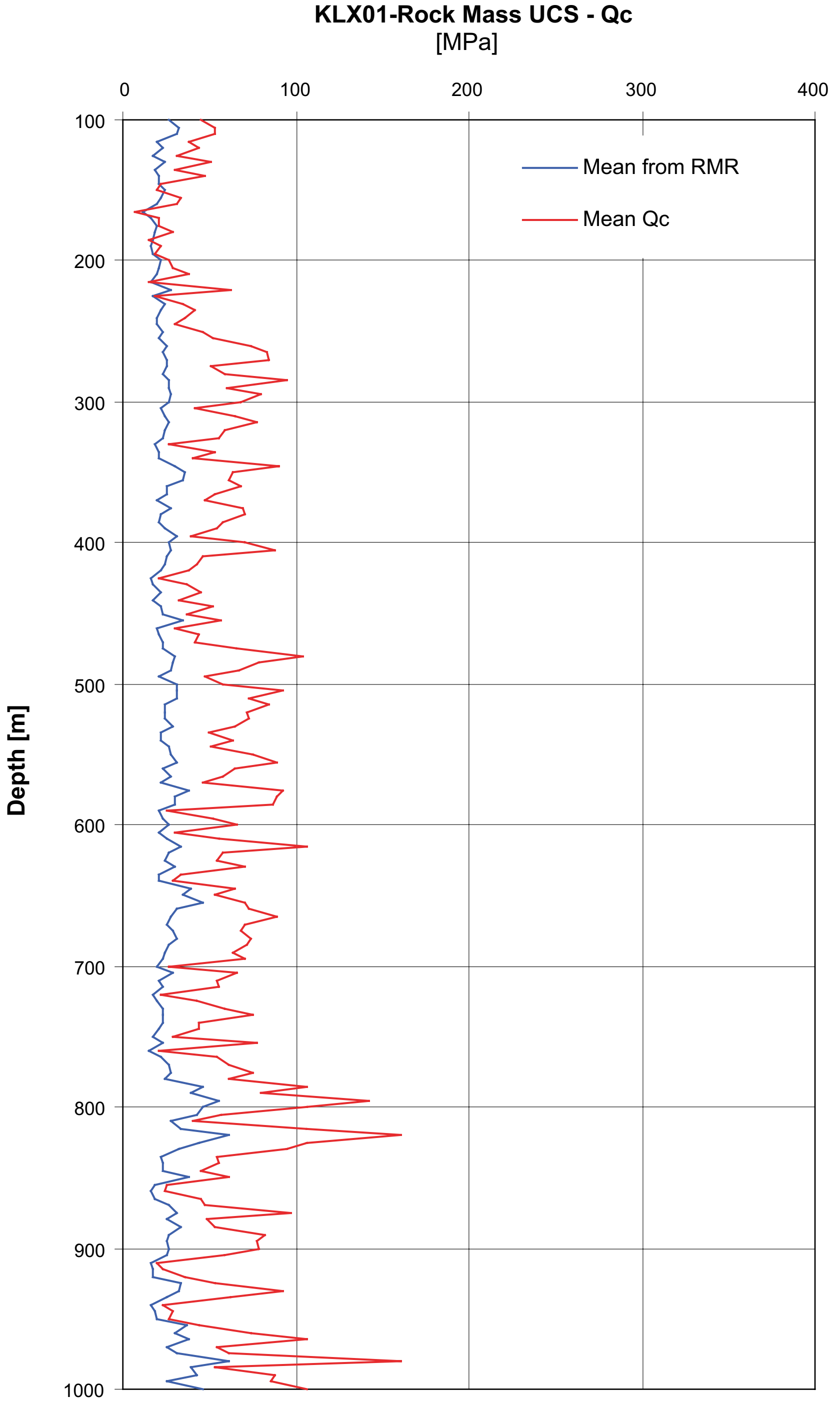
* Location of the potential deformation zones identified in Borehole KLX01.

Variation of Qc with depth for borehole KLX01. The values are given every 5 m.



1.6.3 Comparison

Comparison of the rock mass compressive strength from RMR and Q for borehole KLX01 (Hoek & Brown's a = 0.5).



1.7 Friction angle and cohesion and of the rock mass

1.7.1 RMR

Summary of the friction angle (φ) of the rock mass derived from RMR for borehole KLX01 (10–30 MPa) (core sections of 5 m, Hoek & Brown's a = 0.5).

Rock unit depth [m]	Minimum φ' [°]	Average φ' [°]	Frequent φ' [°]	Maximum φ' [°]	Standard deviation φ' [°]	Min possible φ' [°]	Max possible φ' [°]
0–585	39.5	43.2	43.1	47.9	1.2	28.2	50.9
585–640	39.7	40.5	40.5	42.1	0.8	26.3	47.5
640–1,000	40.8	43.9	43.7	47.9	1.7	29.8	50.9
DZ, 1,000–1,020*	37.7	40.0	39.5	43.3	2.4	29.9	48.8
1,020–1,078	42.2	43.9	44.0	46.2	1.3	34.1	49.7
RU3, 640–1,078	37.7	43.8	43.7	47.9	1.9	29.8	50.9
Competent rock	39.5	43.3	43.2	47.9	1.5	26.3	50.9
Fractured rock	37.7	40.0	39.5	43.3	2.4	29.9	48.8
Whole borehole	37.7	43.3	43.2	47.9	1.6	26.3	50.9

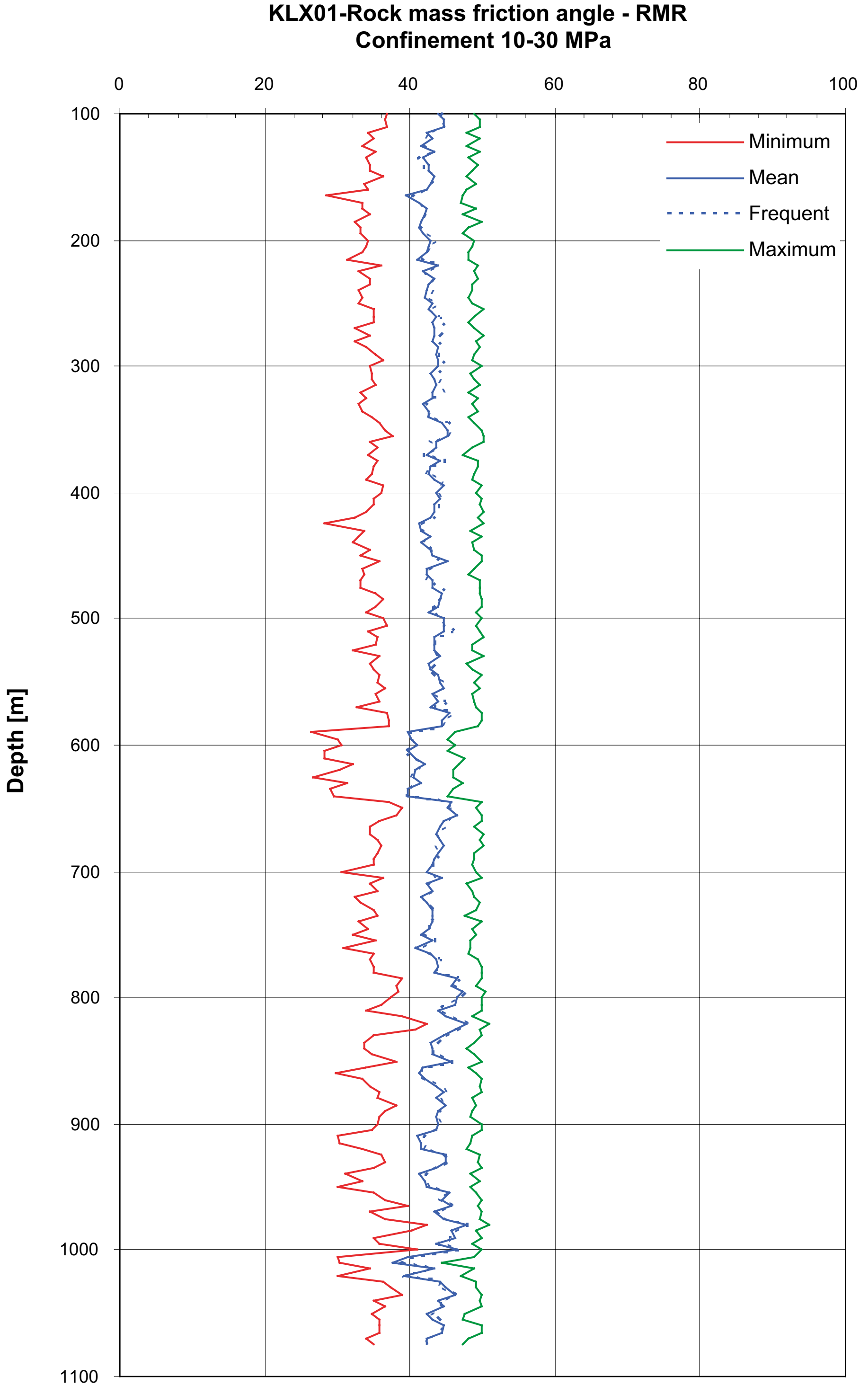
* Location of the potential deformation zones identified in Borehole KLX01.

Summary of the cohesion c' of the rock mass derived from RMR for borehole KLX01 under confinement stress between 10 and 30 MPa) (core sections of 5 m, Hoek & Brown's a = 0.5).

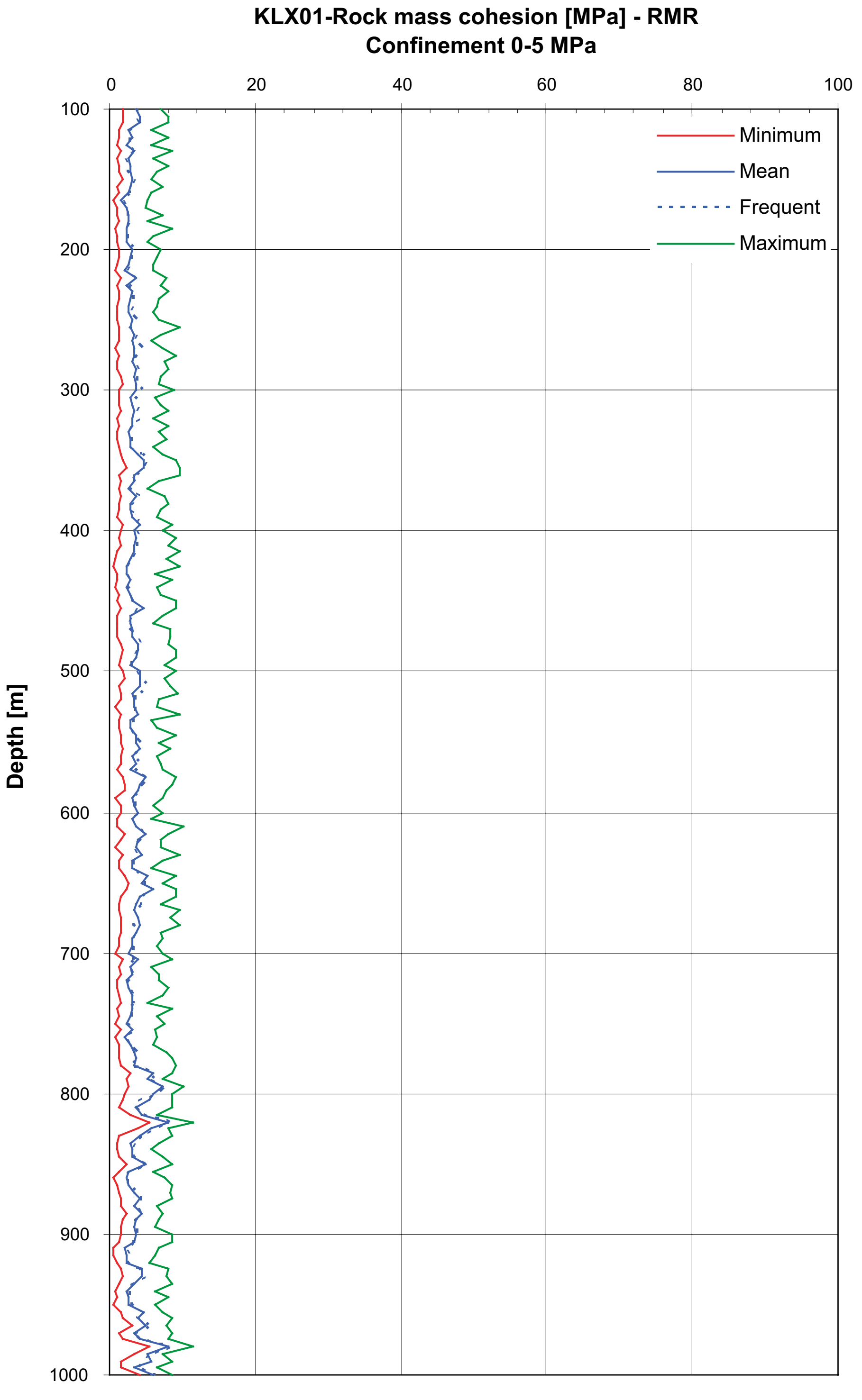
Rock unit depth [m]	Minimum c' [MPa]	Average c' [MPa]	Frequent c' [MPa]	Maximum c' [MPa]	Standard deviation c' [MPa]	Min possible c' [MPa]	Max possible c' [MPa]
0–585	14.5	17.1	17.0	22.5	1.0	9.3	26.9
585–640	15.2	15.9	15.8	17.3	0.7	8.6	23.8
640–1,000	15.4	17.9	17.5	22.5	1.6	9.9	26.9
DZ, 1,000–1,020*	13.6	14.9	14.5	17.1	1.5	10.0	22.4
1,020–1,078	16.3	17.7	17.7	20.0	1.1	11.9	24.1
RU3, 640–1,078	13.6	17.7	17.5	22.5	1.7	9.9	26.9
Competent rock	14.5	17.3	17.1	22.5	1.3	8.6	26.9
Fractured rock	13.6	14.9	14.5	17.1	1.5	10.0	22.4
Whole borehole	13.6	17.3	17.1	22.5	1.4	8.6	26.9

* Location of the potential deformation zones identified in Borehole KLX01.

Variation of the rock mass friction angle φ’ from RMR for borehole KLX01 under stress confinement 10–30 MPa (Hoek & Brown’s a = 0.5).



Variation of the rock mass cohesion c' from RMR for borehole KLX01 under stress confinement 10–30 MPa (Hoek & Brown's a = 0.5).



Appendix 2: KLX03

Characterisation of the rock mass

2.1 Fracture orientation

The characterization of this borehole was carried out before the actual version of Site Descriptive Model for Simpevarp version 1.2 /SKB 2005/ was completed. Thus, the fracture sets identified by the Model for Simpevarp 1.1 /SKB 2004/ were adopted.

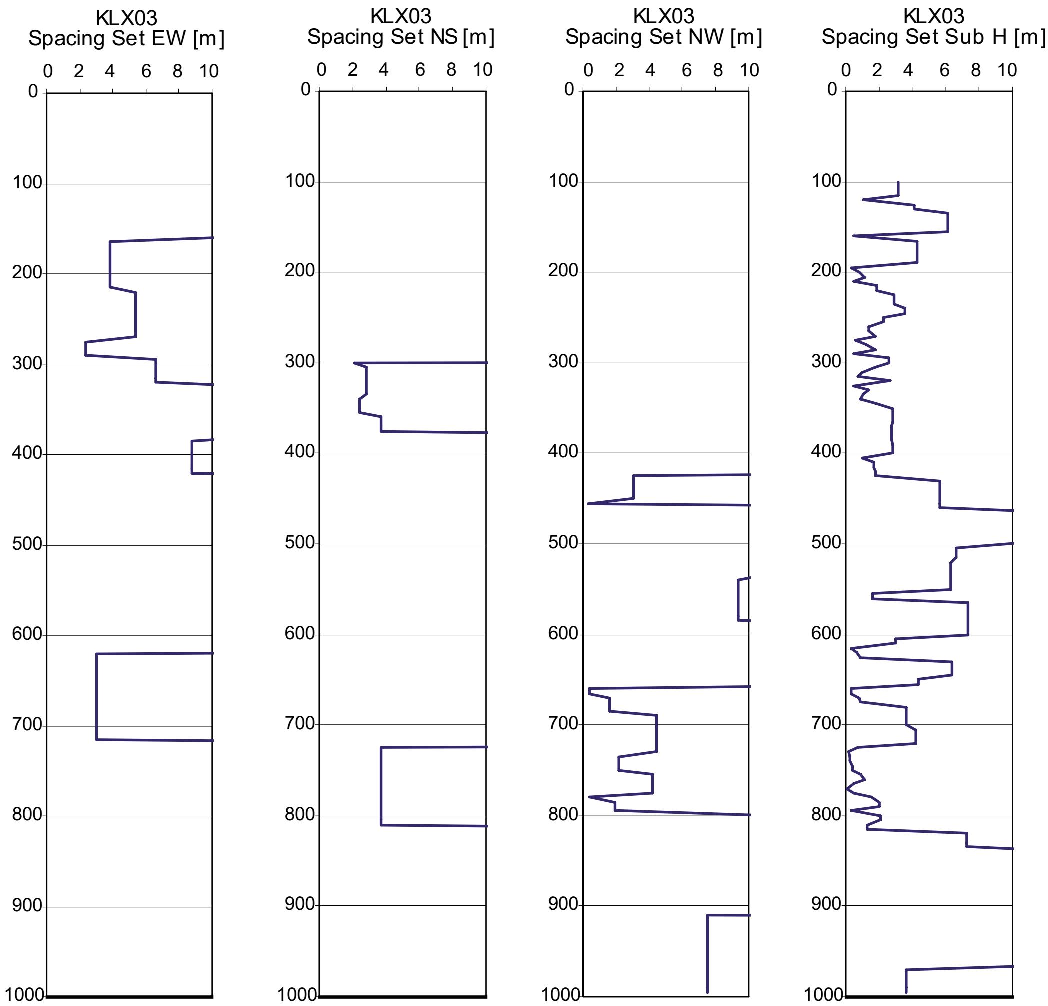
Set identification from the fracture orientation mapped for borehole KLX03 (SICADA, 04-11-25). The orientations are given as strike/dip (right-hand rule).

Depth [m]	No. of fract.	EW	NS	NW	Sub H
RU1, 101–426	255	88/89	353/83		68/09
RU2, 426–620	76			295/85	137/05
620–723	85	251/85		296/89	208/01
DZ1, 723–814	231		358/84	294/75	65/10
814–1,000	36	64/78		281/89	325/05

Fisher's constant of the fracture sets identified for borehole KLX03 (SICADA, 04-11-25).

Depth [m]	No. of fract.	EW	NS	NW	Sub H
RU1, 101–426	255	28	81		10
RU2, 426–620	76			49	15
620–723	85	59		13	9
DZ1, 723–814	231		34	29	7
814–1,000	36	40		28	43

Fracture spacing with depth for the four facture sets in borehole KLX03. The values are averaged for each 5 m length of borehole.

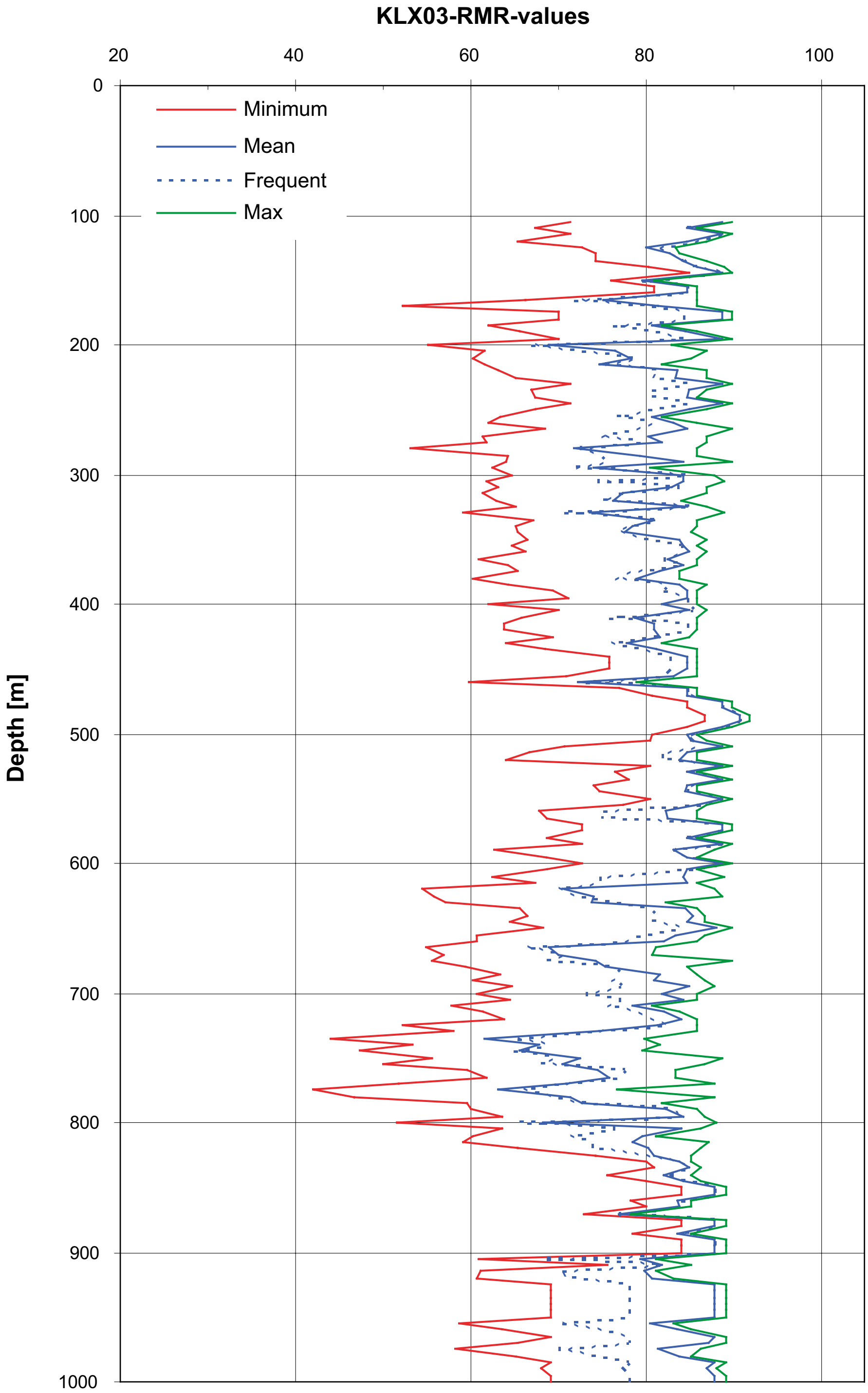


2.2 RMR

RMR values along borehole KLX03 (core sections of 5 m).

Rock unit depth [m]	Minimum RMR [–]	Average RMR [–]	Frequent RMR [–]	Maximum RMR [–]	Standard deviation RMR [–]	Min possible RMR [–]	Max possible RMR [–]
RU1, 101–426	68.9	82.3	83.5	88.7	4.3	52.3	89.9
RU2, 426–620	70.6	85.1	84.8	90.8	4.2	54.4	92.0
620–723	68.9	80.2	81.9	88.0	5.5	54.9	89.9
DZ1, 723–814	61.7	73.7	72.8	84.4	6.8	42.1	88.9
814–1,000	76.9	85.0	86.9	87.9	3.3	58.3	89.2
RU3, 620–798	61.7	76.7	75.6	88.0	7.1	42.1	89.9
RU4, 798–1,000	76.9	84.7	84.7	87.9	3.4	58.3	89.2
Competent rock	68.9	83.3	84.4	90.8	4.6	52.3	92.0
Deformation zones	61.7	73.7	72.8	84.4	6.8	42.1	88.9
Whole borehole	61.7	82.3	83.9	90.8	5.7	42.1	92.0

Variation of RMR with depth for borehole KLX03. The values are given every 5 m.

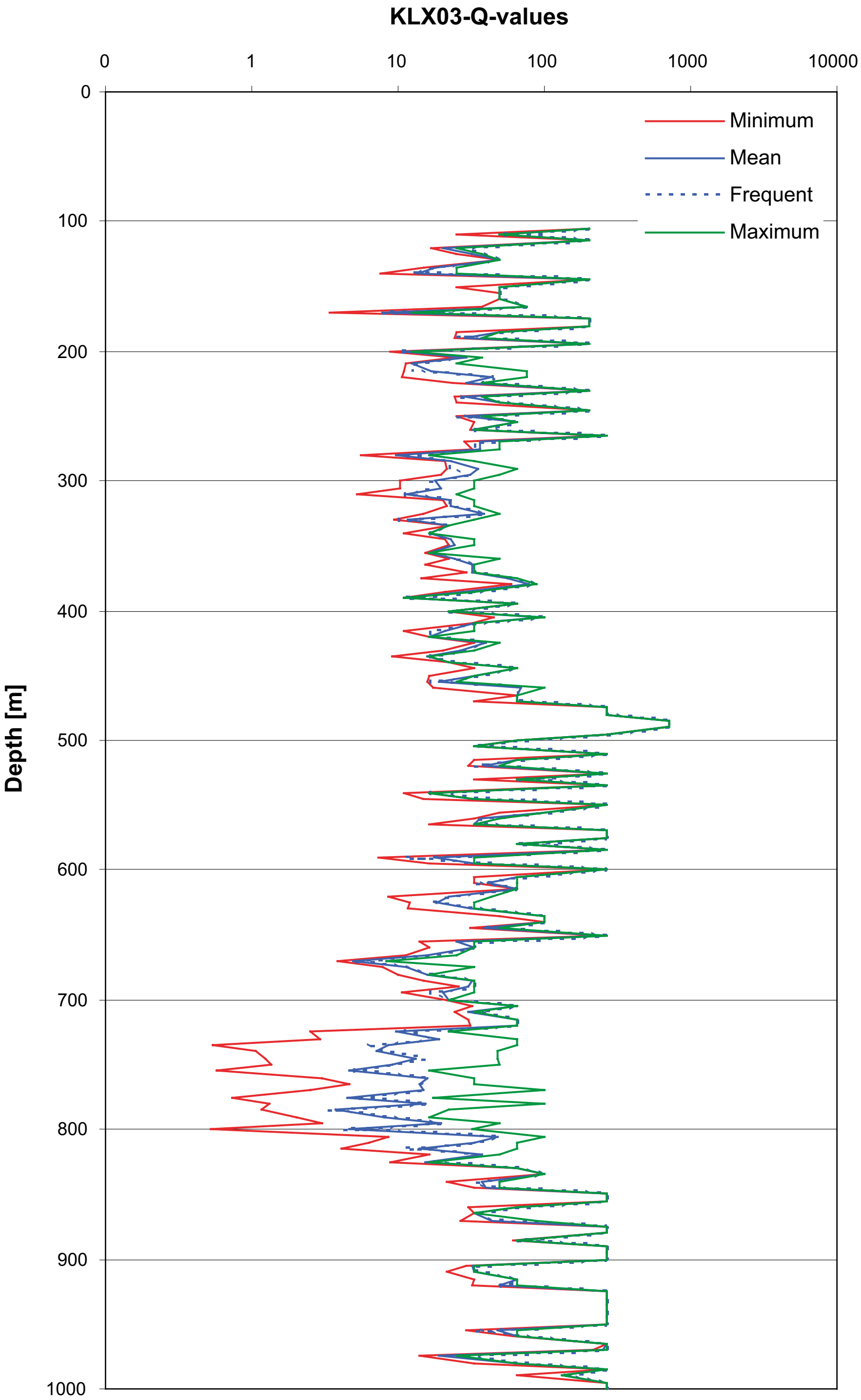


2.3 Q

Q values along borehole KLX03 (core sections of 5m).

Rock unit depth [m]	Minimum Q [–]	Average Q [–]	Frequent Q [–]	Maximum Q [–]	Min possible Q [–]	Max possible Q [–]
RU1, 101–426	7.8	56.5	32.1	259.2	3.4	264.0
RU2, 426–620	15.7	140.9	66.0	704.0	7.3	704.0
620–723	5.0	49.0	30.7	257.1	3.8	264.0
DZ1, 723–814	3.7	14.0	13.0	47.4	0.5	99.0
814–1,000	15.5	155.5	132.0	264.0	8.8	264.0
RU3, 620–798	3.7	32.0	17.3	257.1	0.5	264.0
RU4, 798–1,000	14.2	146.2	82.5	264.0	4.1	264.0
Competent rock	5.0	98.8	44.0	704.0	3.4	704.0
Deformation zones	3.7	14.0	13.0	47.4	0.5	99.0
Whole borehole	3.7	89.8	37.1	704.0	0.5	704.0

Variation of Q with depth for borehole KLX03. The values are given every 5 m.



Rock mass properties

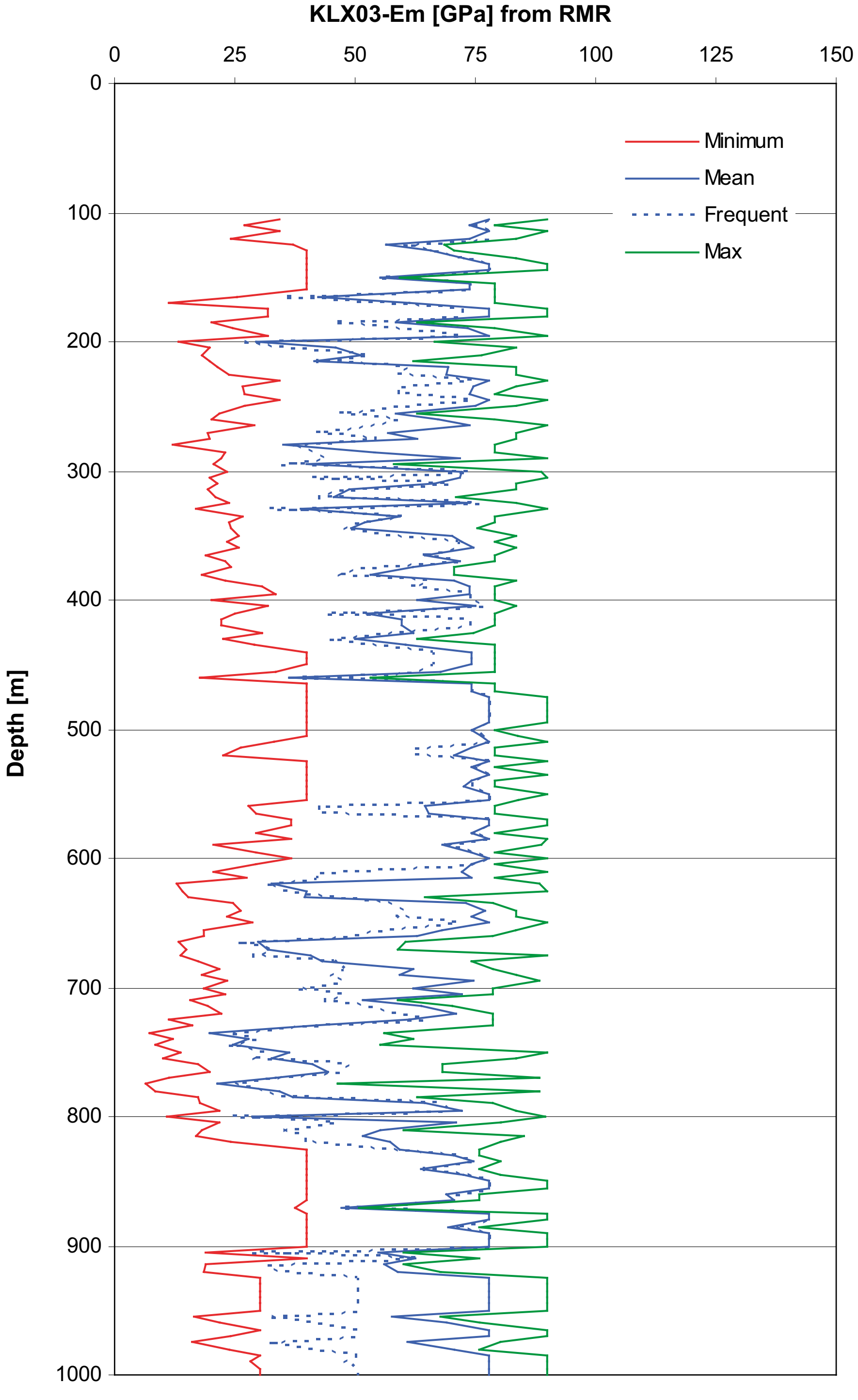
2.4 Deformation modulus

2.4.1 RMR

Deformation modulus Em derived from RMR along for borehole KLX03 (core sections of 5 m).

Rock unit depth [m]	Minimum Em [GPa]	Average Em [GPa]	Frequent Em [GPa]	Maximum Em [GPa]	Standard deviation Em [GPa]	Min possible Em [GPa]	Max possible Em [GPa]
RU1, 101–425	29.6	64.1	68.8	78.0	12.5	11.4	90.0
RU2, 425–620	32.7	71.6	74.1	78.0	10.5	12.9	90.0
620–725	29.6	58.7	62.7	78.0	15.9	13.3	90.0
DZ1, 725–815	19.6	42.0	37.1	72.3	16.3	6.3	90.0
815–1,000	47.0	70.9	78.0	78.0	9.0	16.2	90.0
RU3, 620–800	19.6	49.9	43.7	78.0	18.4	6.3	90.0
RU4, 800–1,000	47.0	70.1	73.5	78.0	9.5	16.2	90.0
Competent rock	29.6	66.8	72.4	78.0	12.6	11.4	90.0
Deformation zones	19.6	42.0	37.1	72.3	16.3	6.3	90.0
Whole borehole	19.6	64.2	70.5	78.0	15.0	6.3	90.0

Variation of the deformation modulus of the rock mass obtained from RMR with depth for borehole KLX03. The values are given every 5 m.



2.4.2 Q

Deformation modulus Em derived from Q along borehole KLX03 (core sections of 5 m).

Rock unit depth [m]	Minimum Em [GPa]	Average Em [GPa]	Frequent Em [GPa]	Maximum Em [GPa]	Standard deviation Em [GPa]	Min possible Em [GPa]	Max possible Em [GPa]
RU1, 101–425	24.6	43.1	39.5	78.0	13.9	16.9	86.3
RU2, 425–620	31.2	54.8	50.3	78.0	17.7	21.7	90.0
620–725	20.9	40.9	38.2	77.6	12.7	16.8	85.9
DZ1, 725–815	18.9	27.8	28.6	42.7	6.2	8.6	62.0
815–1,000	29.5	59.0	60.1	75.8	17.3	22.1	81.7
RU3, 620–800	18.9	34.3	31.5	77.6	12.3	8.6	85.9
RU4, 800–1,000	28.6	57.3	51.2	75.8	17.7	17.2	81.7
Competent rock	20.9	49.3	43.0	78.0	17.1	16.8	90.0
Deformation zones	18.9	27.8	28.6	42.7	6.2	8.6	62.0
Whole borehole	18.9	47.1	41.1	78.0	17.6	8.6	90.0

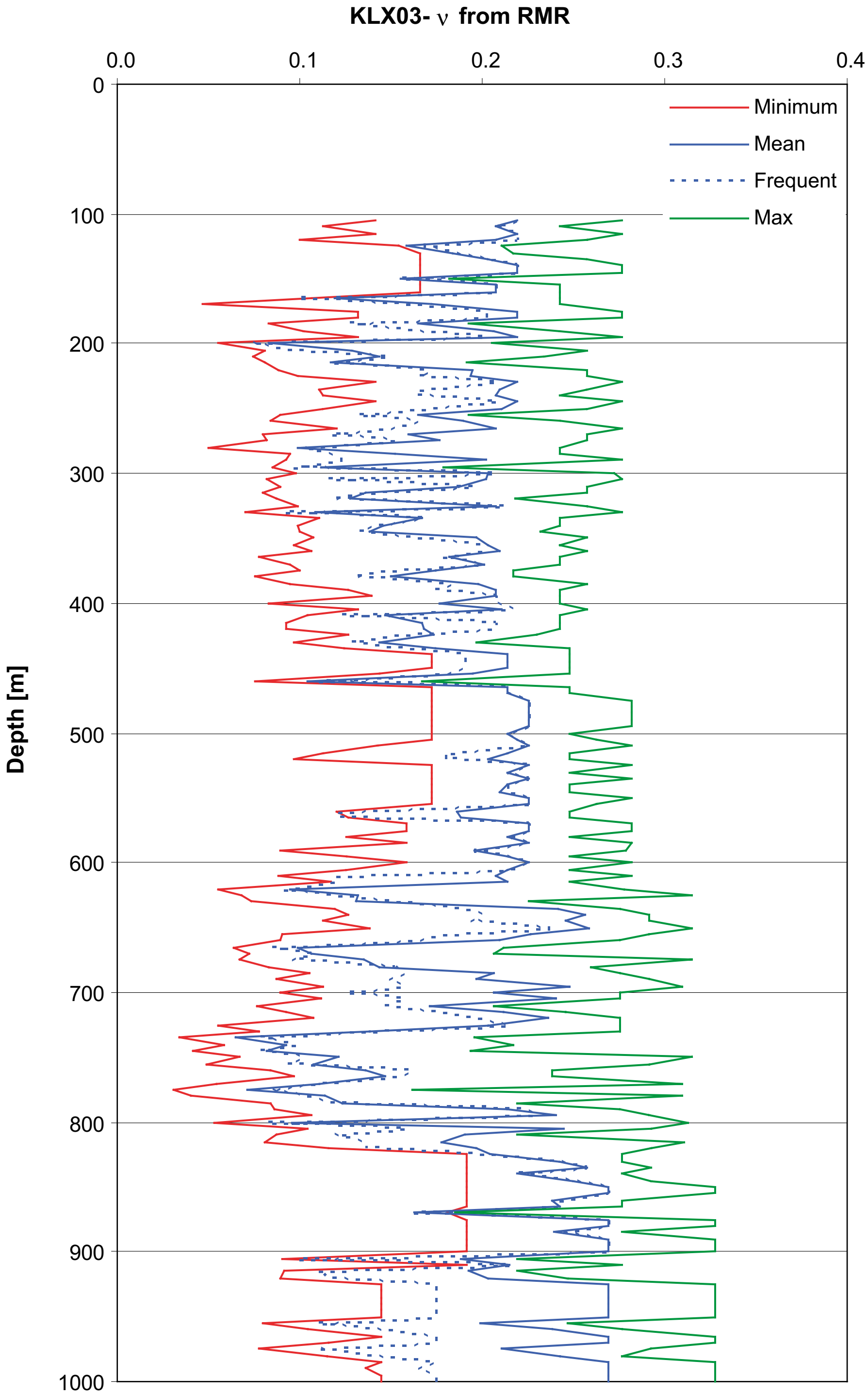
2.5 Poisson's ratio

2.5.1 RMR

Summary of Poisson's ratio (ν) derived from RMR for borehole KLX03 (core sections of 5 m, Hoek & Brown's a = 0.5).

Rock unit depth [m]	Minimum ν [–]	Average ν [–]	Frequent ν [–]	Maximum ν [–]	Standard deviation ν [–]	Min possible ν [–]	Max possible ν [–]
RU1, 101–425	0.08	0.18	0.19	0.22	0.04	0.05	0.028
RU2, 425–620	0.09	0.21	0.21	0.23	0.03	0.06	0.28
620–725	0.10	0.20	0.21	0.26	0.05	0.06	0.32
DZ1, 725–815	0.07	0.14	0.12	0.24	0.06	0.03	0.32
815–1,000	0.16	0.24	0.27	0.27	0.03	0.08	0.33
RU3, 620–800	0.07	0.17	0.15	0.26	0.06	0.03	0.32
RU4, 800–1,000	0.16	0.24	0.25	0.27	0.03	0.08	0.33
Competent rock	0.08	0.20	0.21	0.27	0.04	0.05	0.33
Deformation zones	0.07	0.14	0.12	0.24	0.06	0.03	0.32
Whole borehole	0.07	0.20	0.21	0.27	0.05	0.03	0.33

Variation of Poisson's ratio (ν) with depth for borehole KLX03 (Hoek & Brown's a = 0.5). The values are given every 5 m.



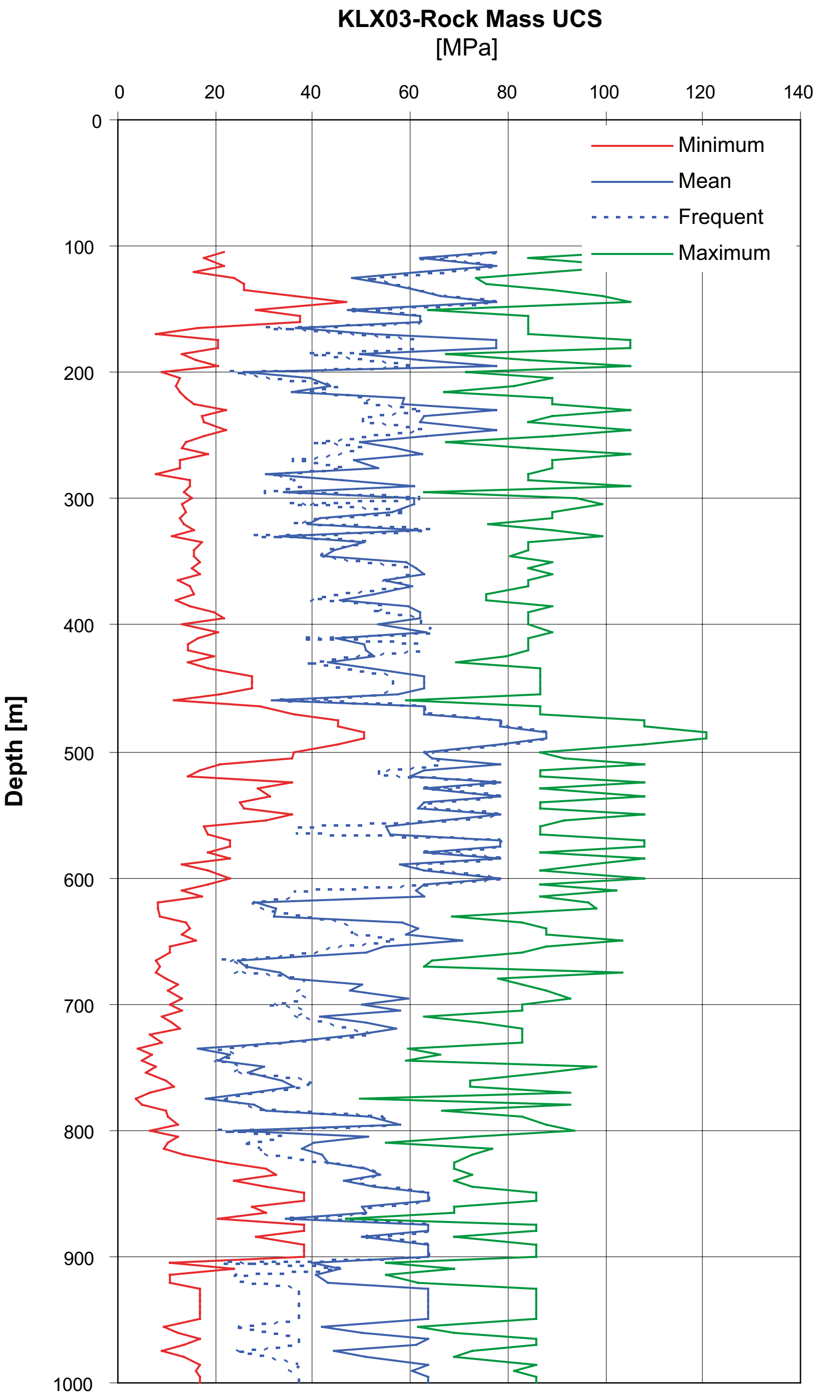
2.6 Uniaxial compressive strength

2.6.1 RMR

Summary of the uniaxial compressive strength of the rock mass derived from RMR and Hoek & Brown's Criterion for borehole KLX03 (core sections of 5 m, Hoek & Brown's a = 0.5).

Rock unit depth [m]	Minimum UCS [MPa]	Average UCS [MPa]	Frequent UCS [MPa]	Maximum UCS [MPa]	Standard deviation UCS [MPa]	Min possible UCS [MPa]	Max possible UCS [MPa]
RU1, 101–425	25.8	55.7	58.1	77.5	12.5	7.6	105.2
RU2, 425–620	28.5	65.5	62.9	87.8	13.2	8.4	120.8
620–725	24.5	47.7	50.4	70.7	13.1	7.7	103.6
DZ1, 725–815	16.4	33.5	30.3	57.9	12.0	3.8	98.0
815–1,000	34.6	55.0	60.3	63.7	9.5	9.2	86.0
RU3, 620–800	16.4	40.6	35.6	70.7	14.8	3.8	103.6
RU4, 800–1,000	34.6	54.1	53.2	63.7	9.8	9.2	86.0
Competent rock	24.5	56.9	60.0	87.8	13.2	7.6	120.8
Deformation zones	16.4	33.5	30.3	57.9	12.0	3.8	98.0
Whole borehole	16.4	54.5	57.9	87.8	14.9	3.8	120.8

Variation of the uniaxial compressive strength of the rock mass with depth for borehole KLX03 (Hoek & Brown's a = 0.5). The values are given every 5 m.



2.7 Friction angle and cohesion and of the rock mass

2.7.1 RMR

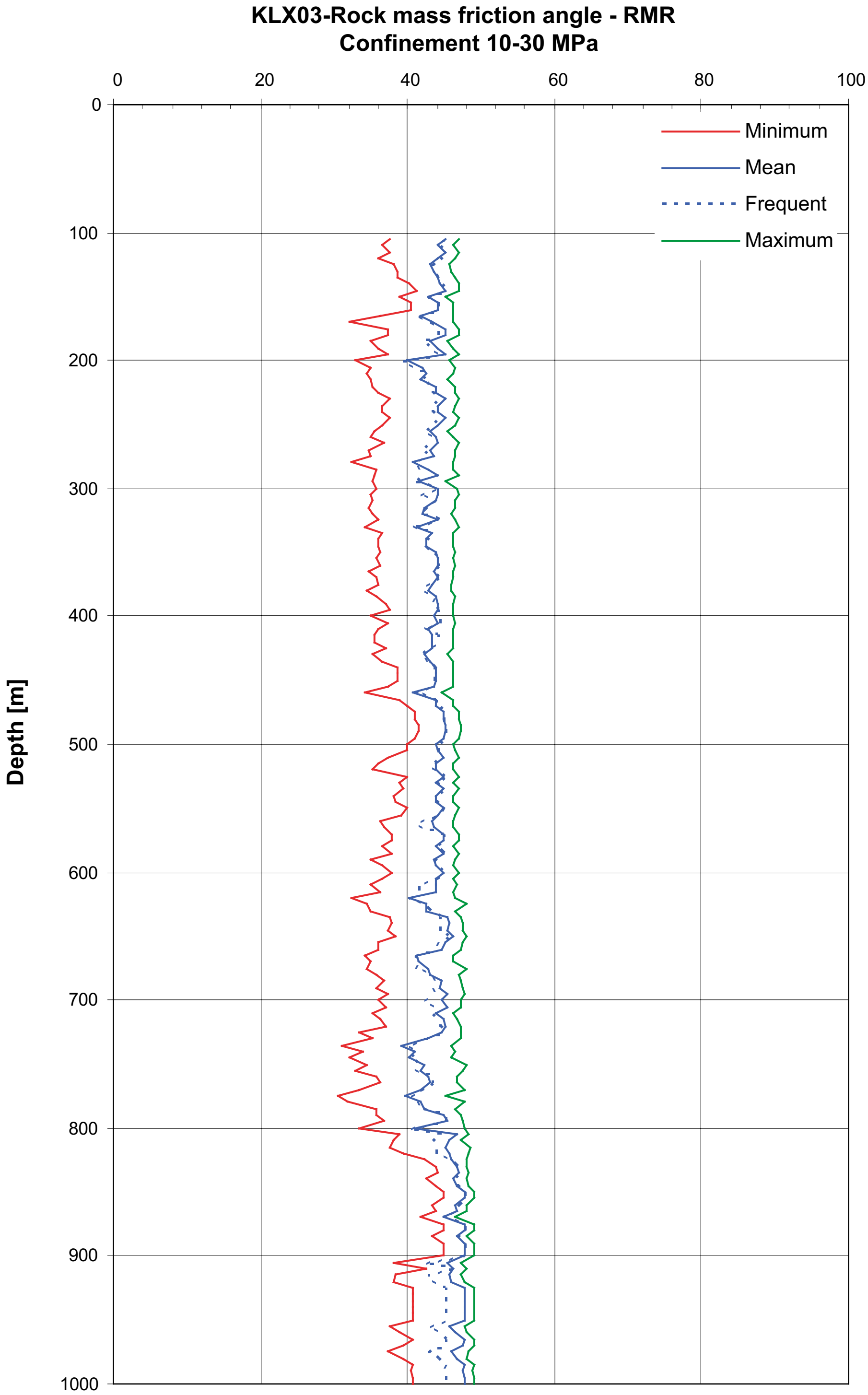
Summary of the friction angle (φ') of the rock mass derived from RMR for borehole KLX03 (10–30 MPa) (core sections of 5 m, Hoek & Brown's a = 0.5).

Rock unit depth [m]	Minimum φ' [°]	Average φ' [°]	Frequent φ' [°]	Maximum φ' [°]	Standard deviation φ' [°]	Min possible φ' [°]	Max possible φ' [°]
RU1, 101–425	40.0	43.5	43.9	45.0	1.1	32.1	47.1
RU2, 425–620	40.3	44.0	44.0	45.3	1.0	32.5	47.2
620–725	41.2	44.3	44.7	46.2	1.4	34.3	48.1
DZ1, 725–815	39.1	42.7	42.3	46.7	2.2	30.5	48.6
815–1,000	44.8	46.9	47.4	47.7	0.8	37.4	49.1
RU3, 620–800	39.1	43.3	43.1	46.2	1.9	30.5	48.1
RU4, 800–1,000	44.8	46.9	46.9	47.7	0.9	37.4	49.1
Competent rock	40.0	44.5	44.2	47.7	1.7	32.1	49.1
Deformation zones	39.1	42.7	42.3	46.7	2.2	30.5	48.6
Whole borehole	39.1	44.3	44.2	47.7	1.8	30.5	49.1

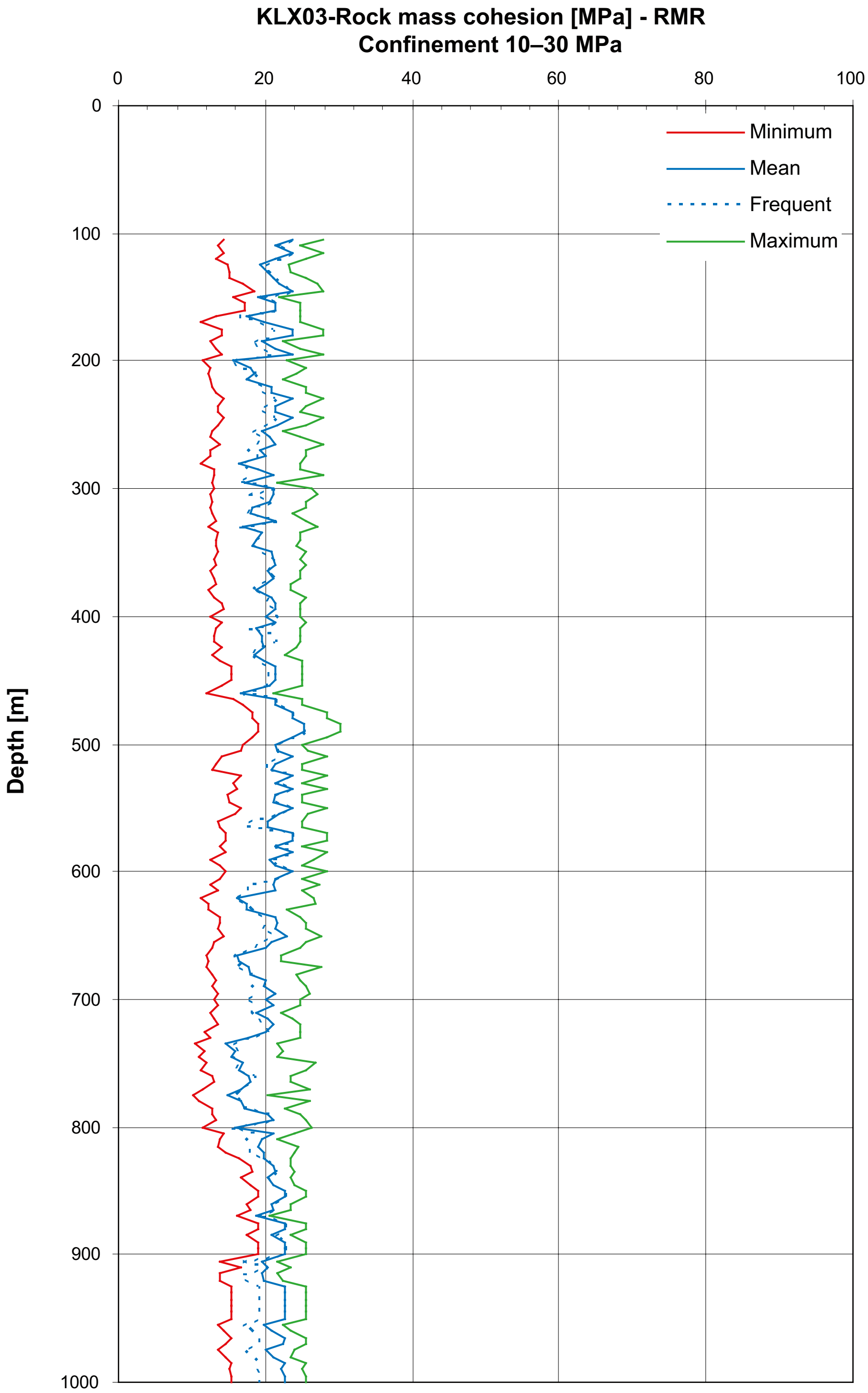
Summary of the cohesion c' of the rock mass derived from RMR for borehole KLX03 under confinement stress between 10 and 30 MPa (core sections of 5 m, Hoek & Brown's a = 0.5).

Rock unit depth [m]	Minimum c' [MPa]	Average c' [MPa]	Frequent c' [MPa]	Maximum c' [MPa]	Standard deviation c' [MPa]	Min possible c' [MPa]	Max possible c' [MPa]
RU1, 101–425	15.7	20.4	20.7	23.6	1.9	11.1	27.8
RU2, 425–620	16.1	21.8	21.4	25.1	2.0	11.3	30.2
620–725	16.1	19.7	20.1	23.0	1.9	12.0	27.7
DZ1, 725–815	14.6	17.7	17.1	21.2	2.0	10.3	26.9
815–1,000	18.6	21.5	22.2	22.7	1.3	13.5	25.6
RU3, 620–800	14.6	18.6	17.9	23.0	2.3	10.3	27.7
RU4, 800–1,000	18.6	21.4	21.3	22.7	1.3	13.5	25.6
Competent rock	15.7	20.9	21.2	25.1	1.9	11.1	30.2
Deformation zones	14.6	17.7	17.1	21.2	2.0	10.3	26.9
Whole borehole	14.6	20.5	21.0	25.1	2.2	10.3	30.2

Variation of the rock mass friction angle φ' from RMR for borehole KLX03 under stress confinement 10–30 MPa (Hoek & Brown's a = 0.5).



Variation of the rock mass cohesion c' from RMR for borehole KLX03 under stress confinement 10–30 MPa (Hoek & Brown's a = 0.5).



Appendix 3: KLX04

Characterisation of the rock mass

3.1 Fracture orientation

The characterization of this borehole was carried out before the actual version of Site Descriptive Model for Simpevarp version 1.2 /SKB 2005/ was completed. Thus, the fracture sets identified by the Model for Simpevarp 1.1 /SKB 2004/ were adopted.

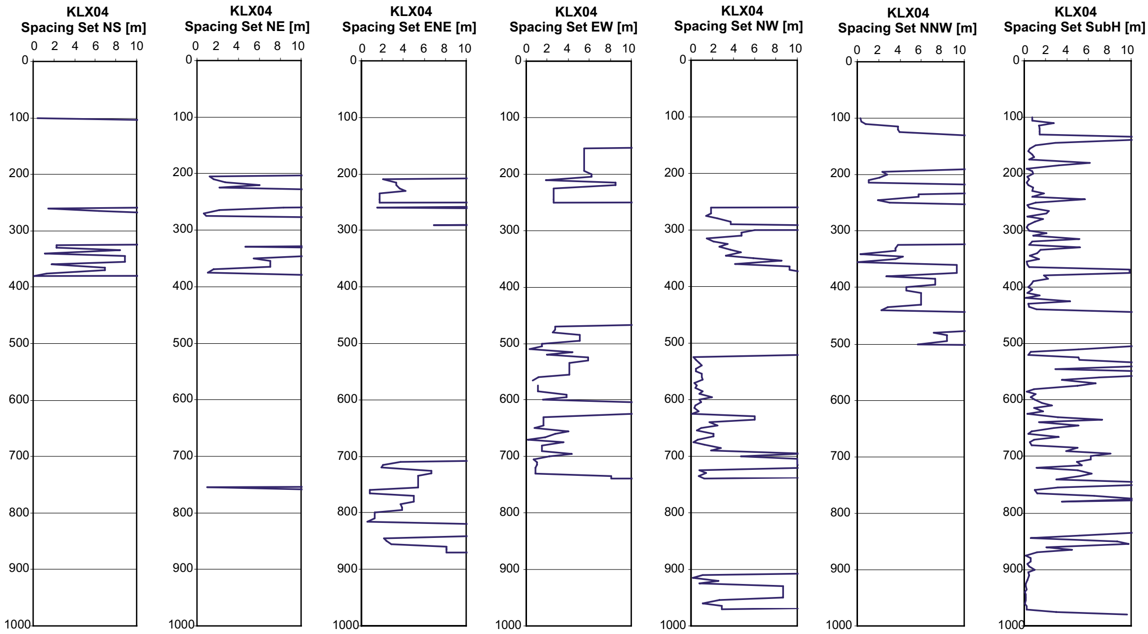
Set identification from the fracture orientation mapped for borehole KLX04 (SICADA, 04-11-25). The orientations are given as strike/dip (right-hand rule).

Depth [m]	No. of fract.	NS	NE	ENE	EW	NW	NNW	SubH
100–255	324	18/73	218/72	60/79	271/88		336/71	324/3
255–260	18							345/10
260–295	70	187/89	218/80	70/86		132/85		69/05
295–300	18							99/14
300–385	188	195/82	216/54			128/82	343/59	176/01
385–555	199				101/86	302/87	334/78	191/06
555–680	271				278/89	309/87		73/07
680–745	70			63/78	280/85	306/86		88/05
745–875	76		219/88	68/73				92/06
875–975	750					124/78		169/04
975–990	12		211/76	246/55	289/79			

Fisher's constant of the fracture sets identified for borehole KLX04 (SICADA, 04-11-25).

Depth [m]	No. of fract.	NS	NE	ENE	EW	NW	NNW	SubH
100–255	324	76	126	57	16		13	19
255–260	18							21
260–295	70	13	5	74		292		18
295–300	18							33
300–385	188	6	29			4	12	19
385–555	199				25	45	15	12
555–680	271				16	19		15
680–745	70			49	19	12		21
745–875	76		34	62				20
875–975	750					106		28
975–990	12		60	24	8			

Fracture spacing with depth for the seven facture sets in borehole KLX04. The values are averaged for each 5 m length of borehole.

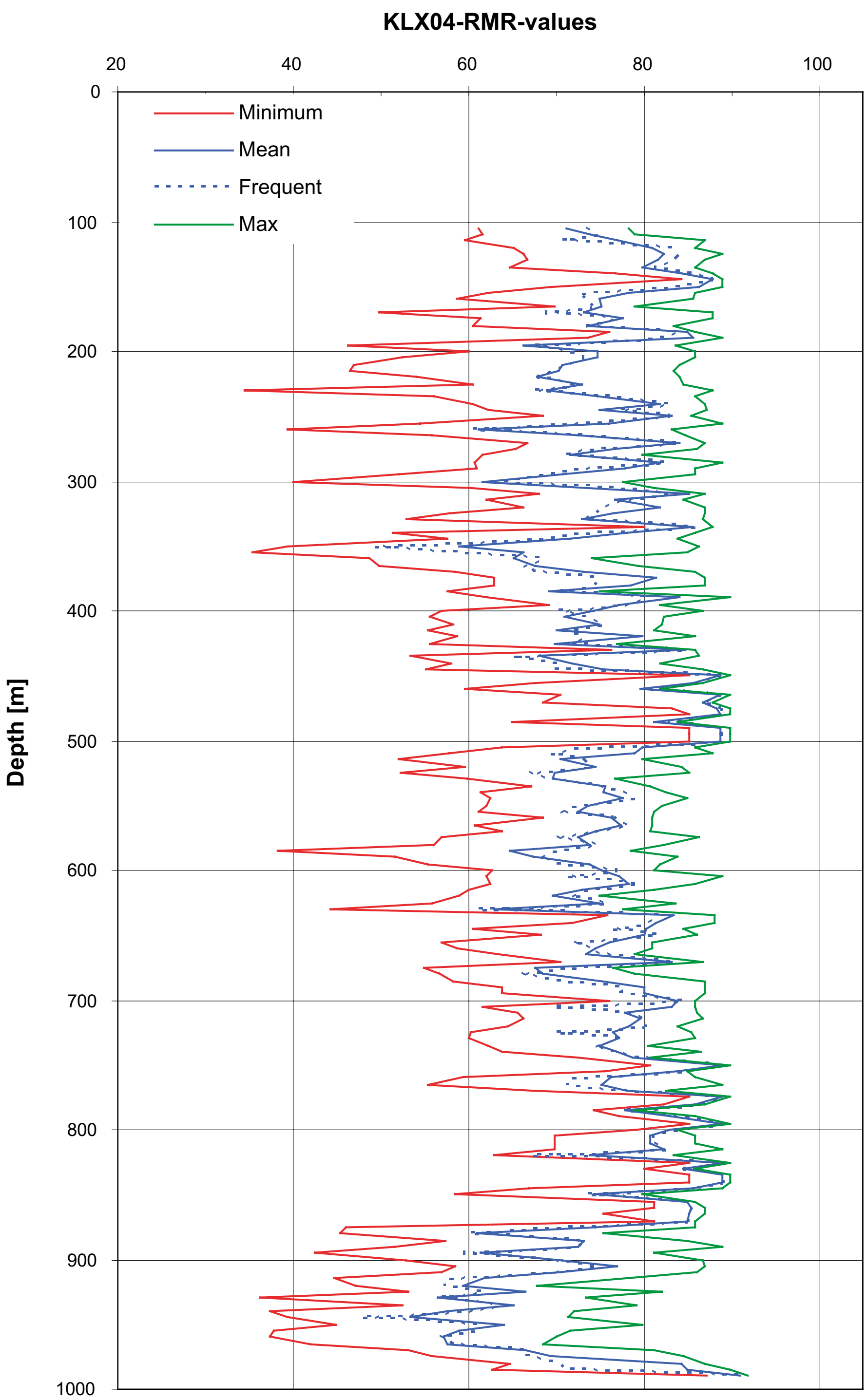


3.2 RMR

RMR values along borehole KLX04 (core sections of 5 m).

Rock unit depth [m]	Minimum RMR [–]	Average RMR [–]	Frequent RMR [–]	Maximum RMR [–]	Standard deviation RMR [–]	Min possible RMR [–]	Max possible RMR [–]
100–227	66.2	77.0	75.2	87.9	6.0	46.2	88.9
DZ1, 227–230	–	69.0	–	–	–	34.4	87.9
230–254	74.7	78.1	76.2	83.1	4.0	54.6	88.9
DZ2, 254–258	–	61.2	–	–	–	39.4	83.1
258–295	70.8	76.5	76.8	84.2	5.2	52.2	88.9
DZ3, 295–298	–	61.6	–	–	–	39.9	77.5
298–346	71.6	78.0	76.7	85.7	5.2	51.3	87.9
DZ5*, 346–355	59.0	62.7	62.7	66.3	5.1	34.5	86.3
355–385	65.2	72.5	71.2	81.4	6.4	48.8	86.9
RU1, 100–385	59.0	75.6	74.9	87.9	6.7	34.4	88.9
RU2, 385–555	68.0	78.6	77.4	88.7	7.0	52.0	89.8
RU1, 555–680	63.0	74.4	74.6	83.4	5.4	38.3	89.0
RU3, 680–745	75.1	78.7	78.3	83.8	2.7	58.2	86.9
745–873	73.8	82.8	84.2	88.9	5.1	46.1	89.9
DZ6, 873–973	53.3	64.0	63.0	77.1	6.6	36.3	88.9
973–992	84.2	86.7	84.9	90.9	3.7	62.7	91.9
RU1, 745–992	53.3	75.3	75.2	90.9	8.4	34.4	91.9
Competent rock	63.0	78.2	77.6	90.6	6.3	38.3	91.9
Fractured rock	53.3	63.9	61.9	77.1	6.1	34.4	88.5
Whole borehole	53.3	76.2	76.3	90.9	8.0	34.4	90.9

Variation of RMR with depth for borehole KLX04. The values are given every 5 m.

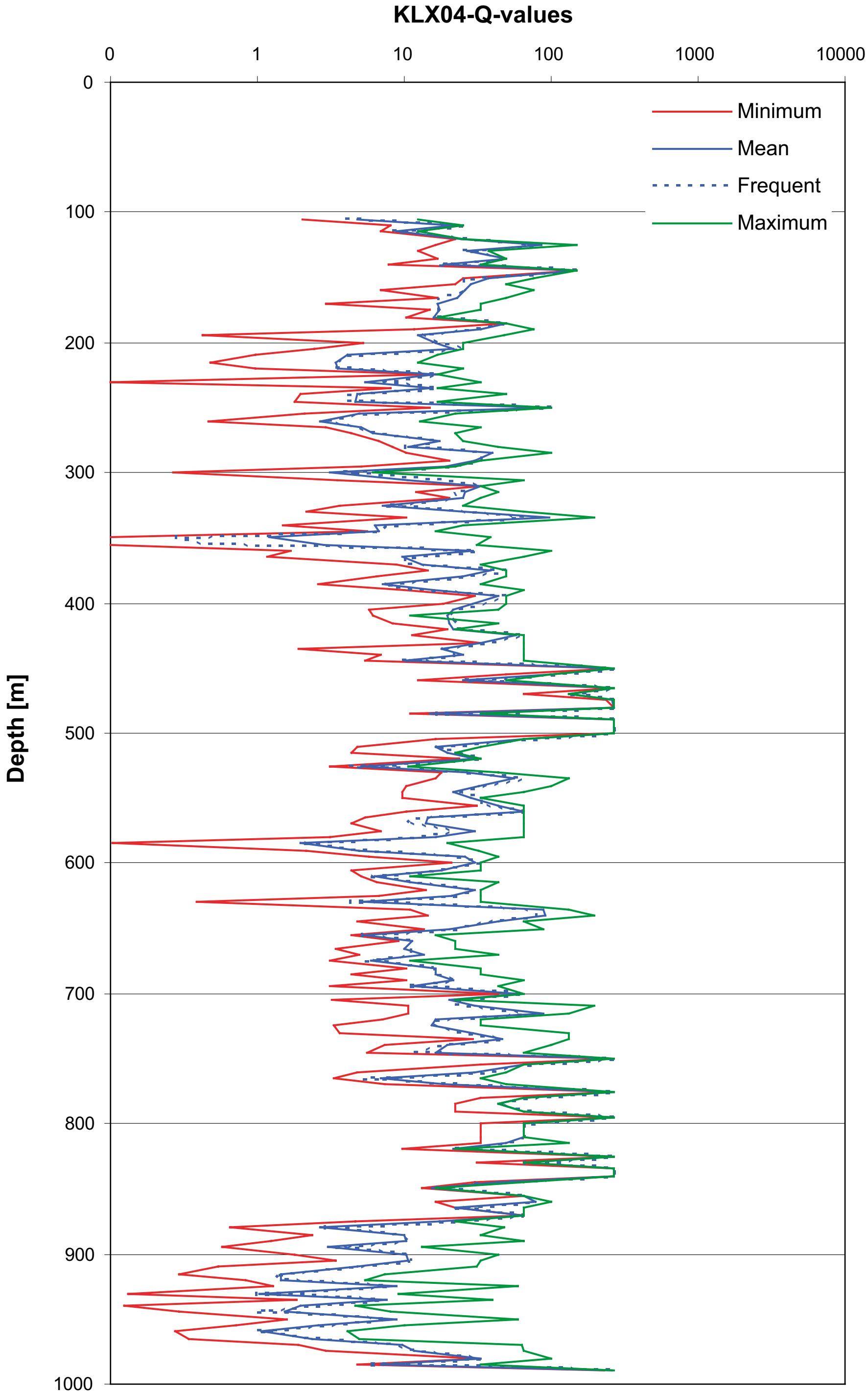


3.3 Q

Q values along borehole KLX04 (core sections of 5 m).

Rock unit depth [m]	Minimum Q [–]	Average Q [–]	Frequent Q [–]	Maximum Q [–]	Min possible Q [–]	Max possible Q [–]
100–227	3.4	28.6	21.3	150.0	150.0	3.4
DZ1, 227–230	–	5.4	–	–	33.3	–
230–254	4.6	25.5	4.9	97.8	100.0	4.6
DZ2, 254–258	–	2.7	–	–	12.7	–
258–295	5.2	18.3	17.5	39.7	99.0	5.2
DZ3, 295–298	–	3.1	–	–	6.2	–
298–346	6.4	26.4	24.9	97.8	198.0	6.4
DZ5*, 346–355	1.2	2.0	2.0	2.8	38.3	1.2
355–385	7.1	20.5	19.1	39.1	99.0	7.1
RU1, 100–385	1.2	23.6	16.6	150.0	198.0	1.2
RU2, 385–555	5.1	81.5	29.7	264.0	264.0	5.1
RU1, 555–680	2.0	24.0	16.2	90.8	198.0	2.0
RU3, 680–745	11.2	30.2	20.3	87.3	198.0	11.2
745–873	6.9	97.1	66.0	264.0	264.0	6.9
DZ6, 873–973	1.0	5.6	3.9	11.7	66.0	1.0
973–992	6.9	98.9	32.7	257.1	264.0	6.9
RU1, 745–992	1.0	37.2	16.6	264.0	264.0	1.0
Competent rock	2.0	51.7	24.8	264.0	264.0	2.0
Fractured rock	1.0	5.1	3.0	11.7	66.0	1.0
Whole borehole	1.0	45.2	20.3	264.0	264.0	1.0

Variation of Q with depth for borehole KLX04. The values are given every 5 m.



Rock mass properties

3.4 Deformation modulus

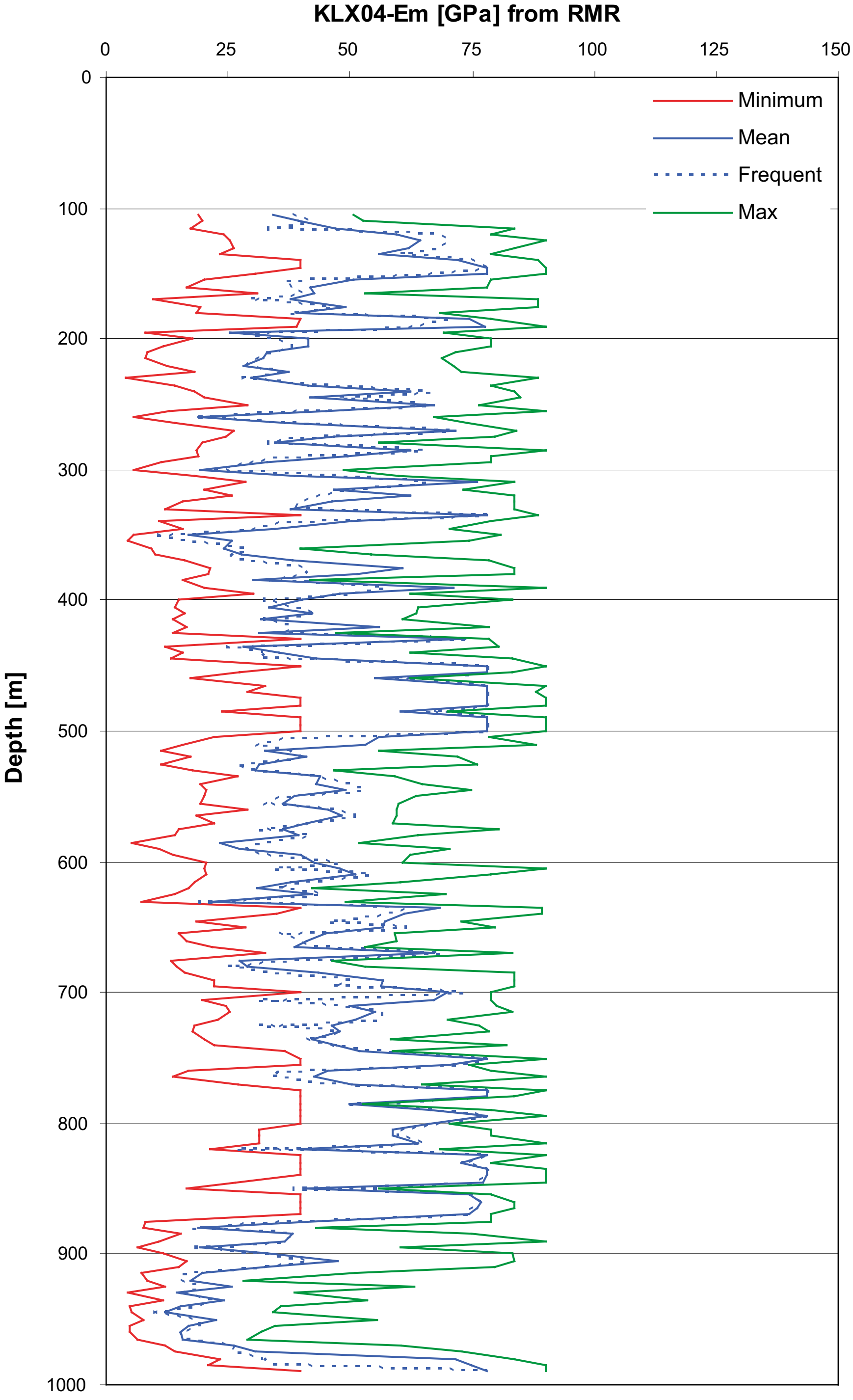
3.4.1 RMR

Deformation modulus Em derived from RMR along for borehole KLX04 (core sections of 5 m).

Rock unit depth [m]	Minimum Em [GPa]	Average Em [GPa]	Frequent Em [GPa]	Maximum Em [GPa]	Standard deviation Em [GPa]	Min possible Em [GPa]	Max possible Em [GPa]
100–227	25.4	49.7	42.7	78.0	16.6	8.0	90.0
DZ1, 227–230	–	29.9	–	–	–	4.1	88.6
230–254	41.4	51.6	45.1	67.2	12.3	13.0	90.0
DZ2, 254–258	–	19.1	–	–	–	5.4	67.2
258–295	33.1	47.8	46.7	71.5	14.7	11.3	90.0
DZ3, 295–298	–	19.5	–	–	–	5.6	48.8
298–346	34.6	52.2	46.6	77.9	16.3	10.8	88.6
DZ5*, 346–355	16.8	21.2	21.2	25.6	6.2	4.3	80.8
355–385	24.0	38.7	34.1	60.8	14.6	9.3	83.7
RU1, 100–385	16.8	46.5	41.9	78.0	16.8	4.1	90.0
RU2, 385–555	28.2	53.1	48.5	78.0	18.5	11.2	90.0
RU1, 555–680	21.1	42.6	41.2	68.5	12.7	5.1	90.0
RU3, 680–745	42.3	52.7	50.9	70.0	8.4	16.1	83.7
745–873	39.4	65.1	71.6	78.0	14.3	8.0	90.0
DZ6, 873–973	12.1	24.0	21.2	47.5	9.5	4.5	90.0
973–992	71.8	74.8	74.7	78.0	3.1	20.8	90.0
RU1, 745–992	12.1	46.7	42.5	78.0	19.3	4.1	90.0
Competent rock	21.1	52.4	48.9	78	16.7	5.1	90
Fractured rock	12.1	23.7	19.9	47.5	8.8	4	90
Whole borehole	12.1	48.3	45.4	78	18.7	4.1	90

* DZ4 is only one meter wide (between 325 and 326 m).

Variation of the deformation modulus of the rock mass obtained from RMR with depth for borehole KLX04. The values are given every 5 m.



3.4.2 Q

Deformation modulus Em derived from Q along borehole KLX04 (core sections of 5 m).

Rock unit depth [m]	Minimum Em [GPa]	Average Em [GPa]	Frequent Em [GPa]	Maximum Em [GPa]	Standard deviation Em [GPa]	Min possible Em [GPa]	Max possible Em [GPa]
100–227	18.7	34.9	34.5	66.3	10.9	8.6	71.2
DZ1, 227–230	–	21.9	–	–	–	3.7	43.1
230–254	20.7	30.3	21.2	57.5	15.8	13.8	62.2
DZ2, 254–258	–	17.3	–	–	–	8.9	31.3
258–295	21.5	31.3	32.4	42.5	7.9	16.4	62.0
DZ3, 295–298	–	18.1	–	–	–	7.3	24.6
298–346	23.1	34.0	36.4	57.5	11.0	13.1	78.1
DZ5*, 346–355	13.3	15.5	15.5	17.6	3.1	3.4	45.2
355–385	23.9	32.9	33.0	42.3	7.3	12.0	62.0
RU1, 100–385	13.3	32.2	31.8	66.3	11.0	3.4	78.1
RU2, 385–555	21.3	45.8	38.4	75.0	17.0	14.0	85.5
RU1, 555–680	15.7	32.9	31.6	56.1	10.4	3.0	78.8
RU3, 680–745	27.5	36.6	33.5	54.5	7.9	15.8	78.5
745–873	23.8	50.7	50.4	75.0	15.6	17.0	86.0
DZ6, 873–973	12.7	20.7	19.5	28.3	5.9	5.7	54.2
973–992	23.7	46.2	39.9	75.0	26.2	19.2	86.0
RU1, 745–992	12.7	34.6	31.8	75.0	14.9	3.0	86.0
Competent rock	15.7	39.6	36.2	75.0	14.9	3.0	86.0
Fractured rock	12.7	20.1	18.0	28.3	5.5	3.4	54.2
Whole borehole	12.7	36.9	33.9	75.0	15.5	3.0	86.0

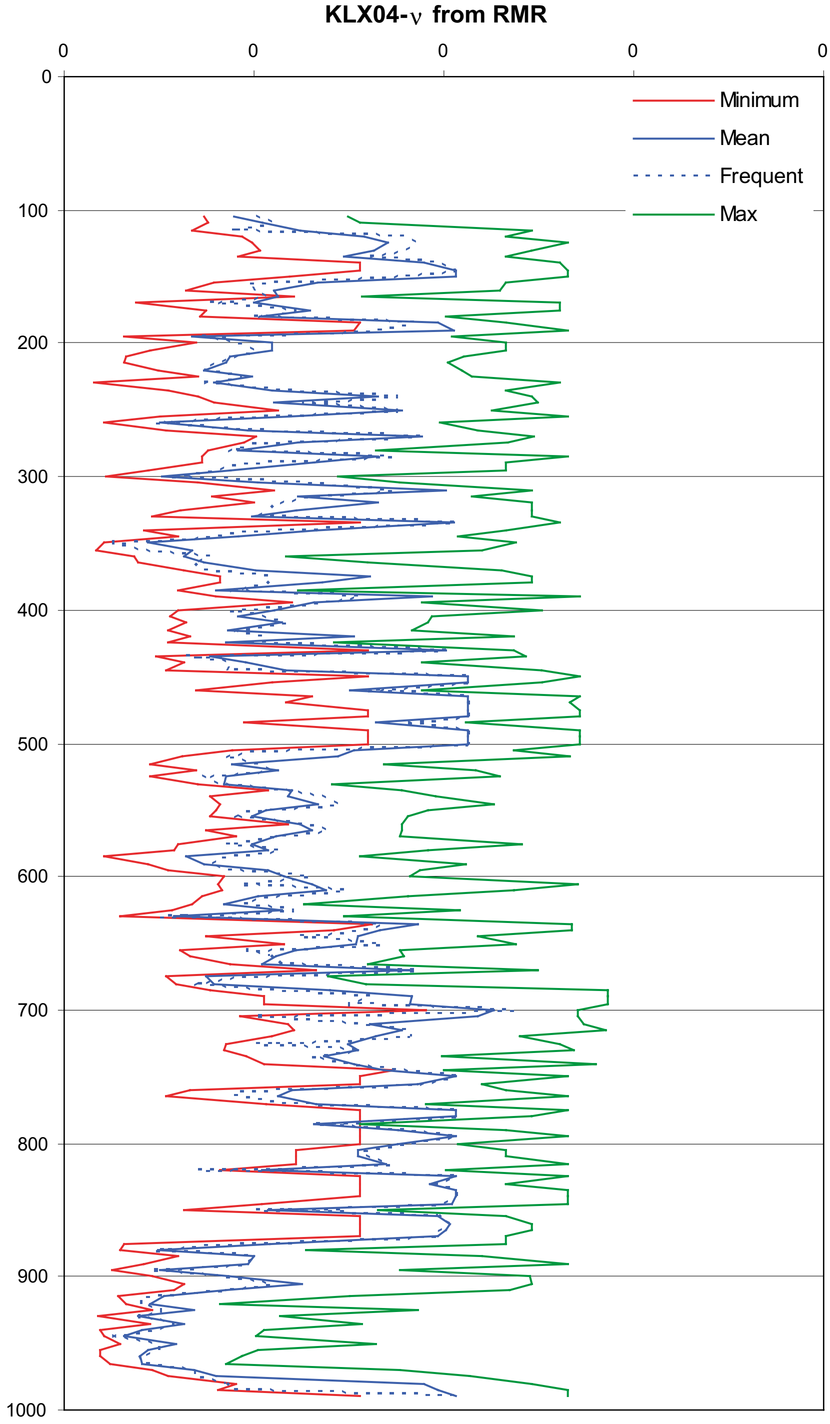
3.5 Poisson's ratio

3.5.1 RMR

Summary of Poisson's ratio (ν) derived from RMR for borehole KLX04 (core sections of 5 m, Hoek & Brown's a = 0.5).

Rock unit depth [m]	Minimum ν [–]	Average ν [–]	Frequent ν [–]	Maximum ν [–]	Standard deviation ν [–]	Min possible ν [–]	Max possible ν [–]
100–227	0.07	0.13	0.11	0.21	0.04	0.03	0.27
DZ1, 227–230	–	0.08	–	–	–	0.02	0.26
230–254	0.11	0.14	0.12	0.18	0.03	0.05	0.27
DZ2, 254–258	–	0.05	–	–	–	0.02	0.20
258–295	0.09	0.13	0.12	0.19	0.04	0.04	0.27
DZ3, 295–298	–	0.05	–	–	–	0.02	0.14
298–346	0.09	0.14	0.12	0.21	0.04	0.04	0.27
DZ5*, 346–355	0.04	0.06	0.06	0.07	0.02	0.02	0.24
355–385	0.06	0.10	0.09	0.16	0.04	0.04	0.25
RU1, 100–385	0.04	0.12	0.11	0.21	0.04	0.02	0.27
RU2, 385–555	0.08	0.15	0.13	0.21	0.05	0.04	0.27
RU1, 555–680	0.06	0.12	0.11	0.19	0.03	0.02	0.27
RU3, 680–745	0.14	0.17	0.16	0.23	0.03	0.08	0.29
745–873	0.10	0.17	0.19	0.21	0.04	0.03	0.27
DZ6, 873–973	0.03	0.06	0.06	0.13	0.03	0.02	0.27
973–992	0.19	0.20	0.20	0.21	0.01	0.08	0.27
RU1, 745–992	0.03	0.12	0.11	0.21	0.05	0.02	0.27
Competent rock	0.06	0.14	0.13	0.23	0.05	0.02	0.29
Fractured rock	0.03	0.06	0.05	0.13	0.02	0.02	0.27
Whole borehole	0.03	0.13	0.12	0.23	0.05	0.02	0.29

Variation of Poisson's ratio (ν) with depth for borehole KLX04 (Hoek & Brown's a = 0.5). The values are given every 5 m.



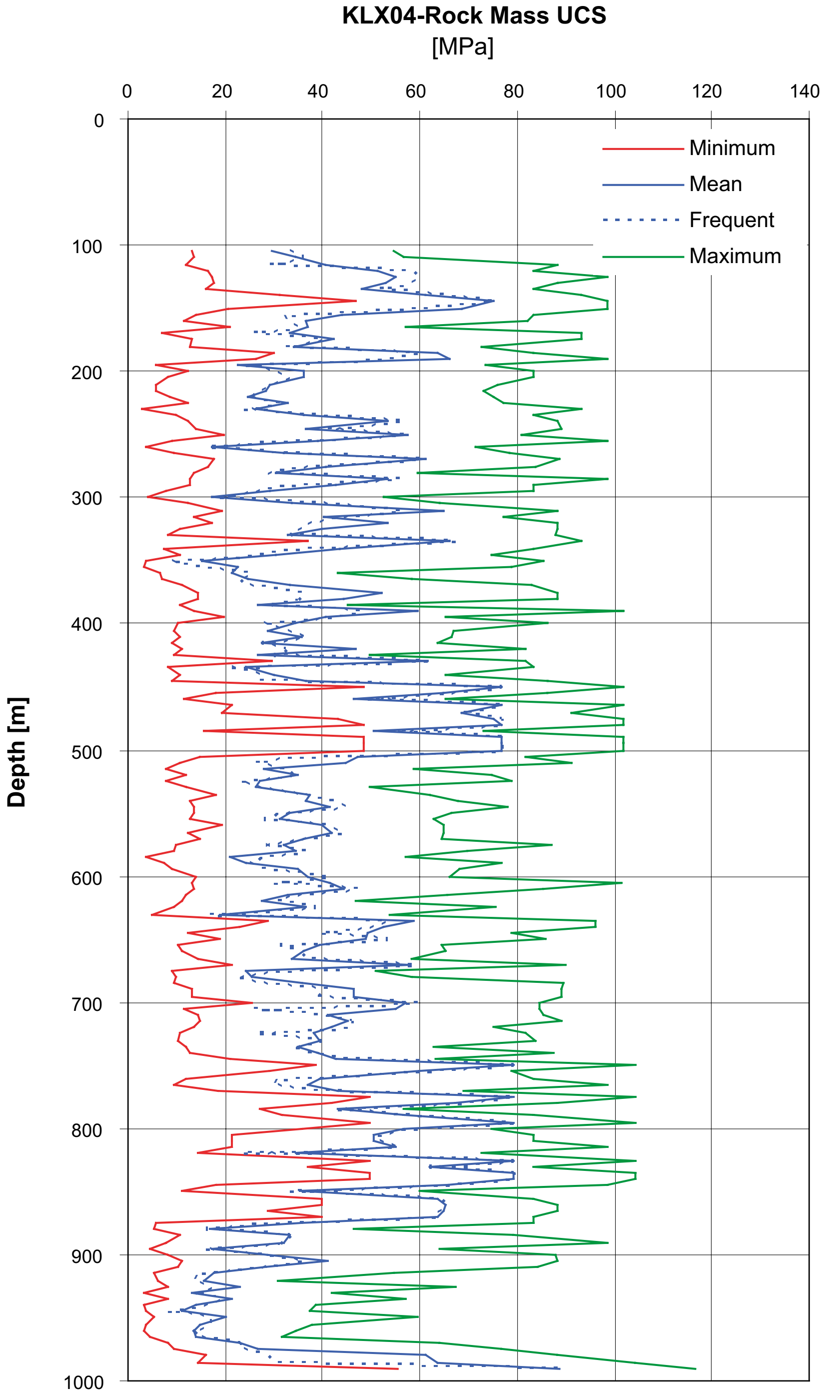
3.6 Uniaxial compressive strength

3.6.1 RMR

Summary of the uniaxial compressive strength of the rock mass derived from RMR and Hoek & Brown's Criterion for borehole KLX04 (core sections of 5 m, Hoek & Brown's a = 0.5).

Rock unit depth [m]	Minimum UCS [MPa]	Average UCS [MPa]	Frequent UCS [MPa]	Maximum UCS [MPa]	Standard deviation UCS [MPa]	Min possible UCS [MPa]	Max possible UCS [MPa]
100–227	22.5	43.3	37.1	75.0	14.7	5.7	98.5
DZ1, 227–230	–	26.3	–	–	–	3.0	93.2
230–254	36.0	44.5	39.1	57.5	10.2	9.1	98.5
DZ2, 254–258	–	17.1	–	–	–	3.9	71.4
258–295	29.0	41.3	40.5	61.0	12.3	7.9	98.5
DZ3, 295–298	–	17.4	–	–	–	4.0	52.4
298–346	30.3	45.0	40.3	66.2	13.5	7.6	93.2
DZ5*, 346–355	15.1	18.9	18.9	22.6	5.3	3.1	85.3
355–385	21.3	33.7	29.8	52.2	12.2	6.6	88.2
RU1, 100–385	15.1	40.3	36.4	75.0	14.5	3.0	98.5
RU2, 385–555	24.3	47.3	41.1	76.8	18.8	7.7	101.9
RU1, 555–680	18.9	37.2	36.0	58.8	10.7	3.6	101.5
RU3, 680–745	35.1	43.3	41.9	57.0	6.7	9.5	89.3
745–873	34.3	58.7	61.1	79.3	15.5	5.7	104.2
DZ6, 873–973	11.0	21.2	18.8	41.1	8.1	3.3	98.5
973–992	61.2	71.2	63.6	88.6	15.2	14.2	116.4
RU1, 745–992	11.0	41.2	37.1	88.6	17.8	3.0	116.4
Competent rock	18.9	46	41.7	88.6	16.1	3.6	116.4
Fractured rock	11	20.9	17.7	41.1	7.5	3	98.5
Whole borehole	11	42.5	39.2	88.6	17.5	3	116.4

Variation of the uniaxial compressive strength of the rock mass with depth for borehole KLX04 (Hoek & Brown's a = 0.5). The values are given every 5 m.



3.7 Friction angle and cohesion and of the rock mass

3.7.1 RMR

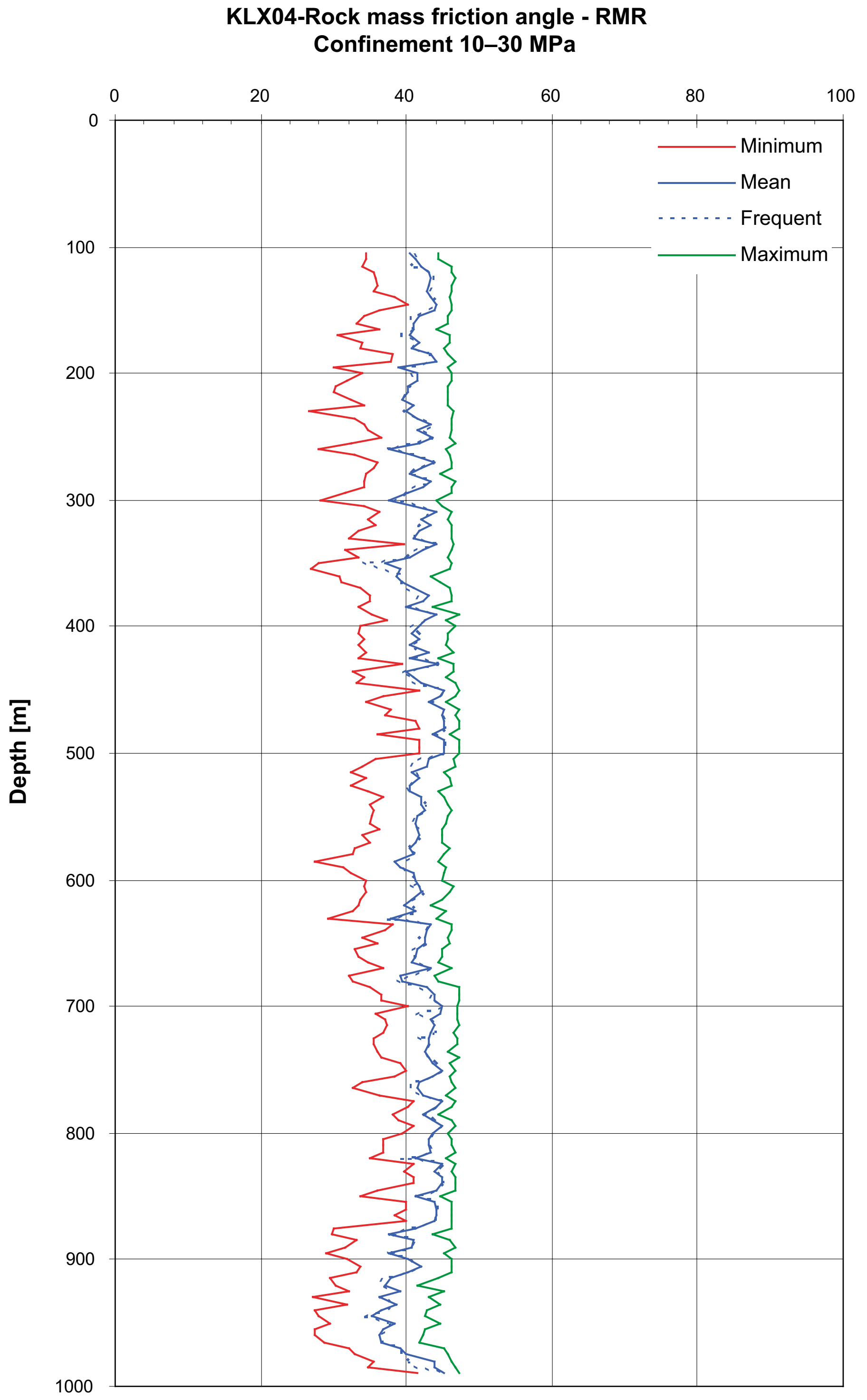
Summary of the friction angle (φ) of the rock mass derived from RMR for borehole KLX04 (10–30 MPa) (core sections of 5 m, Hoek & Brown's a = 0.5).

Rock unit depth [m]	Minimum φ' [°]	Average φ' [°]	Frequent φ' [°]	Maximum φ' [°]	Standard deviation φ' [°]	Min possible φ' [°]	Max possible φ' [°]
100–227	39.0	41.8	41.4	44.1	1.5	30.0	46.7
DZ1, 227–230	–	39.8	–	–	–	26.6	46.5
230–254	41.4	42.3	41.8	43.5	1.0	32.4	46.7
DZ2, 254–258	–	37.6	–	–	–	28.0	45.5
258–295	40.3	41.8	42.0	43.8	1.3	31.7	46.7
DZ3, 295–298	–	37.7	–	–	–	28.2	44.2
298–346	40.5	42.2	41.9	44.1	1.3	31.5	46.5
DZ5*, 346–355	36.9	38.0	38.0	39.1	1.5	26.9	46.2
355–385	38.8	40.8	40.4	43.1	1.7	30.7	46.3
RU1, 100–385	36.9	41.5	41.4	44.1	1.7	26.6	46.7
RU2, 385–555	39.9	42.8	42.5	45.2	1.8	32.3	47.2
RU1, 555–680	37.9	41.1	41.2	43.4	1.4	27.4	46.5
RU3, 680–745	42.6	43.5	43.5	44.9	0.7	34.9	47.2
745–873	41.2	43.4	43.8	44.8	1.2	30.0	46.9
DZ6, 873–973	35.2	38.4	38.1	42.0	1.9	27.1	46.7
973–992	43.8	44.3	44.0	45.2	0.8	34.8	47.2
RU1, 745–992	35.2	41.4	41.4	45.2	2.2	26.6	47.2
Competent rock	37.9	42.4	42.3	45.2	1.7	27.4	47.2
Fractured rock	35.2	38.3	37.8	42	1.8	26.6	46.7
Whole borehole	35.2	41.8	41.9	45.2	2.2	26.6	47.2

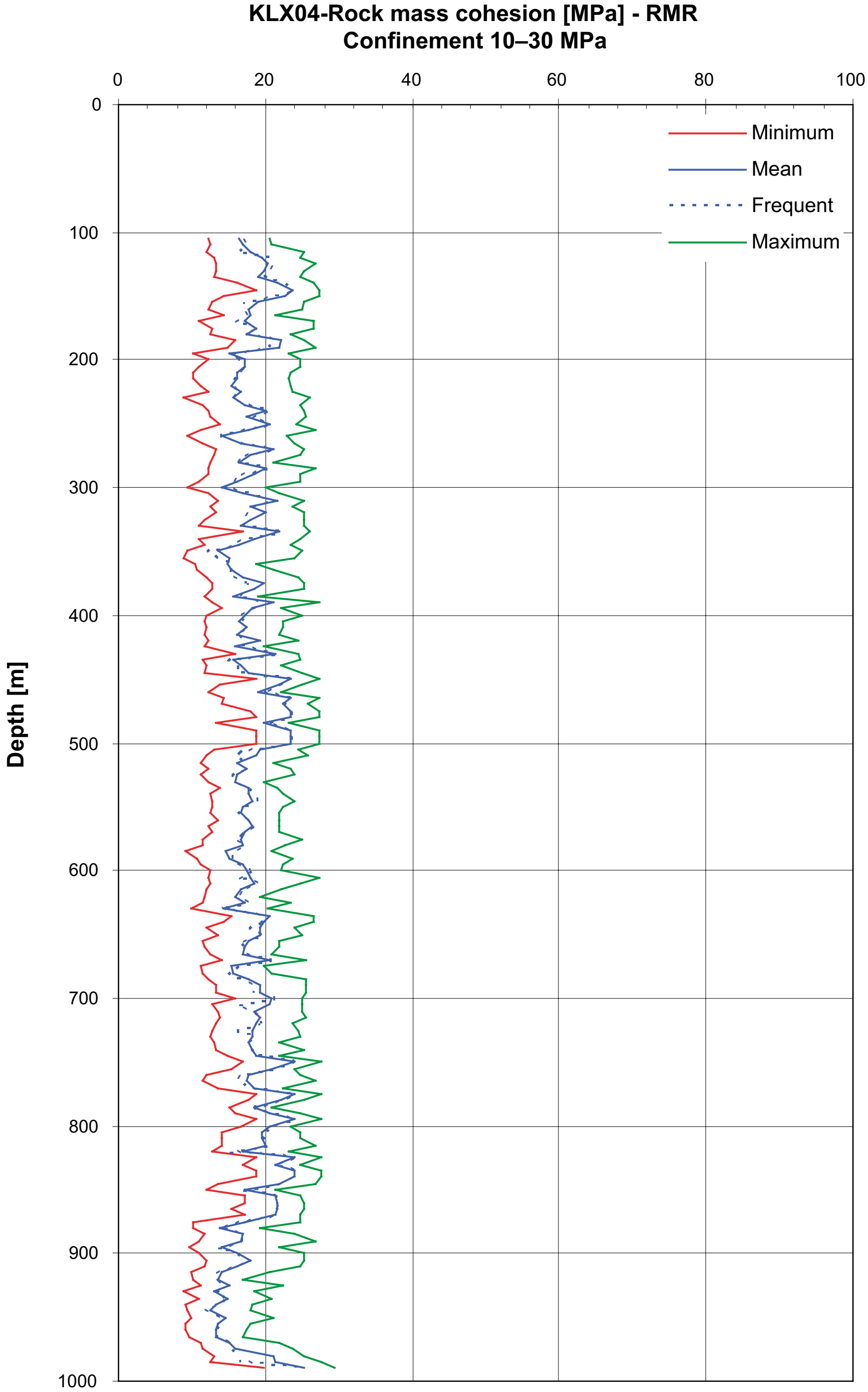
Summary of the cohesion c' of the rock mass derived from RMR for borehole KLX04 under confinement stress between 10 and 30 MPa (core sections of 5 m, Hoek & Brown's a = 0.5).

Rock unit depth [m]	Minimum c' [MPa]	Average c' [MPa]	Frequent c' [MPa]	Maximum c' [MPa]	Standard deviation c' [MPa]	Min possible c' [MPa]	Max possible c' [MPa]
100–227	15.0	18.6	17.9	23.8	2.4	10.1	27.4
DZ1, 227–230	–	15.7	–	–	–	8.7	26.1
230–254	17.3	18.6	17.8	20.6	1.6	11.3	26.8
DZ2, 254–258	–	14.0	–	–	–	9.3	22.9
258–295	16.2	18.1	18.0	21.1	1.9	10.9	26.8
DZ3, 295–298	–	14.0	–	–	–	9.4	20.1
298–346	16.4	18.7	18.0	21.9	2.1	10.8	26.1
DZ5*, 346–355	13.6	14.3	14.3	15.1	1.1	8.8	24.9
355–385	14.8	16.9	16.3	19.8	2.0	10.5	25.3
RU1, 100–385	13.6	18.0	17.8	23.8	2.3	8.7	27.4
RU2, 385–555	15.6	19.2	18.3	23.6	2.8	11.2	27.4
RU1, 555–680	14.3	17.3	17.2	20.7	1.7	9.0	27.3
RU3, 680–745	17.7	18.9	18.7	20.9	1.0	12.3	25.6
745–873	17.0	20.7	21.1	23.8	2.3	10.1	27.7
DZ6, 873–973	12.6	14.7	14.3	18.1	1.5	8.9	26.8
973–992	21.1	22.6	21.5	25.3	2.3	12.6	29.5
RU1, 745–992	12.6	18.0	17.5	25.3	2.8	8.7	29.5
Competent rock	14.3	18.9	18.3	25.3	2.5	9	29.5
Fractured rock	12.6	14.6	14.1	18.1	1.4	8.7	26.8
Whole borehole	12.6	18.3	17.8	25.3	2.8	8.7	29.5

Variation of the rock mass friction angle φ' from RMR for borehole KLX04 under stress confinement 10–30 MPa (Hoek & Brown's a = 0.5).



Variation of the rock mass cohesion c' from RMR for borehole KLX04 under stress confinement 10–30 MPa (Hoek & Brown's a = 0.5).



Appendix 4: KAV04

Characterisation of the rock mass

4.1 Fracture orientation

Set identification from the fracture orientation mapped for borehole KAV04 (SICADA, 04-11-25). The orientations are given as strike/dip (right-hand rule).

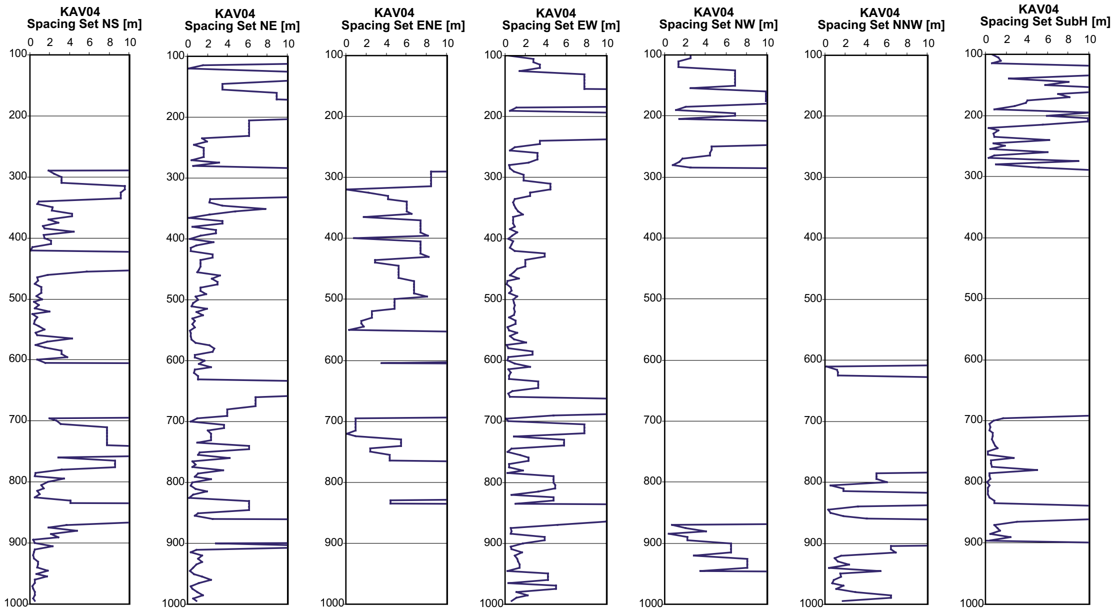
Depth [m]	No. of fract.	NS	NE	ENE	EW	NW	NNW	SubH
100–290	408		250/36		79/87	290/59		091/01
290–610	865	183/47	238/56	066/73	280/71			
610–690	166		228/69		285/70		349/51	
690–840	759	182/52	122/57	050/65	290/64		158/79	221/10
840–865	50		028/72				347/64	
865–900	131	189/55			268/65	299/52		268/07
900–950	205	184/54	229/55		268/65	139/72	158/49	
950–1,000	223	194/55	232/56		089/57		149/49	

The characterization of this borehole was carried out before the actual version of Site Descriptive Model for Simpevarp version 1.2 /SKB 2005/ was completed. Thus, the fracture sets identified by the Model for Simpevarp 1.1 /SKB 2004/ were adopted.

Fisher's constant of the fracture sets identified for borehole KAV04 (SICADA, 04-11-25).

Depth [m]	No. of fract.	NS	NE	ENE	EW	NW	NNW	SubH
100–290	408		54		21	57		39
290–610	865	18	19	66	16			
610–690	166		88		32		56	
690–840	759	60	25	104	39		154	12
840–865	50		121				22	
865–900	131	50			11	59		11
900–950	205	27	26		19	410	71	
950–1,000	223	23	28		32		45	

Fracture spacing with depth for the five facture sets in borehole KAV04. The values are averaged for each 5 m length of borehole.

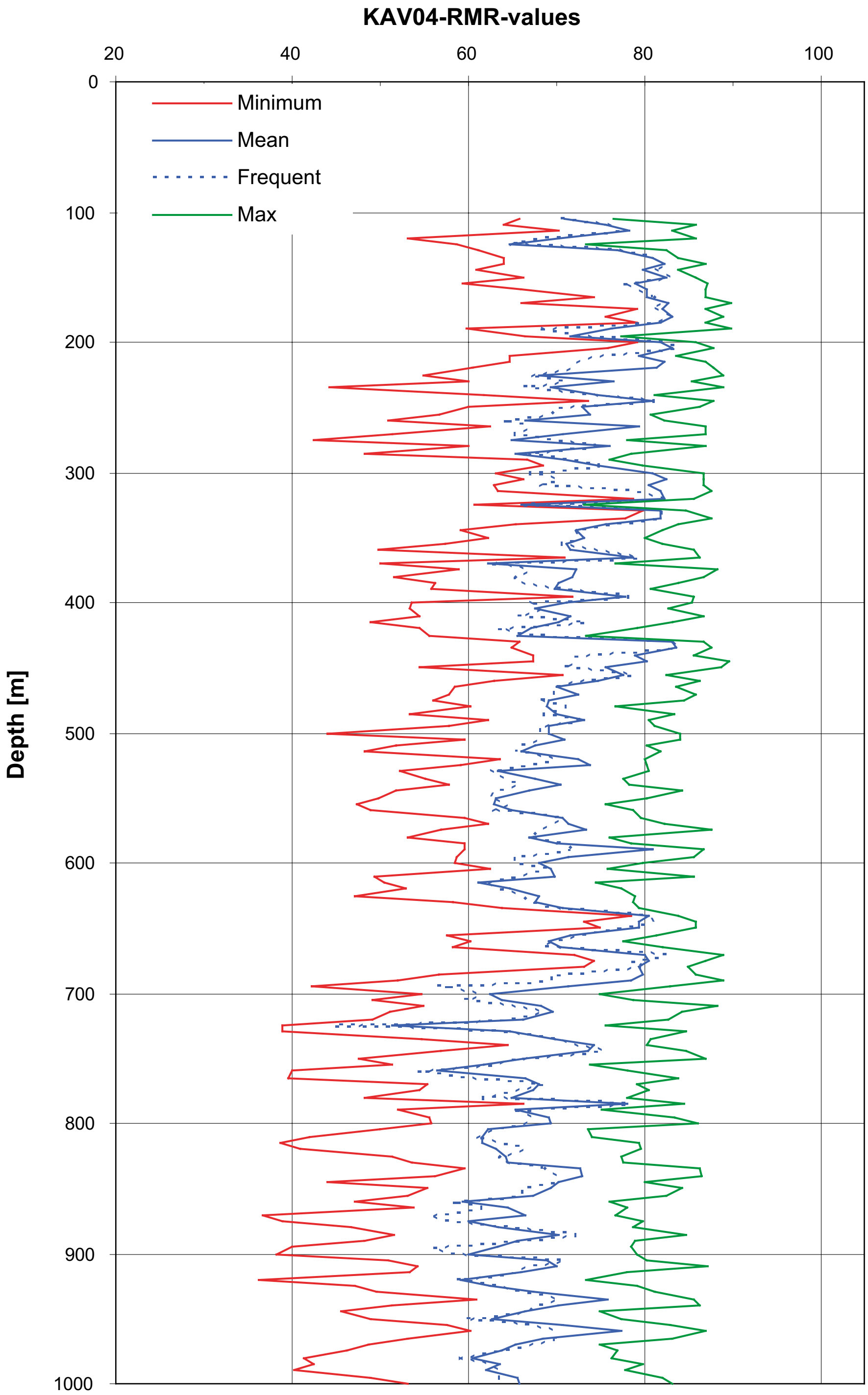


4.2 RMR

RMR values along borehole KAV04 (core sections of 5 m).

Rock unit depth [m]	Minimum RMR [–]	Average RMR [–]	Frequent RMR [–]	Maximum RMR [–]	Standard deviation RMR [–]	Min possible RMR [–]	Max possible RMR [–]
RU1, 100–290	64.8	76.3	77.6	83.3	5.8	42.4	89.9
RU2, 290–610	62.4	72.4	71.3	83.6	5.6	44.1	89.7
RU3, 610–690	61.1	73.8	75.1	80.6	6.6	47.2	88.9
690–840	51.4	66.4	66.3	78.1	5.4	38.8	88.4
DZ1, 840–900	59.5	65.0	65.0	70.3	3.9	36.8	84.9
900–950	59.1	67.0	67.0	75.9	4.8	36.3	87.2
RU6, 950–1,005	60.4	66.4	65.4	77.5	4.9	40.2	86.9
RU4, 690–865	51.4	66.4	66.3	78.1	5.2	38.8	88.4
RU5, 865–950	60.0	64.2	63.4	70.3	3.7	36.8	84.9
Competent rock	51.4	71.7	70.7	83.6	6.7	36.3	89.9
Deformation zones	59.5	65.0	65.0	70.3	3.9	36.8	84.9
Whole borehole	51.4	71.2	70.3	83.6	6.7	36.3	89.9

Variation of RMR with depth for borehole KAV04. The values are given every 5 m.

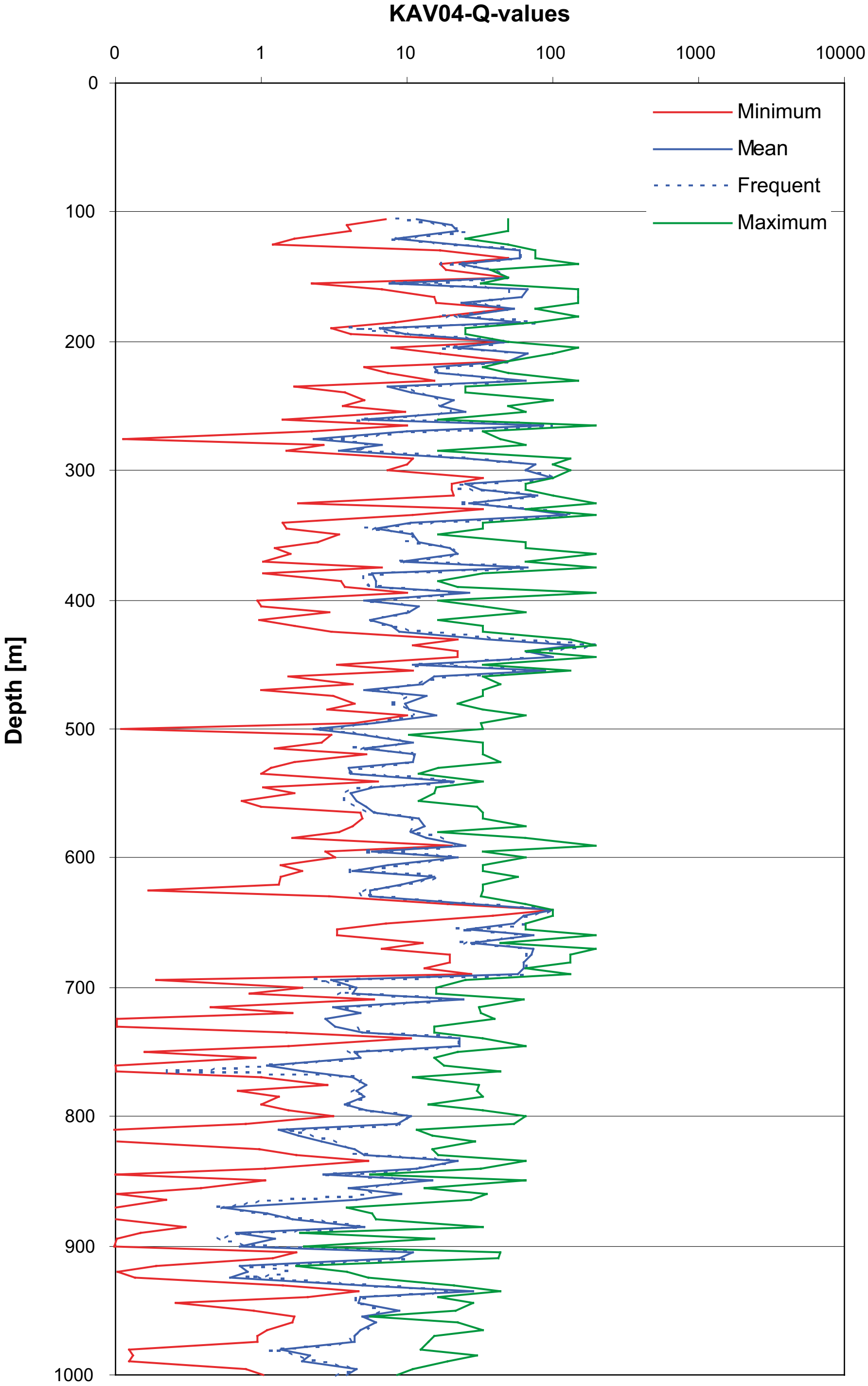


4.3 Q

Q values along borehole KAV04 (core sections of 5 m).

Rock unit depth [m]	Minimum Q [–]	Average Q [–]	Frequent Q [–]	Maximum Q [–]	Min possible Q [–]	Max possible Q [–]
RU1, 100–290	2.3	29.7	22.0	86.8	0.1	198.0
RU2, 290–610	2.3	24.8	11.1	141.4	0.1	198.0
RU3, 610–690	5.5	45.9	55.8	99.0	0.2	198.0
690–840	1.1	7.0	4.5	24.2	0.03	66.0
DZ1, 840–900	0.5	3.8	2.2	14.9	0.01	66.0
900–950	0.6	7.4	4.9	28.7	0.01	44.0
RU6, 950–1,005	1.4	3.9	4.4	6.2	0.1	33.0
RU4, 690–865	1.1	7.0	4.5	24.2	0.03	66.0
RU5, 865–950	0.5	1.6	1.1	5.1	0.01	33.0
Competent rock	0.6	22.5	10.7	141.4	0.01	198.0
Deformation zones	0.5	3.8	2.2	14.9	0.01	66.0
Whole borehole	0.5	21.2	10.0	141.4	0.01	198.0

Variation of Q with depth for borehole KAV04. The values are given every 5 m.



Rock mass properties

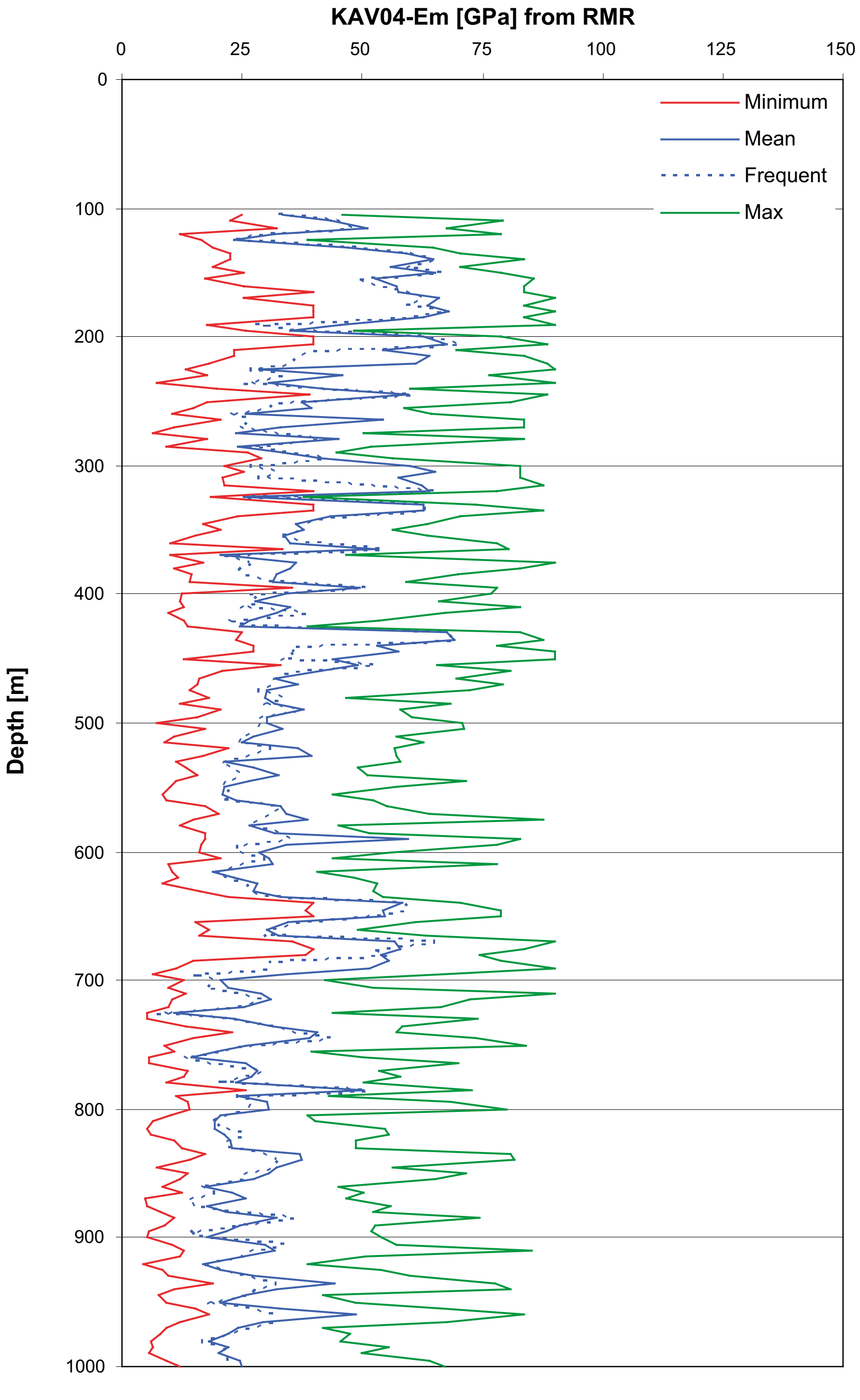
4.4 Deformation modulus

4.4.1 RMR

Deformation modulus Em derived from RMR along for borehole KAV04 (core sections of 5 m).

Rock unit depth [m]	Minimum Em [GPa]	Average Em [GPa]	Frequent Em [GPa]	Maximum Em [GPa]	Standard deviation Em [GPa]	Min possible Em [GPa]	Max possible Em [GPa]
RU1, 100–290	23.4	47.8	49.1	68.0	14.4	6.5	90.0
RU2, 290–610	20.4	38.2	34.0	69.1	13.2	7.1	90.0
RU3, 610–690	18.9	42.0	43.2	58.2	14.4	8.5	90.0
690–840	10.8	26.9	25.5	50.4	8.3	5.2	90.0
DZ1, 840–900	17.3	24.3	23.8	32.2	5.4	4.7	74.4
900–950	16.9	27.5	26.6	44.3	7.8	4.6	85.1
RU6, 950–1,005	18.2	26.7	24.3	48.7	8.9	5.7	83.6
RU4, 690–865	10.8	26.8	25.6	50.4	7.9	5.2	90.0
RU5, 865–950	17.8	23.1	21.6	32.2	5.1	4.7	74.4
Competent rock	10.8	37.4	33	69.1	14.5	4.6	90
Deformation zones	17.3	24.3	23.8	32.2	5.4	4.7	74.4
Whole borehole	10.8	36.5	32.2	69.1	14.4	4.6	90

Variation of the deformation modulus of the rock mass obtained from RMR with depth for borehole KAV04. The values are given every 5 m.



4.4.2 Q

Deformation modulus Em derived from Q along borehole KAV04 (core sections of 5 m).

Rock unit depth [m]	Minimum Em [GPa]	Average Em [GPa]	Frequent Em [GPa]	Maximum Em [GPa]	Standard deviation Em [GPa]	Min possible Em [GPa]	Max possible Em [GPa]
RU1, 100–290	16.5	35.8	34.9	55.2	10.5	5.5	78.5
RU2, 290–610	16.2	31.4	27.3	63.8	11.8	5.3	76.9
RU3, 610–690	21.7	41.4	47.0	56.9	11.4	6.1	77.9
690–840	12.9	22.1	20.7	36.3	6.4	3.5	55.3
DZ1, 840–900	10.4	17.6	16.2	30.8	6.4	2.6	55.3
900–950	10.8	21.8	21.6	39.0	8.9	2.6	50.7
RU6, 950–1,005	13.7	19.1	20.3	22.8	2.9	5.6	43.2
RU4, 690–865	12.9	22.3	20.8	36.3	6.2	3.5	55.3
RU5, 865–950	10.4	13.8	13.1	22.0	4.0	2.6	46.1
Competent rock	10.8	30.4	27.1	63.8	12.0	2.6	78.5
Deformation zones	10.4	17.6	16.2	30.8	6.4	2.6	55.3
Whole borehole	10.4	29.5	26.5	63.8	12.1	2.6	78.5

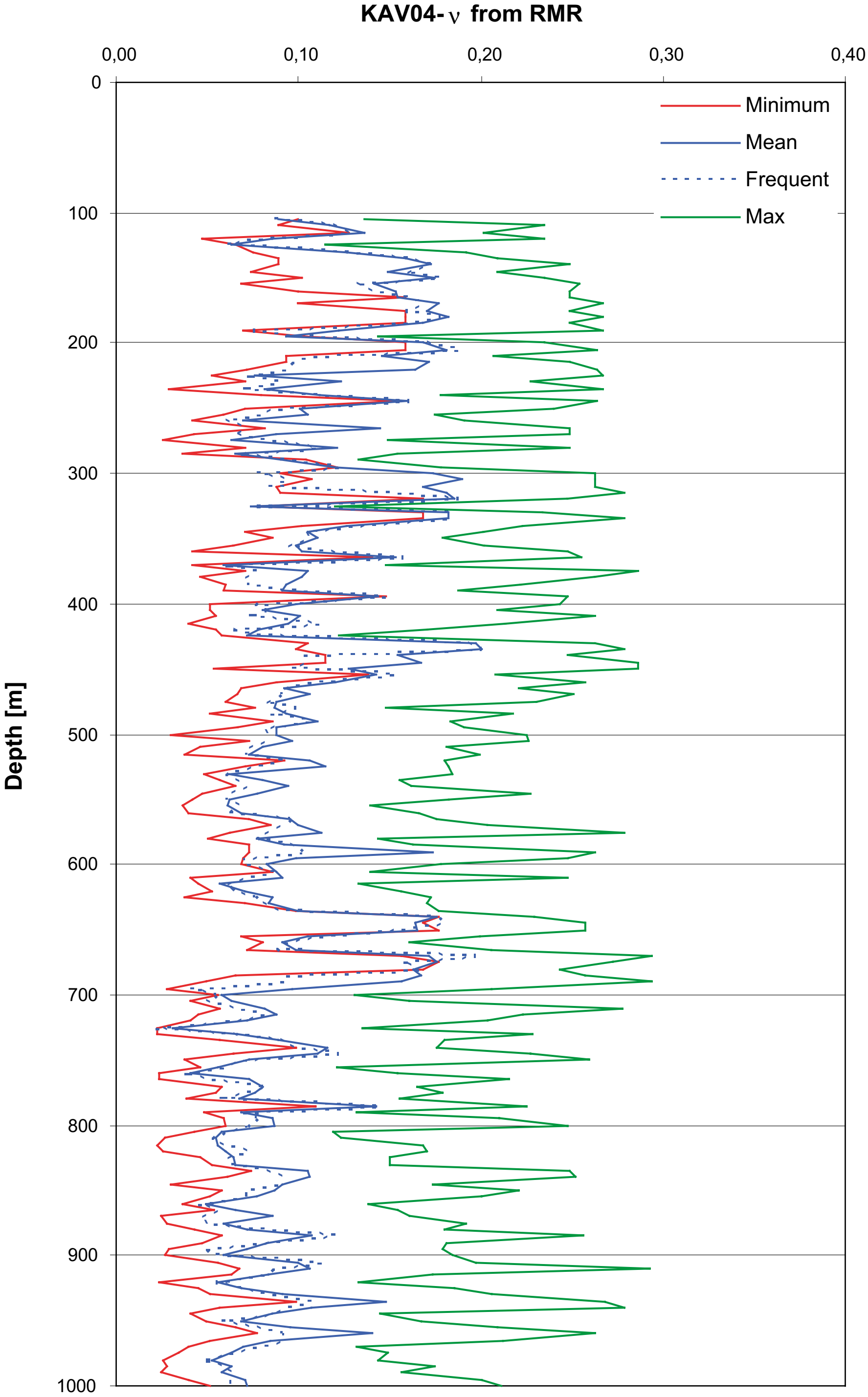
4.5 Poisson's ratio

4.5.1 RMR

Summary of Poisson's ratio (ν) derived from RMR for borehole KAV04 (core sections of 5 m, Hoek & Brown's a = 0.5).

Rock unit depth [m]	Minimum ν [–]	Average ν [–]	Frequent ν [–]	Maximum ν [–]	Standard deviation ν [–]	Min possible ν [–]	Max possible ν [–]
RU1, 100–290	0.06	0.13	0.13	0.18	0.04	0.03	0.27
RU2, 290–610	0.06	0.11	0.10	0.20	0.04	0.03	0.29
RU3, 610–690	0.06	0.13	0.13	0.18	0.04	0.04	0.29
690–840	0.03	0.08	0.07	0.14	0.02	0.02	0.28
DZ1, 840–900	0.05	0.08	0.07	0.11	0.02	0.02	0.26
900–950	0.06	0.09	0.09	0.15	0.03	0.02	0.29
RU6, 950–1,005	0.05	0.08	0.07	0.14	0.03	0.02	0.29
RU4, 690–865	0.03	0.08	0.07	0.14	0.02	0.02	0.28
RU5, 865–950	0.06	0.08	0.07	0.11	0.02	0.02	0.26
Competent rock	0.03	0.11	0.10	0.20	0.04	0.02	0.29
Deformation zones	0.05	0.08	0.07	0.11	0.02	0.02	0.26
Whole borehole	0.03	0.11	0.09	0.20	0.04	0.02	0.29

Variation of Poisson's ratio (ν) with depth for borehole KAV04 (Hoek & Brown's a = 0.5). The values are given every 5 m.



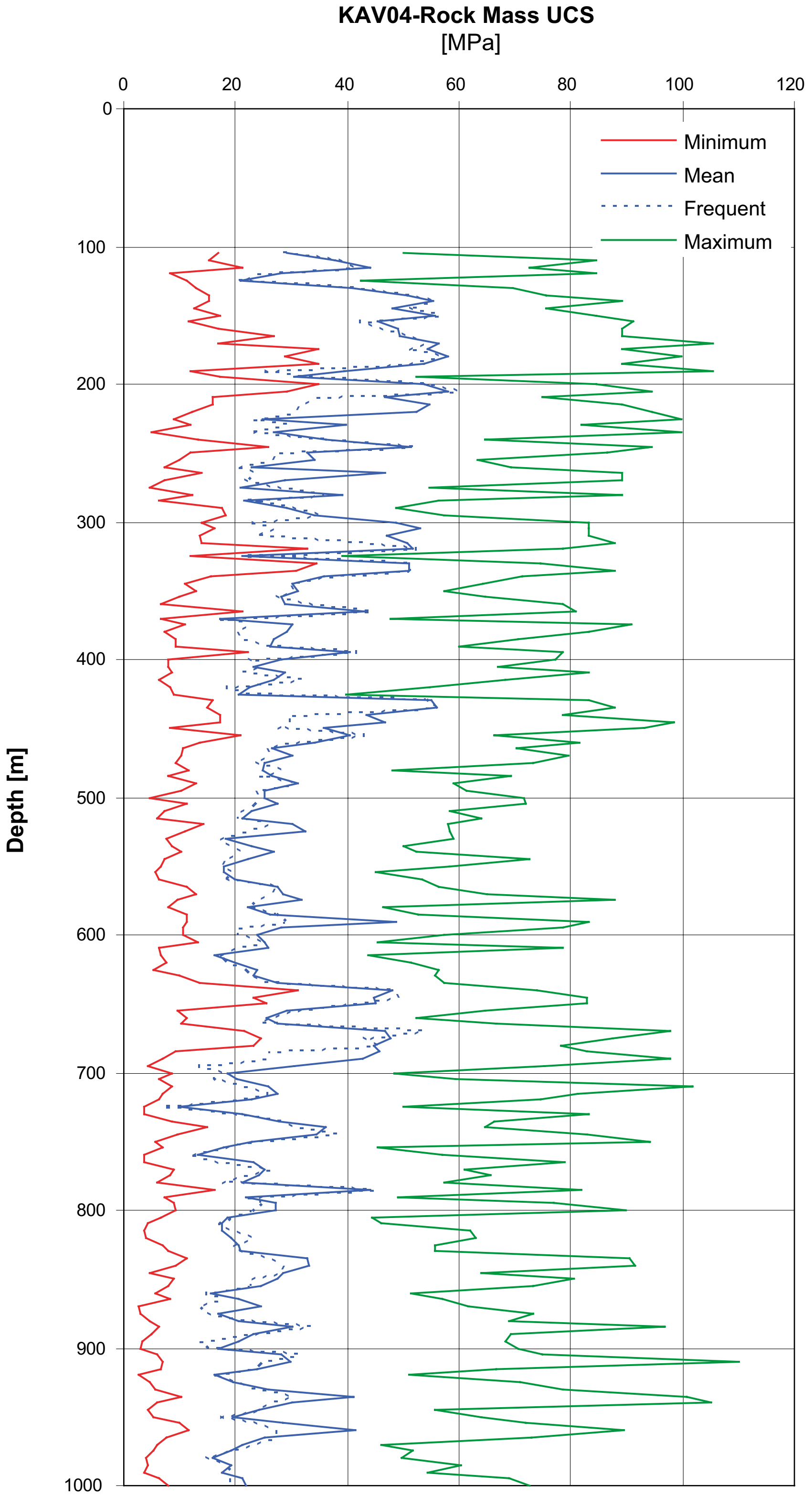
4.6 Uniaxial compressive strength

4.6.1 RMR

Summary of the uniaxial compressive strength of the rock mass derived from RMR and Hoek & Brown's Criterion for borehole KAV04 (core sections of 5 m, Hoek & Brown's a = 0.5).

Rock unit depth [m]	Minimum UCS [MPa]	Average UCS [MPa]	Frequent UCS [MPa]	Maximum UCS [MPa]	Standard deviation UCS [MPa]	Min possible UCS [MPa]	Max possible UCS [MPa]
RU1, 100–290	20.8	41.3	42.4	58.1	12.0	4.5	105.5
RU2, 290–610	17.2	31.6	28.3	55.9	10.5	4.8	98.3
RU3, 610–690	16.2	34.9	35.9	48.0	11.6	5.4	97.7
690–840	10.0	24.1	22.9	44.2	7.2	3.5	101.8
DZ1, 840–900	15.7	22.5	22.0	30.1	4.7	2.7	96.7
900–950	16.1	25.8	25.0	41.0	7.1	2.6	110.1
RU6, 950–1,005	16.1	23.2	21.2	41.4	7.4	3.8	89.5
RU4, 690–865	10.0	24.0	23.0	44.2	6.9	3.5	101.8
RU5, 865–950	17.0	21.8	20.5	30.1	4.6	2.7	96.7
Competent rock	10.0	31.9	28.1	58.1	11.8	2.6	110.1
Deformation zones	15.7	22.5	22	30.1	4.7	2.7	96.7
Whole borehole	10.0	31.3	27.8	58.1	11.7	2.6	110.1

Variation of the uniaxial compressive strength of the rock mass with depth for borehole KAV04 (Hoek & Brown's a = 0.5). The values are given every 5 m.



4.7 Friction angle and cohesion and of the rock mass

4.7.1 RMR

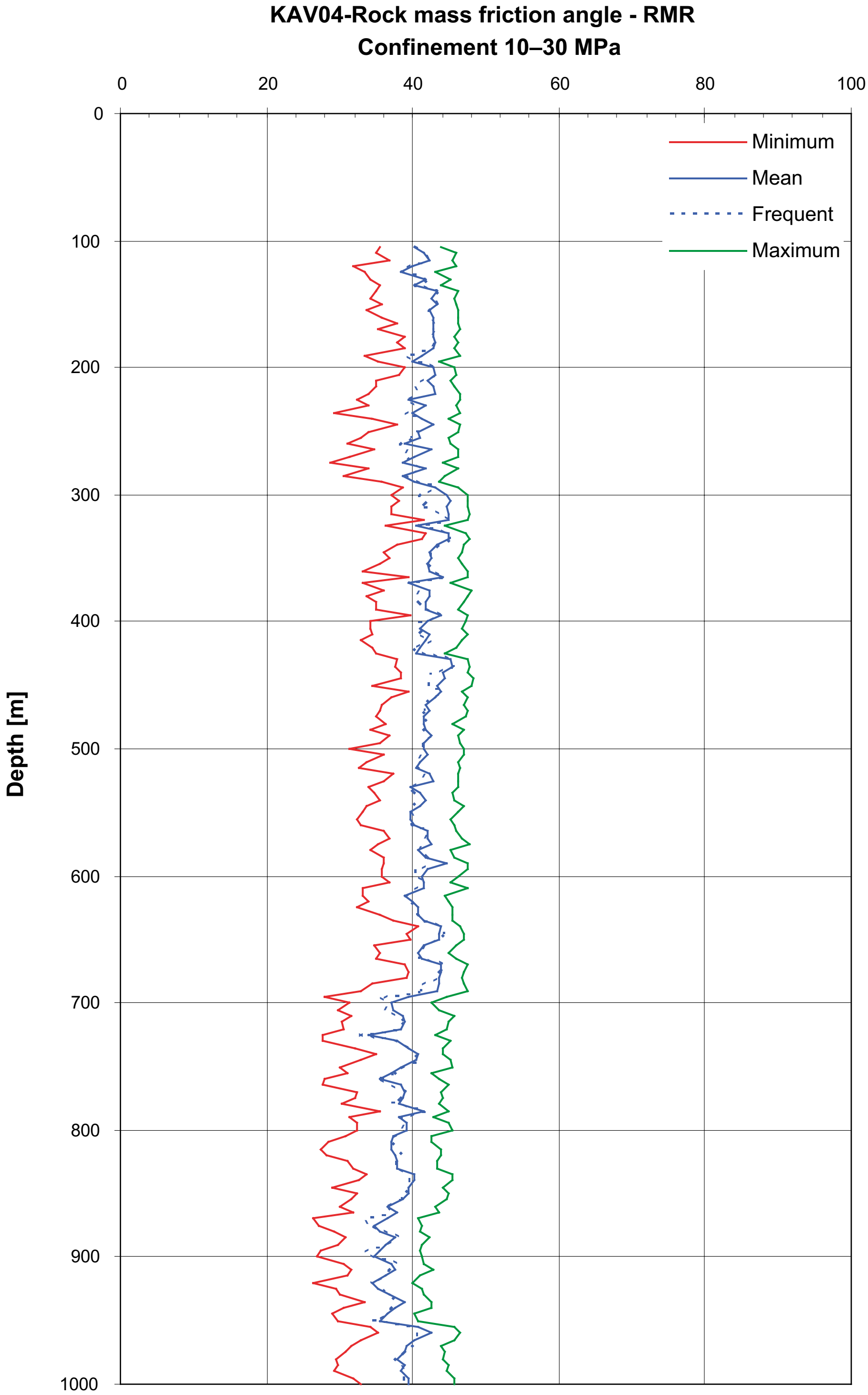
Summary of the friction angle (φ’) of the rock mass derived from RMR for borehole KAV04 (10–30 MPa) (core sections of 5 m, Hoek & Brown’s a = 0.5).

Rock unit depth [m]	Minimum φ’ [°]	Average φ’ [°]	Frequent φ’ [°]	Maximum φ’ [°]	Standard deviation φ’ [°]	Min possible φ’ [°]	Max possible φ’ [°]
RU1, 100–290	38.5	41.5	41.8	43.3	1.5	28.7	46.6
RU2, 290–610	39.5	42.3	42.1	45.3	1.5	31.5	48.2
RU3, 610–690	38.8	42.2	42.5	43.9	1.7	32.3	47.5
690–840	34.0	38.4	38.4	41.6	1.5	27.5	47.5
DZ1, 840–900	34.6	36.9	36.5	39.5	1.7	26.4	45.0
900–950	34.4	36.6	36.6	39.0	1.3	26.3	42.8
RU6, 950–1,005	37.8	39.5	39.3	42.6	1.4	29.2	46.6
RU4, 690–865	34.0	38.4	38.4	41.6	1.5	27.5	45.7
RU5, 865–950	34.6	35.8	35.6	37.5	1.0	26.4	42.4
Competent rock	34.0	40.9	41.3	45.3	2.4	26.3	48.2
Deformation zones	34.6	36.9	36.5	39.5	1.7	26.4	45.0
Whole borehole	34.0	40.6	41.0	45.3	2.5	26.3	48.2

Summary of the cohesion c’ of the rock mass derived from RMR for borehole KAV04 under confinement stress between 10 and 30 MPa) (core sections of 5 m, Hoek & Brown’s a = 0.5).

Rock unit depth [m]	Minimum c’ [MPa]	Average c’ [MPa]	Frequent c’ [MPa]	Maximum c’ [MPa]	Standard deviation c’ [MPa]	Min possible c’ [MPa]	Max possible c’ [MPa]
RU1, 100–290	14.7	17.8	17.9	20.3	1.8	9.6	27.0
RU2, 290–610	14.9	17.5	17.0	21.3	1.7	10.7	27.8
RU3, 610–690	14.5	17.6	17.7	19.5	1.8	11.1	26.8
690–840	12.0	14.9	14.8	18.2	1.3	9.1	26.2
DZ1, 840–900	12.7	14.1	14.0	15.7	1.1	8.7	23.6
900–950	12.5	14.3	14.2	16.8	1.2	8.6	25.5
RU6, 950–1,005	14.0	15.4	15.1	18.4	1.3	9.7	25.5
RU4, 690–865	12.0	14.9	14.8	18.2	1.2	9.1	26.2
RU5, 865–950	12.7	13.6	13.4	15.0	0.8	8.7	23.6
Competent rock	12.0	16.8	16.6	21.3	2.0	8.6	27.8
Deformation zones	12.7	14.1	14	15.7	1.1	8.7	23.6
Whole borehole	12.0	16.6	16.4	21.3	2.1	8.6	27.8

Variation of the rock mass friction angle φ' from RMR for borehole KAV04 under stress confinement 10–30 MPa (Hoek & Brown's a = 0.5).



Variation of the rock mass cohesion c' from RMR for borehole KAV04 under stress confinement 10–30 MPa (Hoek & Brown's a = 0.5).