P-05-283

Oskarshamn site investigation

Rock mechanics characterisation of borehole KSH01A and B, KSH02, KSH03A and B, KAV01 and KLX02

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December 2005

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ISSN 1651-4416
SKB Rapport P-05-283

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Abstract

The report illustrates the characterisation of borehole KSH01A and B, KSH02, KSH03A and B at Simpevarp, KAV01 at Ävrö and KLX02 at Laxemar. 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 for the rock mass in the Rock Units and Deformation Zones identified by the geological single-hole interpretation are also provided. The rock quality of the competent rock mass (outside the Deformation Zones) is also provided.

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, thus it was decided to obtain all the other mechanical properties of the rock mass from the values of RMR, since 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, respectively.

The deformation modulus of the rock mass ranges on average between 32 and 40 GPa for the competent rock mass along the boreholes at Simpevarp and Ävrö, 49 GPa for borehole KLX02 at Laxemar, and between 16 and 27 GPa for the Deformation Zones, respectively.

The equivalent cohesion and friction angle of the rock mass, for a confinement stress between 10 and 30 MPa, range on average between 15 MPa and 19 MPa and between 38° and 45°, respectively. The equivalent compressive strength of the rock mass can be determined by extrapolation of the linear Mohr-Coulomb criterion to a zero confinement stress. The uniaxial compressive strength of the rock mass varies, for the competent rock mass, between 66 and 94 MPa and, for the Deformation Zones, between 61 and 72 MPa, respectively. These values are often larger than two times those obtained by using the curvilinear Hoek and Brown's Strength Criterion.

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. This estimation was performed separately on the properties of the competent rock mass and of the Deformation Zones.

The uncertainty on the average deformation modulus of the competent rock mass is usually around ± 6%. For the Deformation Zones, this value should be doubled. The uncertainty of the average cohesion and friction angle are about ± 8% and ± 3%, respectively, while the uncertainty of the parameters of the Deformation Zones should be at least three times as large.

Sammanfattning

I denna rapport beskrivs den empiriska karakteriseringen av borrhål KSH01A och B, KSH02, KSH03A och B från Simpevarp, KAV01 från Ävrö och KLX02 från Laxemar. Karakteriseringen genomfördes med hjälp av de två oberoende empiriska systemen RMR och Q. Systemen tillämpas på geomekanisk data i digitalformat enligt SKBs metodologi för ”karakterisering” av bergmassan.

Q och RMR värden beräknades för 5 m långa borrhålsavsnitt. Medelvärden för bergenheterna och deformationszonerna i den geologiska enhålstolkningen redovisas. Bergkvaliteten i den kompetenta bergmassan (utanför deformationszonerna) studerades också separat.

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

Deformationsmodulen hos bergmassan varierade mellan 32 och 40 GPa för den kompetenta bergmassan längs borrhålen från Simpevarp och Ävrö. Den var 49 GPa för borrhålet KLX02 från Laxemar och mellan 16 och 27 GPa för deformationszonerna.

Bergmassans ekvivalenta kohesion och friktionsvinkel varierade mellan 15 MPa och 19 MPa respektive mellan 38° och 45°, för en omgivande spänning mellan 10 och 30 MPa. Från friktionsvinkeln och kohesionen kan den enaxiella tryckhållfastheten hos bergmassan uppskattas med hjälp av en extrapolering av Mohr-Coulombs lineära kriterium. Tryckhållfasthet resulterar ligga mellan 66 och 94 MPa för den kompetenta bergmassan, och mellan 61 och 72 MPa för deformationszonerna. Dess värde är mer än dubbel det värdet beräknat genom Hoek and Browns brottskriterium för 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 ± 6 %. För deformationszonerna torde detta värde fördubblas. Osäkerheten för medelvärdet hos kohesionen och friktionsvinkeln är ± 8 % respektive ± 3 %, medan osäkerheten hos parametrarna från deformationszonerna borde vara minst tre gånger högre.

Contents

1 Introduction

1.1 Background

The analysed boreholes are located in the Simpevarp Peninsula (KSH01A and B, KSH02, KSH03A and B), on the island of Ävrö (KAV01) and on the Laxemar area on the mainland (KLX02) (Figure 1-1). All the borehole are sub-vertical and, except one, reach the depth of 1,000 m (Table 1-1). For the boreholes, BIPS images are also available.

Table 1-1. Borehole information.

Borehole	Bearing angle	Inclination	Borehole depth
KSH01A	354°	80°	100–1,000
KSH02A	331°	86°	20–1,001
KSH03A	272°	86°	100–1,001
KAV01	237°	89°	0–757
KLX02	009°	85°	200–1,006

Figure 1-1. Overview of the Simpevarp Site with indication of the boreholes analysed in this report: KSH01A and B, KSH02A, KSH03A and B, KAV01 and KLX02. (Borehole KAV04A and B, and KLX01 are also indicated but are not treated here.)

1.2 Objectives

The objectives of this study on borehole KSH01A and B, KSH02, KSH03A and B, KAV01 and KLX02 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 that come directly from the borehole and contained in the geological single-hole interpretation of the available information /Hultgren et al. 2004, Matsson et al. 2004ab/. 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 typical rock types at the site and of the rock fractures.
- Application of the RMR and Q empirical systems for determination of the rock quality along the boreholes (see also Appendix 1 to 5). The determination of the input parameters is illustrated as well as some spatial variation 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 continuum mechanical properties determination are also treated (see also Appendix 1 to 5).
- Discussion of the results.
- Recommendations on the data acquisition, processing and storage in SICADA.
- Appendices.

2 Boremap data

The analysed boreholes (KSH01A and B, KSH02, KSH03A and B, KAV01 and KLX02) were mapped by examining the core and the BIPS pictures taken on its wall /Ehrenborg and Stejskal 2004abcde/. The main geological parameters obtained and stored in SKB's database SICADA were:

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

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).
- Width and aperture.

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" fractures.

A direct estimation of the Q-parameter Joint Alteration Number (J_a) was performed on the core directly after drilling and an the results were stored in the SICADA together with the rock fracture information.

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

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

The recognition of the local fracture sets occurring in the rock mass along the borehole was based, not only of the BOREMAP information directly available, but also on the results of the Discrete Fracture Network modelling (DFN) reported for Simpevarp Site Descriptive Model version 1.1 in /SKB 2004/. At the time of the characterisation, the available DFN Model was only based on one borehole and some outcrops. However, for the purpose of the characterisation, the exact orientation of the fracture sets is not critical as the number of sets occurring in the same Rock Unit or Deformation Zone.

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 within each rock unit along the borehole, the mean orientation of each set and its Fisher's constant were determined (see Appendix 1 to 5). Based on the orientation pole concentrations shown on the stereonet plots, the fractures were assigned to the 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 to correct for the linear fractures sampling applied by the borehole.

Since the assignment of the fracture to the different fracture sets is performed in each rock unit, not all fracture sets can be seen at all depth. If in the stereogram there is not a pole concentration that corresponds to one of the DFN fracture sets for a certain rock unit, then these fractures are not assigned to any fracture set and constitute the group of "random fractures" (according to the definition required by the Q-system, see Section 4.1). For the application of the whole range of the Joint Number Coefficient J_n, the Q-system necessitates the presence of fractures assigned to the group of random fractures. If no random fractures are allowed, abrupt jumps of J_n might occur.

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 in every 5 m section of borehole are shown. In the following sections, 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, the plot of the number of fracture sets contemporarily occurring in each 5 m section of core along the borehole is obtained.

The determination of the RMR-rating for the fracture length requires an evaluation of the average trace length of the fractures. The concept of average trace length is obsolete compared to the description of the trace length variation provided by the DFN Model. The power-law describing the trace length in the DFN Model implies that the average trace length of the fractures to be used for RMR varies with the scale of the observation. Thus, to be able to use the DFN parameters to determine the average fracture trace length, the scale at which the estimation is performed must be specified. Considering that the empirical methods were developed based on outcrop and tunnel information, a reasonable scale of evaluation could be around 30 m. This would correspond to the typical size of the observable rock face or to the maximum trace length in practice observable in a tunnel.

The probability Prob of having fracture traces longer than a threshold x_0 is provided by the equation:

$$\text{Prob}\left(x > x_0\right) = \left(\frac{x_0}{x}\right)^{Kt} \qquad (1)$$

The average fracture trace can be obtained by integrating the derivative of the probability in Equation (1) (e.g. frequency of occurrence):

$$\mathrm{f}\left(\mathrm{x}\right) = \frac{\mathrm{dProb}}{\mathrm{dx}} \qquad (2)$$

The mean fracture trace is then provided by:

$$\mathrm{m_X} = \frac{\int_{\mathrm{x_0}}^{\mathrm{X}} \mathrm{x}\cdot\mathrm{f}\left(\mathrm{x}\right)dx}{\int_{\mathrm{x_0}}^{\mathrm{X}} \mathrm{f}\left(\mathrm{x}\right)dx} \qquad (3)$$

where X is the size of the largest considered trace length. The DFN Model version 1.1 in /SKB 2004/ provides different sets of parameters for NE, NW and WNW-lineament related fractures: K_t typically varies between –1.51 and –1.76 while x_0 varies between 0.1 and 0.5. Thus, inputting these parameters in Equation (3), the fracture trace length would vary between 1 to 1.5 m, with an average value of 1.3 m, thus in the range between 1 and 3 m.

2.1 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). For Rock Mechanics purposes, the partitioning was adopted to investigate the possible correlation of the rock type with the quality of the rock mass. Moreover, the open fractures within each rock unit were analysed to determine the occurrence of the DFN fracture sets (Simpevarp Site Descriptive Model version 1.1 /SKB 2004/) with depth for each borehole. The fractured/deformation zones were also accurately checked but only the ones that would correspond to considerably reduced rock mass quality were considered as separated objects in the present Rock Mechanics analysis.

The single hole interpretations for the boreholes in this report are reported in Chapter 4.

2.2 KSH01A and B

Figure 2-1 shows the stereonet plot of the poles of the fractures observed in KSH01A and B. The fracture set identified according to Simpevarp version 1.1 are also marked. In Table 2-1, the occurrence of the fracture sets together with the variation in orientation are shown along the borehole. The division of the borehole into rock units is provided by /Matsson et al. 2004a/, see Section 4.2.1.

Figure 2-2, shows the variation of some of the frequency properties of the fractures in the borehole. Marked peaks of the fracture frequency are observed at about 420 and 620 m. These two depths also correspond to two decreases of the RQD indicating not only higher frequency but also clustering of the fractures to produce small core pieces. Sub-horizontal fractures seem to occur particularly at the depth of about 690 m, where they also appear to be de dominant set at that depth. The upper 500 m of the borehole are characterised by the presence of 3 to 4 fracture sets, while part deeper that 500 m exhibit between 2 and 3 fracture sets.

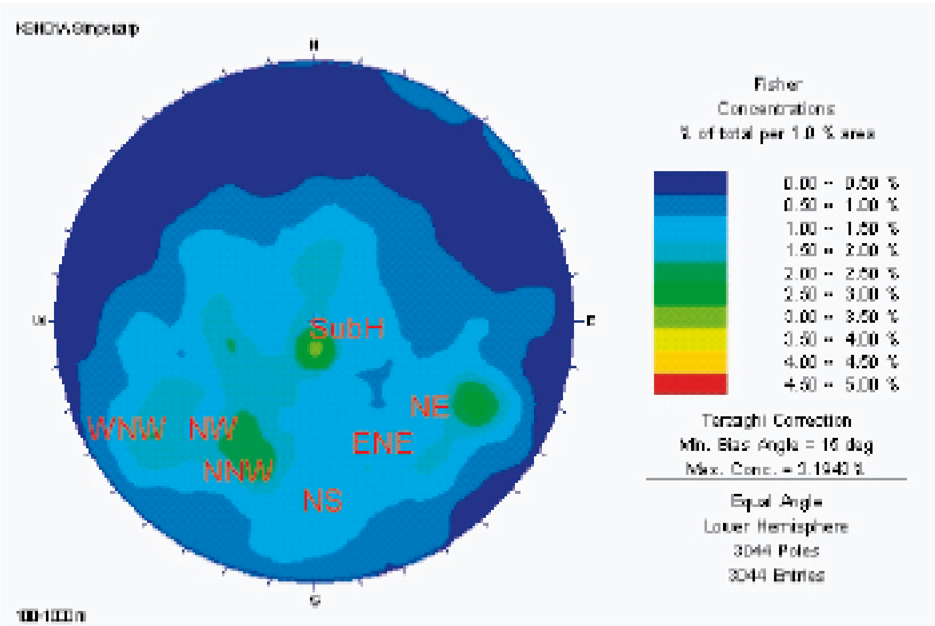

Figure 2-1. Equiangular pole plot of the fractures logged along borehole KSH01A and B and indication of the main fracture sets.

Table 2-1. Set identification from the fracture orientation mapped for borehole KSH01A (based on SICADA data ordered on 15/08/03). The orientations are given as strike/dip (right-hand rule).

Borehole length (m)	No of open fractures	NS	NNE	NE	ENE	EW	WNW	NW	NNW	SubH
100–205	310			224/63	275/63				177/81	154/04
205–247	165			183/56	266/61			309/62		262/01
247–322	376	035/53				139/54				109/02
322–365	134				264/81	110/48		294/61		357/05
365–420	200					088/38		285/68		266/09
420–455	249	348/44					319/80	305/56		
455–540	262	007/36		225/58		124/38	325/71	287/72		211/04
540–607	382						336/64	298/51		
607–631	201	346/40						299/47		302/03
631–719	371		207/68							090/04
719–839	199			238/62			323/85			050/05
839–957	178			250/59			314/72			311/09
957–1,000	17									320/04

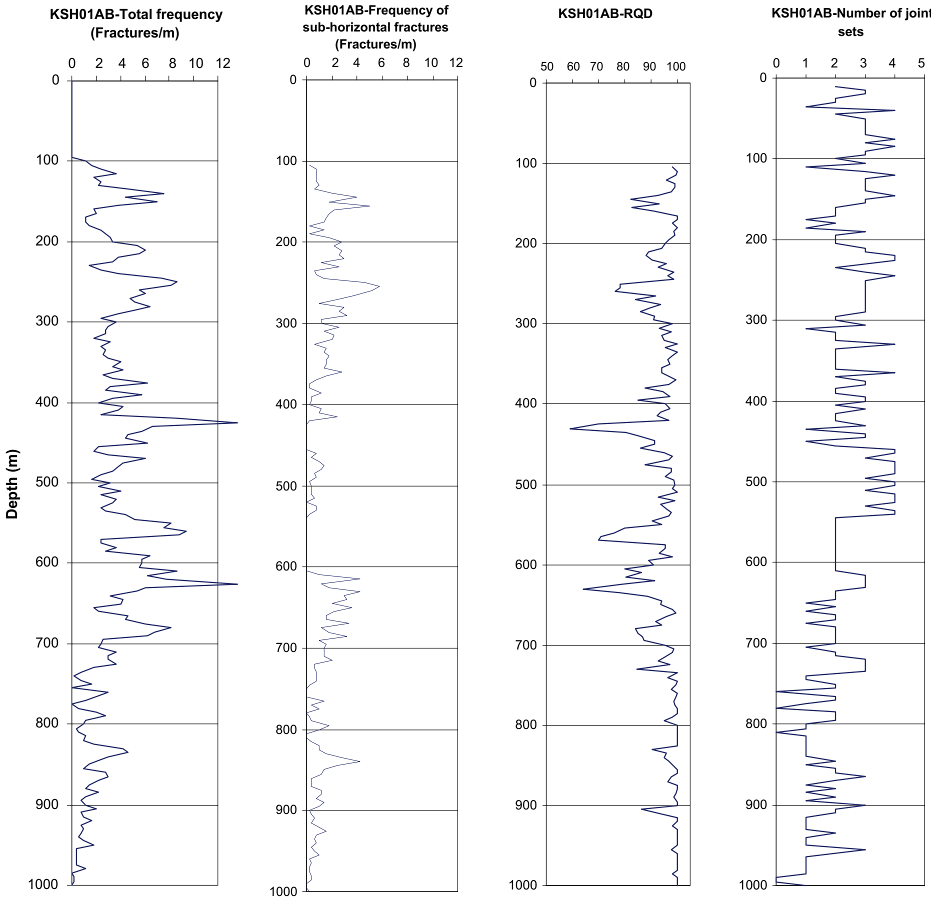

Figure 2-2. *Variation of the total fracture frequency, frequency of the sub-horizontal fractures, RQD and number of joint sets along borehole KSH01A and B. The values are averaged for each 5 m length of borehole.*

2.3 KSH02

In Figure 2-3, the stereonet plot of the poles of the fracture planes for borehole KSH02 is shown. The fractures intersected by this borehole seem to be prevalently sub-horizontal. This is also shown in Table 2-2 where the occurrence of the fracture sets defined by the DFN Model is shown along the borehole. The division of the borehole into rock units is provided by /Matsson et al. 2004b/, see Section 4.3.1. It can be noticed that there are large similarities between the plot of the total frequency and that of the frequency of the sub-horizontal fractures in Figure 2-4. A very localised peak of the fracture frequency is observed at about 300 m, where also RQD has an abrupt trough. Between the depths of around 470 and 800 m the fracture frequency is higher than in the rest of the borehole. Lower values of RQD can be observed at the same depth. The number of fracture sets all occurring in the same 5 m section does not exceed 3 in this borehole. A background value seem to be 1 fracture set (mainly due to the sub-horizontal set) with higher values in the upper 300 m and between approximately 650 and 870 m.

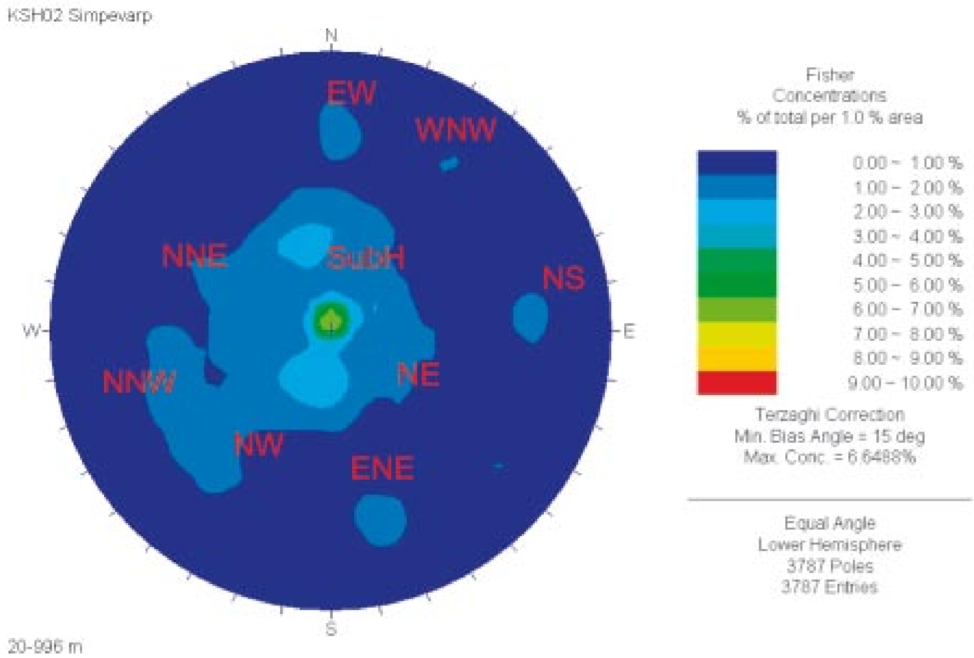

Figure 2-3. *Equiangular pole plot of the fractures logged along borehole KSH02 and indication of the main fracture sets.*

Table 2-2. Set identification from the fracture orientation mapped for borehole KSH02 (based on SICADA data ordered on 07/05/2004). The orientations are given as strike/dip (right-hand rule).

Borehole length (m)	No of open fractures	NS	NNE	NE	ENE	EW	WNW	NW	NNW	SubH
20–80	228	174/71		055/76			118/74	326/65		082/07
80–234	477	007/77		036/89	258/71	093/61	122/80	325/72		116/11
234–281	123		013/73	220/76	253/68		291/81		341/71	059/03
281–304	137				258/73		112/71			005/09
304–470	585				250/66					022/07
470–511	218	179/65				093/75		124/73	331/59	346/04
511–532	151		024/46							097/01
532–654	828									354/05
654–681	193		205/55		074/44		305/65		342/58	353/06
681–743	276					097/65		312/61		286/14
743–1,007	571	178/62							334/55	160/06

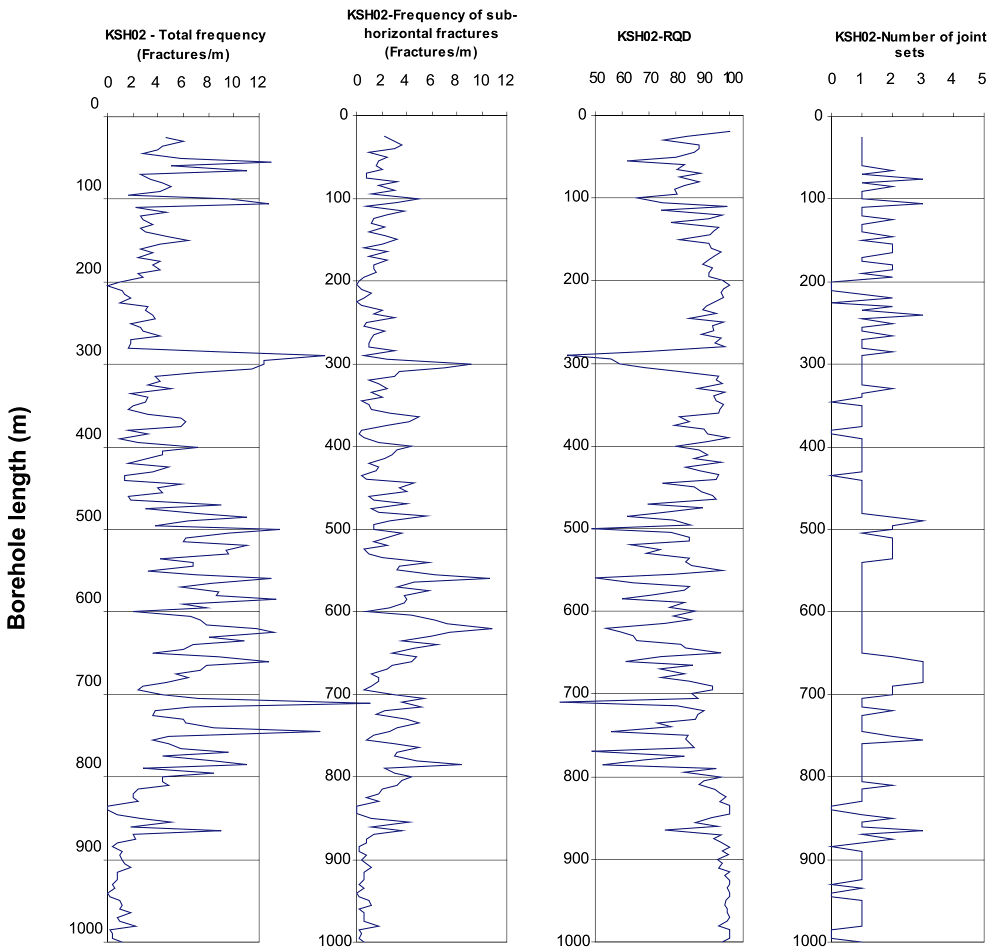

***Figure 2-4.** Variation of the total fracture frequency, frequency of the sub-horizontal fractures, RQD and number of joint sets along borehole KSH02. The values are averaged for each 5 m length of borehole.*

2.4 KSH03A and B

Borehole KSH03A and B show a predominance of fractures oriented approximately EW and NW (Figure 2-5). Also the sub-horizontal fracture set is rather well defined as shown in the stereonet plot. The fracture sets defined by the DFN Model can be observed at different depth in Table 2-3. The partition of the borehole is provided by the single-hole interpretation /Hultgren et al. 2004/, see Section 4.4.1.

The fracture frequency is rather low along the borehole except for a section between about 190 and 280 m where it reaches a value of over 12 fractures per meter (on average for sections of 5 m length). This peak also precisely coincides with the occurrence of the sub-horizontal fractures and the drop of RQD. RQD also exhibit other local minima, which are, however, not comparably low. The very fractured part of the borehole present often 4 fracture sets all occurring at the same time. Below around 500 m, the number of fracture sets appearing is usually between 1 and 2.

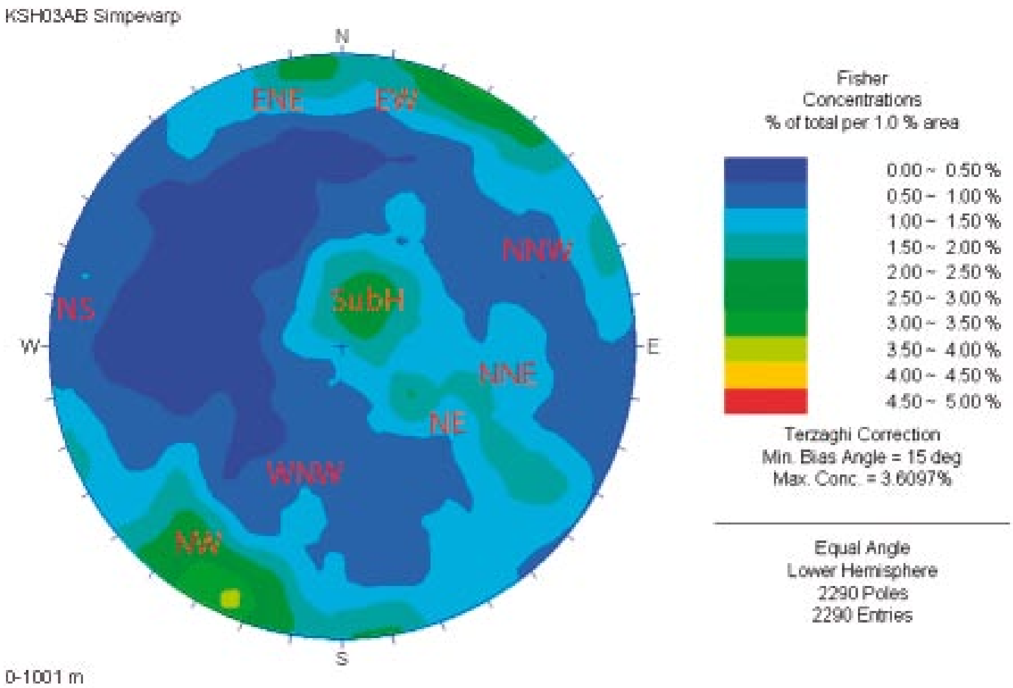

Figure 2-5. *Equiangular pole plot of the fractures logged along borehole KSH03A and B and indication of the main fracture sets.*

Table 2-3. Set identification from the open fracture orientation mapped for borehole KSH03A and B (based on SICADA data ordered on 07/05/2004). The orientations are given as strike/dip (right-hand rule).

Borehole length (m)	No of open fractures	NS	NNE	NE	ENE	EW	WNW	NW	NNW	SubH
0–120	178	006/84					283/61	138/70		143/03
120–165	105			230/39						108/28
165–190	110	181/55		224/69	250/80					100/07
190–275	718		214/82			262/76			170/79	171/10
275–295	58		196/44				118/58	143/83		
295–340	72		196/65			92/87		104/54	334/88	
340–360	115		197/78		080/85		101/46			
360–460	268		202/50						167/74	137/12
460–1,000	671							299/88		146/08

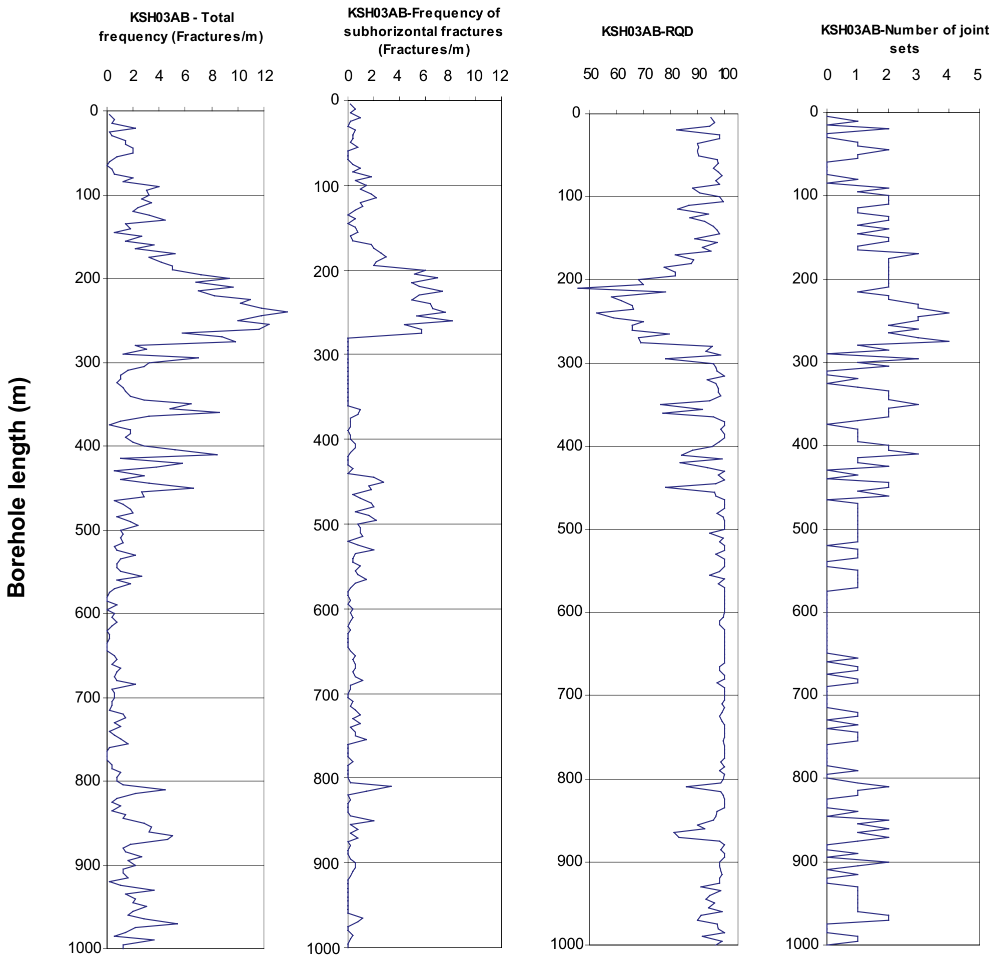

Figure 2-6. Variation of the total fracture frequency, frequency of the sub-horizontal fractures, RQD and number of joint sets along borehole and AB. The values are averaged for each 5 m length of borehole.

2.5 KAV01

Borehole KAV01 show a very localised NE fracture set that dominates over all the others included the sub-horizontal set (Figure 2-7). In Table 2-4, the occurrence of the fracture sets given by the DFN Model is shown along the borehole. The partition of the borehole into rock units is given in /Matsson et al. 2004b/, see Section 4.5.1. Also the comparison of the total fracture frequency and the frequency of the sub-horizontal fracture set provide the same piece of information (Figure 2-8). The fracture frequency drastically increases at depth larger than 400 m. However, RQD assumes low values localised between 400 m and 580 m, indicating a higher degree of crushing of the rock mass at that depth. This depth interval also corresponds to the maximum number of fracture sets occurring in each 5 m of borehole length (4 sets). On average, there are less fracture sets occurring in the upper part of the borehole.

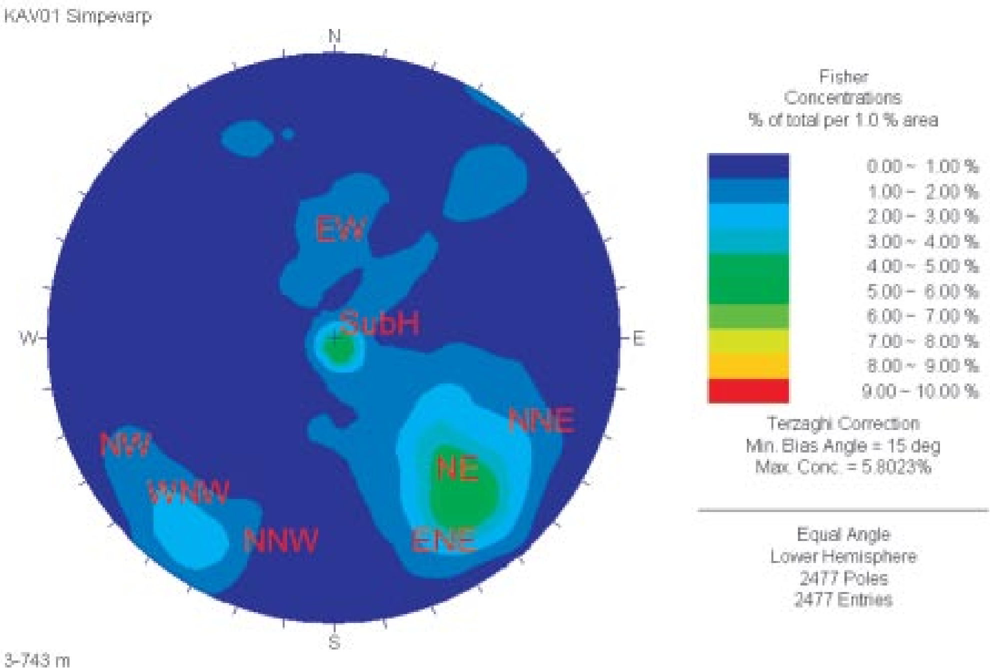

Figure 2-7. *Equiangle pole plot of the fractures logged along borehole KAV01 and indication of the main fracture sets.*

Table 2-4. Set identification from the fracture orientation mapped for borehole KAV01 (based on SICADA data ordered on 25/05/2004). The orientations are given as strike/dip (right-hand rule).

Borehole length (m)	No of open fractures	NS	NNE	NE	ENE	EW	WNW	NW	NNW	SubH
20–70			No fracture orientation available							
70–135	127		209/76					328/75	298/75	291/02
135–185	176		211/53				299/87			238/09
185–364	306		214/60		246/90					230/16
364–427	170			225/64						025/06
427–464	277			235/60		087/47		315/71		006/03
464–494	175			229/59	080/37		298/63			018/00
494–565	414			226/70			309/80			107/10
565–605	112			229/75			103/53	315/78		225/04
605–686	335			237/64			305/76			238/12
686–750	261			219/51						227/05

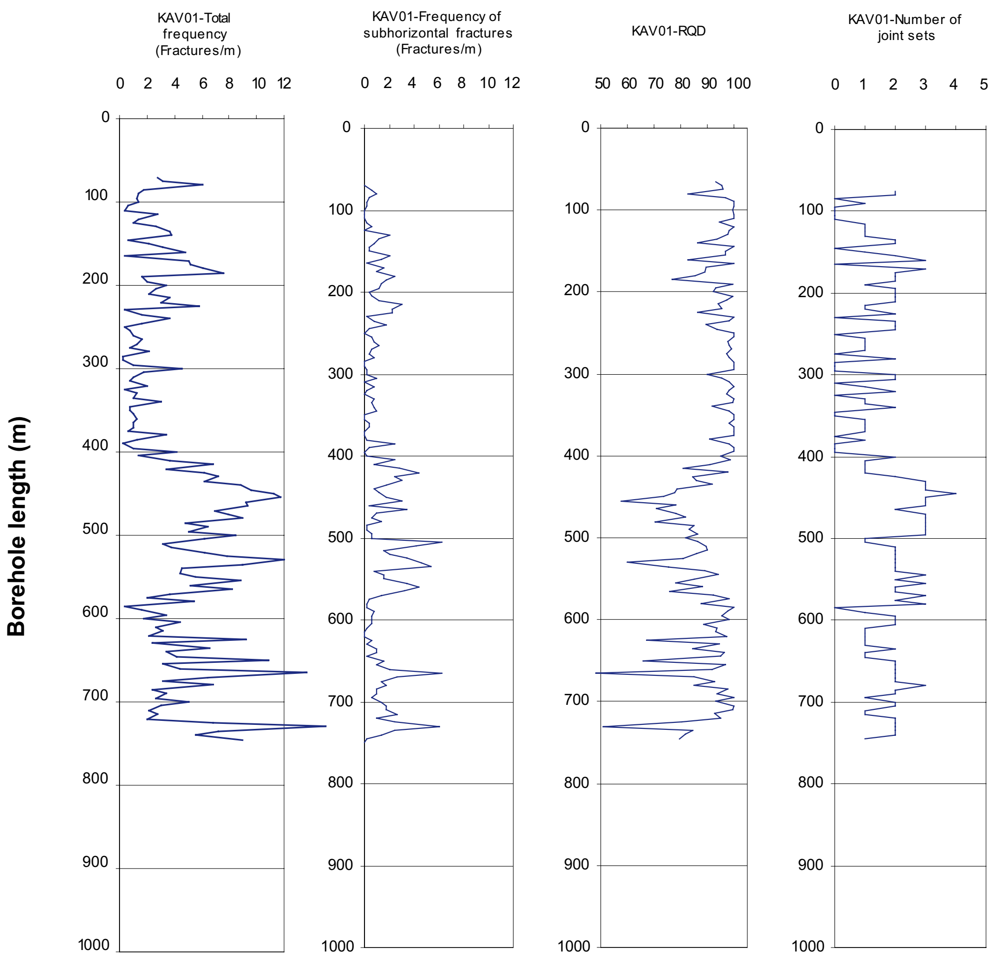

Figure 2-8. Variation of the total fracture frequency, frequency of the sub-horizontal fractures, RQD and number of joint sets along borehole KAV01. The values are averaged for each 5 m length of borehole.

2.6 KLX02

Borehole KLX02, located in the Laxemar area on the mainland, presents a wide spread of fracture orientations (Figure 2-9). This explains the apparent dominance of the sub-horizontal fractures over the other orientations also shown in Table 2-4. According to Figure 2-10, the fracture frequency increases below 700 m. Above this depth, some localised peaks of the frequency are found between 390 and 470 m, and at about 660 m. The sub-horizontal fracture frequency increases below 800 m, representing a fraction of about one third of the total frequency. The occurrence of the sub-horizontal fractures below 800 m also increase the number of fracture sets occurring every 5 m of core, that for the rest of the borehole is between 0 to 2 fracture sets. The single-hole interpretation of this borehole is provided by /Hultgren et al. 2004/, see Section 4.6.1.

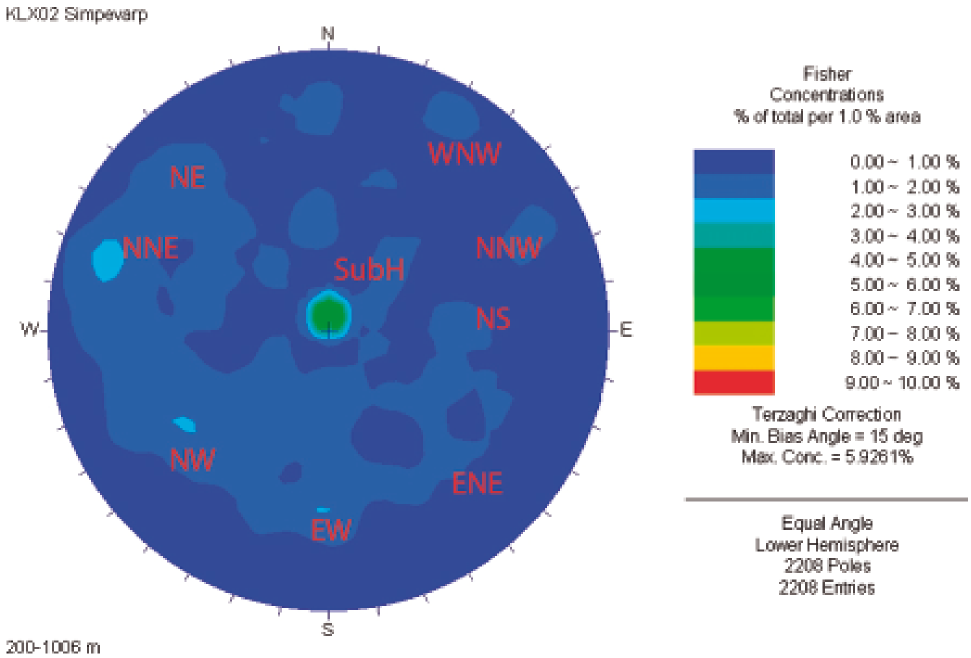

Figure 2-9. *Equiangle pole plot of the fractures logged along borehole KLX02 and indication of the main fracture sets.*

Table 2-5. Set identification from the open fracture orientation mapped for borehole KLX02 (based on SICADA data ordered on 07/05/2004). The orientations are given as strike/dip (right-hand rule).

Borehole length (m)	No of open fractures	NS	NNE	NE	ENE	EW	WNW	NW	NNW	SubH
200–420	183		024/79		074/80	269/63	116/86		339/79	282/05
420–480	119			043/80		269/89	300/74		333/61	111/04
480–550	94	009/79		214/87	235/52				155/79	
550–610	65					268/65	128/54			280/02
610–630	49				011/79			318/53		287/03
630–655	27		024/59					294/47		091/06
655–665	41									100/14
665–725	84			231/80		275/80		312/53		333/11
725–795	218		193/52	030/75		260/75		136/82	331/48	066/02
795–820	152									095/06
820–845	98			038/65			103/62	319/55		088/08
845–870	257			210/41	238/71				158/66	102/04
870–880	24									265/11
880–905	180		193/48		074/60		293/42			
905–940	219		195/57						337/68	218/10
940–960	183								327/80	111/06
960–1,000	215	007/77								006/03

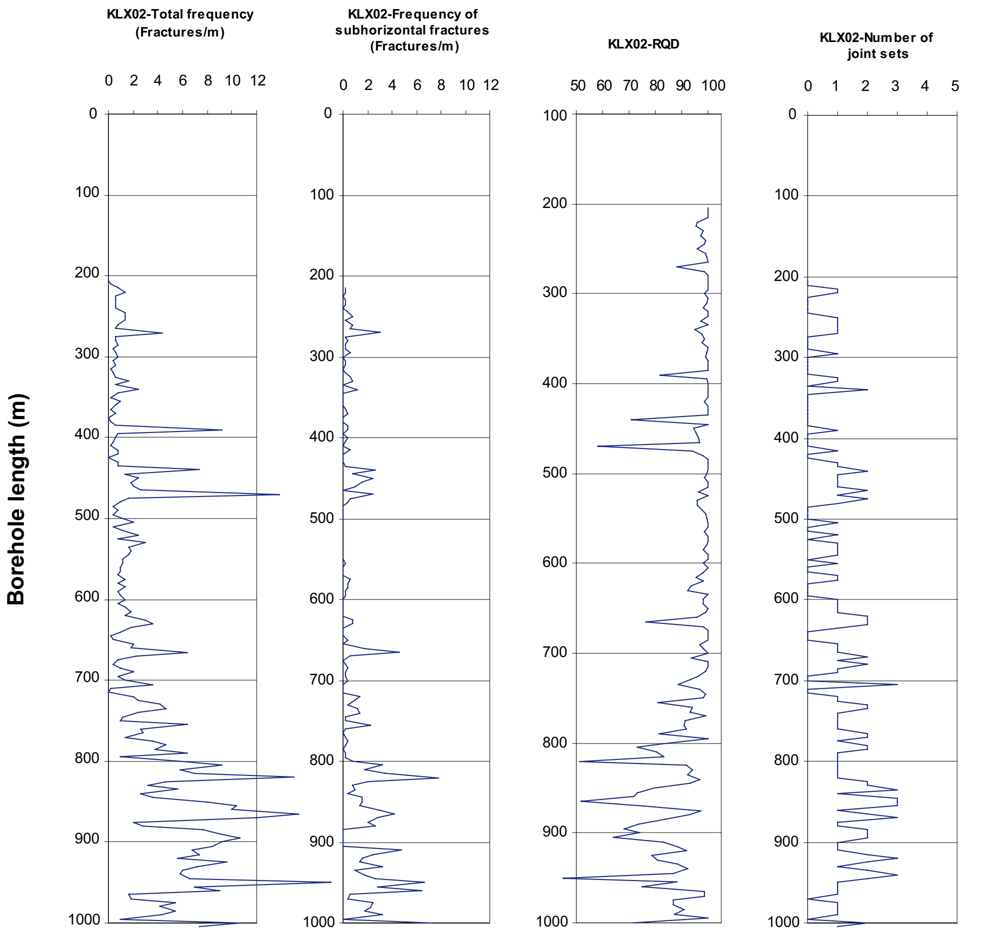

Figure 2-10. Variation of the total fracture frequency, frequency of the sub-horizontal fractures, RQD and number of joint sets along borehole KLX02. The values are averaged for each 5 m length of borehole.

3 Mechanical properties of intact rock and rock fractures

The mechanical properties of the intact rock and the rock fractures were provided by the modelling stage at which the characterisation of the borehole was performed. In particular:

- For KSH01A and B, the mechanical properties used for the characterisation were included in Simpevarp Site Descriptive Model version 1.1 /SKB 2004/.
- For KSH01A and B, KSH02, KSH03A and B, KAV01 and KLX02, the summary of the mechanical properties was provided in the "Summary of the primary data" for Simpevarp Site Descriptive Model version 1.2 /Lanaro and Fredriksson 2006/.

Since the properties of the intact rock and fractures in the two model versions did not differ too much, here only the second model properties are reported in Table 3-1 and Table 3-2. The dominant rock types tested in laboratory are fine-grained dioritoid (metavolcanite, volcanite) and quartz monzonite to monzodiorite (equigranular to weakly porphyritic). Table 3-1 contains the uniaxial compressive strength of the intact rock (UCSi) and the parameter mi of the Hoek and Brown's Criterion that is typical for each rock type /Hoek et al. 2002/. Table 3-2 reports the range of variation of the Young's modulus and of the Poisson's ratio obtained in uniaxial conditions.

Table 3-1. Parameters for the Hoek and Brown's Criterion based on the results of uniaxial and triaxial tests performed on intact rock sampled from borehole KSH01A and KSH02 /Lanaro and Fredriksson 2006/.

Rock type	Number of samples	Minimum USCi (MPa)	mi	Mean UCSi (MPa)	mi	Maximum UCSi (MPa)	mi
Fine-grained dioritoid	16	120	15	205	14	295	13
Quartz monzonite to monzodiorite	16	125	33	160	31	195	29

Table 3-2. Young's modulus and Poisson's ratio from uniaxial compressive tests performed on intact rock sampled from borehole KSH01A and KSH02 /Lanaro and Fredriksson 2006/.

Rock type	Number of samples	Minimum Em (GPa)	v (–)	Mean Em (GPa)	v (–)	Maximum Em (GPa)	v (–)
Fine-grained dioritoid	10	78	0.21	85	0.26	101	0.31
Quartz monzonite to monzodiorite	10	69	0.19	78	0.27	86	0.33

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 RMR and Q are reported here for convenience of the reader. The basic equation for the RMR /Bieniawski 1989/ is:

$$RMR = RMR_{strength} + RMR_{RQD} + RMR_{spacing} + RMR_{fracture\ conditions} + \\ + RMR_{water} + RMR_{orientation} \qquad (4)$$

where the subscripts strength, RQD, spacing, fracture 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:

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF} \qquad (5)$$

where, besides RQD, Jn depends on the number of fracture sets, Jr and Ja on the roughness and alteration of the fractures, Jw 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 KSH01A and B

4.2.1 Single-hole interpretation

The geological single-hole interpretation provides a partitioning of borehole KFM01A and B into pseudo-homogeneous sections /Mattsson et al. 2004a/ that apply also for the rock mechanics analysis. Four different rock type groups are recognised together with 13 fractured/deformation zones. In Table 4-2, the Rock Units, rock type groups and the decision process for the choice of the fractured/Deformation Zones for Rock Mechanics are reported.

- RU1: dominated by quartz monzodiorite with subordinate sections of fine-grained granite, pegmatite and sparsely porhyritic Ävrö granite.
- RU2: dominated by fine-grained dioritoid with subordinate sections of quartz monzodiorite, fine- to medium-grained granite, pegmatite and fine-grained diorite to gabbro.
- RU3: characterized by a mixture of sparsely porphyritic Ävrö granite and quartz monzodiorite, with subordinate sections of fine- to finely medium-grained granite, medium- to coarse-grained granite, fine- grained diorite to gabbro and pegmatite.
- RU4: dominated by sparsely porphyritic Ävrö granite with subordinate sections of fine- to finely medium-grained granite, fine-grained diorite- to gabbro, pegmatite and diorite to gabbro.

Table 4-2. Partitioning of borehole KSH01A and B according to the single-hole interpretation /Matsson et al. 2004a/: Rock Units and Deformation Zones.

Borehole length (m)	Rock Unit	Depth (m)	Deformation zones
100–205	RU1	137–160	DZ1
205–247	RU2		
247–322	RU1	240–252	DZ 2a*
		252–259	DZ 2b* (ductile shear zone)
		259–287	DZ 2c*
322–631	RU2	420–455	DZ 3
		540–608	DZ 4a**
		608–614	DZ 4b** (ductile shear zone)
		614–631	DZ 4c**
631–719	RU3	672–687	DZ 5a***
		687–692	DZ 5b*** (ductile shear zone)
		692–693	DZ 5c***
719–839	RU3	766–767	DZ 6 (ductile shear zone)
		834–835	DZ 7 (ductile shear zone)
839–957	RU4		
957–1,000	RU3		

*, ** and ***: The geological single-hole interpretation identified these sections as part of the same feature. However, some of the properties changed from section to section (e.g. fracture frequency).

4.2.2 Characterisation with RMR

For each 5 m sections of borehole, the geomechanical parameters from borehole logging were scrutinized (Figure 4-1 and Appendix 1). The minimum, average, most frequent and maximum rating for RMR was determined for each borehole section. The plots in Figure 4-1 are obtained for the RQD, fracture conditions, 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. The RMR-rating for trace length (RMR_{length} = 4) was chosen for average trace lengths between 1 and 3 m according to Section 2.

The RMR values were also summarised for each rock type group, for competent rock mass, fractures zones and for the whole borehole as shown in Appendix 1. RMR seems to be rather constant outside the deformation zones, with a slight increase below about 700 m. In summary:

1) The minimum RMR in the borehole corresponds to "fair rock" (RMR = 57).
2) The fractured rock in the deformation zones show an average RMR of about 65, which means a rock mass at the lower range of the "good rock" class.

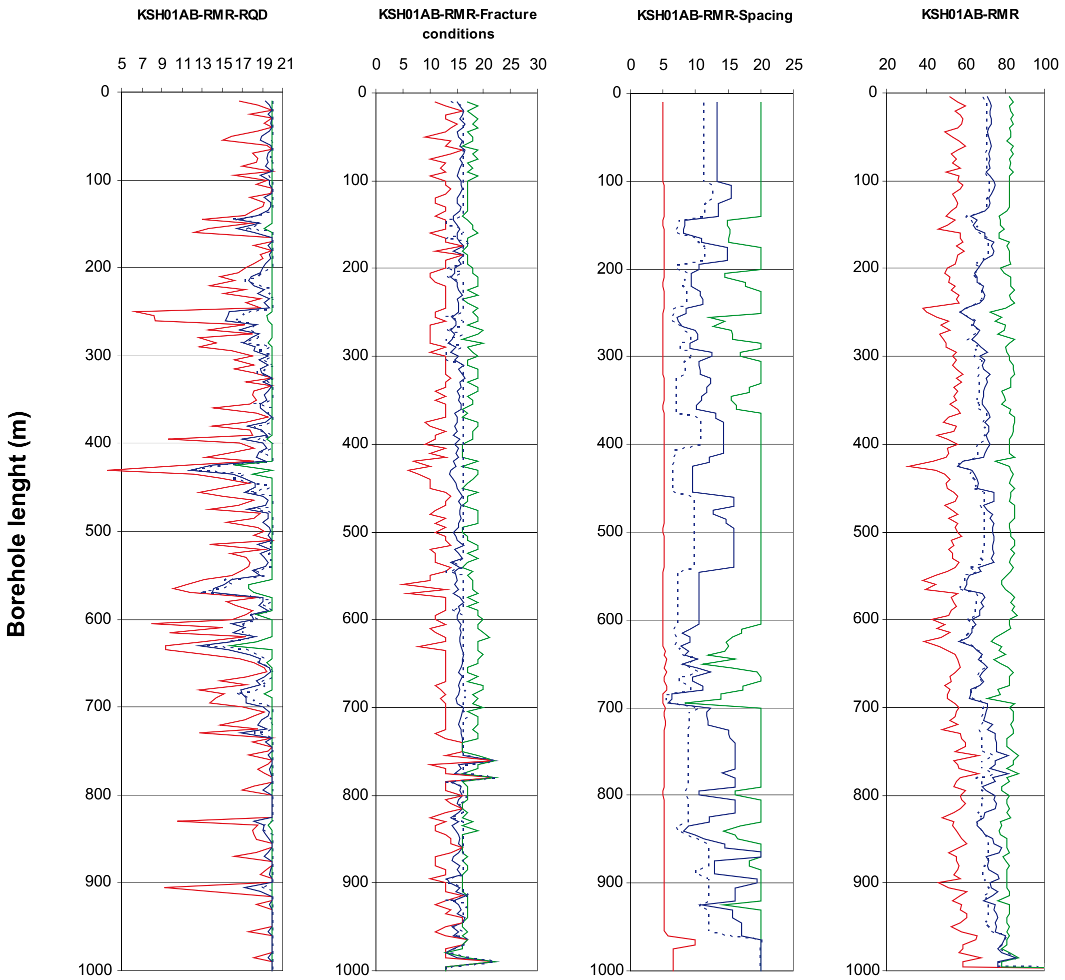

Figure 4-1. Ratings for RMR characterisation and resulting RMR values along borehole KSH01A and B. The ratings for RQD, fracture conditions, fracture spacing are plotted with depth together with RMR. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed every core section of 5 m, respectively.

3) The competent rock mass has a mean RMR of 73 that place 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 a RMR of 86 ("very good rock").

Rock Unit 4 exhibits a higher average RMR than the other units (RMR = 74), while Rock Unit 2 has the lowest average RMR (RMR = 69).

4.2.3 Characterisation with Q

The input numbers for the Q systems and the resultant rock quality index for 5 m long core sections are plotted in Figure 4-2. 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, 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 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 Deformation Zones listed in Table 4-2 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.

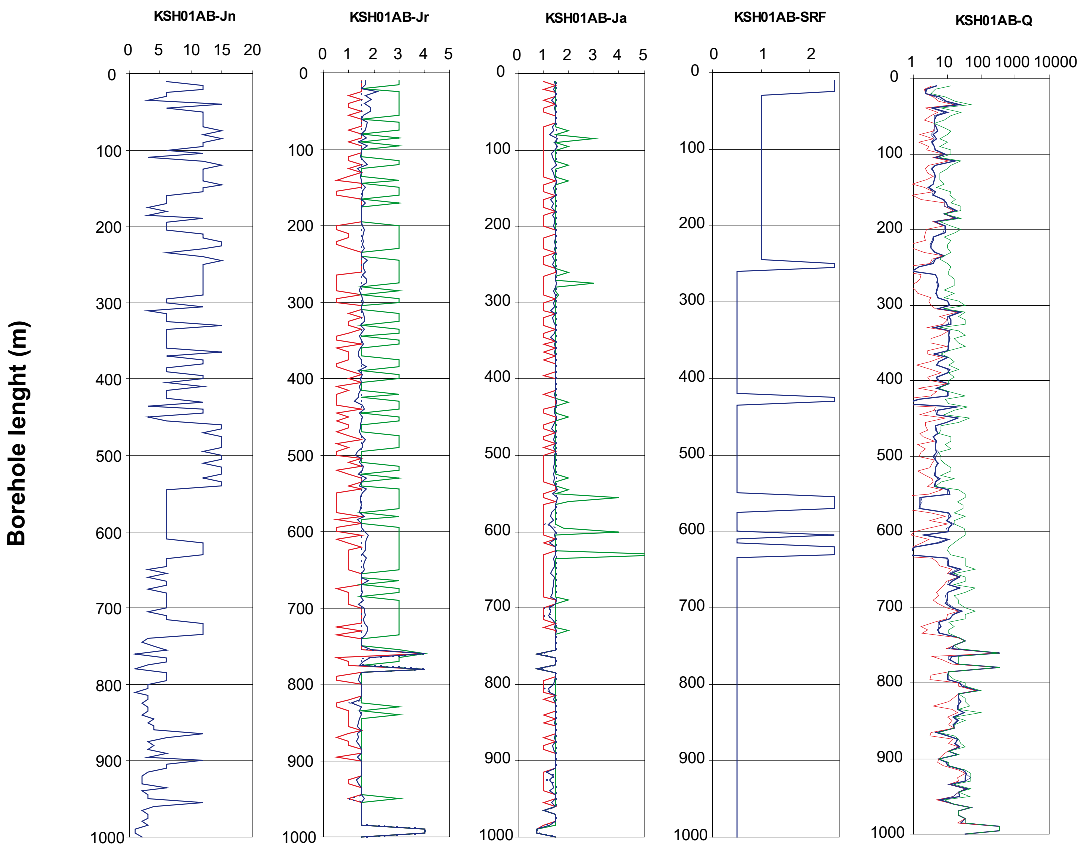

Figure 4-2. *Numbers for Q characterisation and resulting Q values along borehole KSH01A and B. The number for fracture set number, fracture roughness, fracture alteration and SRF are plotted with depth together with Q. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed every core section of 5 m, respectively.*

According to the Q system, the rock along borehole KSH01A and B can be classified as "good rock" as the average Q is larger than 10 and the most frequent value is exactly 10. The Rock Unit 3 and 4 have average Q values 19 and 45, respectively, higher than the other two rock units (both with average Q of 7).

The Q values for borehole KFM01A and B can be summarised as follows:

1) The minimum Q in the Deformation Zones and is 0.5 ("very poor rock").
2) The rock in the deformation zones has an average and frequent Q of 7 and 5 that makes it belong to the class of "fair rock".
3) The competent rock mass has average and frequent Q of 21 and 10, respectively, thus in the class of "good rock".
4) The best rock within the competent mass rock has Q of 352, which means "very good" rock.

4.3 KSH02

4.3.1 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 4-3 /Mattsson et al. 2004b/. The Rock Units are characterised by the following rock types:

- RU1: completely dominated by fine-grained dioritoid with a few < 5 m long sections of pegmatite. Furthermore, a few scattered thin sections of fine- to medium-grained granite occur. Sealed fracturing.
- RU2: characterized by a mixture of fine-grained dioritoid and up to 20 m long sections of fine- to medium-grained granite. Furthermore, a few < 4 m long sections of pegmatite occur. Sealed fracturing.
- RU3: very similar to RU 1, i.e. completely dominated by fine-grained dioritoid. A ca 10 long section of fine-grained diorite to gabbro was observed between ca 970 and 980 m.

The deformation zones are described as follows:

- DZ1: Increased fracturing and strong alteration (280–304 m).
- DZ2: Strong alteration.
- DZ3: Medium to strong alteration and increased fracturing.

Table 4-3. Partitioning of borehole KSH02 according to the single-hole interpretation /Mattsson et al. 2004b/: Rock Units and Deformation Zones.

Borehole length (m)	Rock Unit	Depth (m)	Deformation zone
80–470	RU1	234–281	DZ 1a*
		281–304	DZ 1b*
470–743	RU2	511–532	DZ 2
		654–681	DZ 3
743–1,007	RU3		

* The two borehole sections were assigned to the same zone. However, they differ for some of the geo-mechanical properties (e.g. fracture frequency, alteration) thus are treated separately in this report.

4.3.2 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 4-3 show the RQD, fracture condition, spacing rating that results into the RMR ranges for rock mass characterisation. The RMR-rating for trace length (RMR_{length} = 4) was chosen for average trace lengths between 1 and 3 m according to Section 2.

The RMR for the whole borehole ranges between 55 and 87, without large differences between the competent rock mass and the deformation zones. More in details:

1) The minimum RMR in the deformation zones has a minimum of 55 (“fair rock”).
2) The average RMR in the deformation zones is 66, that makes it at the lower range of the “good rock” class.
3) The average rock quality in the competent rock mass is 69, thus in “good rock”.
4) The maximum RMR in the competent rock mass is 87, which means “very good rock”.

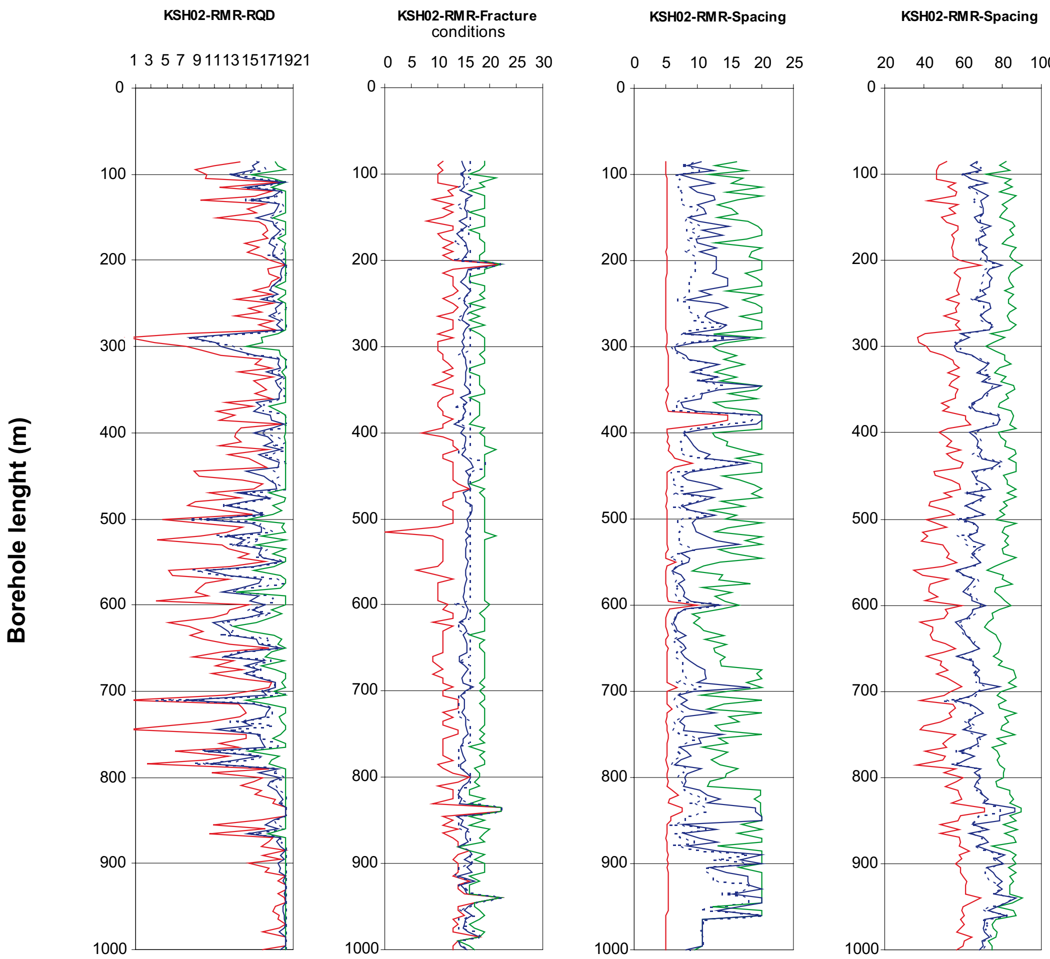

Figure 4-3. *Ratings for RMR characterisation and resulting RMR values along borehole KSH02. The ratings for RQD, fracture conditions, fracture spacing are plotted with depth together with RMR. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed every core section of 5 m, respectively.*

There are rather large differences between the average RMR in the different rock units (which contain both competent mass and deformation zone rock). Rock Unit 3 has the best rock quality (average 72), while Rock Unit 2 has lowest RMR (average 65). Rock Unit 1 has an average RMR (70) in the range of values of the other two units.

4.3.3 Characterisation with Q

The input numbers for the Q systems and the resultant rock quality index for 5 m long borehole sections are plotted in Figure 4-4, 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.

As for RMR, also Q shows that the rock quality in Rock Unit 3 is better than for the other two rock units: 18, 11 and 45 are the average Q values for Rock Unit 1, 2 and 3, respectively.

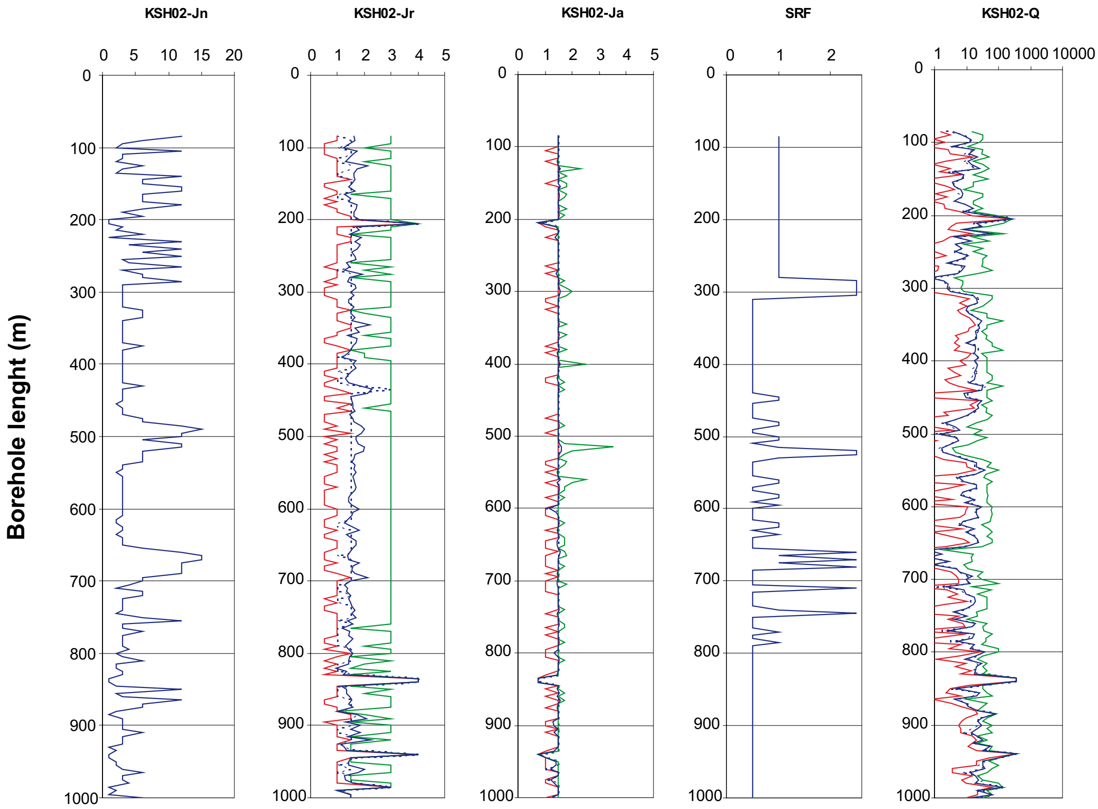

***Figure 4-4.** Numbers for Q characterisation and resulting Q values along borehole KSH02. The number for fracture set number, fracture roughness; fracture alteration and SRF are plotted with depth together with Q. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed every core section of 5 m, respectively.*

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

1) In the Deformation Zones, Q has a minimum of 0.6 that corresponds to "very poor" rock.
2) The deformation zones have an average and frequent value of Q of 3.8 and 2.8, respectively, both values being in "poor rock".
3) The average and frequent Q values for the competent rock mass are in the range of "good rock", respectively being 26 and 18.
4) The best rock section in the competent rock mass classes as "very good" rock according to Q (maximum value 352).

4.4 KSH03A and B

4.4.1 Single-hole interpretation

Table 4-4 contains the list of the Rock Units and Deformation Zones identified along borehole KSH03A and B /Hultgren et al. 2004/. The Rock Units are shortly described as:

- RU1: mixture of Ävrö granite and quartz monzodiorite. Some sections of fine- to medium-grained granite and pegmatite.
- RU2: totally dominated by Ävrö granite. Certain sections of fine- to medium-grained granite and a few sections of diorite-gabbro.
- RU3: mixture of fine- to medium-grained granite and Ävrö granite. Higher degree of alteration than what is normal for fine- to medium-grained granite.

One possible major deformation zone has been identified in KSH03A:

- DZ1: inhomogeneous, low-grade, ductile deformation. High frequency of open and sealed fractures and crush zones. Brecciation between 220–235 m and mylonitization between 270–275 m.
- A number of sections with increased fracturing may indicate minor deformation zones.

Table 4-4. Partitioning of borehole KSH03A and B according to the single-hole interpretation /Hultgren et al. 2004/: Rock Units and Deformation Zones.

Borehole length (m)	Rock Unit	Depth (m)	Deformation zone
0–270	RU1	160–270	DZ1
270–440	RU2		
440–575	RU3		
575–755	RU2		
755–864	RU3		
864–1,000	RU2		

4.4.2 Characterisation with RMR

In Appendix 3, the minimum, average, most frequent and maximum rating for RMR are tabulated for each borehole section of 5 m. The plots in Figure 4-5 show the RQD, fracture condition, spacing rating that results into the RMR ranges, respectively. The RMR-rating for trace length (RMR_{length} = 4) was chosen for average trace lengths between 1 and 3 m according to Section 2. 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.

The rock mass quality in Rock Unit 1 appears to be worse (average RMR 66) than for the other two rock units, which have similar properties (average RMR 73–74). In the section between 100 and 400 m, which mainly corresponds to Rock Unit 2, RMR shows lower values than for the rest of the borehole.

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

1) The lowest rock quality observed in the borehole is RMR = 50 ("fair rock").
2) The average RMR in the deformation zones is 57 ("fair rock").
3) The average RMR for the competent rock mass is 73 ("good rock").
4) The maximum rock mass quality in the competent rock mass was RMR = 86, which means "very good" rock.

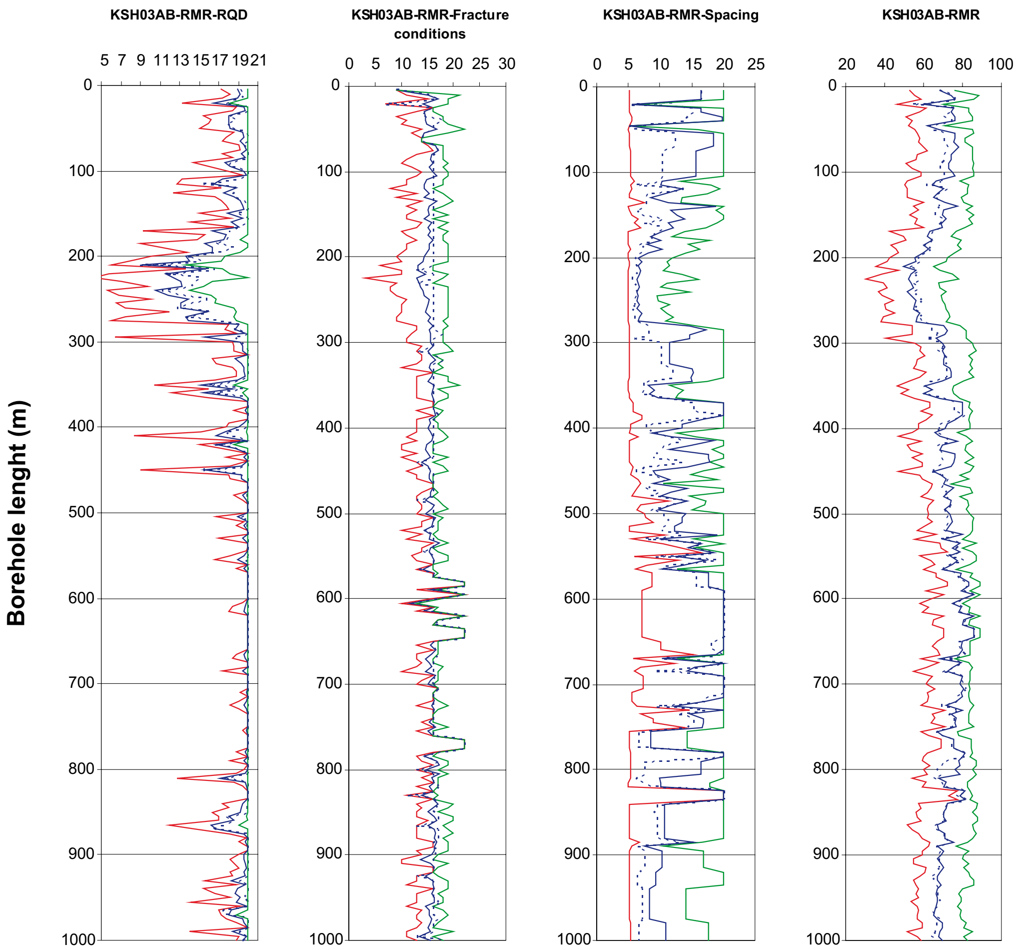

Figure 4-5. Ratings for RMR characterisation and resulting RMR values along borehole KSH03A and B. The ratings for RQD, fracture conditions, fracture spacing are plotted with depth together with RMR. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed every core section of 5 m, respectively.

4.4.3 Characterisation with Q

The input numbers for the Q systems and the resultant rock quality index for 5 m long section are plotted in Figure 4-6. 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.

The characterisation with Q shows that the section between 200 and 300 m presents very low rock mass quality. This section is located at the bottom of Rock Unit 1. The average value of Q in this section is about 15 ("good rock"). However, the same section also shows a minimum Q of 0.6 that corresponds to "very poor rock". The differences between competent and fractured rock mass can be summarised as:

1) The poorest rock quality in the deformation zone is Q = 0.6 ("very poor rock").
2) An average Q of 3.2 is observed in the deformation zones ("poor rock").
3) The competent rock mass has an average Q of 43 that indicates "very good rock".
4) The maximum observed Q value belongs to the competent rock mass and is 264 ("very good" rock).

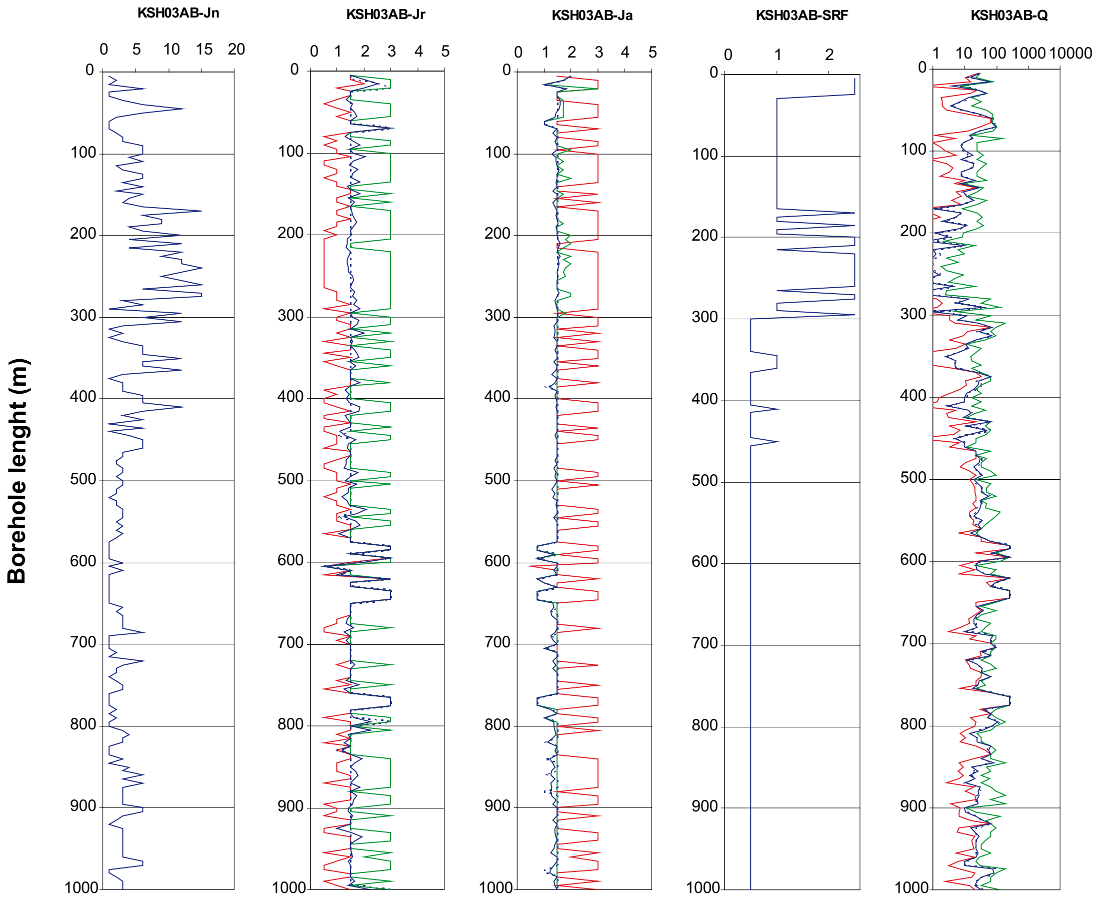

Figure 4-6. *Numbers for Q characterisation and resulting Q values along borehole KSH03A and B. The number for fracture set number, fracture roughness; fracture alteration and SRF are plotted with depth together with Q. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed every core section of 5 m, respectively.*

4.5 KAV01

4.5.1 Single-hole interpretation

In borehole KAV01, the following Rock Units were recognised /Mattsson et al. 2004b/:

- RU1: dominated by Ävrö granite with subordinate sections of fine- to medium-grained granite and fine-grained diorite to gabbro.
- RU2: dominated by fine-grained dioritoid, with < 4 m long sections of fine-grained diorite to gabbro and subordinate sections of Ävrö granite.
- RU3: very similar to rock unit 1. Completely dominated by Ävrö granite, with a few thin sections of fine- to medium-grained granite.
- RU4: dominated by Ävrö granite with a few < 5 m long sections of fine- to medium-grained granite, fine-grained diorite to gabbro, medium- to coarse-grained granite and fine-grained dioritoid.
- RU5: very similar to rock units 1 and 3. Completely dominated by Ävrö granite.
- RU6: slightly dominated by Ävrö granite with up to 10 m long sections of fine-grained dioritoid and fine- to medium-grained granite and subordinate medium- to coarse-grained granite.
- RU7: very similar to rock units 1, 3 and 5. Completely dominated by Ävrö granite.

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

- DZ1: is characterized by increased fracture frequency and weak to medium alteration. Medium to strong alteration is observed in section 431–464 m. Section 520–565 m appears heavily fractured.

Table 4-5. Partitioning of borehole KAV01 according to the single-hole interpretation /Mattsson et al. 2004b/: Rock Units and Deformation Zones in this report.

Borehole length (m)	Rock Unit	Depth (m)	Deformation zone
20–135	RU1		
135–185	RU2		
185–364	RU3		
364–494	RU4	425–440	DZ 1a*
		440–465	DZ 1b*
		465–494	DZ 1c*
494–605	RU5	494–565	DZ 1d*
605–686	RU6		
686–750	RU7		

* These sections belong to the same Deformation Zone but differ for some of the geomechanical parameters (e.g. fracture frequency, alteration). The border between RU4 and RU5 is also considered in this report.

4.5.2 Characterisation with RMR

For each 5 m long 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 4-7 are obtained for the RQD, fracture condition, spacing rating that results into the RMR ranges shown on the right plot. The RMR-rating for trace length (RMR_{length} = 4) was chosen for average trace lengths between 1 and 3 m according to Section 2. 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.

The different Rock Units seem to have similar rock mass quality with an average RMR around 69 ("good rock"). More in detail:

1) The deformation zones show a minimum RMR of about 55 ("fair rock").
2) On average, the RMR in the deformation zones is rather high (63, "good rock").
3) The competent rock mass exhibit an average RMR of 71 (also "good rock").
4) The rock mass quality is topped by the competent rock mass that has a maximum RMR of 88 ("very good rock").

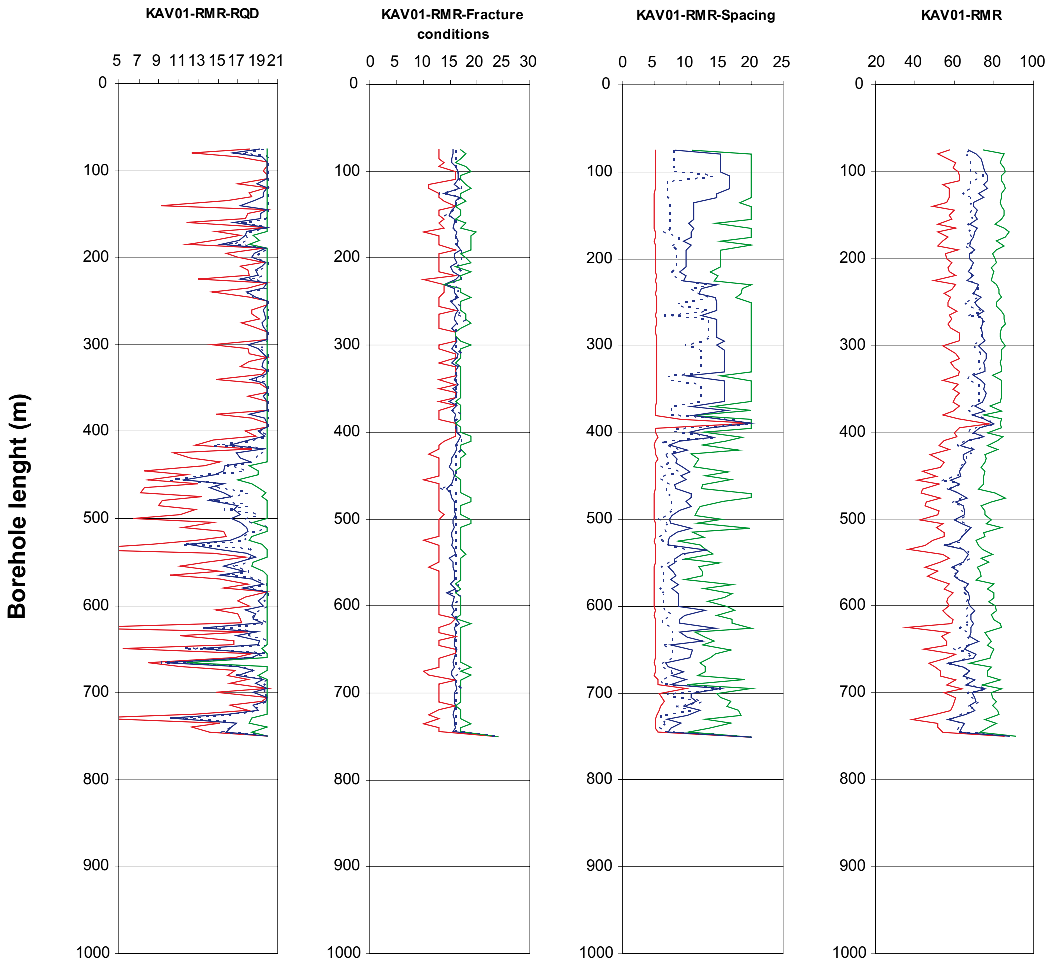

__Figure 4-7.__ Ratings for RMR characterisation and resulting RMR values along borehole KAV01. The ratings for RQD, fracture conditions, fracture spacing are plotted with depth together with RMR. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed every core section of 5 m, respectively.

4.5.3 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 4-8. SRF and water factor are assigned according to the procedure for rock mass characterisation.

There are two troughs in the plot of the Q values along the borehole: one between 150 and 250 m, and another at about 430 and 530 m. The second trough corresponds to the four Deformation Zones, while the first one is a relative minimum. The quality of the competent and fractured rock mass can be listed as:

1) The minimum Q in the Deformation Zones is 0.5 ("very poor rock").
2) The average quality in the deformation zones is Q = 2.8 ("poor rock").
3) The average quality in the competent rock mass is Q = 28 ("good rock").
4) The best quality rock is in within the competent rock mass and has a maximum Q value of 704 ("extremely good rock").

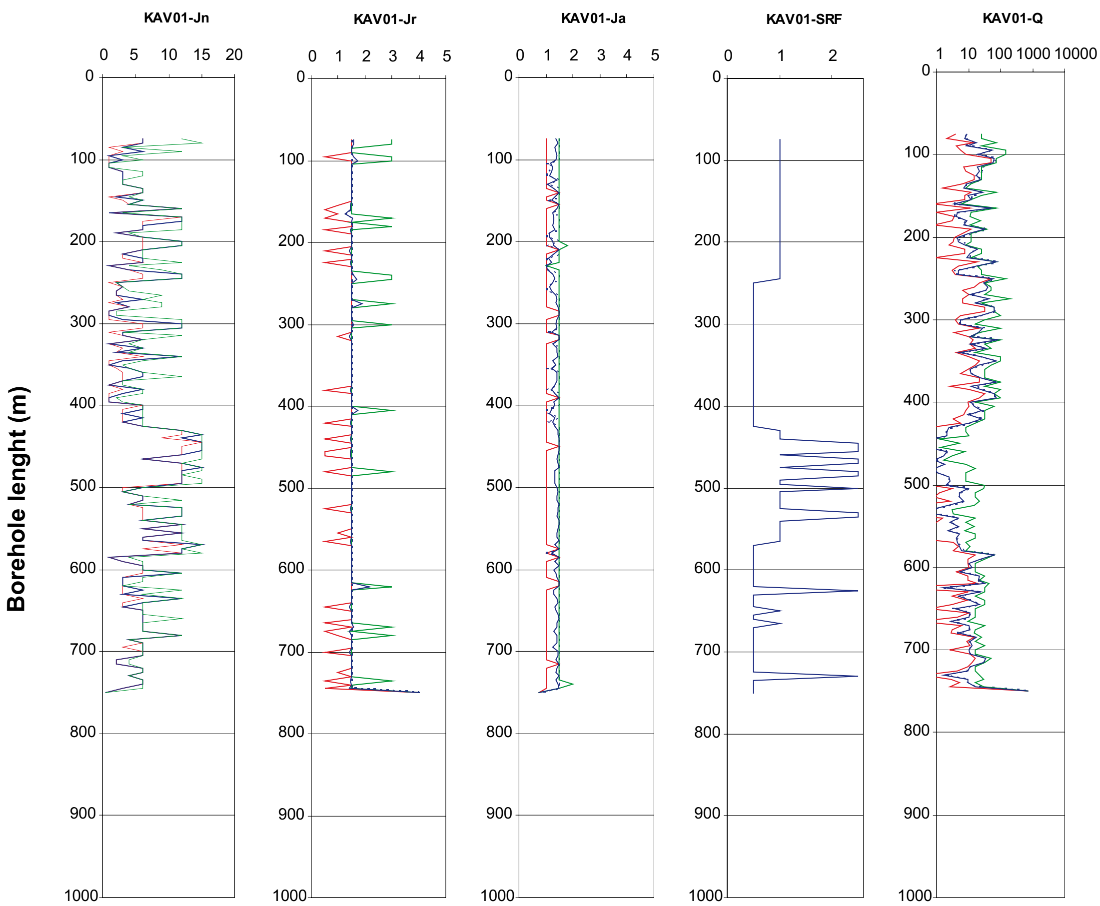

Figure 4-8. Numbers for Q characterisation and resulting Q values along borehole KAV01. The number for fracture set number, fracture roughness; fracture alteration and SRF are plotted with depth together with Q. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed every core section of 5 m, respectively.

4.6 KLX02

4.6.1 Single-hole interpretation

The single-hole interpretation of KLX02 provide the Rock Unit and Deformation Zone definitions /Hultgren et al. 2004/. The Rock Units are:

- RU1: totally dominated by Ävrö granite, with certain sections of fine-grained diorite to gabbro.
- RU2: mixture of Ävrö granite, slightly dominating, and fine-grained dioritoid. Certain sections shorter than 10 m of fine-grained diorite to gabbro.

One possible deformation zone has been identified in KLX02:

- DZ1: generally increased frequency of open fractures and higher oxidation. The most intensive part of the zone is located between 845–880 m.

A number of sections with increased fracturing may indicate minor deformation zones.

Table 4-6. Partitioning of borehole KLX02 according to the single-hole interpretation /Hultgren et al. 2004/: Rock Units and Deformation Zones.

Borehole length (m)	Rock Unit	Depth (m)	Deformation zone
200–550	RU1		
550–960	RU2	770–960	DZ1
960–1,005	RU1		

4.6.2 Characterisation with RMR

The minimum, average, most frequent and maximum rating for RMR was determined for each section of 5 m based on the geomechanical parameters logged along the borehole (Appendix 5). The plots in Figure 4-9 show the RQD, fracture condition, spacing rating that results into the RMR. The RMR-rating for trace length (RMR_{length} = 4) was chosen for average trace lengths between 1 and 3 m according to Section 2. The RMR-ratings for tunnel orientation and water pressure were assumed for "fair conditions" and for a "completely dry" borehole, as prescribed for rock mass characterisation.

The two Rock Units show rock mass quality in terms of RMR very close to each other (between 72 and 77). On the other hand, the plot of RMR with depth shows a rather abrupt deterioration of the quality below 700 m in relation to the very extensive Deformation Zone 1. The fractured and competent rock mass in the borehole presents the following properties:

1) Deformation Zone 1 presents a minimum RMR of 53 ("fair rock").
2) The average RMR of the rock mass in the Deformation Zone 1 is 66 ("good rock").
3) The average RMR of the competent rock mass is 77 ("good rock").
4) The best rock observed within the competent rock mass has a RMR of 88 ("very good rock").

There is a difference in rating between the competent and fractured rock mass of about 10 points.

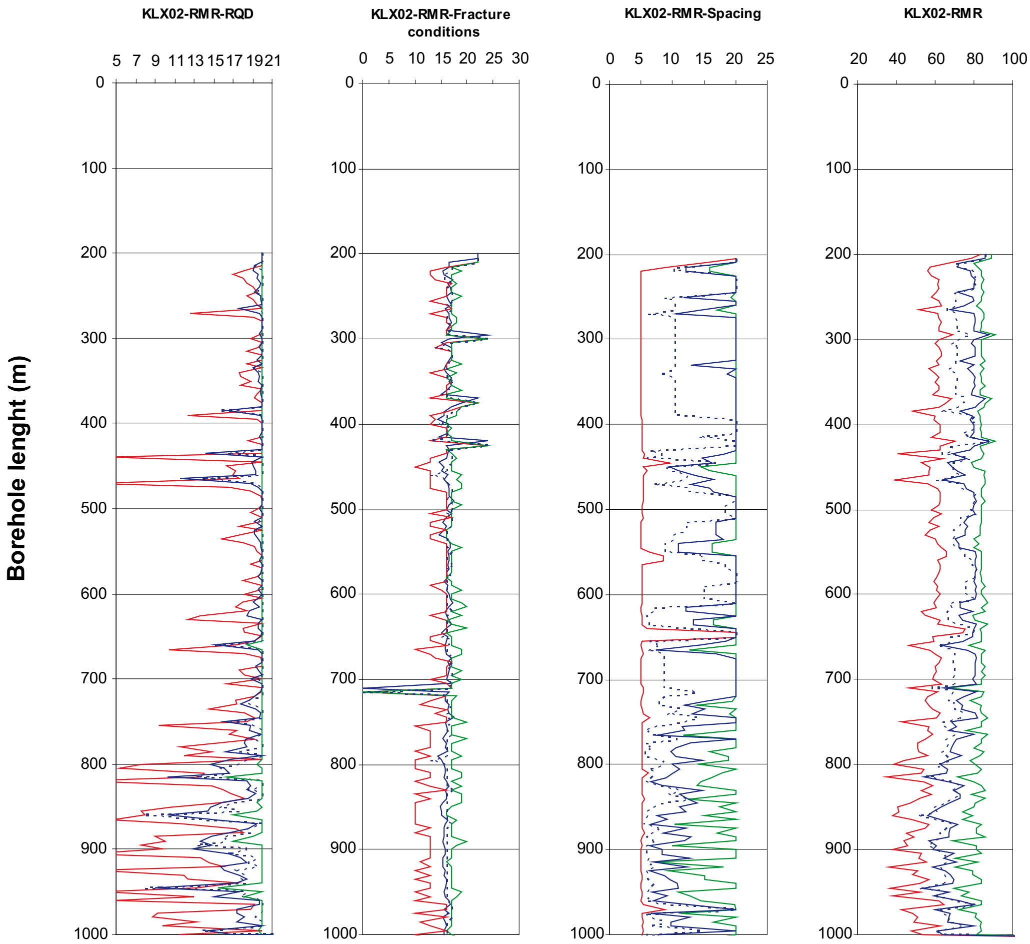

Figure 4-9. *Ratings for RMR characterisation and resulting RMR values along borehole KLX02. The ratings for RQD, fracture conditions, fracture spacing are plotted with depth together with RMR. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed every core section of 5 m, respectively.*

4.6.3 Characterisation with Q

The Q parameters 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 5). SRF and Jw are chosen for rock mass characterisation.

Although Q presents a more jagged plot along the borehole than RMR, it also shows a drop that correspond to the only Deformation Zone mapped in the borehole. Rock Unit 1 has an average rock quality Q in the class of "very good rock", while Rock Unit 2, which contains the deformation zone, has and average Q value of 22 ("good rock"). Moreover:

1) The poorest rock in the Deformation Zone has a minimum Q of 0.7 ("very poor rock").
2) The average Q in Deformation Zone 1 is 7.2 (frequent value 4.7) in the class of "fair rock".
3) The competent rock mass is between "very good" (average Q = 48) and "good rock" (frequent Q = 26).
4) The best rock in the competent rock mass has a maximum Q value of 528 ("extremely good rock").

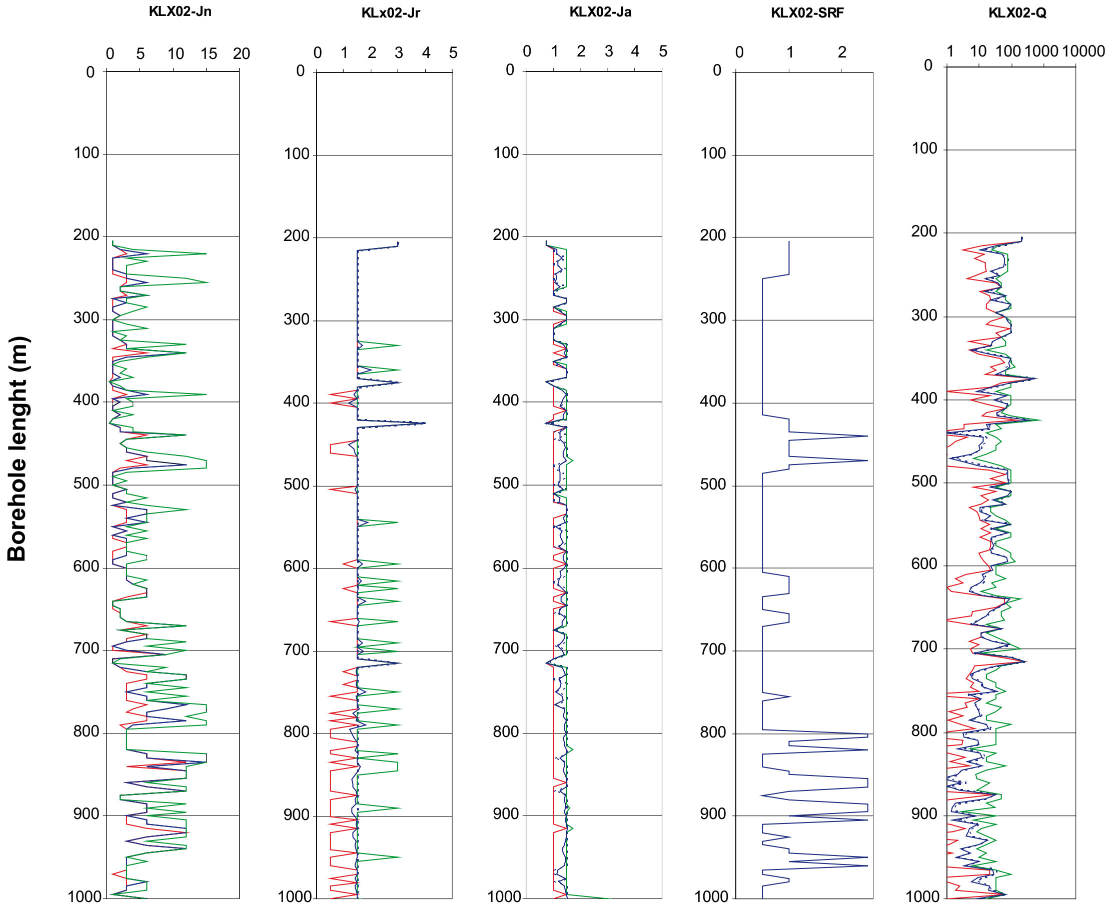

***Figure 4-10.** Numbers for Q characterisation and resulting Q values along borehole KLX02. The number for fracture set number, fracture roughness; fracture alteration and SRF are plotted with depth together with Q. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed every core section of 5 m, respectively.*

4.7 Empirical methods and single-hole interpretation

In Figure 4-11 and Figure 4-12, the mean Q and RMR values for each 5 m section of borehole are plotted along the five boreholes included in the present report. In the same figures, the location of the deformation zones according to the single-hole interpretation are shown. Assumed that the geological definition of the deformation zones either coincides or overlap the rock mechanics definition, all the deformation zones in the single-hole interpretation should coincide with the relative minima of the ratings according to Q and RMR. In general, this is true, however, some sections either independent or just outside the geological deformation zones can be observed. This is particularly the case of the following sections:

- KFM02A: between about 480 and 505 m.
- KFM03A: between about 320 and 430 m.
- KAV01: at about 730 m.
- KLX02: between 430 and 470 m.

These potential deformation zones will be probably included in next Deformation Zone Model for Laxemar (version 1.2) or will be considered as minor deformation zones and possibly treated stochastically.

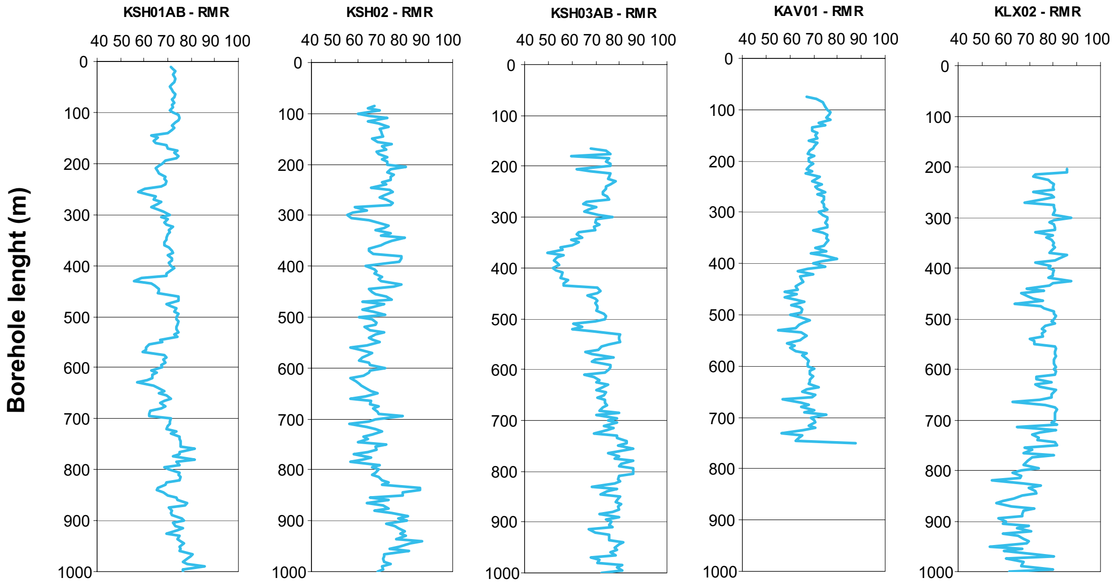

Figure 4-11. *Plot of the RMR values for each 5 m section of borehole and indication of the position of the deformation zones according to the single-hole interpretation.*

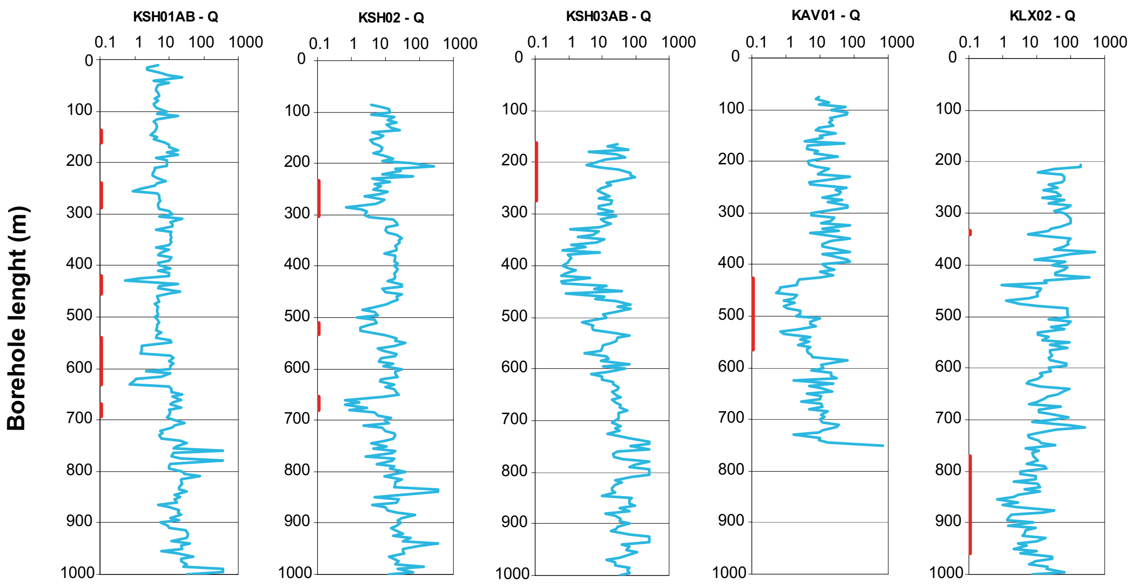

Figure 4-12. *Plot of the Q values for each 5 m section of borehole and indication of the position of the deformation zones according to the single-hole interpretation.*

4.8 Evaluation of the uncertainties

4.8.1 Background

The empirical classification systems used for characterisation of the rock mass are affected by the uncertainties on the geological and rock mechanical data and the intrinsic uncertainties due to the structure of the empirical systems themselves. The uncertainty on a single parameter can widely vary depending on the acquisition technique, subjective interpretation or size of the sample population. Uncertainties 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 value of Q or RMR for a certain section of borehole may also result from the combination of the possible ratings that range from a minimum to maximum value.

In this report, it was decided to correlate the uncertainty on 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 with respect to the mean value. Each obtained normalised value is considered as a sample from a statistical population of "uncertainty 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 $\Delta_{\text{conf mean}}$ is obtained as:

$$\Delta_{conf\ mean} = \pm \frac{1.96\,\sigma}{\sqrt{n}} \qquad (6)$$

where σ is the standard deviation of the population and n is the number of values of the each sample (also equal to the number of considered borehole sections). The value of 95% is chosen because commonly used in practice. The two extremes of the confidence intervals are determined by the proposed technique, one related to the maximum value of the parameter P, and the other related to the minimum value:

$$\Delta P_{+conf\ mean} = \frac{P_{MAX} - P_{MEAN}}{\sqrt{n}}$$
$$\Delta P_{-conf\ mean} = \frac{P_{MEAN} - P_{MIN}}{\sqrt{n}} \qquad (7)$$

where P can be the rating, either RMR or Q, with its possible maximum and minimum values and mean value, respectively. The confidence interval would then contain 95% of all possible mean values obtainable from each group of n samples from the population P. This technique also applies to the rock mechanical parameters derived from the empirical systems (in Section 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 mass in borehole KSH01A and B, KSH02, KSH03A and B, KAV01 and KLX02. The uncertainty on the mean value is larger for the fractured rock (Deformation Zones) than for the competent rock mass. This is due to the large 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 mass in the five boreholes. The confidence of RMR is generally higher than that of Q due to the wide range of variation of the Q values (that usually spans over several orders of magnitude). However, this kind of variations is compatible with the use of Q for design applications.

Table 4-7. Confidence on the mean values of RMR for boreholes KSH01A and B, KSH02, KSH03A and B, KAV01 and KLX02 for borehole sections of 5 m.

	Competent rock mass		Fractured rock mass	
	Lower confidence on the mean	Upper confidence on the mean	Lower confidence on the mean	Upper confidence on the mean
KSH01AB	–2%	+1%	–4%	+4%
KSH02	–2%	+1%	–5%	+5%
KSH03AB	–1%	+1%	–5%	+6%
KAV01	–1%	+1%	–4%	+4%
KLX02	–2%	+1%	–4%	+4%

Table 4-8. Confidence on the mean values of Q for boreholes KSH01A and B, KSH02, KSH03A and B, KAV01 and KLX02 for borehole sections of 5 m.

	Competent rock mass		Fractured rock mass	
	Lower confidence on the mean	Upper confidence on the mean	Lower confidence on the mean	Upper confidence on the mean
KSH01AB	–3%	+6%	–9%	+71%
KSH02	–5%	+18%	–17%	+91%
KSH03AB	–4%	+10%	–17%	+87%
KAV01	–5%	+16%	–14%	+72%
KLX02	–5%	+12%	–13%	+62%

5 Mechanical properties of the rock mass

5.1 Deformation modulus of the rock mass

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

$$E_m = 10^{\frac{RMR-10}{40}} \quad (8)$$

and according to /Barton 2002/ by:

$$E_m \approx 10\, Q_c^{1/3} \text{ (GPa)} \quad (9)$$

where Q_c is the modified version of Q that takes into account the uniaxial compressive strength of the intact UCS rock (MPa).

$$Q_c = Q \cdot \frac{\text{UCS}}{100} \quad (10)$$

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 mean deformation modulus with a continuous blue line, while the maximum and minimum possible values are respectively plotted in red and green. These two values are used in Section 5.1.6 for the evaluation of the uncertainties according to Section 4.8.1. In the following sections, reference to the range of variation of the mean deformation modulus is given when addressing the peaks and troughs of the blue continuous curve, which represent the expected average value of the deformation modulus along the boreholes. In all the figures, the dotted line represents the expected frequent values.

5.1.1 KSH01A and B

In Figure 5-1, the plots of the minimum, average, most frequent and maximum expected deformation modulus of the rock mass are given for borehole KSH01A and B. Comparing the mean values obtained independently by means of RMR and Q, a rather good agreement can be observed in the lower half of the borehole. Larger differences are found above 150 m and between about 450 and 570 m. This is probably due to the influence of SRF = 2.5 in the deformation zones that does not have a counterpart in the RMR. In fact, this produces deformation modulus derived from the Q values lower than those derived from RMR. In general, Q gives deformation moduli lower and more varying than RMR. On average, the deformation modulus of the competent rock mass is 37 GPa, when obtained from RMR, and 24 when obtained from Q. The values are much closer to each other when the deformation zones are concerned: the deformation modulus from RMR is 28 GPa while the deformation modulus from Q is 22 GPa, respectively on average. The minimum obtained deformation modulus is in the more fractured rock of the deformation zones and is between 10 and 15 GPa, according to RMR and Q, respectively. 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 (8) and (9). This value corresponds to the Young's modulus of the intact rock samples in laboratory (Section 3).

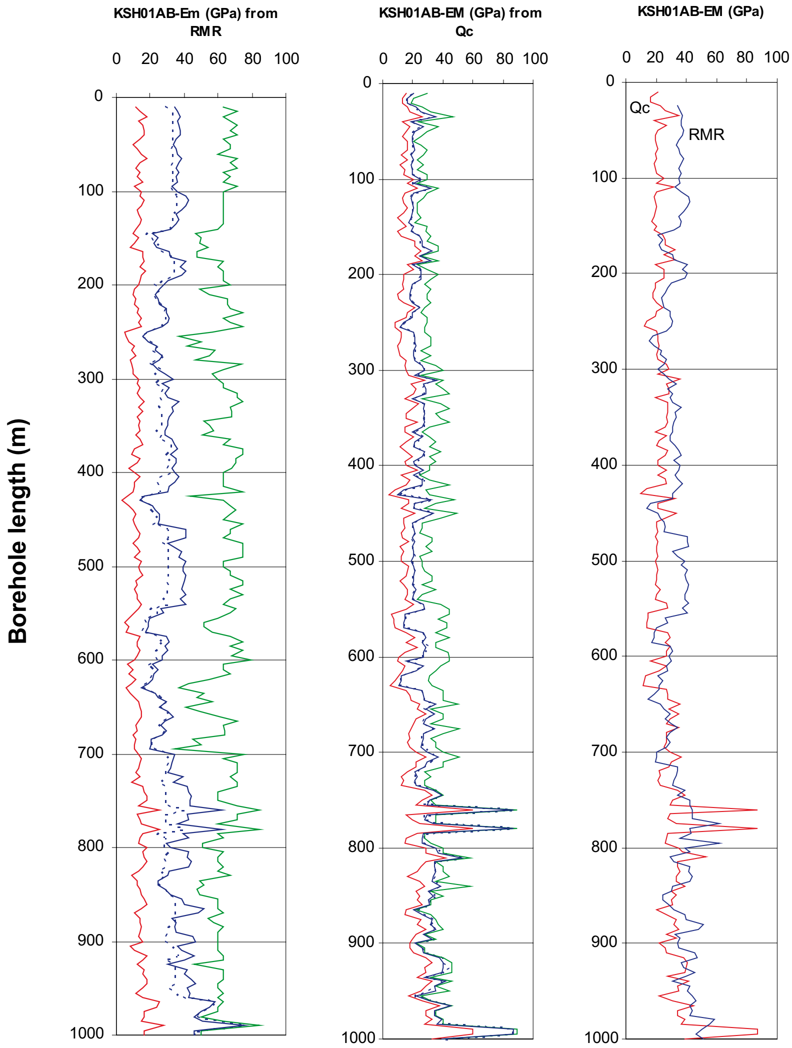

Figure 5-1. *Deformation modulus of the rock mass derived from RMR and Q values for each core section of 5 m for borehole KSH01A and B. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed every core section of 5 m, respectively. The comparison of the mean values from RMR and Q along the borehole is given in the graph on the right.*

5.1.2 KSH02

In Figure 5-2, the plots of the minimum, average, most frequent and maximum expected deformation modulus are given for borehole KSH02. For this borehole, the agreement between the results from the two empirical systems is very good. In fact, the average deformation modulus obtained from RMR and Q ranges between 32 and 33 GPa for the competent rock mass, and between 19 and 27 GPa for the deformation zones (where the effect of the Q parameter SRF cannot be avoided). Both the empirical Equations (8) and (9) provide minimum values of the deformation modulus between 11 and 14 GPa in the deformation zones, thus showing a rather good agreement between the two independent methods.

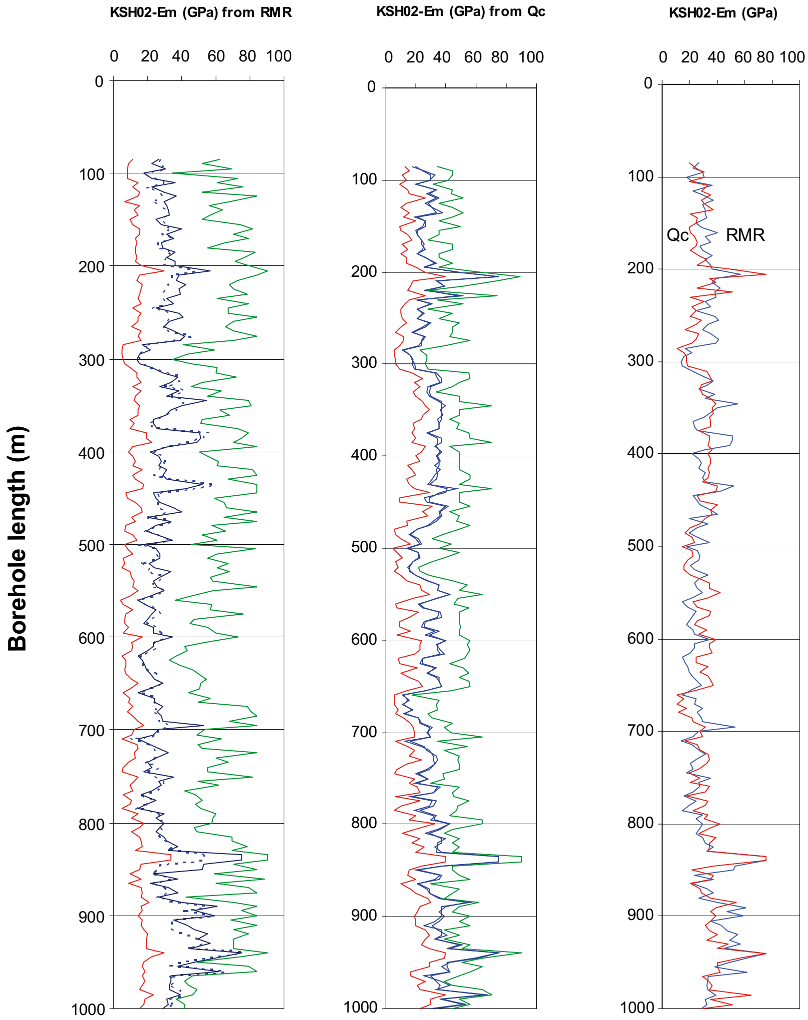

Figure 5-2. Deformation modulus of the rock mass derived from RMR and Q values for each core section of 5 m for borehole KSH02. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed every core section of 5 m, respectively. The comparison of the mean values from RMR and Q along the borehole is given in the graph on the right.

5.1.3 KSH03A and B

In Figure 5-3, the plots of the minimum, average, most frequent and maximum expected deformation modulus are given for borehole KSH03A and B. The average deformation modulus of the competent rock mass given by the empirical relations with RMR and Q provide values between 37 and 40 GPa, respectively. Also the average values for the deformation zones are in very good agreement when the two methods are concerned: both give a deformation modulus of 16 GPa. The minimum value of the deformation modulus in the deformation zones might be very close to 10 GPa, since both methods give this result. The very good agreement between the two empirical methods is clearly shown in Figure 5-3.

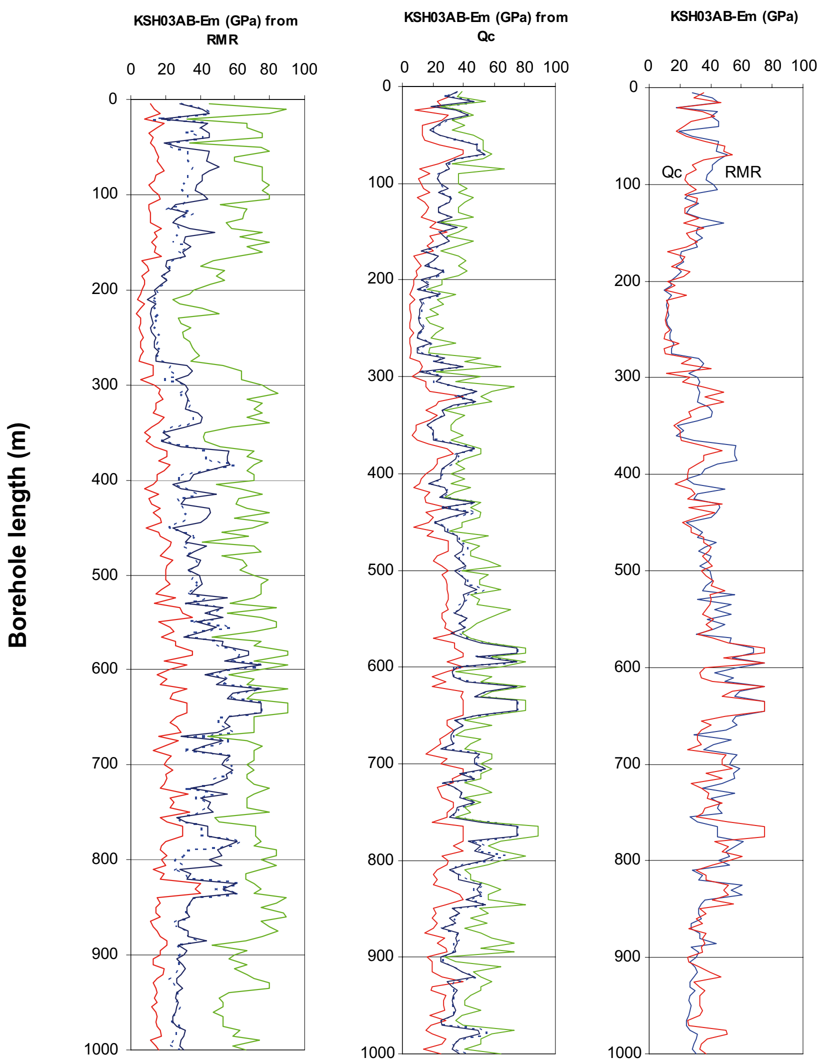

***Figure 5-3.** Deformation modulus of the rock mass derived from RMR and Q values for each core section of 5 m for borehole KSH03A and B. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed every core section of 5 m, respectively. The comparison of the mean values from RMR and Q along the borehole is given in the graph on the right.*

5.1.4 KAV01

In Figure 5-4, the plots of the minimum, average, most frequent and maximum expected deformation modulus are given for borehole KAV01. Although the deformation modulus obtained from Q shows a larger scatter than those from RMR, the values of the deformation modulus provided by the two methods are very consistent. For the competent rock mass, the average deformation modulus predicted varies between 31 and 34 GPa. The correspondent values for the deformation zones are 16 and 21 GPa, the first value being obtained by means of Q. The minimum value observed in the deformation zones is very similar for the two methods, which is between 11 and 12 GPa. The maximum calculated value is affected by the truncation at 75 GPa imposed to all the empirically calculated values.

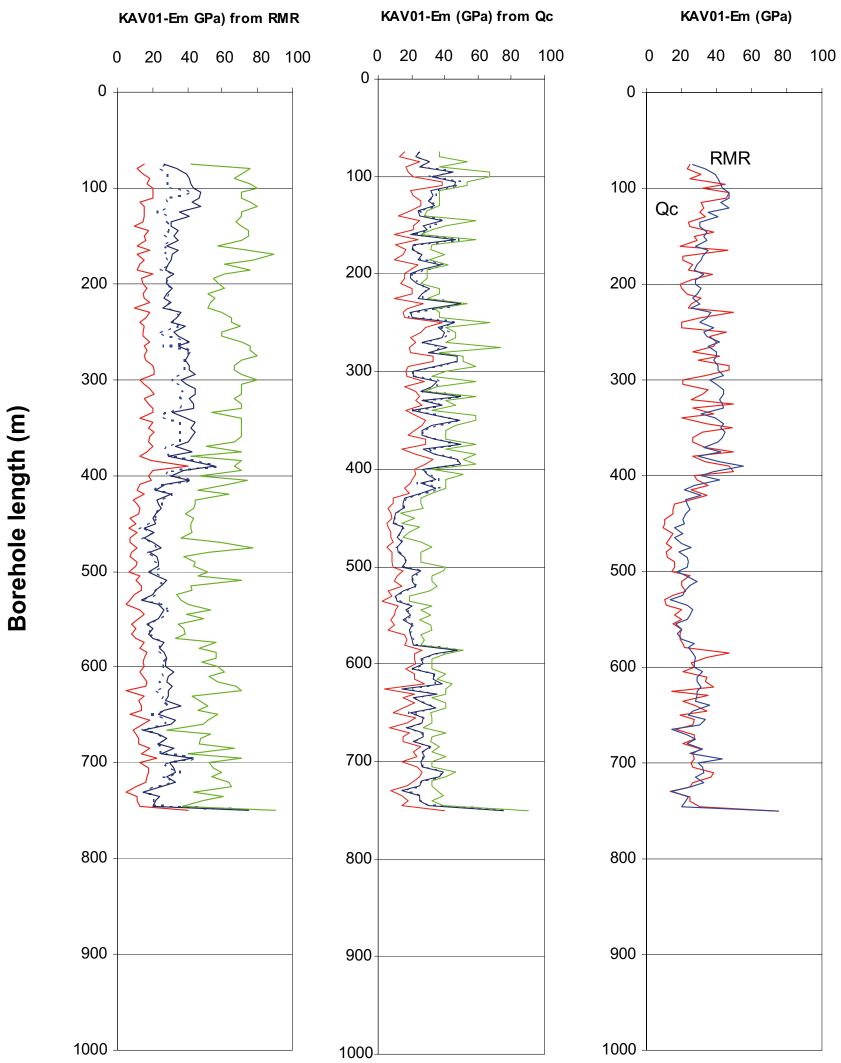

Figure 5-4. *Deformation modulus of the rock mass derived from RMR and Q values for each core section of 5 m for borehole KAV01. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed every core section of 5 m, respectively. The comparison of the mean values from RMR and Q along the borehole is given in the graph on the right.*

5.1.5 KLX02

In Figure 5-5, the plots of the minimum, average, most frequent and maximum expected deformation modulus are given for borehole KLX02. For this borehole, the agreement between the results from RMR and Q is good except for the interval between 550 and 720 m, where Equation (8) gives higher values than Equation (9). This can be due to the fracture properties that have more influence on the Q values than on RMR. The vicinity of the really wide Deformation Zone 1 might also affect the fracture conditions, and consequently the empirical results. The deformation modulus of the competent rock mass obtained by Q and RMR was on average 38 and 49 GPa, respectively. For the deformation zones, the average values were instead 22 and 26 GPa. The two methods agree on the minimum expected value of the deformation modulus in the deformation zones that should be around 11 GPa.

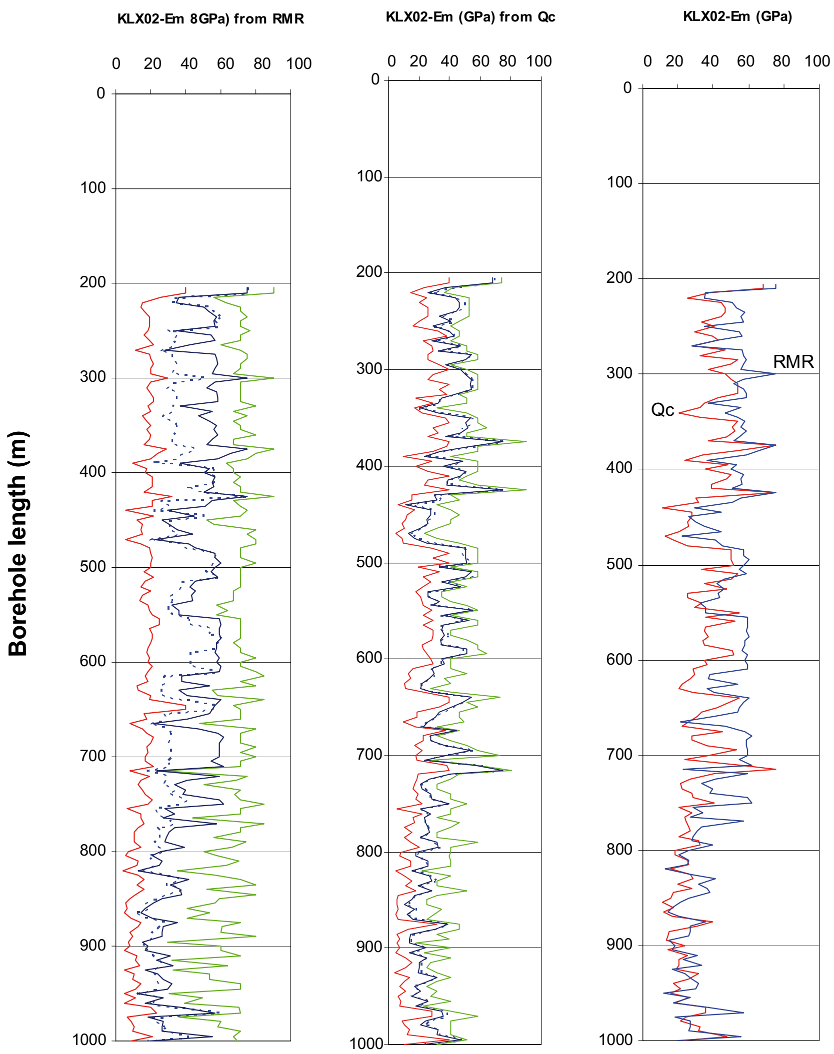

Figure 5-5. Deformation modulus of the rock mass derived from RMR and Q values for each core section of 5 m for borehole KLX02. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed every core section of 5 m, respectively. The comparison of the mean values from RMR and Q along the borehole is given in the graph on the right.

5.1.6 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 determinations are shown in Table 5-1 and Table 5-2. According to RMR and Equation (8), the uncertainty estimated for the deformation modulus of the deformation zones is almost three times the uncertainty in competent rock mass. This is due, first, 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 sample of values than for the deformation zones, which greatly diminishes the uncertainties. For the competent rock mass, the uncertainty on the mean value might range from –5% to +9%. For example, if an average deformation modulus of 30 GPa is calculated, the actual range of variation of the mean value might be between 28.5 GPa and 32.7 GPa for the competent rock mass. For the deformation modulus obtained from Q this range could slightly smaller, between 29 GPa and 31.2 GPa.

For the deformation zones, the range of the uncertainty of the mean deformation modulus is estimated as –10% and +25%, for values obtained from RMR, and between –8% and +13%, for the values obtained from Q.

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.

Table 5-1. Confidence on the mean values of the deformation modulus E_m from RMR for borehole KSH01A and B, KSH02, KSH03A and B, KAV01 and KLX02 and borehole sections of 5 m.

	Competent rock mass		Fractured rock mass	
	Lower confidence on the mean	Upper confidence on the mean	Lower confidence on the mean	Upper confidence on the mean
KSH01AB	–5%	+7%	–10%	+25%
KSH02	–4%	+9%	–12%	+29%
KSH03AB	–4%	+6%	–11%	+30%
KAV01	–4%	+7%	–9%	+20%
KLX02	–5%	+4%	–9%	+22%

Table 5-2. Confidence on the mean values of the deformation modulus E_m from Q_c for borehole KSH01A and B, KSH02, KSH03A and B, KAV01 and KLX02 and borehole sections of 5 m.

	Competent rock mass		Fractured rock mass	
	Lower confidence on the mean	Upper confidence on the mean	Lower confidence on the mean	Upper confidence on the mean
KSH01AB	–3%	+3%	–7%	+14%
KSH02	–3%	+4%	–10%	+15%
KSH03AB	–2%	+2%	–10%	+16%
KAV01	–2%	+3%	–8%	+12%
KLX02	–2%	+2%	–7%	+10%

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 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 be assumed to coincide with that of the deformation modulus of the rock mass in Section 5.1.6.

5.2.1 KSH01A and B

Figure 5-6 shows the variation of the Poisson's ratio determined by means of RMR along borehole KSH01A and B. The average Poisson's ratio for the Rock Units varies between 0.09 and 0.13. For the competent rock mass, the average Poisson's ratio is 0.12 with maximum values of 0.25 (value close to the Poisson's ratio of the intact rock). For the rock in the deformation zones, the estimated average Poisson's ratio is 0.07 while the minimum expected value is 0.04.

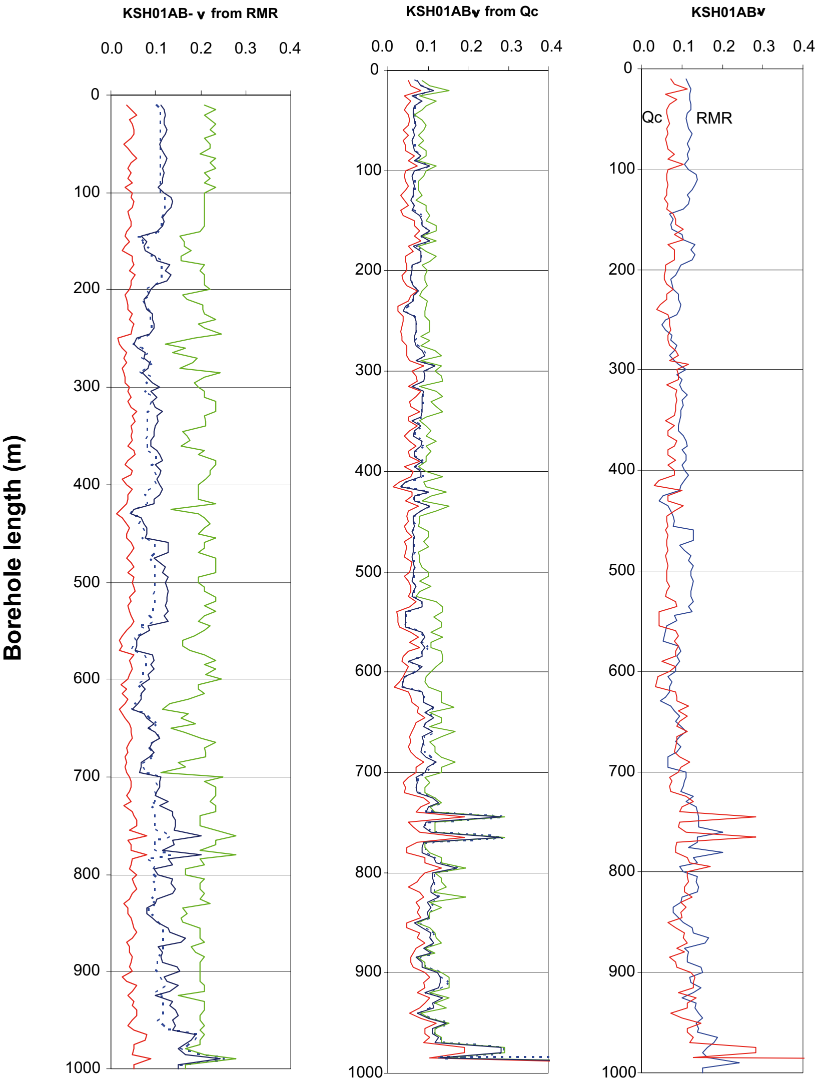

***Figure 5-6.** Poisson's ratio derived from RMR and Q values for each core section of 5 m along borehole KSH01A and B. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed every core section of 5 m, respectively. The comparison of the mean values from RMR and Q along the borehole is given in the graph on the right.*

5.2.2 KSH02

For borehole KSH02, the average Poisson's ratio can be estimated about 0.10 and 0.08 for the competent and fractured rock mass, respectively. The maximum and minimum values of the Poisson's ratio along the borehole are estimated as 0.23 and 0.04, respectively (Figure 5-7).

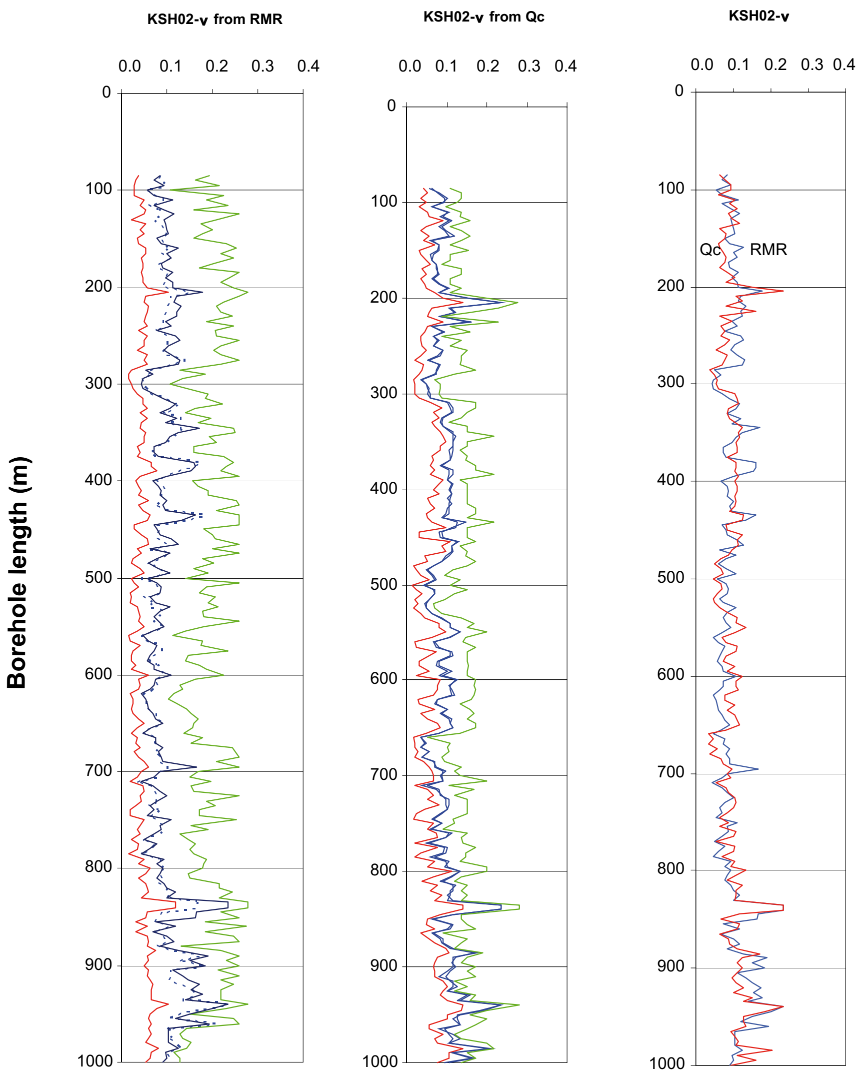

Figure 5-7. *Poisson's ratio derived from RMR and Q values for each core section of 5 m along borehole KSH02. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed every core section of 5 m, respectively. The comparison of the mean values from RMR and Q along the borehole is given in the graph on the right.*

5.2.3 KSH03A and B

In Figure 5-8, the variation of the Poisson's ratio along borehole KSH03A and B is shown. In this borehole, the competent rock mass shows an average and maximum value of respectively 0.13 and 0.24. The rock in the deformation zones, has an average Poisson's ratio of 0.05 and a minimum value of 0.03. The Rock Units present average values varying between 0.09 and 0.13.

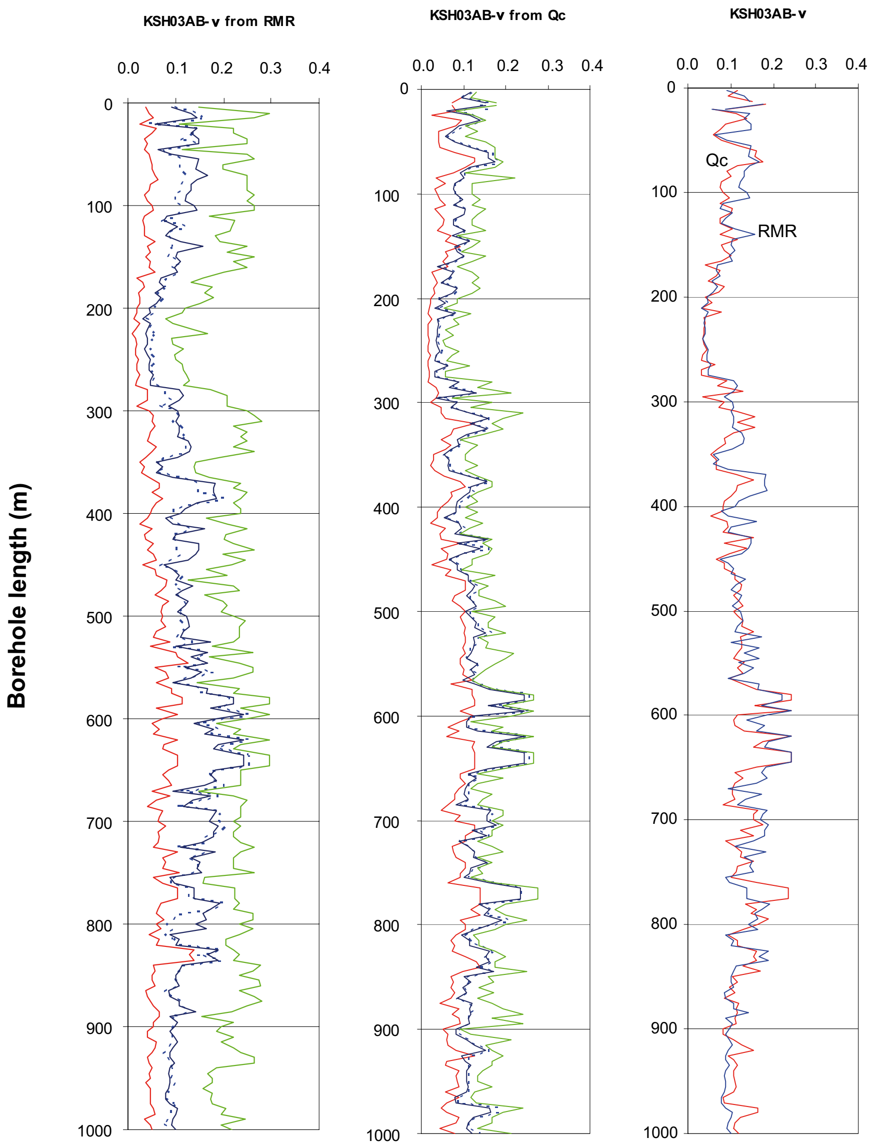

Figure 5-8. Poisson's ratio derived from RMR and Q values for each core section of 5 m along borehole KSH03A and B. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed every core section of 5 m, respectively. The comparison of the mean values from RMR and Q along the borehole is given in the graph on the right.

5.2.4 KAV01

Borehole KAV01 presents Poisson's ratio values between 0.04 and 0.24 (Figure 5-9). The average Poisson's ratio in the competent rock mass and Deformation Zones is 0.11 and 0.07, respectively. The average for the Rock Units varies between 0.06 and 0.13.

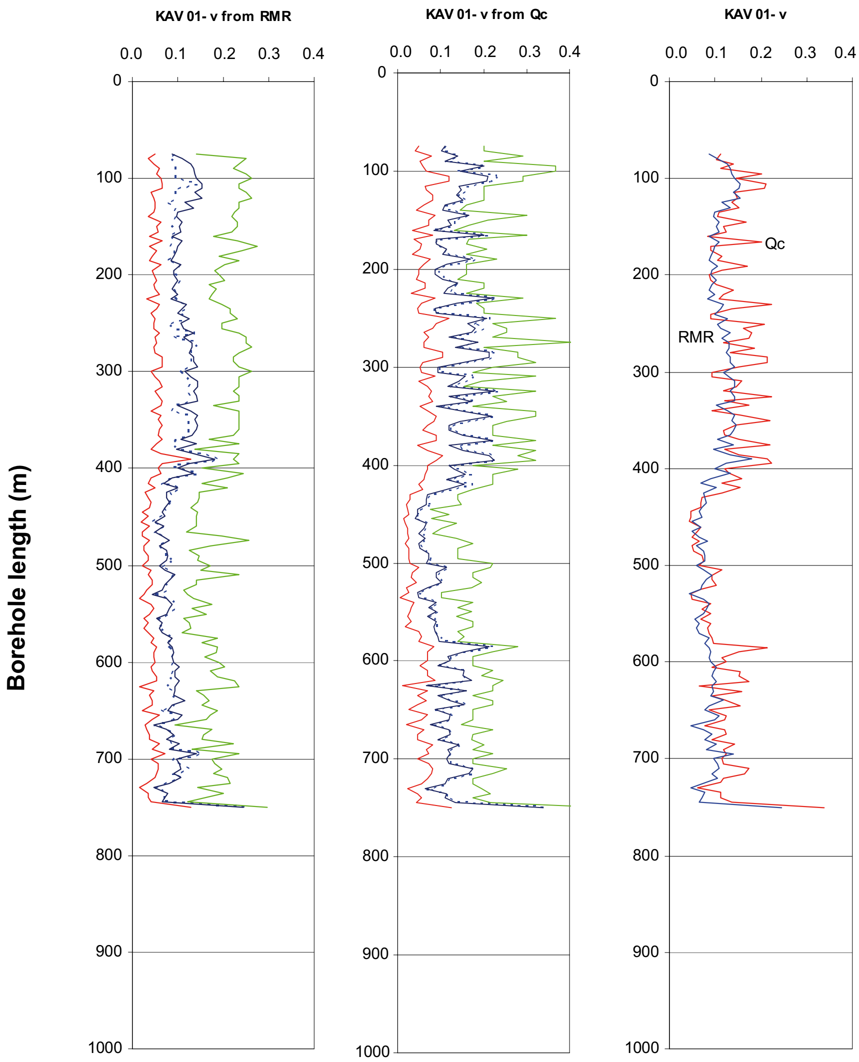

Figure 5-9. *Poisson's ratio derived from RMR and Q values for each core section of 5 m along borehole KAV01. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed every core section of 5 m, respectively. The comparison of the mean values from RMR and Q along the borehole is given in the graph on the right.*

5.2.5 KLX02

The rock in KLX02 presents higher values of the Poisson's ratio compared to the other boreholes (Figure 5-10). Rock Unit 1 has an average of 0.16 while Rock Unit 2 exhibits an average of 0.13. The average Poisson's ratio for the competent and fractured rock mass is 0.16 and 0.08, respectively. For the whole borehole, the Poisson's ratio ranges between 0.04 and 0.24.

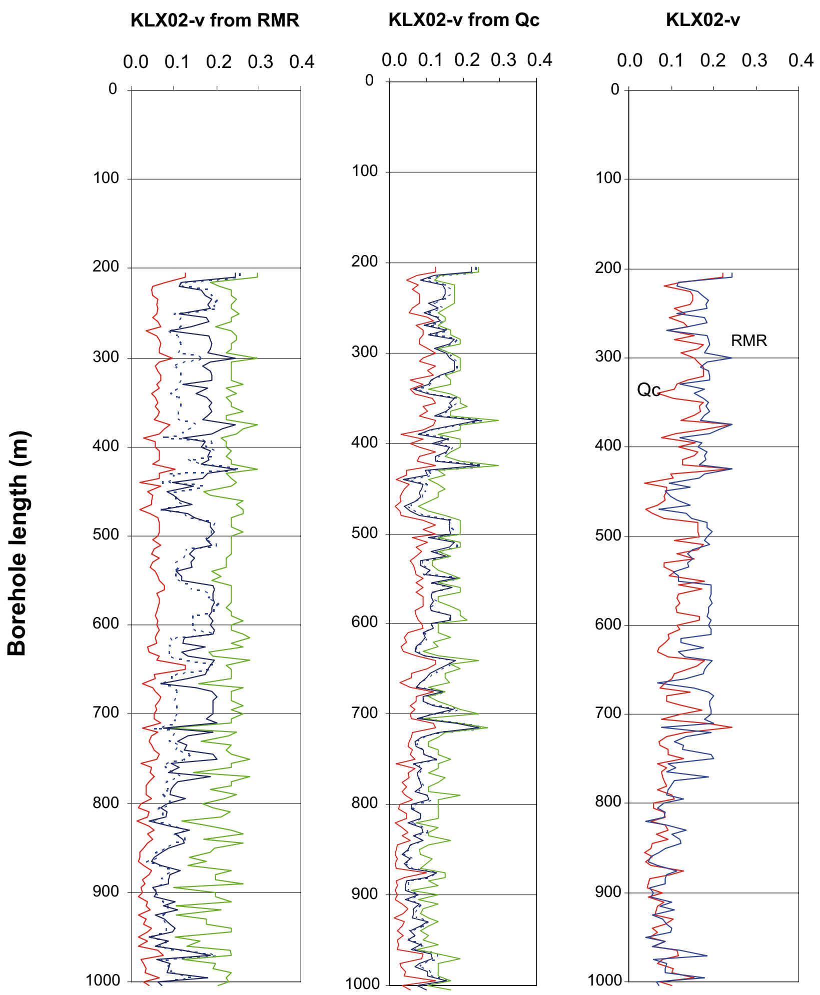

Figure 5-10. *Poisson's ratio derived from RMR and Q values for each core section of 5 m along borehole KLX02. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed every core section of 5 m, respectively. The comparison of the mean values from RMR and Q 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 is here determined in two ways:

- by means of the relations between GSI /Hoek et al. 2002/, RMR and the Hoek and 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 and Brown's Criterion, thus do 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 and Brown Criterion for the five boreholes are tabulated and plotted in the Appendices 1 to 5. The values of $UCS_{M\text{-}C}$ can be easily obtained from the following equation /Hoek et al. 2002/:

$$UCS_{M-C} = \frac{2\,c'\cos\phi'}{1-\sin\phi'} \qquad (11)$$

where c' and φ' are the cohesion and friction angle resulting from the linear fit of the Hoek and 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 not a clear physical definition.

5.3.1 KSH01A and B

The variation of the rock mass compressive strength from RMR and Qc for KSH01A and B is shown in Figure 5-11. The uniaxial compressive strength from RMR in the Rock Units varies between 26 and 33 MPa. The competent rock mass exhibits an average $UCS_{H\&B}$ of 31 MPa while the fractured rock mass in the Deformation Zones has an average $UCS_{H\&B}$ of 20 MPa. The $UCS_{H\&B}$ values along the borehole vary between 13 and 63 MPa.

On the other hand, the uniaxial compressive strength $UCS_{M\text{-}C}$ determined from the Mohr-Coulomb parameters ranges between 72 and 87 MPa for the deformation zones and competent rock mass, respectively.

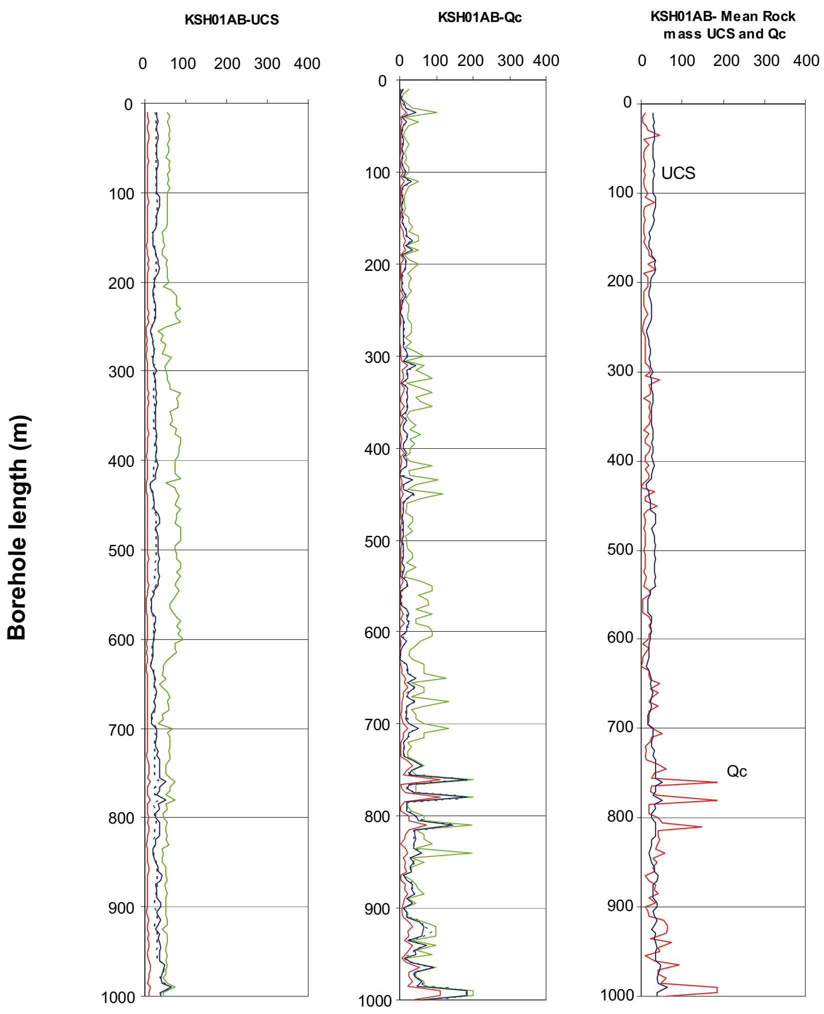

Figure 5-11. *Variation of the rock mass compressive strength from RMR and Q along borehole KSH01A and B. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed every core section of 5 m, respectively. The comparison of the mean values from RMR and Q along the borehole is given in the graph on the right.*

5.3.2 KSH02

Figure 5-12 shows the variation of the rock mass compressive strength from RMR and Q in borehole KSH02. The average $UCS_{H\&B}$ from RMR ranges between 23 and 36 MPa for the three Rock Units. For the whole borehole, instead, a variation of $UCS_{H\&B}$ between 13 and 76 MPa can be observed. The competent rock mass exhibits an average value of 30 MPa and the Deformation Zones an average $UCS_{H\&B}$ of 25 MPa, respectively.

The $UCS_{M\text{-}C}$ of the competent rock mass is on average 66 while for the fractured rock is 61 MPa, respectively.

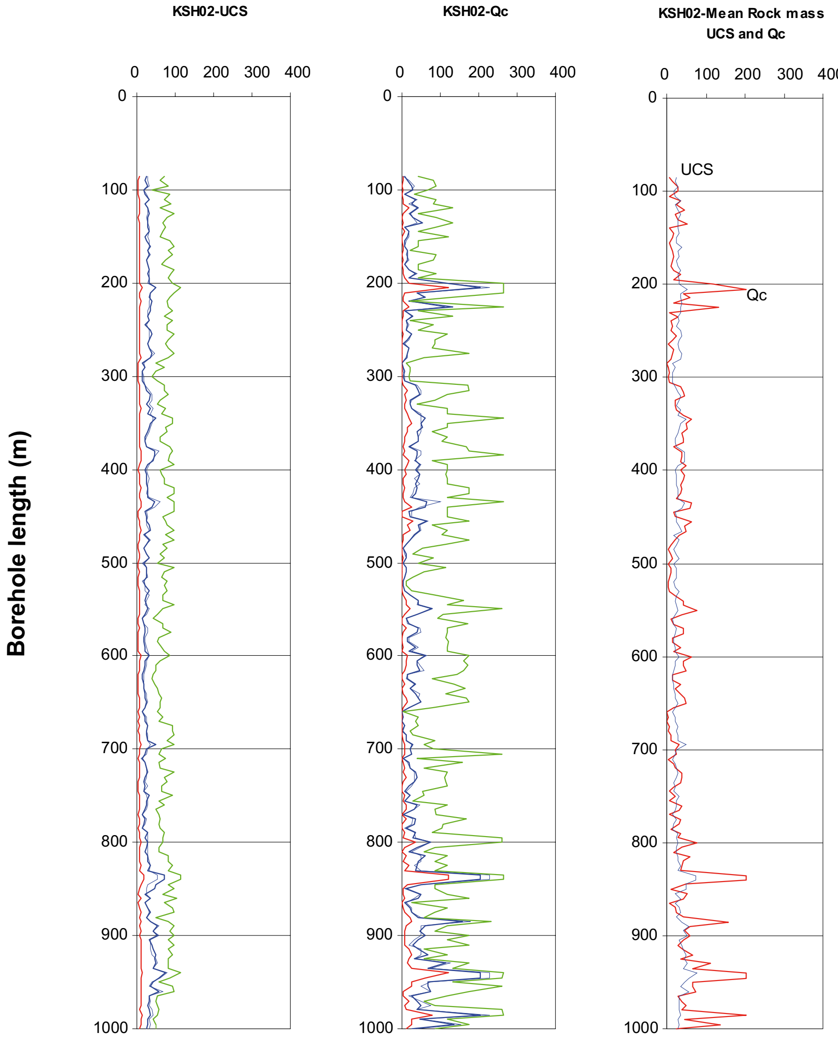

Figure 5-12. *Variation of the rock mass compressive strength from RMR and Q along borehole KSH02. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed every core section of 5 m, respectively. The comparison of the mean values from RMR and Q along the borehole is given in the graph on the right.*

5.3.3 KSH03A and B

The rock mass compressive strength from RMR and Q is plotted along the borehole in Figure 5-13. From RMR, the average $UCS_{H\&B}$ of the Rock Units varies between 21 and 30 MPa. On average, for the Deformation Zones and competent rock mass, $UCS_{H\&B}$ varies between 12 and 29 MPa, respectively.

The range of average UCS_{M-C} values for borehole is between 61 and 81 MPa, for the fractured and competent rock mass respectively.

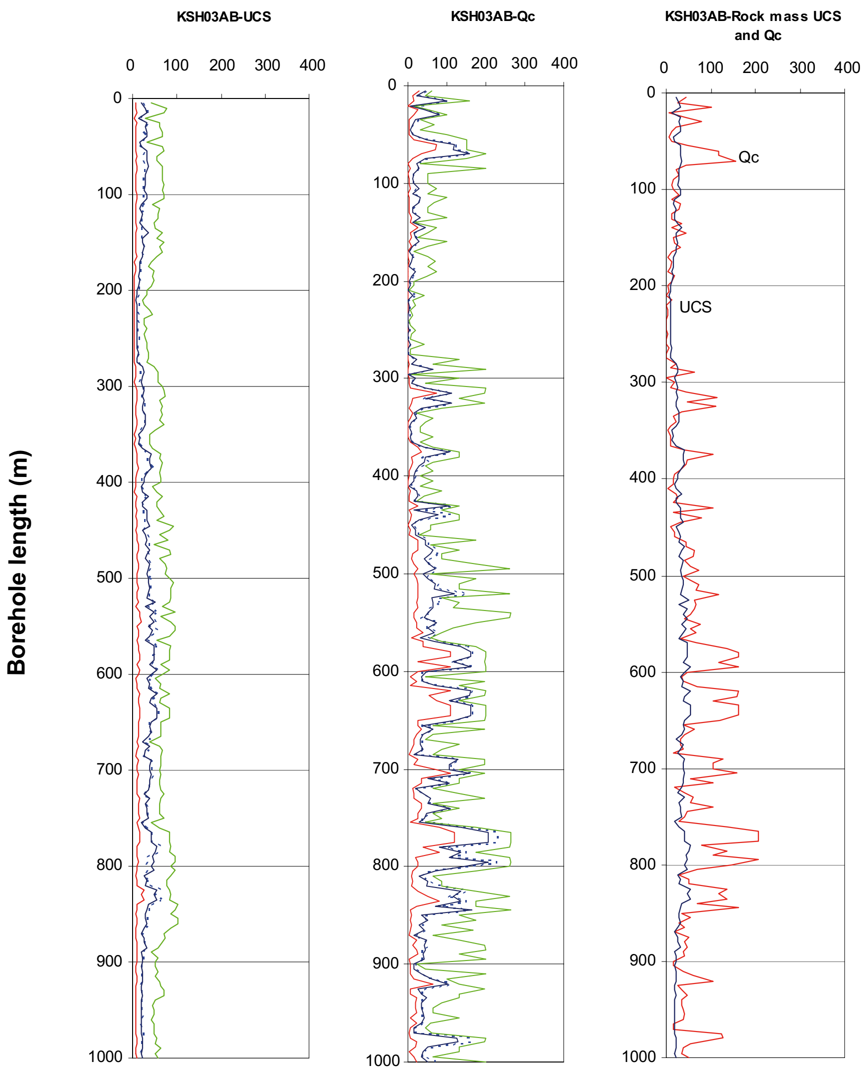

Figure 5-13. *Variation of the rock mass compressive strength from RMR and Q along borehole KSH03A and B. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed every core section of 5 m, respectively. The comparison of the mean values from RMR and Q along the borehole is given in the graph on the right.*

5.3.4 KAV01

The variation of the rock mass compressive strength $UCS_{H\&B}$ from RMR and Qc along borehole KAV01 can be seen in Figure 5-14. The average $UCS_{H\&B}$ in the seven Rock Units ranges between 14 and 29 MPa. For the whole borehole, the maximum and minimum observed values of $UCS_{H\&B}$ are respectively 62 and 10 MPa. The competent rock mass shows an average $UCS_{H\&B}$ of 26 MPa, which is 10 MPa larger than the average $UCS_{H\&B}$ of the Deformation Zones.

The average UCS_{M-C} for the deformation zones is 68 MPa and for the competent rock mass 77 MPa, respectively.

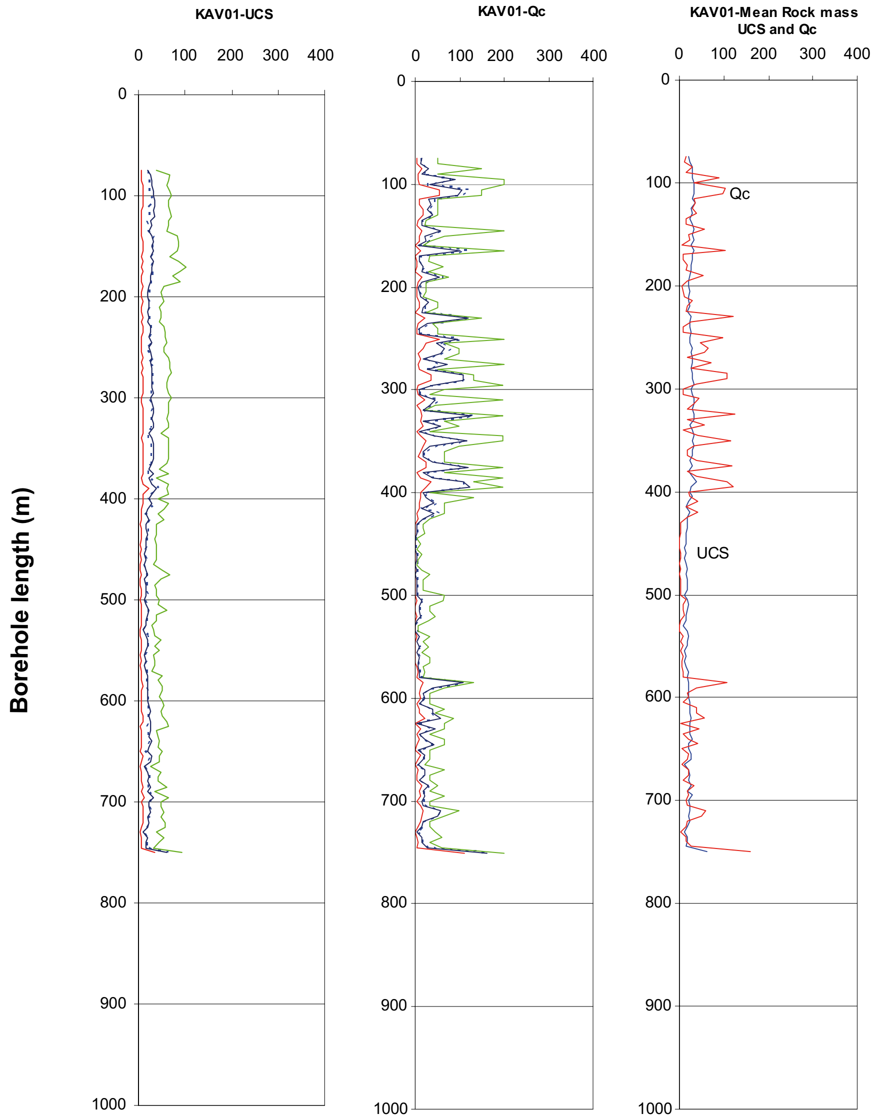

Figure 5-14. Variation of the rock mass compressive strength from RMR and Q along borehole KAV01. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed every core section of 5 m, respectively. The comparison of the mean values from RMR and Q along the borehole is given in the graph on the right.

5.3.5 KLX02

For the Laxemar borehole KLX02, the variation of the rock mass compressive strength from RMR and Qc is shown in Figure 5-15. The $UCS_{H\&B}$ from RMR ranges between 10 and 62 MPa. The two Rock Units in this borehole show very similar average $UCS_{H\&B}$, respectively 35 and 32 MPa. The competent rock mass has a higher average $UCS_{H\&B}$ than the deformation zones, respectively 37 MPa and 22 MPa.

The UCS_{M-C} of the competent rock mass is on average 94 while for the fractured rock is 65 MPa, respectively.

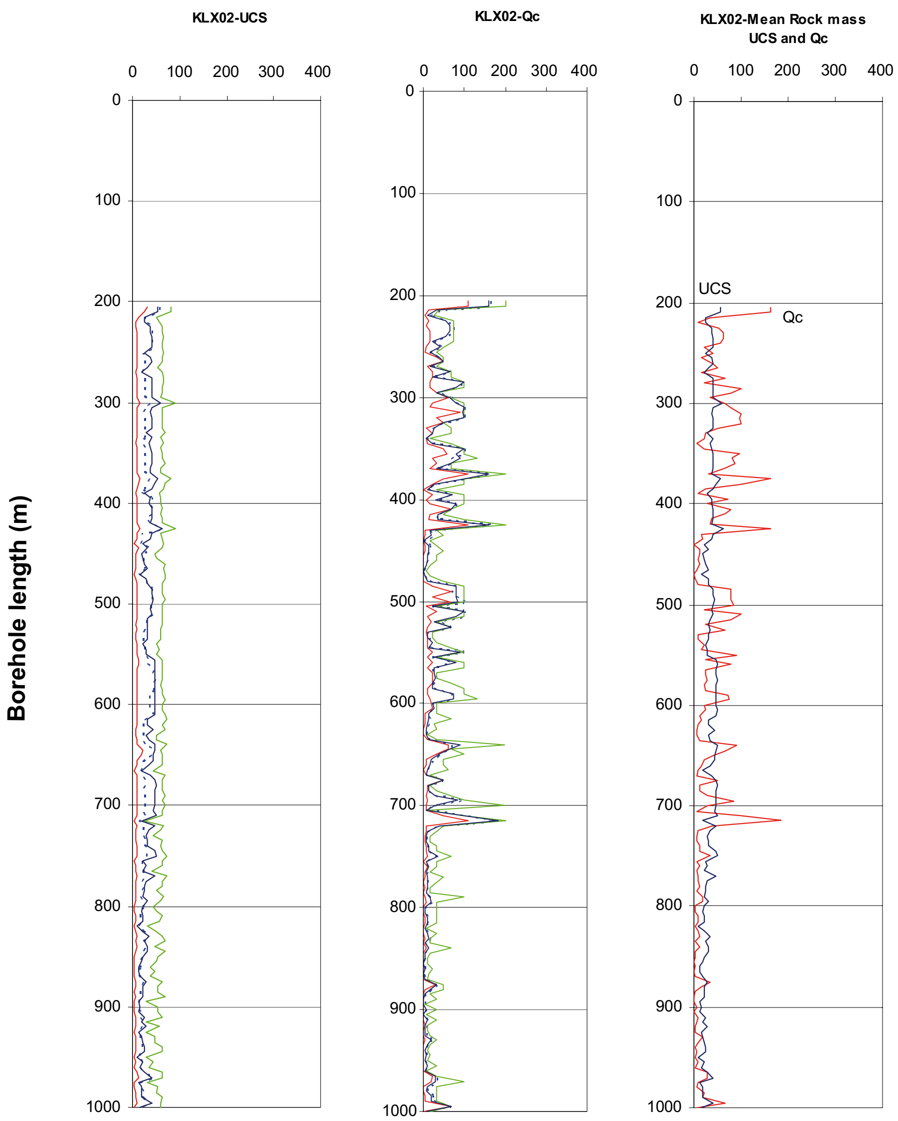

Figure 5-15. *Variation of the rock mass compressive strength from RMR and Q along borehole KLX02. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed every core section of 5 m, respectively. The comparison of the mean values from RMR and Q along the borehole is given in the graph on the right.*

5.3.6 Uncertainties

Table 5-3 summarises the uncertainty of the mean uniaxial compressive strength $UCS_{H\&B}$ from the Hoek and Brown's Criterion reported in the former sections. It can be seen that the uncertainty for the competent rock mass in the Rock Units ranges between –7% and +16%, while the uncertainty for the Deformation Zones ranges between –13% and +47%.

According to Section 4.8.1, the values in Table 5-3 can also be to represent the uncertainties on the uniaxial compressive strength UCS_{M-C} obtained by extrapolating the linear fit of the Hoek and Brown's Criterion for confinement stresses between 10 and 30 MPa.

Table 5-3. Confidence on the mean values of the Uniaxial Compressive Strength of the rock mass derived from RMR ($UCS_{H\&B}$) for borehole KSH01A and B, KSH02, KSH03A and B, KAV01 and KLX02 and borehole sections of 5 m.

	Competent rock mass		Fractured rock mass	
	Lower confidence on the mean	Upper confidence on the mean	Lower confidence on the mean	Upper confidence on the mean
KSH01AB	–7%	+16%	–13%	+47%
KSH02	–5%	+11%	–13%	+35%
KSH03AB	–4%	+7%	–12%	+33%
KAV01	–4%	+9%	–10%	+22%
KLX02	–5%	+5%	–10%	+24%

5.4 Cohesion and friction angle of the rock mass

Based on the Hoek and Brown's Criterion /Hoek et al. 2002/, the estimated equivalent Mohr-Coulomb's parameters (cohesion and friction angle) can be obtained when a certain confinement stress range is specified. In this Report, the stress 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 along the boreholes are tabulated and plotted in Appendix 1 to 5.

5.4.1 KSH01A and B

The plot of the cohesion and friction angle is shown in Figure 5-16 along borehole KSH01A and B for a confinement stress between 10 and 30 MPa. The average cohesion in the Rock Units ranges between 17 and 19 MPa, while that of the Deformation Zones and competent rock mass between 16 and 18 MPa, respectively. For the whole borehole, the cohesion spans between 15 and 23 MPa.

For the same range of confinement stress (10 to 30 MPa), the friction angle along the borehole ranges between 40° and 48°. The four Rock Units have very similar friction angle of about 44°–45°. A larger difference can be observed between the average friction angle of the competent rock mass and that of the Deformation Zones, which are respectively 45° and 42°.

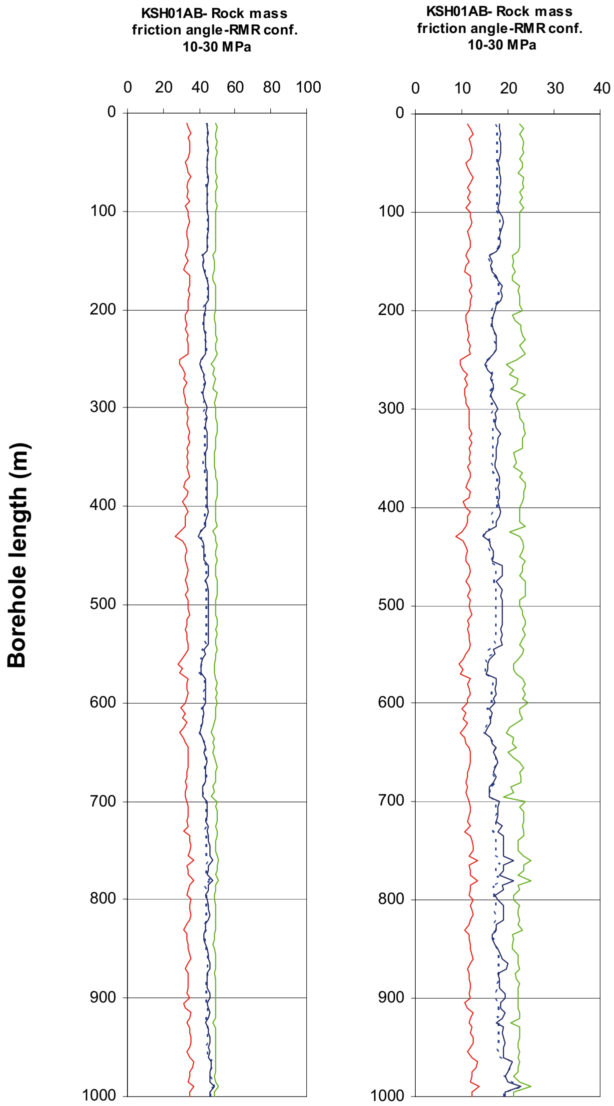

Figure 5-16. *Variation of the rock mass friction angle and cohesion from RMR and Q along borehole KSH01A and B under a confinement stress between 10 and 30 MPa. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed every core section of 5 m, respectively.*

5.4.2 KSH02

Figure 5-17 shows the plots of the cohesion and friction angle calculated for a confinement stress between 10 and 30 MPa along borehole KSH02.

On average, the cohesion of the rock mass in the Deformation Zones (15 MPa) is very close to that of the competent rock mass (16 MPa). Also the Rock Units have cohesion very close to each others (14 and 17 MPa). The range of variation of the cohesion along the borehole is between 13 and 23 MPa.

The friction angle of the rock mass should vary between 35° and 43° degrees for the whole borehole. The average values are instead 38° and 39° for the Deformation Zones and competent rock mass, respectively.

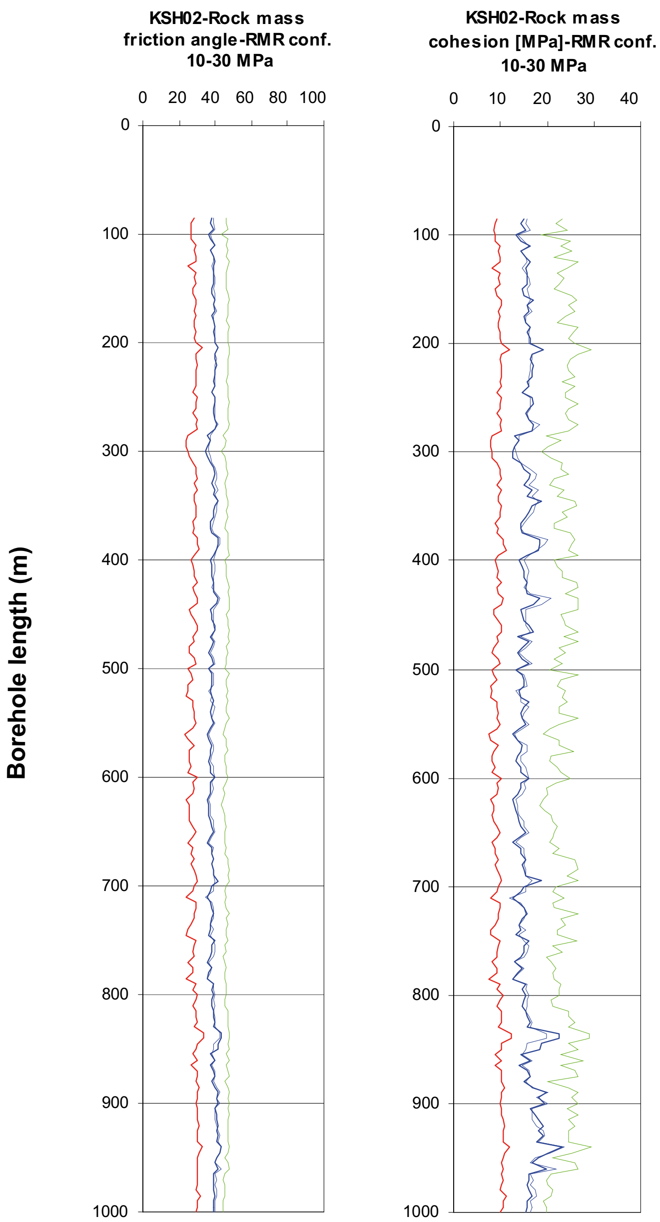

Figure 5-17. Variation of the rock mass friction angle and cohesion from RMR and Q along borehole KSH02 under confinement stress between 10 and 30 MPa. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed every core section of 5 m, respectively.

5.4.3 KSH03A and B

For KSH03A and B, the cohesion and friction angle obtained by the empirical methods plot as in Figure 5-18. These values are determined for a confinement stress between 10 and 30 MPa.

The average cohesion of the Rock Units ranges between 16 and 18 MPa. That of the competent rock mass and Deformation zones ranges between 15 MPa and 18 MPa. For the whole borehole, cohesion values are observed within the interval 13 to 22 MPa.

The friction angle might vary between 37° and 47° along the borehole. The average values for the competent rock mass and Deformation Zones are, instead, 39° and 43°. The Rock Units have average friction angles in the range 40°–44°.

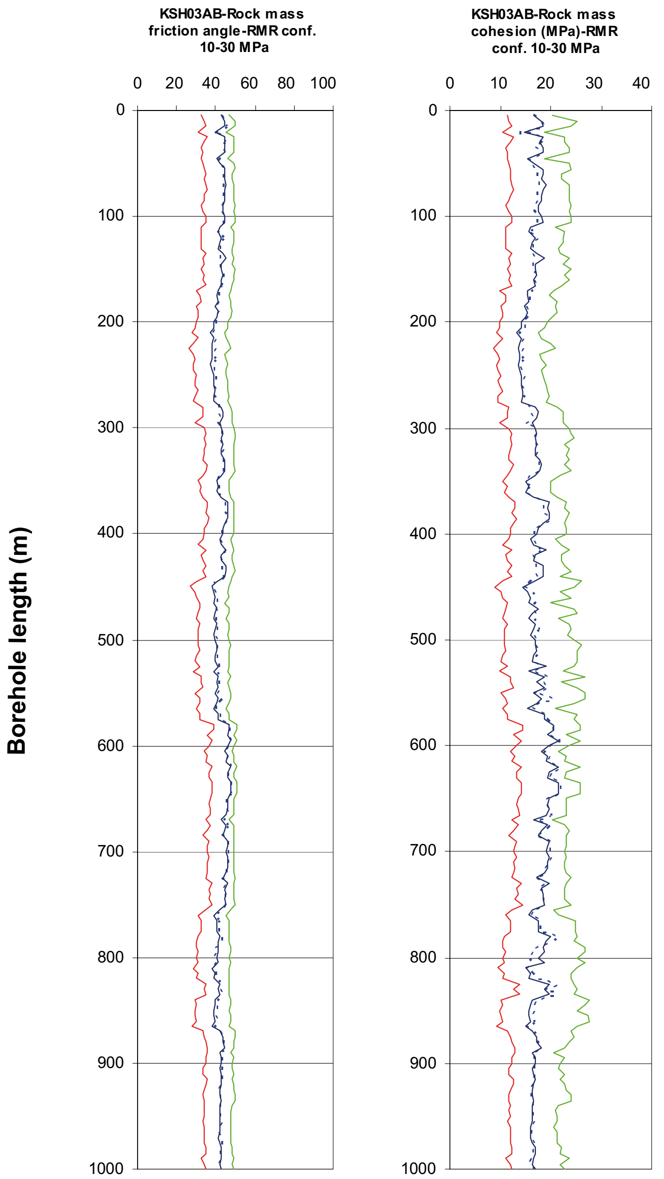

Figure 5-18. *Variation of the rock mass friction angle and cohesion from RMR and Q along borehole KSH03A and B under a confinement stress between 10 and 30 MPa. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed every core section of 5 m, respectively.*

5.4.4 KAV01

Figure 5-19 show the plots of the cohesion and friction angle along borehole KAV01. These values are obtained by interpolating the Hoek and Brow's Criterion between the stresses of 10 and 30 MPa.

On average, the cohesion of the rock mass should vary between 14 and 23 MPa, with an average value for the rock mass in the Deformation Zones of 16 MPa, and an average value for the competent rock mass of 17 MPa. Also the seven Rock Units seem to have very similar average cohesion, which ranges between 15 and 18 MPa.

The friction angle varies between 39° and 48° for the whole borehole. The average friction angle of the Rock Units ranges instead between 39° and 44° respectively. The competent rock mass has an average friction angle (43°) larger than the average friction angle of the Deformation Zones (41°).

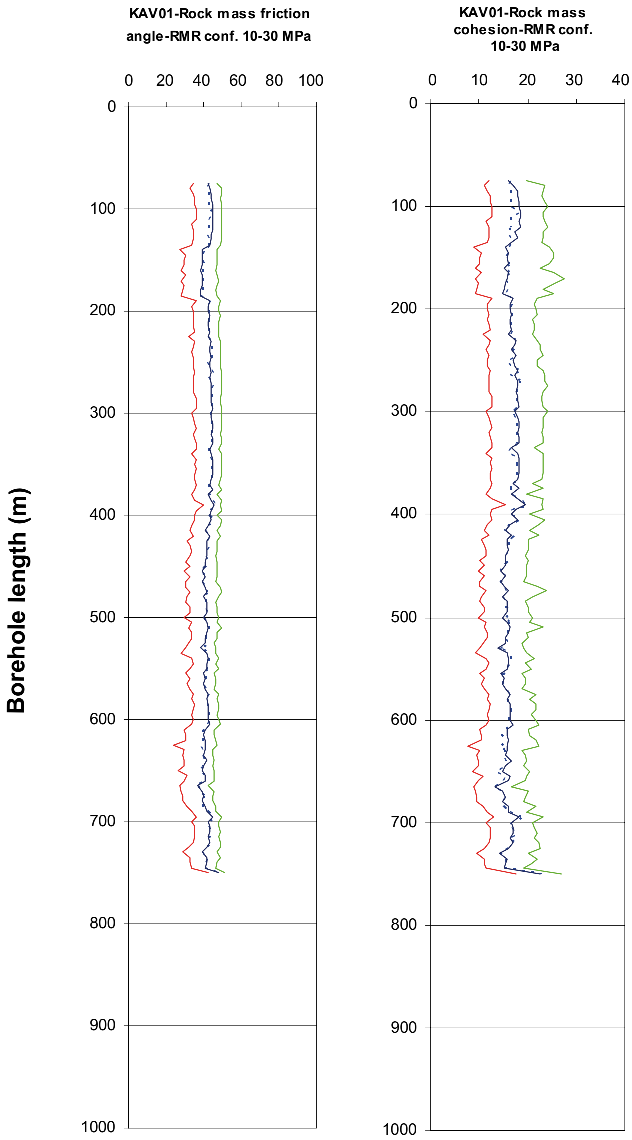

Figure 5-19. Variation of the rock mass friction angle and cohesion from RMR and Q along borehole KAV01 under as confinement stress between 10 and 30 MPa. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed every core section of 5 m, respectively.

5.4.5 KLX02

For the Laxemar borehole KLX02, the cohesion and friction angle plot as in Figure 5-20. These values apply for a confinement stress between 10 and 30 MPa.

For this borehole, the range of variation of the cohesion is between 13 and 23 MPa. The two Rock Units have very similar average cohesion (18–19 MPa). The difference between the average cohesion of the competent rock mass and the Deformation Zone is more marked: respectively 19 and 15 MPa.

The friction angle ranges between 36° and 48° for the whole borehole. The average friction angle of the competent rock mass is 45°. That of the Deformation Zone is 40°. The Rock Units have high average friction angle (43°–45°) despite the Deformation Zones within them.

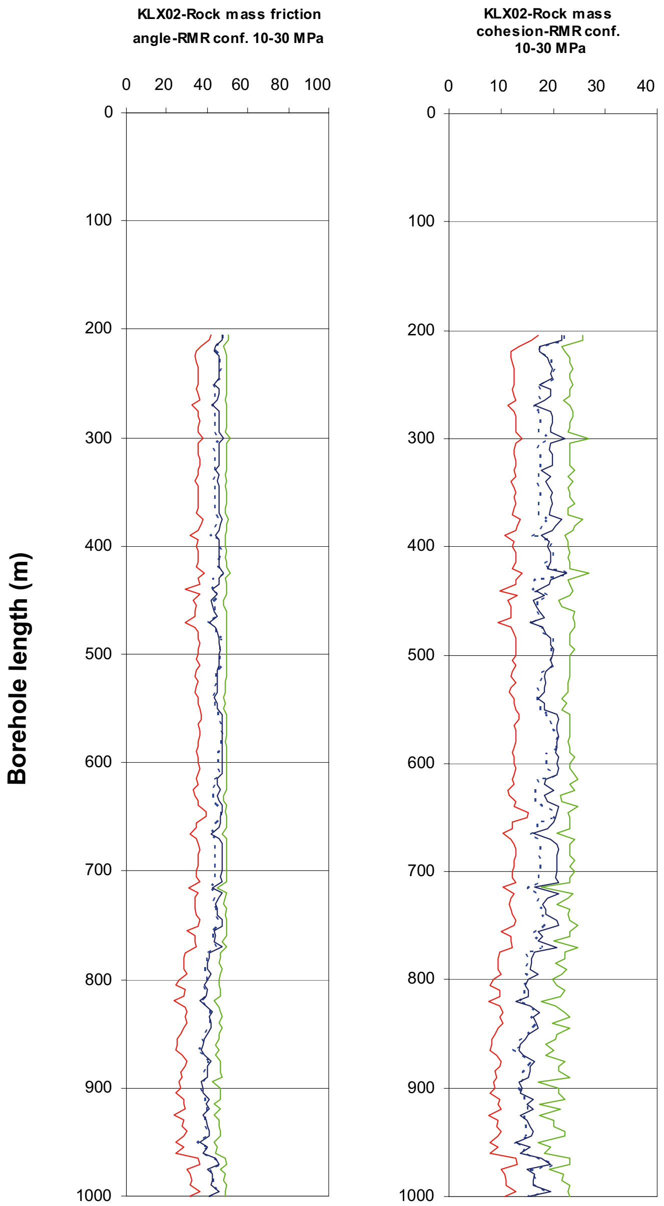

Figure 5-20. *Variation of the rock mass friction angle and cohesion from RMR and Q along borehole KLX02 under a confinement stress between 10 and 30 MPa. The lines in red, blue, dashed blue and green represent the minimum, average, most frequent and maximum values observed every core section of 5 m, respectively.*

5.4.6 Uncertainties

The uncertainties of the average cohesion are reported in Table 5-4. Borehole KSH01A and B seem to have higher uncertainties than the other boreholes, probably due to the larger variation of the geomechanical parameters for this borehole. In general, for the competent rock mass, the uncertainty on the cohesion varies between –6% and +11%. The range of uncertainty of the average cohesion of the Deformation Zones is at most –12% and +33%.

Also the uncertainty on the friction angle could be quantified according to Section 4.8.1. The uncertainty of the mean friction angle for the competent rock mass in the Rock Units and for the Deformation Zones does not exceed the range between –9% and +5%.

Table 5-4. Confidence on the mean values of the rock mass cohesion (confinement stress 10–30 MPa) for borehole KSH01A and B, KSH02, KSH03A and B, KAV01 and KLX02 and borehole sections of 5 m.

	Competent rock mass		Fractured rock mass	
	Lower confidence on the mean	Upper confidence on the mean	Lower confidence on the mean	Upper confidence on the mean
KSH01AB	–6%	+11%	–12%	+33%
KSH02	–4%	+4%	–10%	+11%
KSH03AB	–3%	+4%	–10%	+25%
KAV01	–2%	+2%	–4%	+5%
KLX02	–2%	+2%	–5%	+6%

Table 5-5. Confidence on the mean values of the rock mass friction angle (confinement stress 10–30 MPa) for borehole KSH01A and B, KSH02, KSH03A and B, KAV01 and KLX02 and borehole sections of 5 m.

	Competent rock mass		Fractured rock mass	
	Lower confidence on the mean	Upper confidence on the mean	Lower confidence on the mean	Upper confidence on the mean
KSH01AB	–3%	+1%	–5%	+3%
KSH02	–3%	+2%	–9%	+5%
KSH03AB	–2%	+1%	–3%	+4%
KAV01	–1%	+1%	–3%	+3%
KLX02	–1%	+1%	–3%	+3%

6 Discussion and conclusions

When comparing the plots of RMR and Q along 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, only giving information in the vertical direction.
- Boreholes KSH01A and B, KSH02 and KSH03A and B show rather uniform values of RMR and Q with depth, were Deformation Zones are frequent but not very extensive.
- Borehole KAV01 and KLX02 present, instead, quite abrupt jumps of RMR and Q at certain depths with long sections of either relatively high or low rock mass quality.
- In general, the competent rock mass in KLX02, that belongs to the Laxemar Area, exhibits the best quality (RMR = 77, Q = 48) among all boreholes (RMR around 70, Q around 30).
- The Deformation Zones present a mean RMR as low as 57 and Q of about 2.8, with extreme values of 53 for RMR and 0.5 for Q, respectively.
- The uncertainties of the average RMR might vary between ± 2% for the competent rock mass and ± 6% for the Deformation Zones. The correspondent uncertainty of the Q values are slightly higher, respectively ± 10% and ± 20%, probably due to the fact that Q usually ranges several orders of magnitude for the same rock mass.
- The average deformation modulus of the rock mass in the competent rock mass ranges between 32 and 40 GPa for the boreholes at Simpevarp and Ävrö, and around 49 GPa for the competent rock mass in KLX02 in Laxemar. The average deformation modulus of the Deformation Zones, on the other hand, ranges between 16 and 27 GPa for all areas.
- Independently on the method adopted, the uncertainty of the average deformation modulus seems to be about ± 6% for the competent rock mass and ± 15% for the Deformation Zones. 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 and elastic medium (e.g. parameters of the Hoek and Brown's and Coulomb's Criterion).
- According to the Hoek and Brown's Criterion, the average uniaxial compressive strength of the rock mass ranges between 26 and 37 MPa for the five boreholes, with the highest values to be assigned to KLX02. In the deformation zones, the average strength drop to 12 to 22 MPa.
- There is a clear difference between the equivalent uniaxial compressive strength calculated from the Hoek and Brown's Criterion and that extrapolated from the linear Mohr-Coulomb approximation of the Hoek and Brown's Criterion for confinement stresses between 10 and 30 MPa. In fact, for the competent rock mass, the average UCS_{M-C} varies between 66 and 94 MPa, while for the deformation zones, it varies between 61 and 72 MPa. These values are larger than for UCS_{H-B} because they do not consider the curvilinearity of the strength criterion of the rock mass.

- The uncertainty of the average uniaxial compressive strength from the Hoek and Brown's Criterion might be about ± 8% for the competent rock mass and about ± 25% for the Deformation Zones, respectively. These values would also apply according to Section 4.8.1 for the linearly extrapolated uniaxial compressive strength from the Mohr-Coulomb Criterion evaluated between 10 and 30 MPa confinement strength.
- The equivalent cohesion of the competent rock mass in the boreholes varies, on average, between 16 and 19 MPa, for confinement stresses between 10 and 30 MPa. For the Deformation Zones, the variation is between 15 and 16 MPa. The cohesion is used to calculate the UCS_{M-C}.
- The uncertainty of the average cohesion reported in Section 5.4 almost coincide with the values provided for the deformation modulus.
- The equivalent friction angle of the rock mass in each borehole ranges between 39° and 45°, for the competent rock mass, and between 38° and 42°, for the Deformation Zones, respectively. The friction angle is also estimated for confinement stresses between 10 and 30 MPa. The friction angle is used to calculate the UCS_{M-C}.
- The uncertainty of the equivalent average friction angle is around ± 3% for the competent rock mass, and about three times as large for the Deformation Zones.

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 apply for the "classification" 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 Design Phase of the Simpevarp Site. The relations between RMR and Q obtained for the five boreholes can be summarised as follows:

KSH01A and B: $RMR = 2.72 \times \ln(Q)+65$ (12)

KSH02: $RMR = 3.46 \times \ln(Q)+60$ (13)

KSH03A and B: $RMR = 4.59 \times \ln(Q)+58$ (14)

KAV01: $RMR = 3.20 \times \ln(Q)+62$ (15)

KLX02: $RMR = 4.20 \times \ln(Q)+62$ (16)

Despite the differences between "classification" and "characterisation" results, the relations from the literature in Figure 6-1 match rather well the empirical results obtained for the Simpevarp area.

The data contained in the Appendices are delivered and inputted into SKB's database SICADA to integrate the geological single-hole interpretation. The Appendices also contain data that quantify the confidence level of the results reported here. The confidence ranges given are a measure of the spatial variability and uncertainty of the results in each rock unit, rock type group and for the whole borehole.

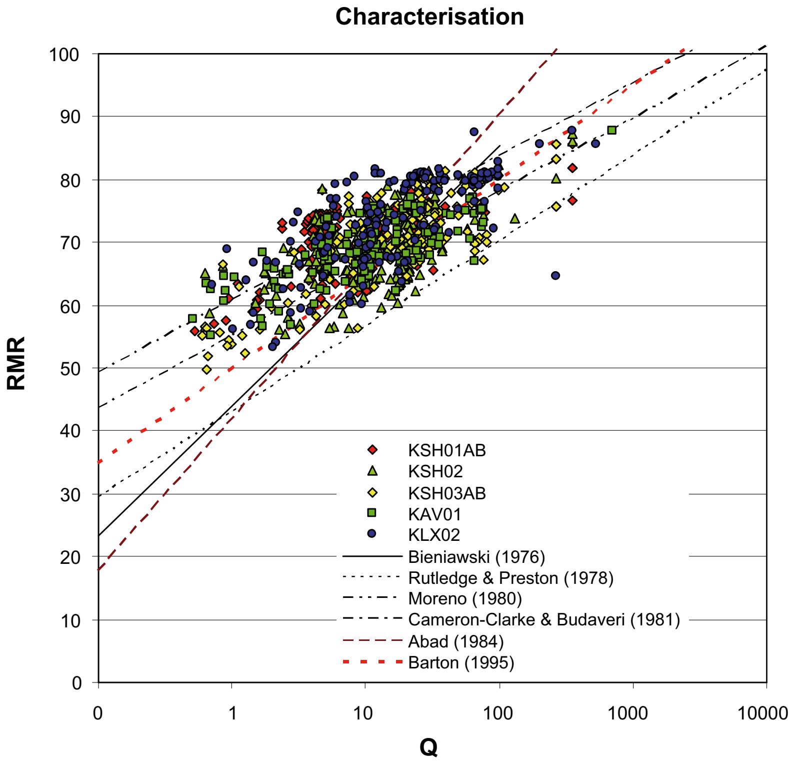

Figure 6-1. *Correlation between RMR and Q from the characterisation of the rock mass along borehole KSH01A and B, KSH02, KSH03A and B, KAV01 and KLX02 (core sections of 5 m). The characterisation results are compared with some design relations from the literature.*

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" (RM280). 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 average RMR and Q, average RMR/most frequent Q, and the maximum average RMR and Q, respectively. Among the rock mechanics properties, the uniaxial compressive strength of the intact rock (UCS) and the deformation modulus (E_m) 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, average and maximum average deformation modulus of the rock mass. Before storage into the database, quality assessment routines were performed on the methods and delivered data.

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Appendix 1

KSH01A and B
Characterisation of the rock mass

A1.1 Fracture orientation

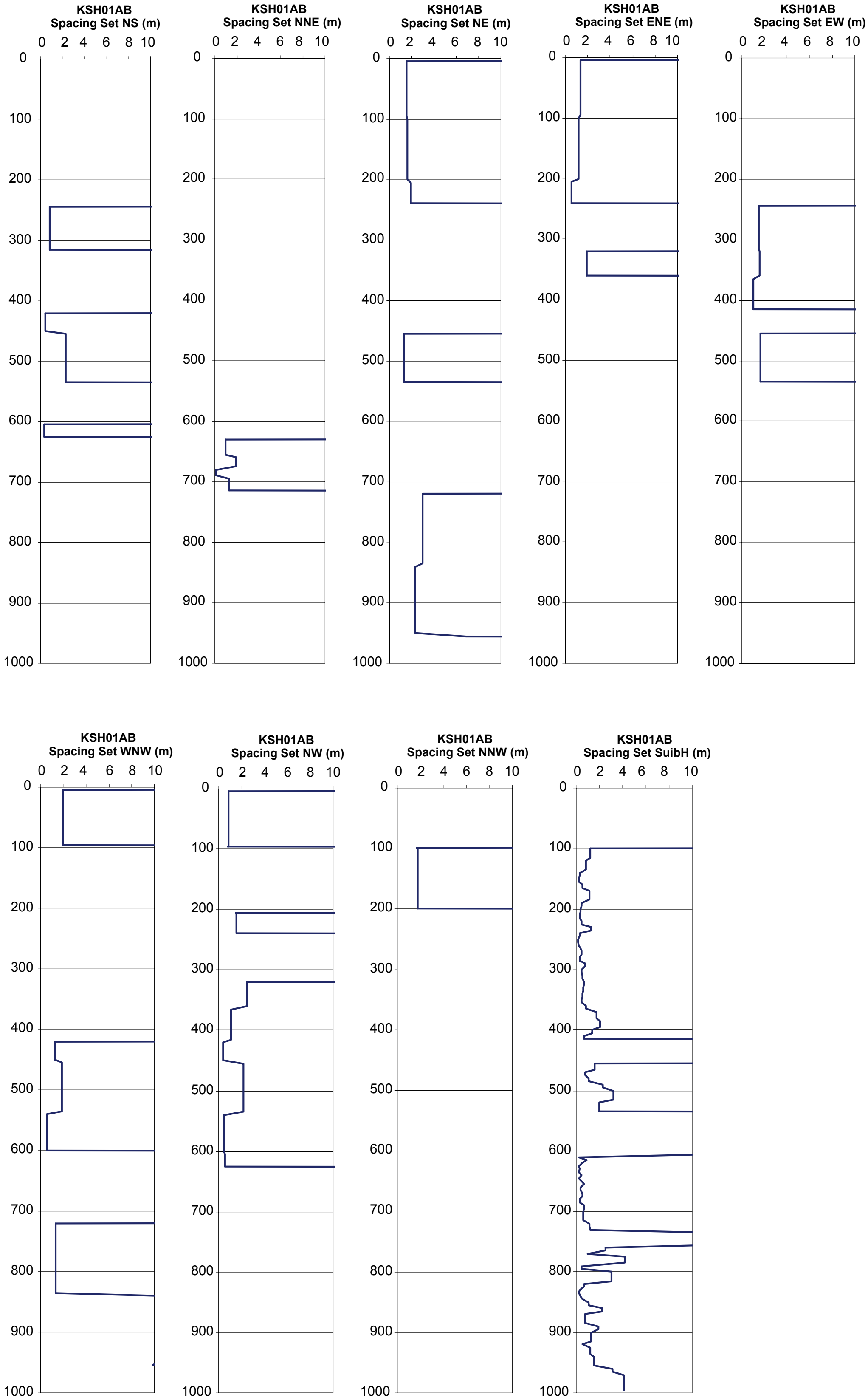
Set identification from the fracture orientation mapped for borehole KSH01A (based on SICADA data received on 15/08/2003). The orientations are given as strike/dip (right-hand rule).

Depth (m)	No of fract	NS	NNE	NE	ENE	EW	WNW	NW	NNW	SubH
100–205	310			224/63	275/63				177/81	154/04
205–247	165			183/56	266/61			309/62		262/01
247–322	376	035/53				139/54				109/02
322–365	134				264/81	110/48		294/61		357/05
365–420	200					088/38		285/68		266/09
420–455	249	348/44					319/80	305/56		
455–540	262	007/36		225/58		124/38	325/71	287/72		211/04
540–607	382						336/64	298/51		
607–631	201	346/40						299/47		302/03
631–719	371		207/68							090/04
719–839	199			238/62			323/85			050/05
839–957	178			250/59			314/72			311/09
957–1,000	17									320/04

Fisher's constant of the fracture sets identified for borehole KSH01A (SICADA, 03-08-15).

Depth (m)	No of fract	NS	NNE	NE	ENE	EW	WNW	NW	NNW	SubH
100–205	310			25	18				93	9
205–247	165			103	27			34		10
247–322	376	40				40				11
322–365	134				76	35		114		11
365–420	200					32		42		27
420–455	249	25					119	50		
455–540	262	65		21		47	50	43		19
540–607	382						43	28		
607–631	201	47						49		21
631–719	371		65							8
719–839	199			31			35			17
839–957	178			27			94			15
957–1,000	17									20

Fracture spacing with depth for the five facture sets in borehole KSH01A and B. The values are averaged for each 5 m length of borehole.



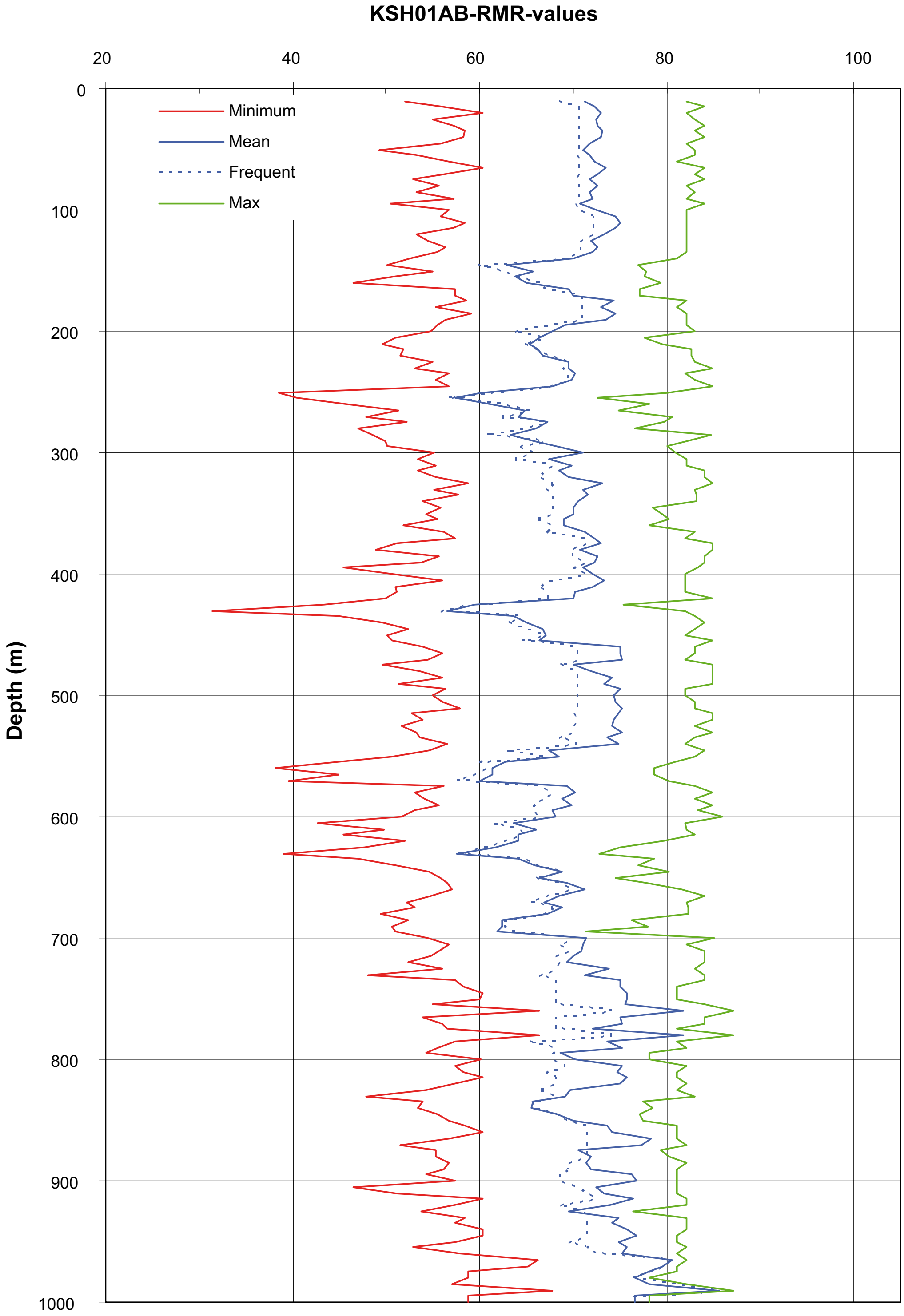
A1.2 RMR

RMR values along borehole KSH01A and B (core sections of 5 m).

Rock Unit	Minimum RMR	Average RMR	Frequent RMR	Maximum RMR	Standard deviation	Min possible RMR	Max possible RMR
5–100 RU 1	71	72	72	73	0.7	49	84
100–205 RU 1*	63	71	72	75	3.9	47	83
205–245 RU 2	65	68	69	70	1.9	50	85
245–320 RU 1**	58	66	66	71	3.9	39	85
320–365 RU 2	69	71	71	73	1.3	52	85
365–420 RU 2	69	72	72	73	1.1	45	85
420–455 DZ 3	56	64	65	67	4.1	31	85
455–540 RU 2	70	74	75	75	1.4	50	85
540–605 DZ 4a	60	66	68	70	3.7	38	86
605–630 DZ 4b and c	58	63	64	66	3.3	39	83
630–720 RU3 ***	62	68	69	71	3.1	47	85
720–840 RU 3 ****	66	74	75	82	4.0	48	87
840–955 RU 4	68	74	74	78	2.7	47	82
955–1,000 RU 3	75	78	77	86	3.0	53	87
RU 1	58	70	71	75	4.1	39	85
RU 2	57	69	70	75	4.6	31	86
RU 3	62	72	72	86	5.3	47	87
RU 4	68	74	74	78	2.7	47	82
Competent rock	64	73	72	86	3.4	45	87
Fractured rock	57	65	65	70	3.5	31	86
Whole borehole	57	71	71	86	4.8	31	87

* Including DZ 1 (136.5–160.0). ** Including DZ 2a, b and c (239.5–251.5(DZ 2a); 251.5–259.0 (DZ 2b); 259.0–287.0 (DZ 2c)). *** Including DZ 5a, b and c (672.0–286.5 (DZ 5a); 686.5–692.5 (DZ 5b); 692.5–693.0 (DZ 5c)). **** Including DZ 6 and 7 (766.0–767.0 (DZ 6); 833.5–834.5 (DZ 7)).

Variation of RMR with depth for borehole KSH01A and B. The values are given every 5 m.



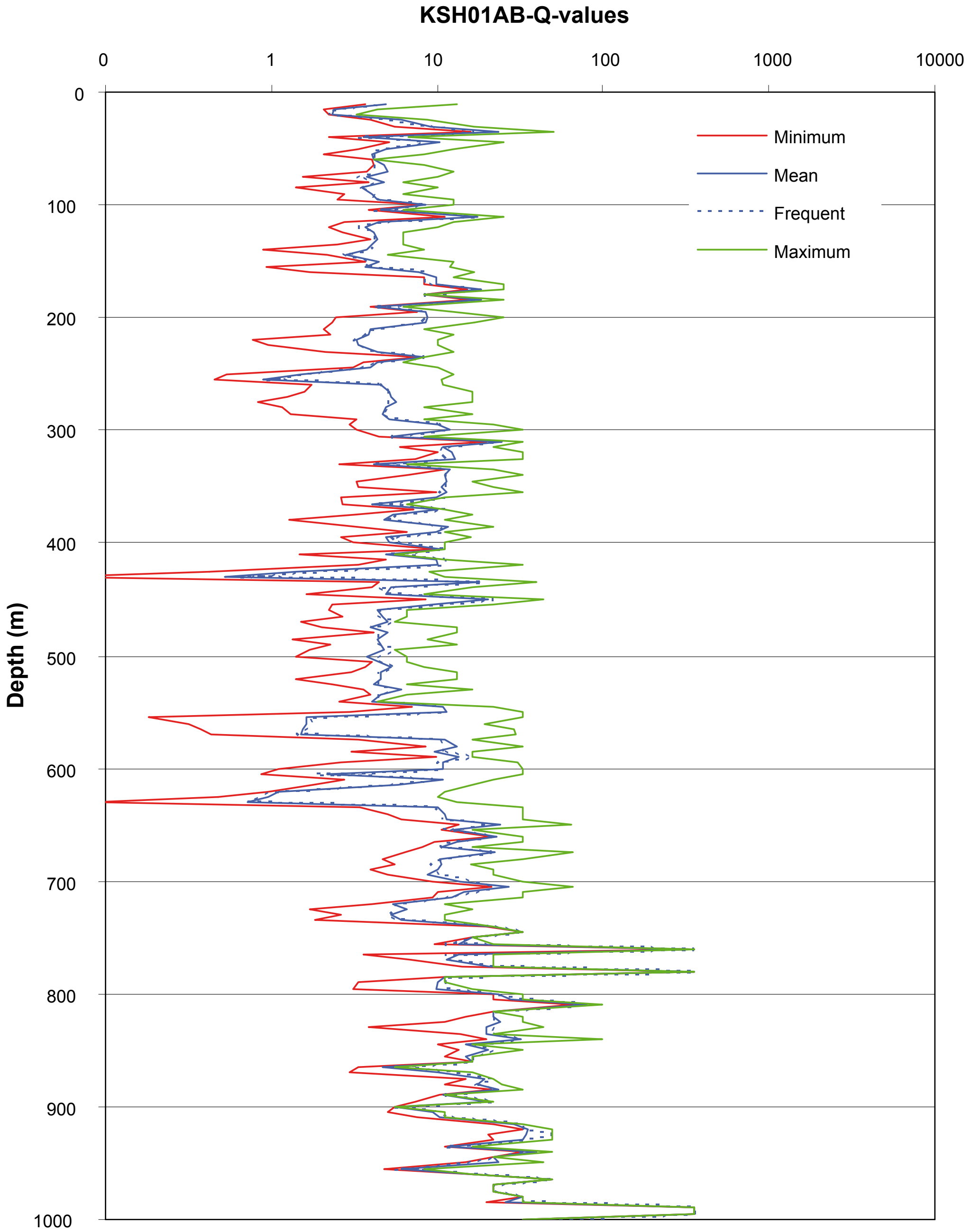
A1.3 Q

Q values along borehole KSH01A and B (core sections of 5 m).

Rock Unit	Minimum Q	Average Q	Frequent Q	Maximum Q	Standard deviation	Min possible Q	Max possible Q
5–100 RU 1	2.4	6	5	24	4.8	1.4	50
100–205 RU 1*	2.8	8	5	18	4.9	0.9	25
205–245 RU 2	3.2	4	4	8	1.6	0.8	13
245–320 RU 1**	0.9	8	5	25	5.9	0.5	33
320–365 RU 2	4.1	10	11	13	3.3	2.6	33
365–420 RU 2	4.8	8	10	12	2.8	1.3	33
420–455 DZ 3	0.5	9	5	20	7.9	0.05	44
455–540 RU 2	3.8	5	5	6	0.6	1.3	17
540–605 DZ 4a	1.5	8	11	13	5.0	0.2	33
605–630 DZ 4b and c	0.7	4	1	11	4.4	0.1	22
630–720 RU3 ***	5.4	14	12	27	6.0	3.4	66
720–840 RU 3 ****	5.3	48	20	352	95	1.7	352
840–955 RU 4	4.7	19	17	40	10	3	50
955–1,000 RU 3	6	80	25	352	127	5	352
RU 1	0.9	7	5	25	5.1	0.5	50
RU 2	0.5	7	5	20	4.2	0.05	44
RU 3	5.3	45	20	352	91	1.7	352
RU 4	4.7	19	17	40	10	3	50
Competent rock	2.4	21	10	352	55	0.8	352
Fractured rock	0.5	7	5	22	5.4	0.05	66
Whole borehole	0.5	18	10	352	49	0.05	352

* Including DZ 1 (136.5–160.0). ** Including DZ 2a, b and c (239.5–251.5(DZ 2a); 251.5–259.0 (DZ 2b); 259.0–287.0 (DZ 2c)). *** Including DZ 5a, b and c (672.0–286.5 (DZ 5a); 686.5–692.5 (DZ 5b); 692.5–693.0 (DZ 5c)). **** Including DZ 6 and 7 (766.0–767.0 (DZ 6); 833.5–834.5 (DZ 7)).

Variation of Q with depth for borehole KSH01A and B. The values are given every 5 m.



Rock mass properties

A1.4 Deformation modulus

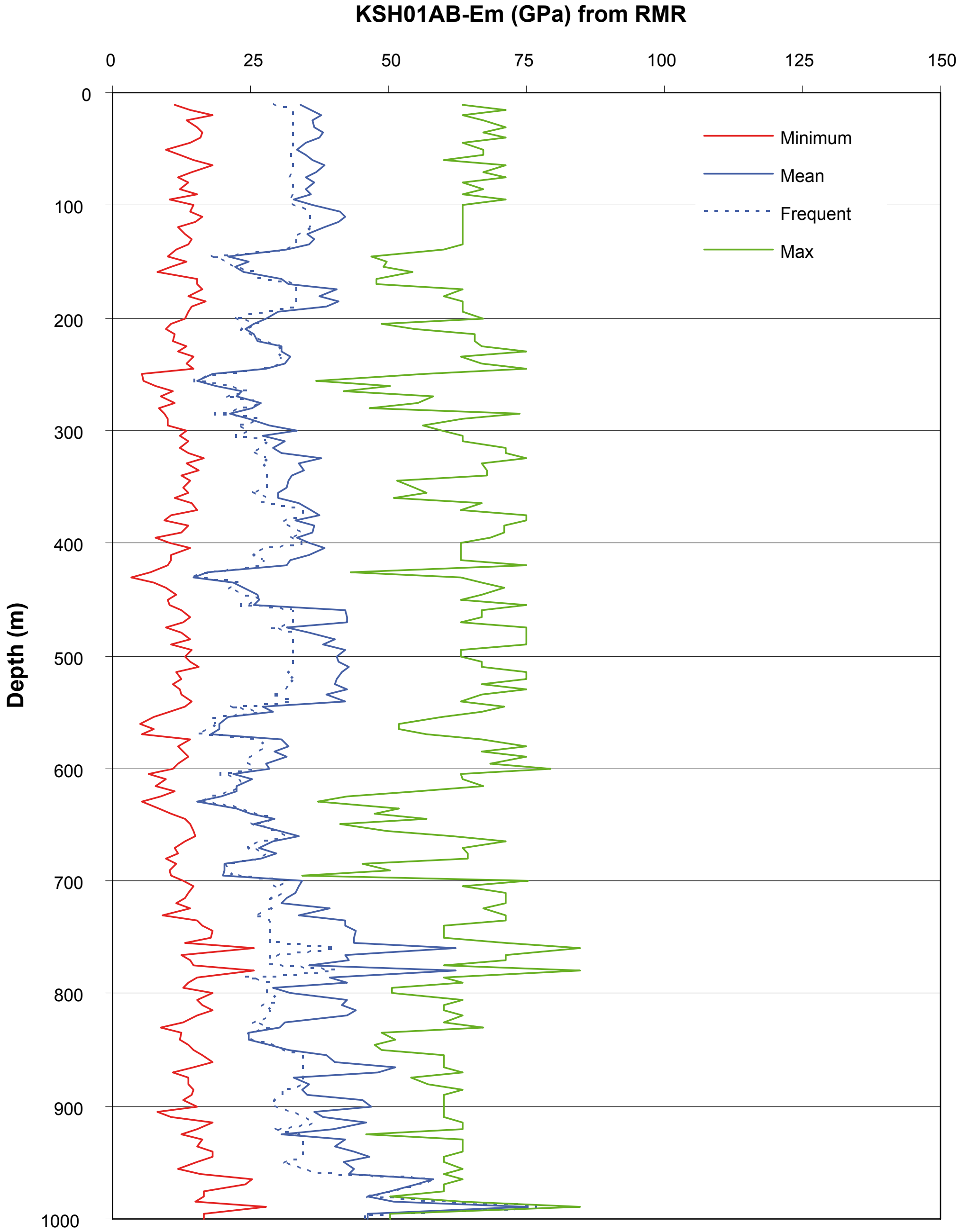
A1.4.1 RMR

Deformation modulus Em derived from RMR along for borehole KSH01A and B (core sections of 5 m).

Rock Unit	Minimum Em (GPa)	Average Em (GPa)	Frequent Em (GPa)	Maximum Em (GPa)	Standard deviation	Min possible Em (GPa)	Max possible Em (GPa)
5–100 RU 1	33	36	36	39	1.5	9.6	71
100–205 RU 1*	21	33	35	42	6.9	8.2	67
205–245 RU 2	24	29	29	32	3.0	9.8	75
245–320 RU 1**	15	25	25	34	5.2	5.2	74
320–365 RU 2	30	33	33	38	2.5	11	75
365–420 RU 2	32	35	36	38	2.2	7.7	75
420–455 DZ 3	15	22	24	27	4.7	3.4	75
455–540 RU 2	32	40	41	43	3.0	9.8	75
540–605 DZ 4a	18	26	28	32	5.1	5.0	79
605–630 DZ 4b and c	16	21	23	25	3.7	5.3	67
630–720 RU3 ***	20	28	29	34	4.8	8.4	75
720–840 RU 3 ****	25	40	42	62	9.3	8.9	85
840–955 RU 4	29	40	40	51	6.1	8.2	64
955–1,000 RU 3	42	50	46	75	9.2	12	85
RU 1	15	32	34	42	6.7	5.2	74
RU 2	15	31	32	43	7.5	3.4	79
RU 3	20	38	36	75	12	8.4	85
RU 4	29	40	40	51	6.1	8.2	64
Competent rock	23	37	36	75	7.7	7.7	85
Fractured rock	15	24	23	32	4.6	3.4	79
Whole borehole	15	34	34	75	9.1	3.4	85

* Including DZ 1 (136.5–160.0). ** Including DZ 2a, b and c (239.5–251.5(DZ 2a); 251.5–259.0 (DZ 2b); 259.0–287.0 (DZ 2c)). *** Including DZ 5a, b and c (672.0–286.5 (DZ 5a); 686.5–692.5 (DZ 5b); 692.5–693.0 (DZ 5c)). **** Including DZ 6 and 7 (766.0–767.0 (DZ 6); 833.5–834.5 (DZ 7)).

Variation of the deformation modulus of the rock mass obtained from RMR with depth for borehole KSH01A and B. The values are given every 5 m.



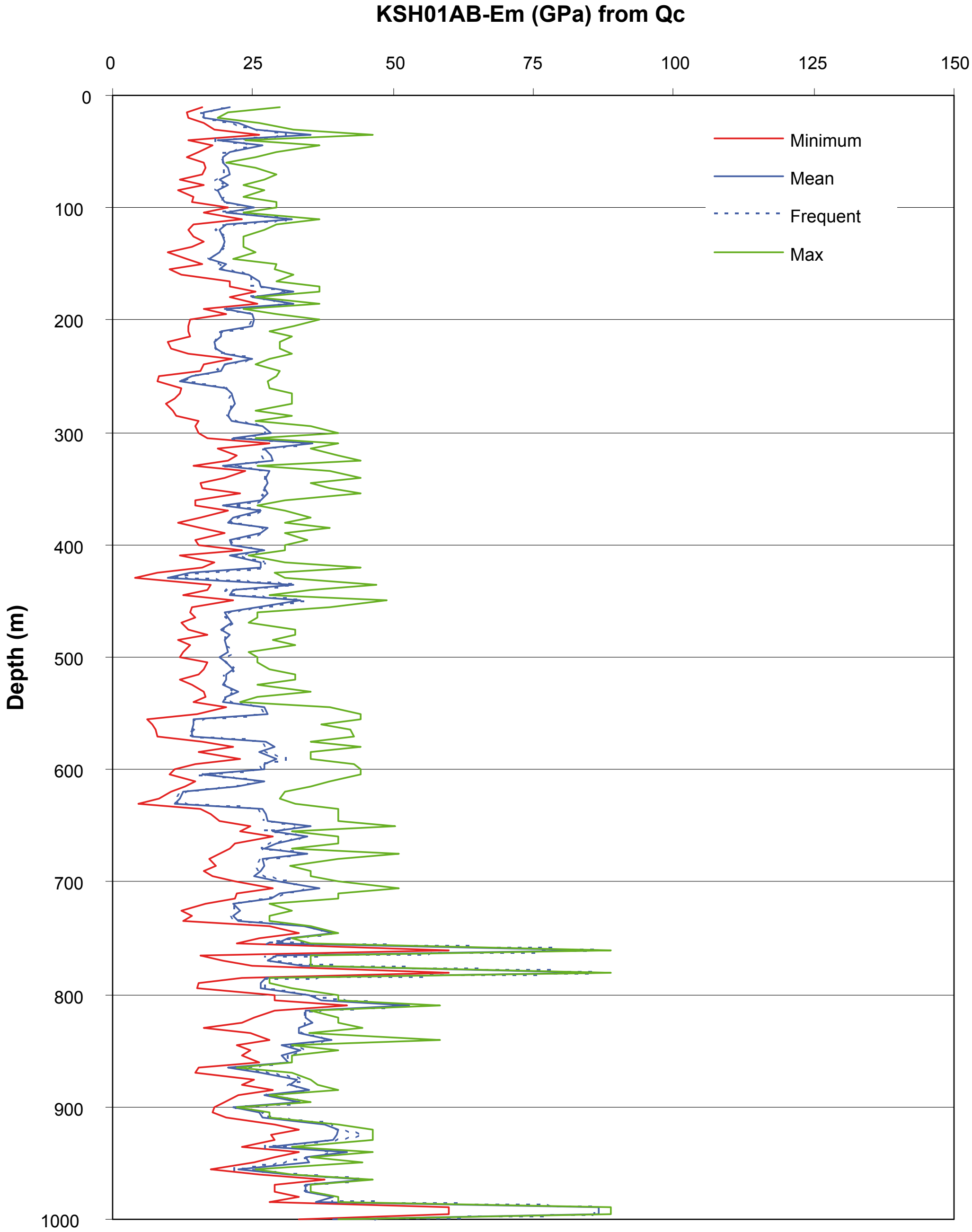
A1.4.2 Q

Deformation modulus Em derived from Q along borehole KSH01A and B (core sections of 5 m).

Rock Unit	Minimum Em (GPa)	Average Em (GPa)	Frequent Em (GPa)	Maximum Em (GPa)	Standard deviation	Min possible Em (GPa)	Max possible Em (GPa)
5–100 RU 1	16	21	21	35	4.3	12	46
100–205 RU 1*	17	23	20	32	4.7	10	37
205–245 RU 2	18	20	19	25	2.1	10	32
245–320 RU 1**	12	23	21	36	5.9	7.9	40
320–365 RU 2	20	26	27	29	3.5	15	44
365–420 RU 2	21	24	26	28	3.0	12	44
420–455 DZ 3	9.9	23	24	34	8.8	3.9	49
455–540 RU 2	19	20	20	23	0.8	12	35
540–605 DZ 4a	14	23	27	29	6.6	6.0	44
605–630 DZ 4b and c	11	17	13	27	7.2	4.7	39
630–720 RU3 ***	22	29	28	37	4.0	16	51
720–840 RU 3 ****	21	37	34	87	17	12	89
840–955 RU 4	21	32	32	42	6.1	15	46
955–1,000 RU 3	22	44	36	87	21	18	89
RU 1	12	23	21	36	4.9	7.9	46
RU 2	9.9	22	21	34	5.1	3.9	49
RU 3	21	36	33	87	16	12	89
RU 4	21	32	32	42	6.1	15	46
Competent rock	16	28	27	87	12	9.7	89
Fractured rock	9.9	22	21	35	6.5	3.9	51
Whole borehole	9.9	27	26	87	11	3.9	89

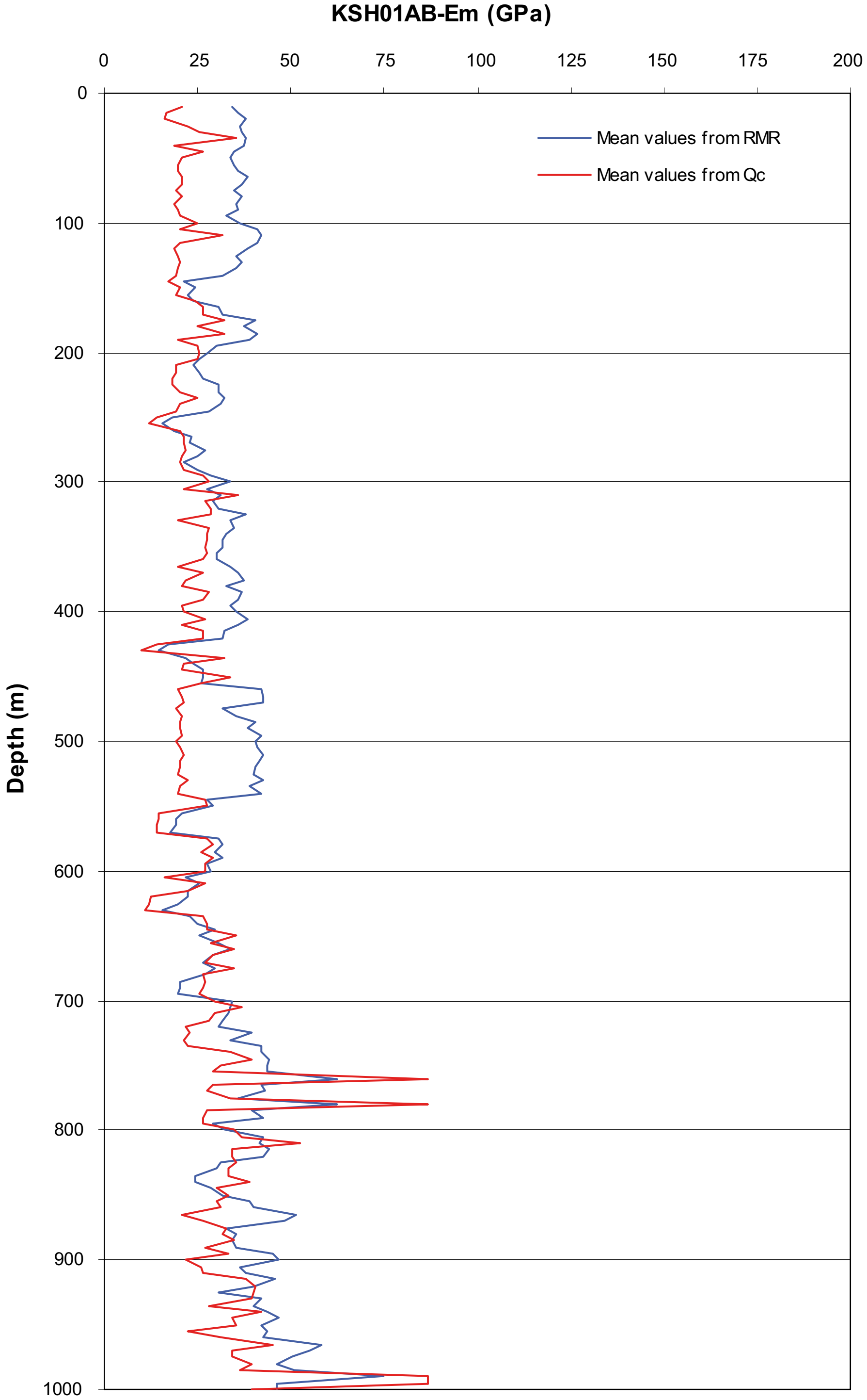
* Including DZ 1 (136.5–160.0). ** Including DZ 2a, b and c (239.5–251.5(DZ 2a); 251.5–259.0 (DZ 2b); 259.0–287.0 (DZ 2c)). *** Including DZ 5a, b and c (672.0–286.5 (DZ 5a); 686.5–692.5 (DZ 5b); 692.5–693.0 (DZ 5c)). **** Including DZ 6 and 7 (766.0–767.0 (DZ 6); 833.5–834.5 (DZ 7)).

Variation of the deformation modulus of the rock mass obtained from Q_c with depth for borehole KSH01A and B. The values are given every 5 m.



A1.4.3 Comparison

Comparison between the mean values of the deformation modulus E_m obtained from RMR and Qc for different depths for borehole KSH01A and B.



A1.5 Poisson's ratio

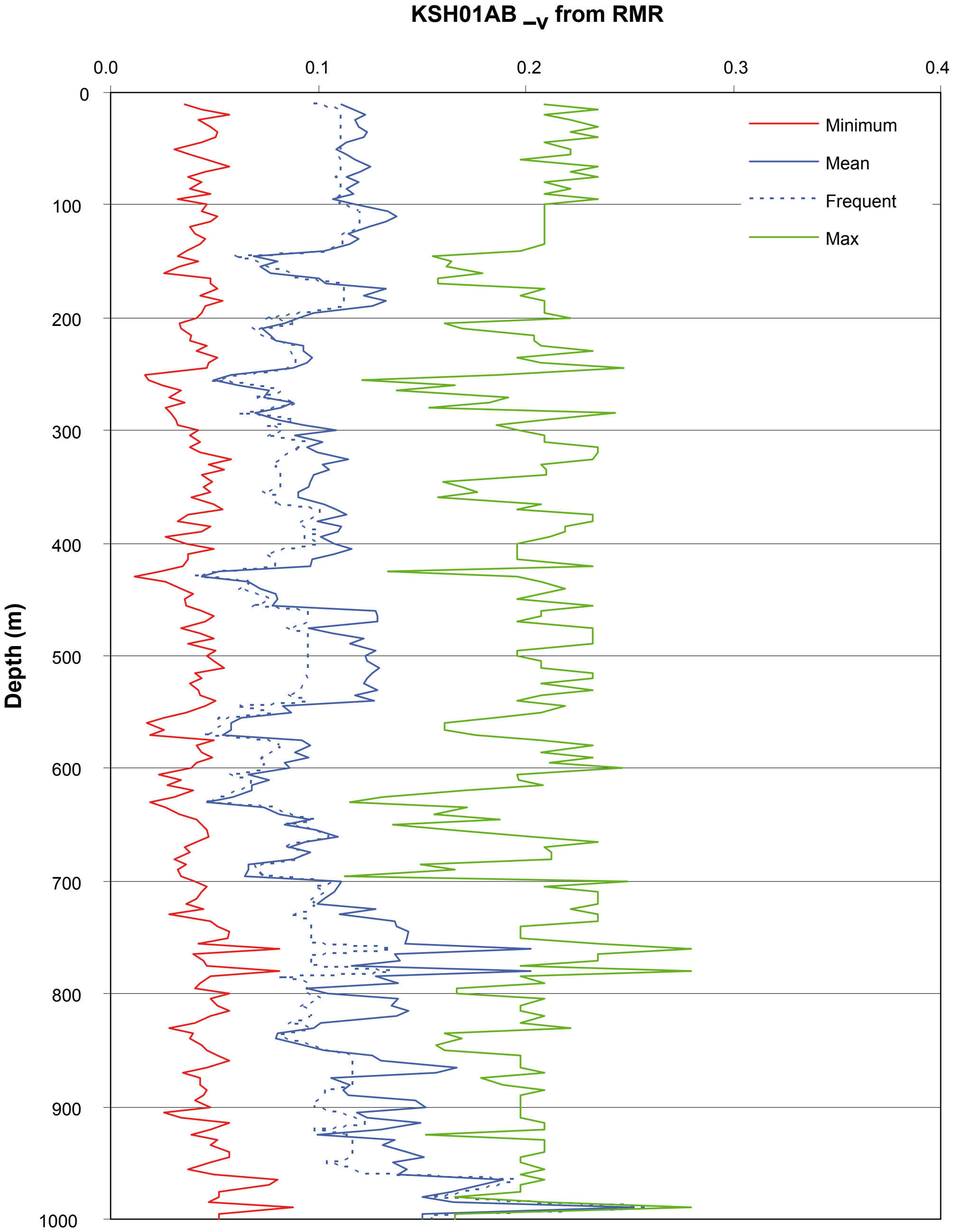
A1.5.1 RMR

Summary of Poisson's ratio (v) derived from RMR for borehole KSH01A and B (core sections of 5 m, Hoek and Brown's a = 0.5).

Rock Unit	Minimum v	Average v	Frequent v	Maximum v	Standard deviation	Min possible v	Max possible v
5–100 RU 1	0.11	0.12	0.12	0.13	0	0.03	0.23
100–205 RU 1*	0.07	0.11	0.11	0.14	0.02	0.03	0.22
205–245 RU 2	0.07	0.09	0.09	0.10	0.01	0.03	0.25
245–320 RU 1**	0.05	0.08	0.08	0.11	0.02	0.02	0.24
320–365 RU 2	0.09	0.10	0.10	0.11	0.01	0.04	0.23
365–420 RU 2	0.10	0.11	0.11	0.12	0.01	0.03	0.23
420–455 DZ 3	0.04	0.07	0.07	0.08	0.01	0.01	0.23
455–540 RU 2	0.10	0.12	0.12	0.13	0.01	0.03	0.23
540–605 DZ 4a	0.05	0.08	0.08	0.10	0.02	0.02	0.25
605–630 DZ 4b and c	0.05	0.06	0.07	0.08	0.01	0.01	0.23
630–720 RU3 ***	0.06	0.09	0.10	0.11	0.02	0.03	0.25
720–840 RU 3 ****	0.08	0.13	0.14	0.20	0.03	0.03	0.28
840–955 RU 4	0.09	0.13	0.13	0.17	0.02	0.03	0.21
955–1,000 RU 3	0.14	0.16	0.15	0.25	0.03	0.04	0.28
RU 1	0.05	0.10	0.11	0.14	0.02	0.02	0.24
RU 2	0.04	0.09	0.10	0.13	0.02	0.01	0.25
RU 3	0.06	0.12	0.12	0.25	0.04	0.03	0.28
RU 4	0.09	0.13	0.13	0.17	0.02	0.03	0.21
Competent rock	0.07	0.12	0.12	0.25	0.03	0.03	0.28
Fractured rock	0.04	0.07	0.07	0.10	0.01	0.01	0.25
Whole borehole	0.04	0.11	0.11	0.25	0.03	0.01	0.28

* Including DZ 1 (136.5–160.0). ** Including DZ 2a, b and c (239.5–251.5(DZ 2a); 251.5–259.0 (DZ 2b); 259.0–287.0 (DZ 2c)). *** Including DZ 5a, b and c (672.0–286.5 (DZ 5a); 686.5–692.5 (DZ 5b); 692.5–693.0 (DZ 5c)). **** Including DZ 6 and 7 (766.0–767.0 (DZ 6); 833.5–834.5 (DZ 7)).

Variation of Poisson's ratio (ν) with depth for borehole KSH01A and B (Hoek and Brown's a = 0.5). The values are given every 5 m.



A1.6 Uniaxial compressive strength

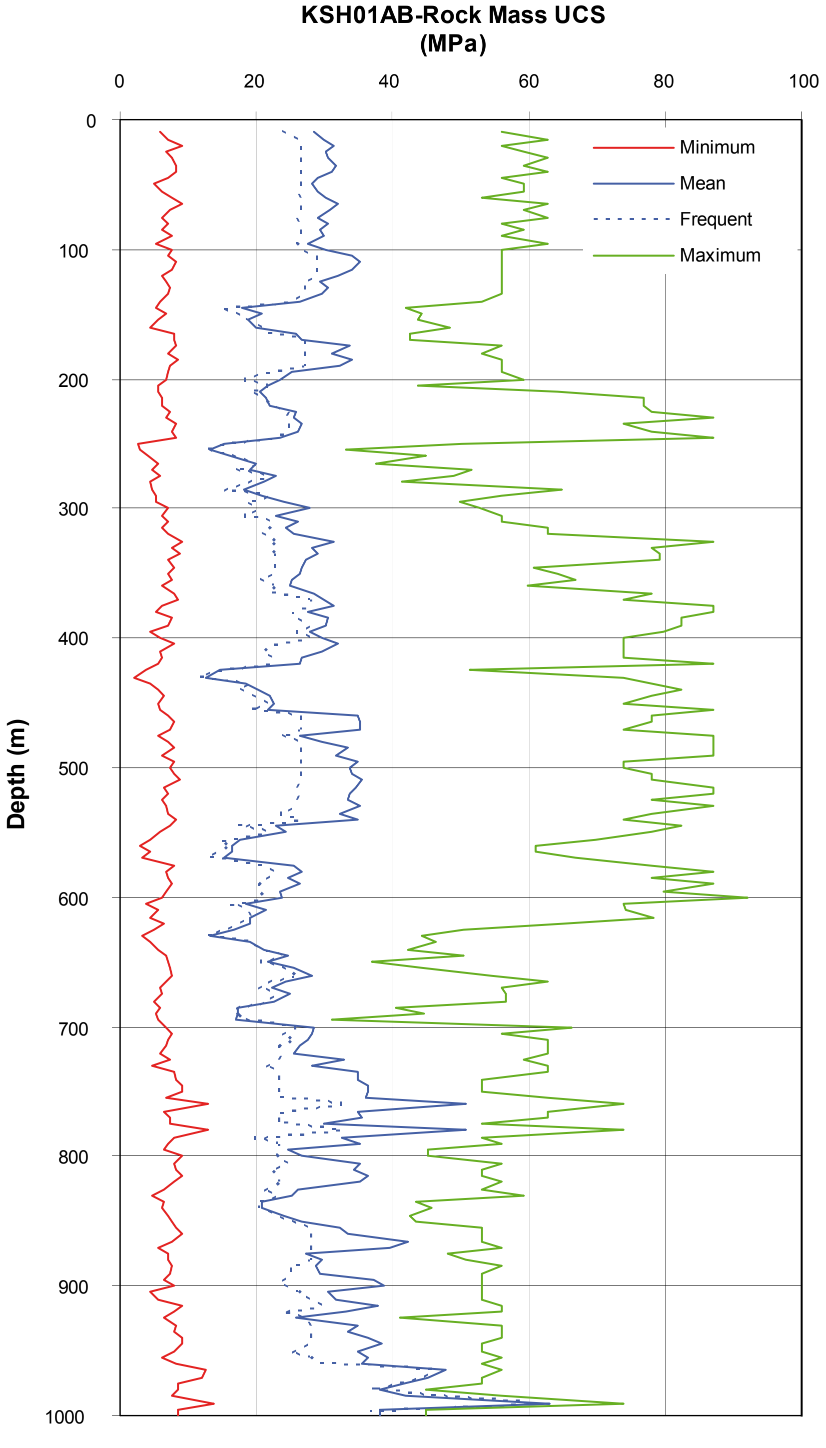
A1.6.1 RMR

Summary of the uniaxial compressive strength of the rock mass derived from RMR for borehole KSH01A and B (core sections of 5 m, Hoek and Brown's a = 0.5).

Rock Unit	Minimum UCS	Average UCS	Frequent UCS	Maximum UCS	Standard deviation	Min possible UCS	Max possible UCS
5–100 RU 1	28	30	30	32	1.2	5.0	63
100–205 RU 1*	18	28	29	35	5.6	4.3	59
205–245 RU 2	20	24	25	27	2.4	5.5	87
245–320 RU 1**	13	21	21	28	4.3	2.7	65
320–365 RU 2	25	28	27	31	2.0	6.3	87
365–420 RU 2	27	29	30	32	1.8	4.4	87
420–455 DZ 3	13	19	20	23	3.9	2.0	87
455–540 RU 2	26	34	34	35	2.4	5.5	87
540–605 DZ 4a	15	22	23	27	4.2	2.9	92
605–630 DZ 4b and c	13	18	19	21	3.0	3.1	78
630–720 RU3 ***	17	24	25	29	3.9	4.4	66
720–840 RU 3 ****	21	33	35	51	7.4	4.6	74
840–955 RU 4	24	33	33	42	4.9	4.3	56
955–1,000 RU 3	35	42	38	63	7.8	6.1	74
RU 1	13	27	29	35	5.4	2.7	65
RU 2	13	26	27	35	6.1	2.0	92
RU 3	17	32	30	63	9.5	4.4	74
RU 4	24	33	33	42	4.9	4.3	56
Competent rock	19	31	30	63	6.2	4.3	87
Fractured rock	13	20	20	27	3.8	2.0	92
Whole borehole	13	29	28	63	7.4	2.0	92

* Including DZ 1 (136.5–160.0). ** Including DZ 2a, b and c (239.5–251.5(DZ 2a); 251.5–259.0 (DZ 2b); 259.0–287.0 (DZ 2c)). *** Including DZ 5a, b and c (672.0–286.5 (DZ 5a); 686.5–692.5 (DZ 5b); 692.5–693.0 (DZ 5c)). **** Including DZ 6 and 7 (766.0–767.0 (DZ 6); 833.5–834.5 (DZ 7)).

Variation of the uniaxial compressive strength of the rock mass with depth for borehole KSH01A and B (Hoek and Brown's a = 0.5). The values are given every 5 m.



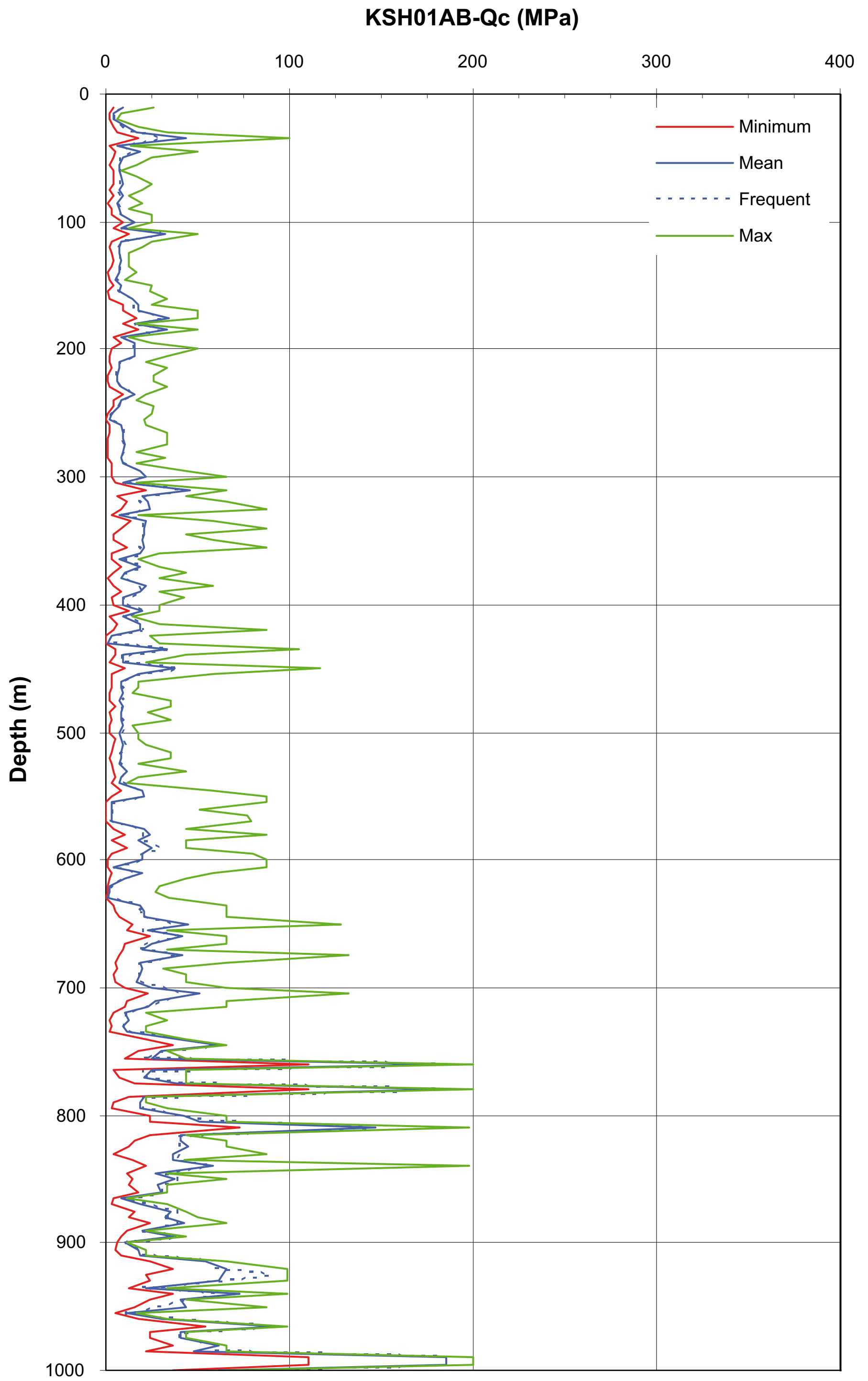
A1.6.2 Q

Summary of Qc derived from Q for borehole KSH01A and B (core sections of 5 m).

Rock Unit	Minimum Qc	Average Qc	Frequent Qc	Maximum Qc	Standard deviation	Min possible Qc	Max possible Qc
5–100 RU 1	4.4	11	8.8	44	8.8	1.6	100
100–205 RU 1*	5.2	14	8.5	34	9.1	1.0	50
205–245 RU 2	6.0	8.1	7.3	15	3.0	0.9	33
245–320 RU 1**	1.7	14	9.8	46	11	0.5	66
320–365 RU 2	7.5	18	21	24	6.1	3.1	88
365–420 RU 2	8.8	15	18	22	5.3	1.5	88
420–455 DZ 3	1.0	16	9.8	38	45	0.1	117
455–540 RU 2	7.0	8.5	8.4	11.3	1.0	1.6	44
540–605 DZ 4a	2.8	14	20	25	9.3	0.2	88
605–630 DZ 4b and c	1.3	7.2	2.0	20	8.1	0.1	58
630–720 RU3 ***	10	26	22	51	11	3.8	132
720–840 RU 3 ****	9.8	50	38	185	50	1.9	200
840–955 RU 4	8.7	35	32	73	19	3.3	99
955–1,000 RU 3	31	83	61	185	61	18	200
RU 1	1.7	13	9.1	46	9.4	0.5	100
RU 2	1.0	12	9.1	38	7.8	0.1	117
RU 3	9.8	47	37	185	47	1.9	200
RU 4	8.7	35	32	73	19	3.3	99
Competent rock	4.4	27	19	185	32	0.9	200
Fractured rock	1.0	13	9.7	42	9.9	0.1	132
Whole borehole	1.0	24	18	185	29	0.1	200

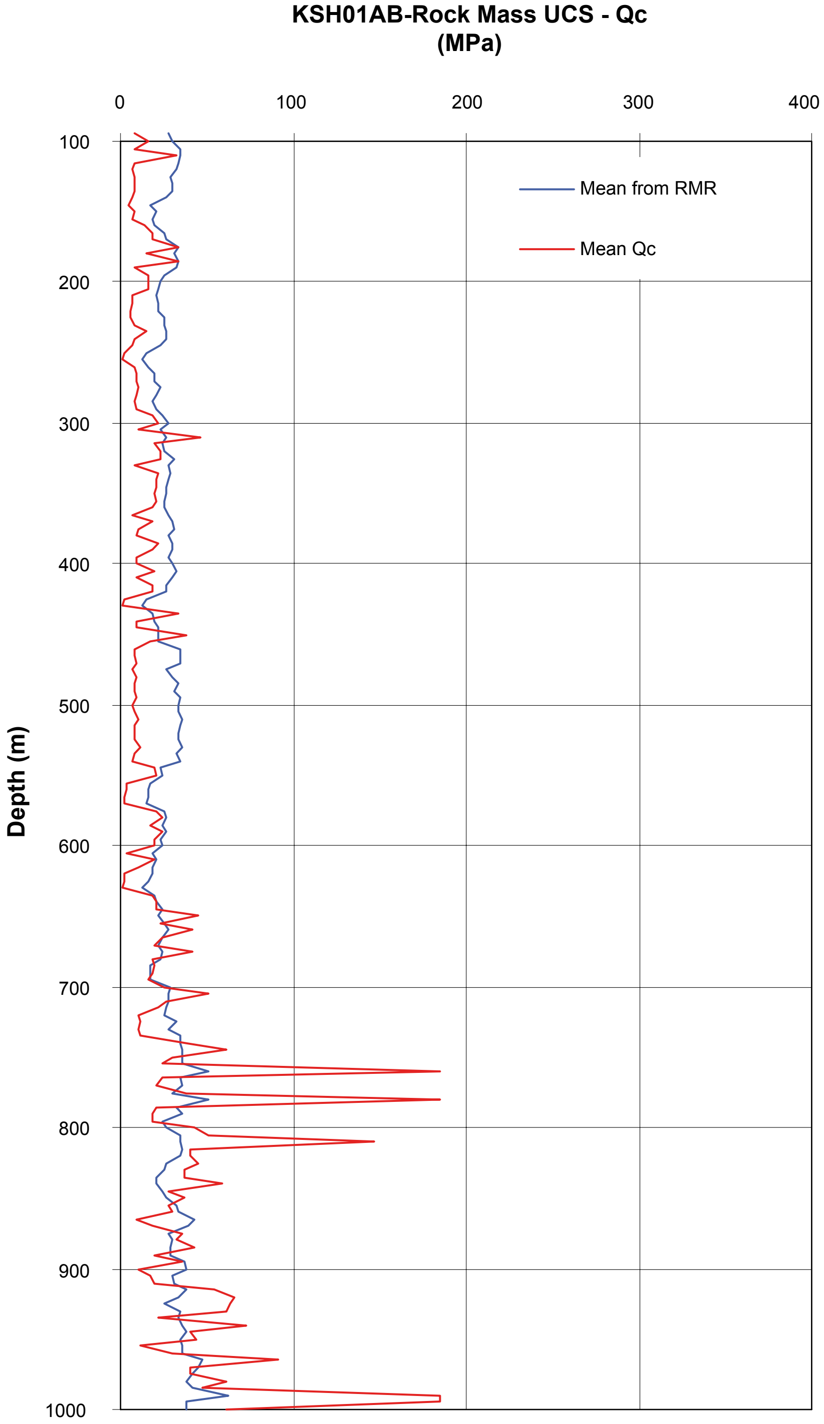
* Including DZ 1 (136.5–160.0). ** Including DZ 2a, b and c (239.5–251.5(DZ 2a); 251.5–259.0 (DZ 2b); 259.0–287.0 (DZ 2c)). *** Including DZ 5a, b and c (672.0–286.5 (DZ 5a); 686.5–692.5 (DZ 5b); 692.5–693.0 (DZ 5c)). **** Including DZ 6 and 7 (766.0–767.0 (DZ 6); 833.5–834.5 (DZ 7)).

Variation of Q_c with depth for borehole KSH01A and B. The values are given every 5 m.



A1.6.3 Comparison

Comparison of the rock mass compressive strength from RMR and Q for borehole KSH01A and B (Hoek and Brown's a = 0.5).



A1.7 Friction angle and cohesion and of the rock mass

A1.7.1 RMR

Summary of the friction angle (φ) of the rock mass derived from RMR for borehole KSH01A and B (10–30 MPa) (core sections of 5 m, Hoek and Brown's a = 0.5).

Rock Unit	Minimum φ'	Average φ'	Frequent φ'	Maximum φ'	Standard deviation	Min possible φ'	Max possible φ'
5–100 RU 1	44	45	45	45	0.2	32	50
100–205 RU 1*	42	44	45	46	1.1	31	50
205–245 RU 2	43	43	44	44	0.5	32	50
245–320 RU 1**	40	43	43	44	1.1	29	50
320–365 RU 2	44	44	44	45	0.4	33	50
365–420 RU 2	44	44	44	45	0.3	31	50
420–455 DZ 3	40	42	42	43	1.2	27	50
455–540 RU 2	44	45	45	45	0.4	32	50
540–605 DZ 4a	41	43	43	44	1.1	29	50
605–630 DZ 4b and c	40	42	42	43	1.0	29	50
630–720 RU3 ***	42	43	44	44	0.9	31	50
720–840 RU 3 ****	43	45	45	47	1.1	32	51
840–955 RU 4	44	45	45	46	0.8	31	49
955–1,000 RU 3	45	46	46	48	0.8	33	51
RU 1	40	44	44	46	1.2	29	50
RU 2	40	44	44	45	1.3	27	50
RU 3	42	45	45	48	1.5	31	51
RU 4	44	45	45	46	0.8	31	49
Competent rock	42	45	45	48	1.0	31	51
Fractured rock	40	42	42	44	1.0	27	50
Whole borehole	40	44	44	48	1.4	27	51

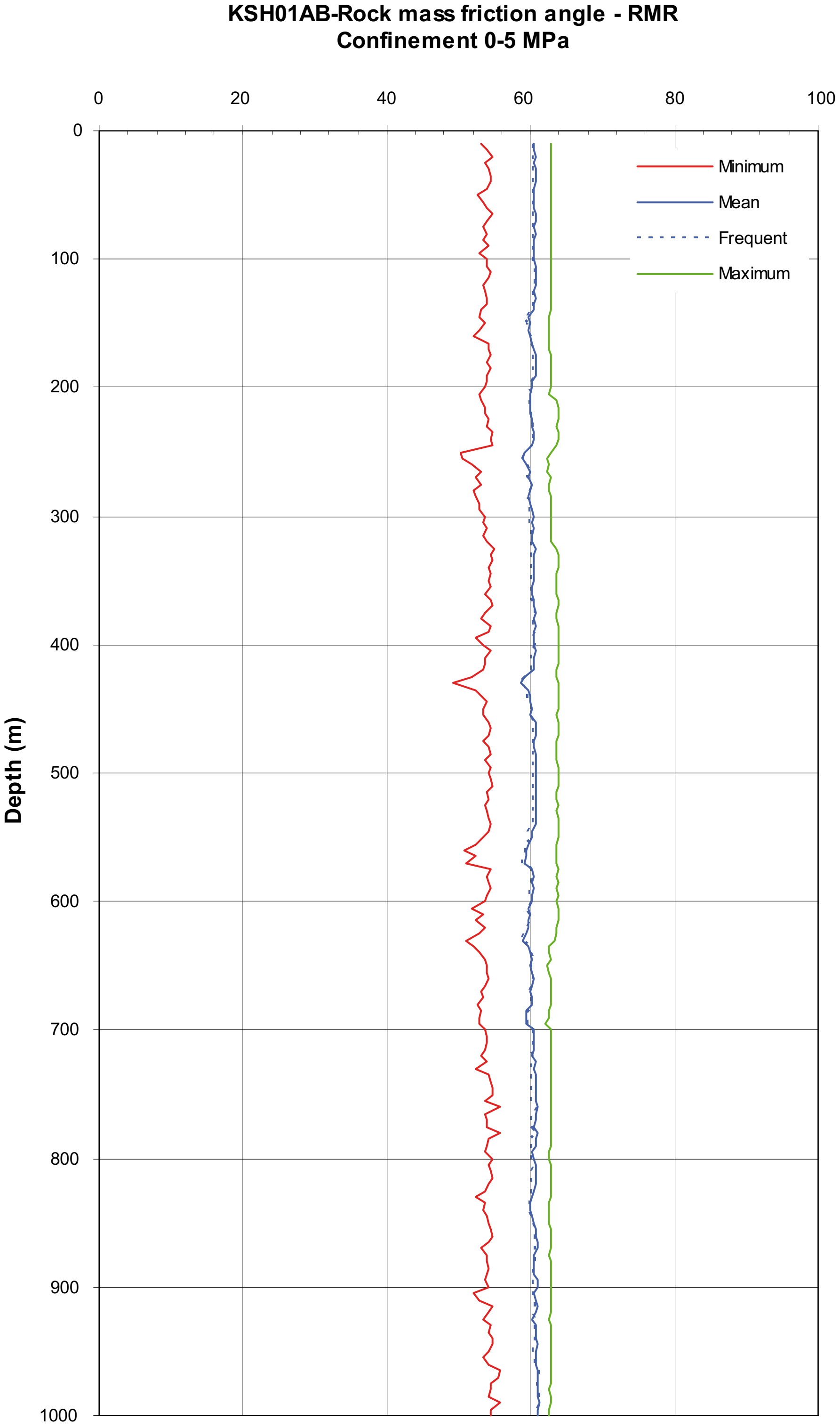
* Including DZ 1 (136.5–160.0). ** Including DZ 2a, b and c (239.5–251.5(DZ 2a); 251.5–259.0 (DZ 2b); 259.0–287.0 (DZ 2c)). *** Including DZ 5a, b and c (672.0–286.5 (DZ 5a); 686.5–692.5 (DZ 5b); 692.5–693.0 (DZ 5c)). **** Including DZ 6 and 7 (766.0–767.0 (DZ 6); 833.5–834.5 (DZ 7)).

Summary of the cohesion c' of the rock mass derived from RMR for borehole KSH01A and B (10–30 MPa) (core sections of 5 m, Hoek and Brown's a = 0.5).

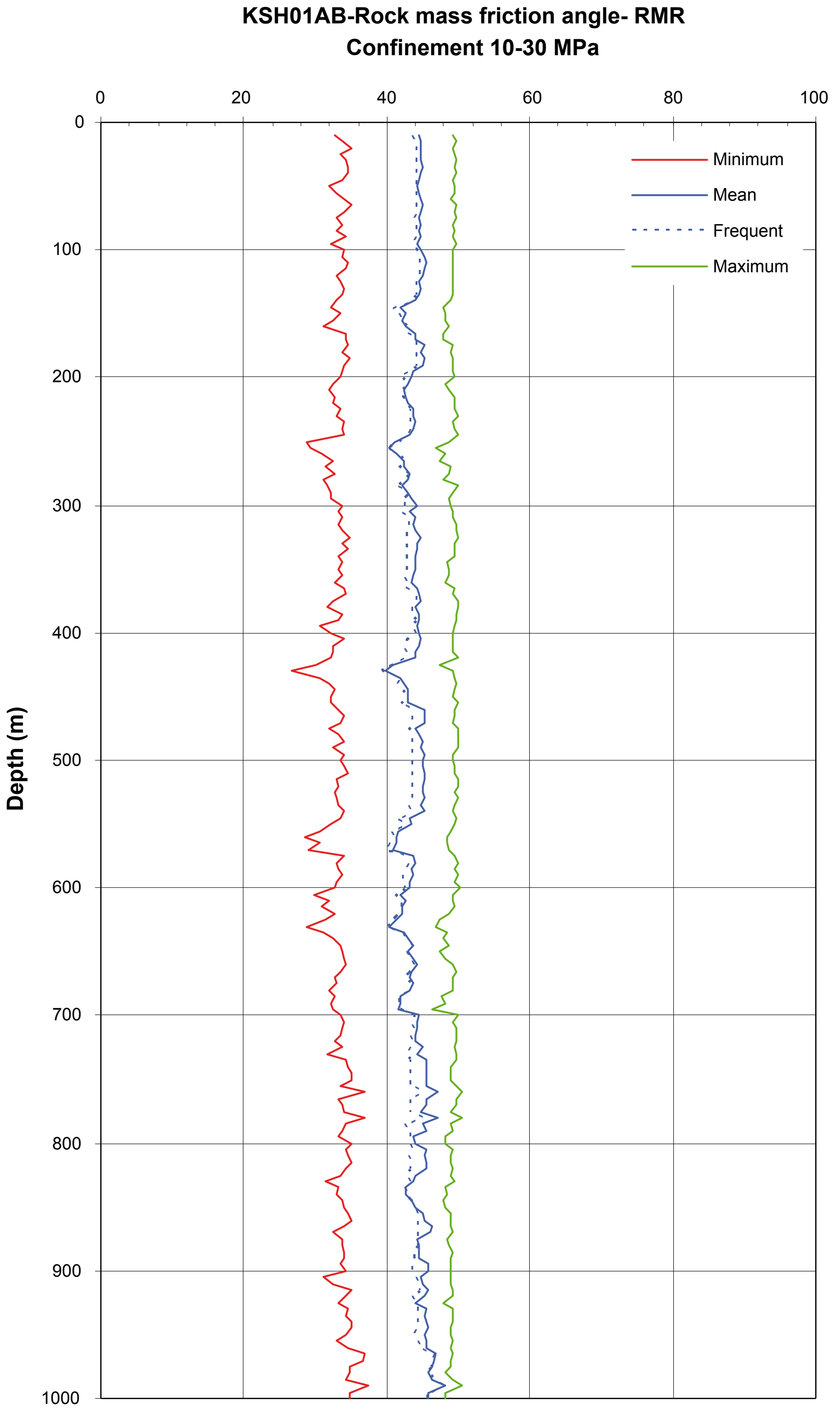
Rock Unit	Minimum C'	Average C'	Frequent C'	Maximum C'	Standard deviation	Min possible C'	Max possible C'
5–100 RU 1	18	18	18	19	0.2	11	24
100–205 RU 1*	16	18	18	19	0.9	11	23
205–245 RU 2	16	17	17	18	0.4	11	24
245–320 RU 1**	15	17	17	18	0.8	10	24
320–365 RU 2	17	18	18	18	0.3	11	24
365–420 RU 2	18	18	18	18	0.3	10	24
420–455 DZ 3	15	16	16	17	0.8	9	24
455–540 RU 2	18	19	19	19	0.4	11	24
540–605 DZ 4a	15	17	17	18	0.8	10	24
605–630 DZ 4b and c	15	16	16	17	0.6	10	23
630–720 RU3 ***	16	17	17	18	0.7	11	24
720–840 RU 3 ****	17	19	19	21	1.1	11	25
840–955 RU 4	17	19	19	20	0.7	11	23
955–1,000 RU 3	19	20	20	23	1.1	11	25
RU 1	15	18	18	19	0.9	10	24
RU 2	15	17	18	19	1.1	9	24
RU 3	16	18	18	23	1.5	11	25
RU 4	17	19	19	20	0.7	11	23
Competent rock	16	18	18	23	1.0	10	25
Fractured rock	15	16	16	18	0.7	9	24
Whole borehole	15	18	18	23	1.2	9	25

* Including DZ 1 (136.5–160.0). ** Including DZ 2a, b and c (239.5–251.5(DZ 2a); 251.5–259.0 (DZ 2b); 259.0–287.0 (DZ 2c)). *** Including DZ 5a, b and c (672.0–286.5 (DZ 5a); 686.5–692.5 (DZ 5b); 692.5–693.0 (DZ 5c)). **** Including DZ 6 and 7 (766.0–767.0 (DZ 6); 833.5–834.5 (DZ 7)).

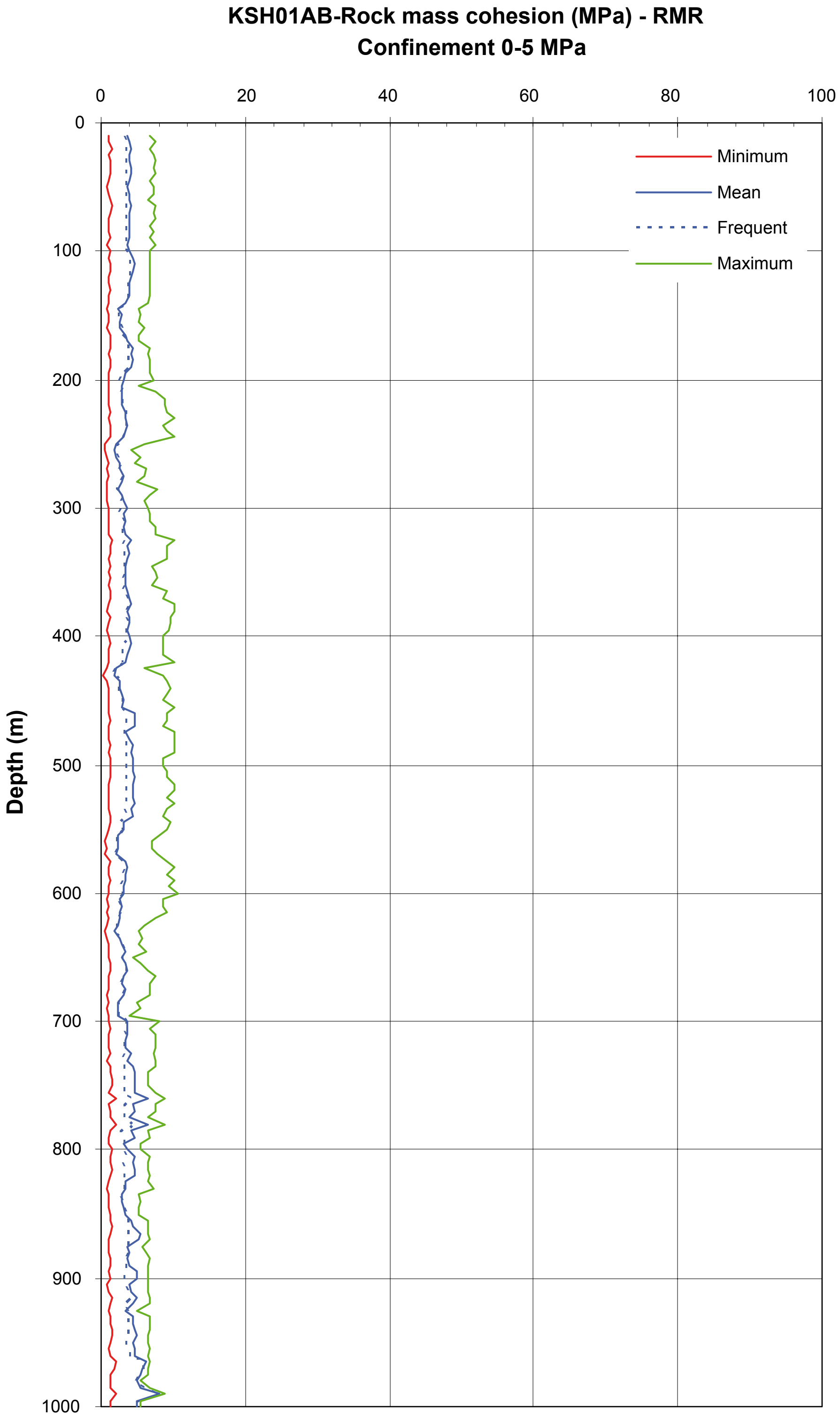
Variation of the rock mass friction angle from RMR for borehole KSH01A and B under stress confinement 0–5 MPa (Hoek and Brown's a = 0.5).



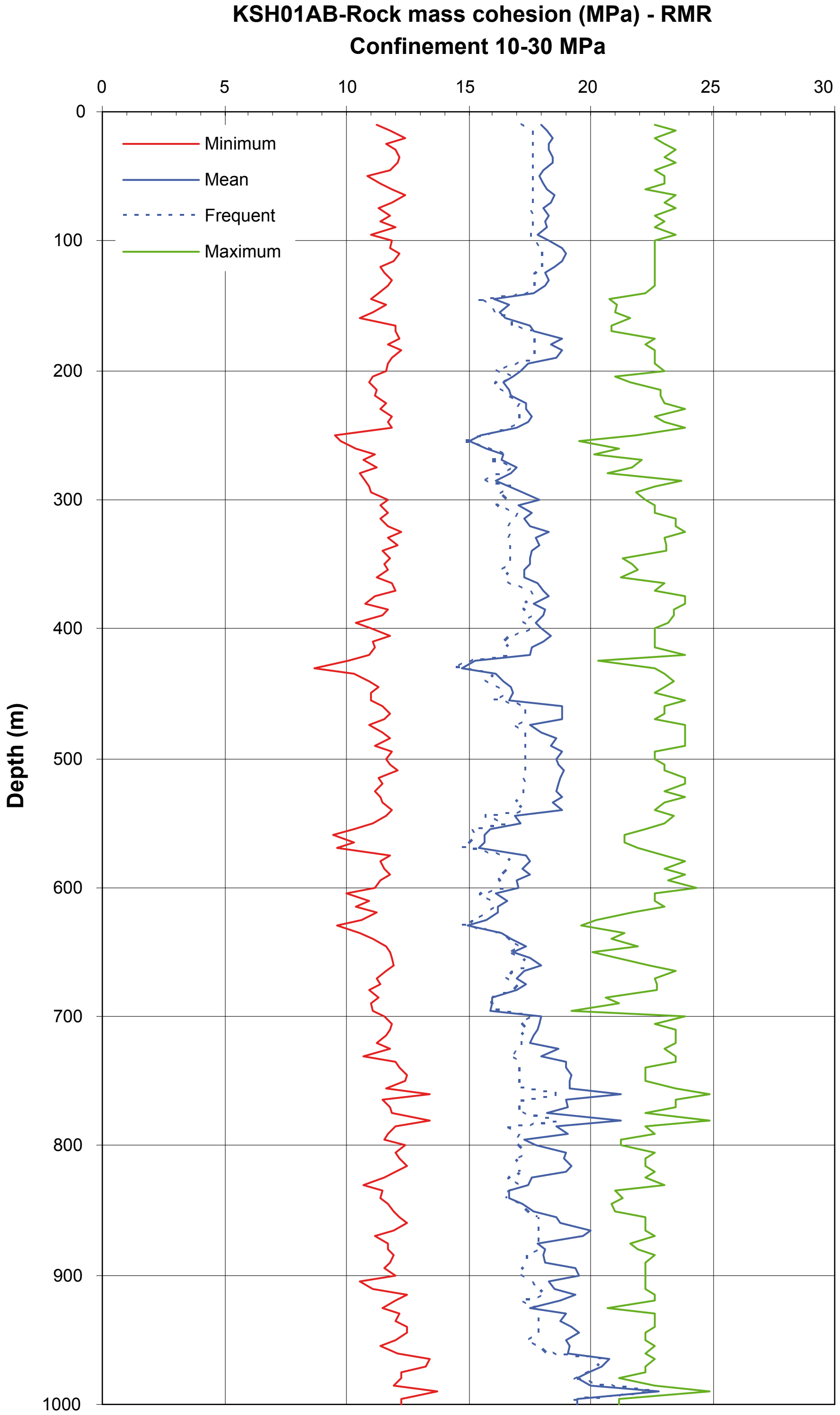
Variation of the rock mass friction angle from RMR for borehole KSH01A and B under stress confinement 10–30 MPa (Hoek and Brown's a = 0.5).



Variation of the rock mass cohesion c' from RMR for borehole KSH01A and B under stress confinement 0–5 MPa (Hoek and Brown's a = 0.5).



Variation of the rock mass cohesion c' from RMR for borehole KSH01A and B under stress confinement 10–30 MPa (Hoek and Brown's a = 0.5).



A1.7.2 Q

Summary of the frictional component FC of the rock mass derived from Qc for borehole KSH01A and B (core sections of 5 m).

Rock Unit	Minimum FC	Average FC	Frequent FC	Maximum FC	Standard deviation	Min possible FC	Max possible FC
5–100 RU 1	26	31	31	43	4.4	14	63
100–205 RU 1*	26	28	28	31	1.4	7.1	56
205–245 RU 2	27	28	28	31	1.3	9.3	56
245–320 RU 1**	18	20	20	30	2.9	3.1	56
320–365 RU 2	17	19	19	21	1.2	6.3	45
365–420 RU 2	17	18	18	20	1.0	6.3	45
420–455 DZ 3	15	18	18	20	1.7	4.7	45
455–540 RU 2	16	19	19	21	1.4	6.3	45
540–605 DZ 4a	17	20	20	23	1.9	2.4	45
605–630 DZ 4b and c	19	21	20	24	1.8	3.1	45
630–720 RU3 ***	17	21	21	24	1.7	6.3	45
720–840 RU 3 ****	14	23	18	60	12	6.3	60
840–955 RU 4	16	19	18	24	1.8	6.3	33
955–1,000 RU 3	18	29	18	60	18	18	60
RU 1	18	27	28	43	5.5	3.1	63
RU 2	15	20	19	31	3.4	2.4	56
RU 3	14	23	20	60	11	6.3	60
RU 4	16	19	18	24	1.8	6.3	33
Competent rock	14	23	20	60	8.0	6.3	63
Fractured rock	15	21	20	31	3.8	2.4	56
Whole borehole	14	23	20	60	7.4	2.4	63

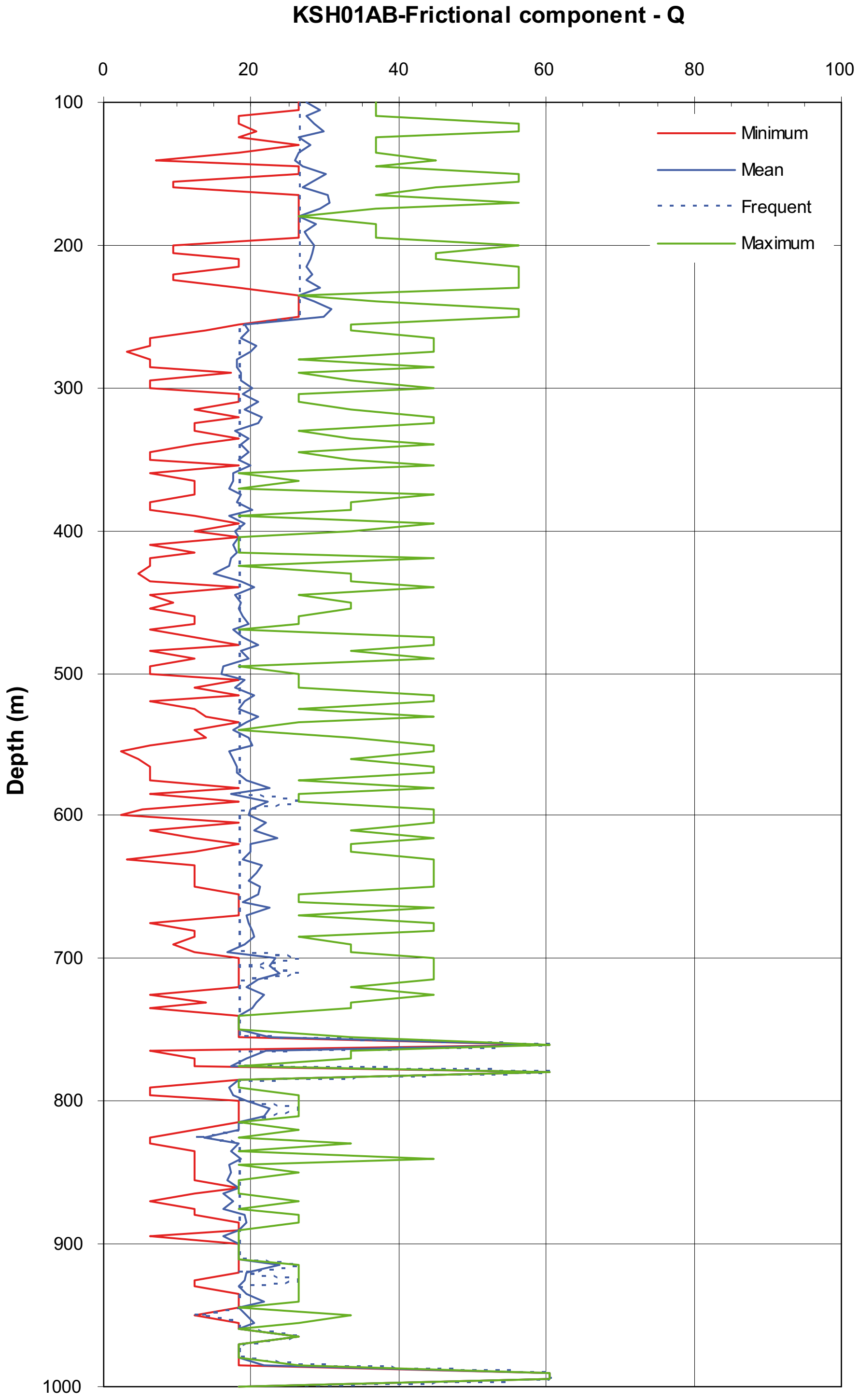
* Including DZ 1 (136.5–160.0). ** Including DZ 2a, b and c (239.5–251.5(DZ 2a); 251.5–259.0 (DZ 2b); 259.0–287.0 (DZ 2c)). *** Including DZ 5a, b and c (672.0–286.5 (DZ 5a); 686.5–692.5 (DZ 5b); 692.5–693.0 (DZ 5c)). **** Including DZ 6 and 7 (766.0–767.0 (DZ 6); 833.5–834.5 (DZ 7)).

Summary of the cohesion component CC of the rock mass derived from Qc for borehole KSH01A and B (core sections of 5 m).

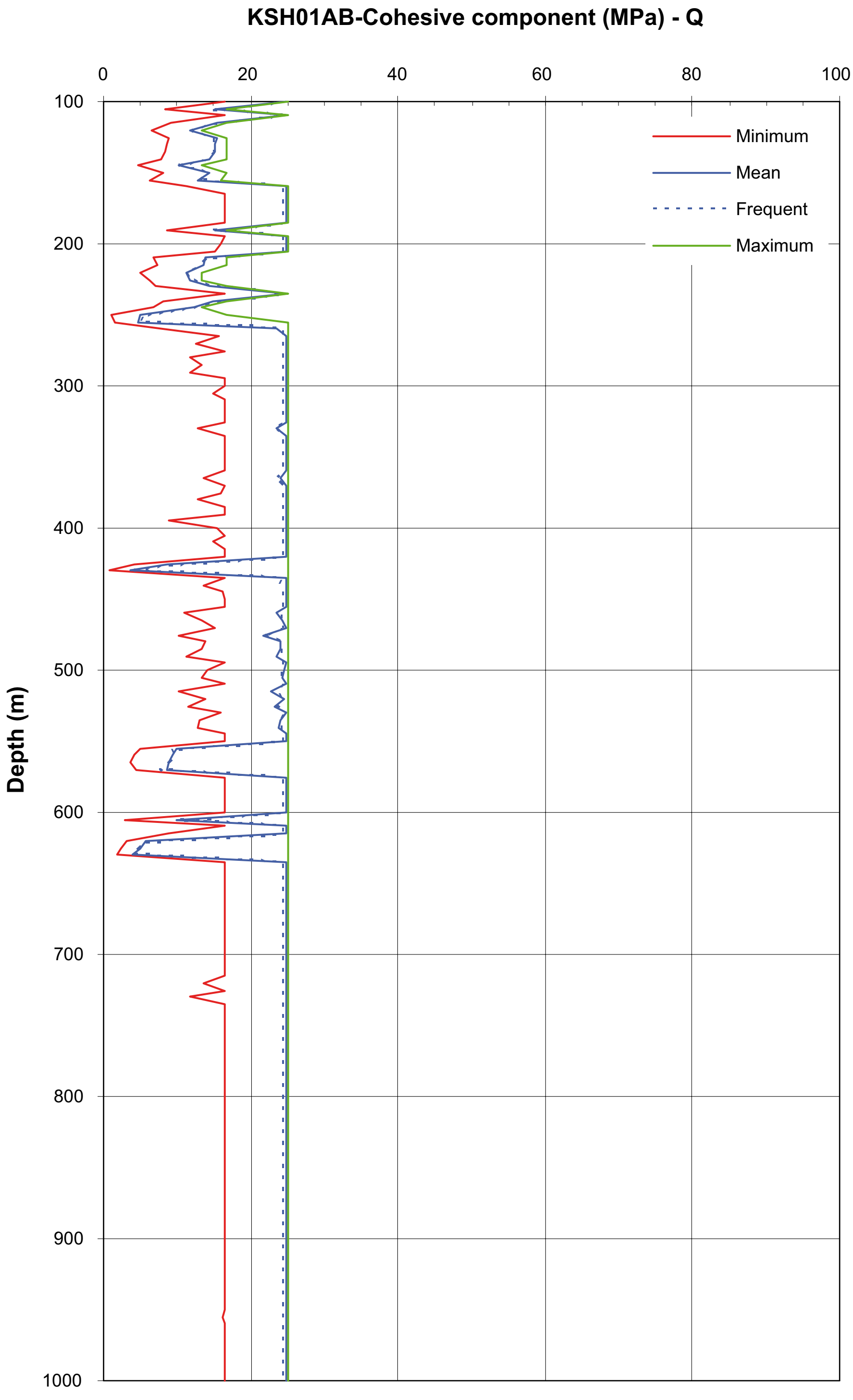
Rock Unit	Minimum CC	Average CC	Frequent CC	Maximum CC	Standard deviation	Min possible CC	Max possible CC
5–100 RU 1	6.1	15	15	25	5.7	3.4	25
100–205 RU 1*	10	19	15	25	5.7	4.8	25
205–245 RU 2	11	15	14	25	4.4	5.1	25
245–320 RU 1**	4.8	22	25	25	7.0	1.2	25
320–365 RU 2	24	25	25	25	0.5	13	25
365–420 RU 2	25	25	25	25	0.0	8.8	25
420–455 DZ 3	3.7	20	25	25	9.3	0.7	25
455–540 RU 2	22	24	24	25	0.9	10	25
540–605 DZ 4a	8.6	19	25	25	7.9	2.9	25
605–630 DZ 4b and c	3.9	13	5.6	25	11	1.7	25
630–720 RU3 ***	25	25	25	25	0.0	14	25
720–840 RU 3 ****	25	25	25	25	0.0	12	25
840–955 RU 4	25	25	25	25	0.0	16	25
955–1,000 RU 3	25	25	25	25	0.0	16	25
RU 1	4.8	19	15	25	6.6	1.2	25
RU 2	3.7	21	25	25	6.7	0.7	25
RU 3	25	25	25	25	0.0	12	25
RU 4	25	25	25	25	0.0	16	25
Competent rock	6.1	23	25	25	4.5	3.4	25
Fractured rock	3.7	19	25	25	8.3	0.7	25
Whole borehole	3.7	22	25	25	5.8	0.7	25

* Including DZ 1 (136.5–160.0). ** Including DZ 2a, b and c (239.5–251.5(DZ 2a); 251.5–259.0 (DZ 2b); 259.0–287.0 (DZ 2c)). *** Including DZ 5a, b and c (672.0–286.5 (DZ 5a); 686.5–692.5 (DZ 5b); 692.5–693.0 (DZ 5c)). **** Including DZ 6 and 7 (766.0–767.0 (DZ 6); 833.5–834.5 (DZ 7)).

Variation of the frictional component FC from Q for borehole KSH01A and B.

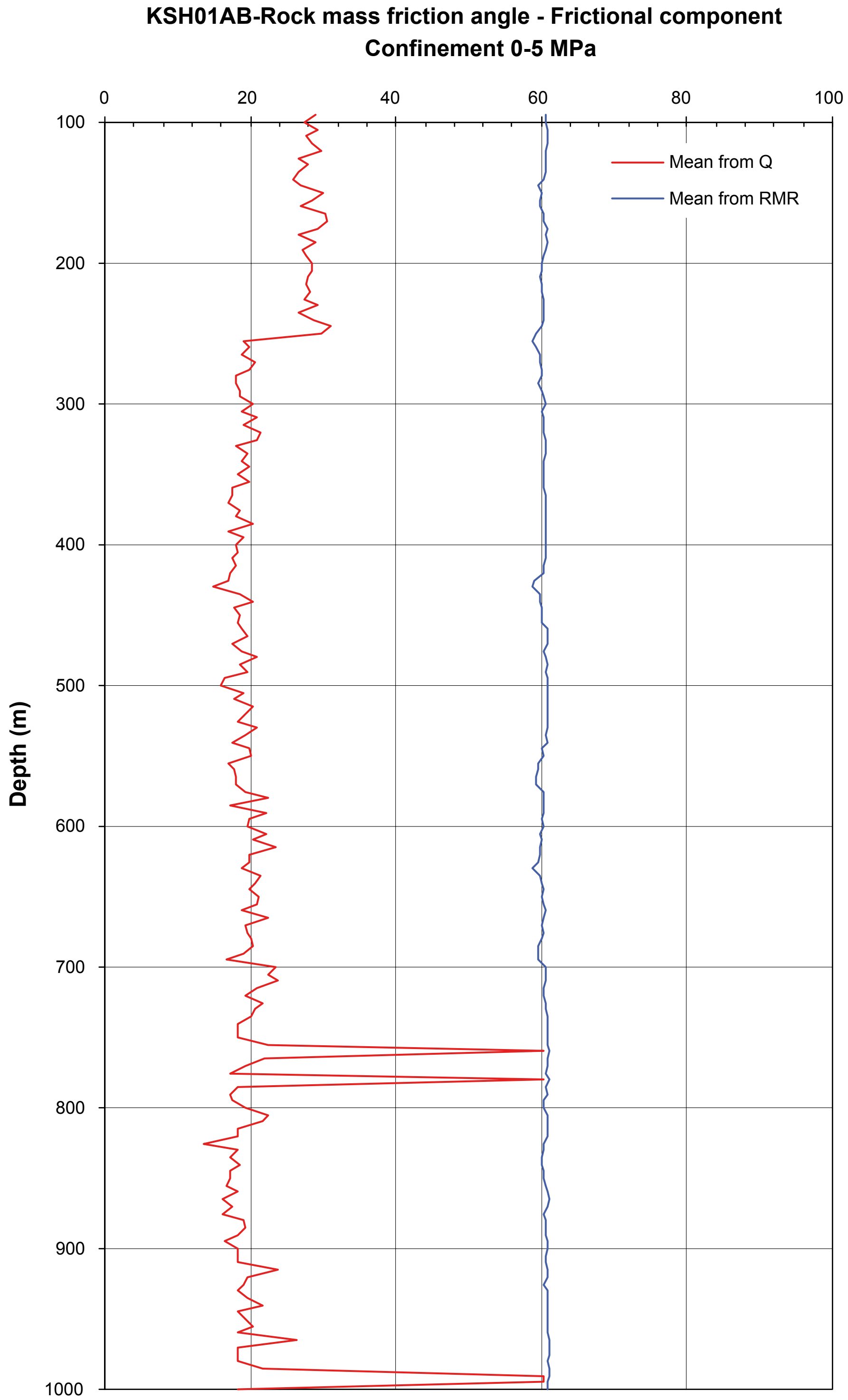


Variation of the cohesive component CC from Qc for borehole KSH01A and B.

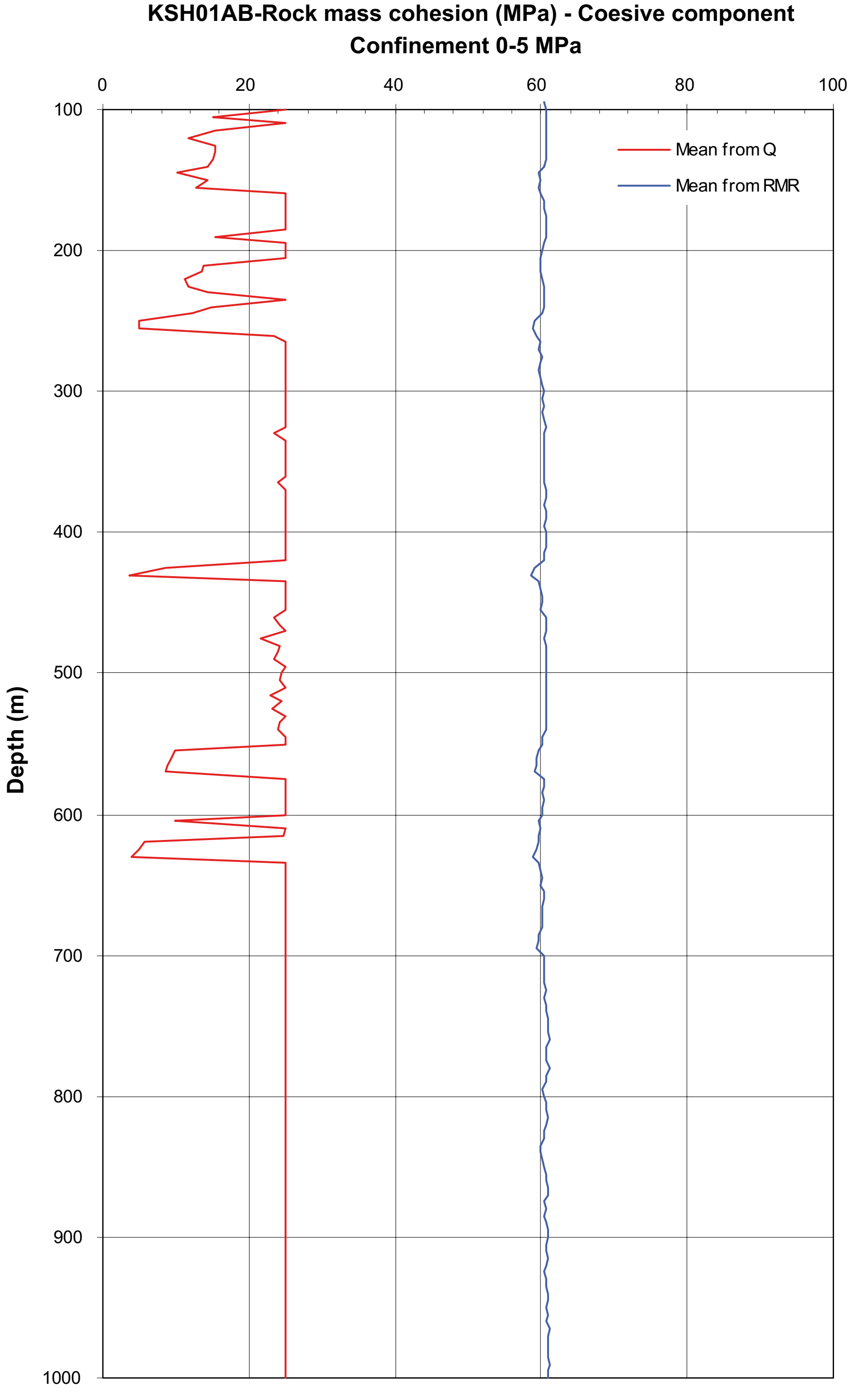


A1.7.3 Comparison

Comparison of the rock mass friction angle from RMR and Q for borehole KSH01A and B under stress confinement 0–5 MPa (Hoek and Brown's a = 0.5).



Comparison of the rock mass cohesion from RMR and Q for borehole KSH01A and B under stress confinement 0–5 MPa (Hoek and Brown's a = 0.5).



Appendix 2

KSH02
Characterisation of the rock mass

A2.1 Fracture orientation and Fisher's constant

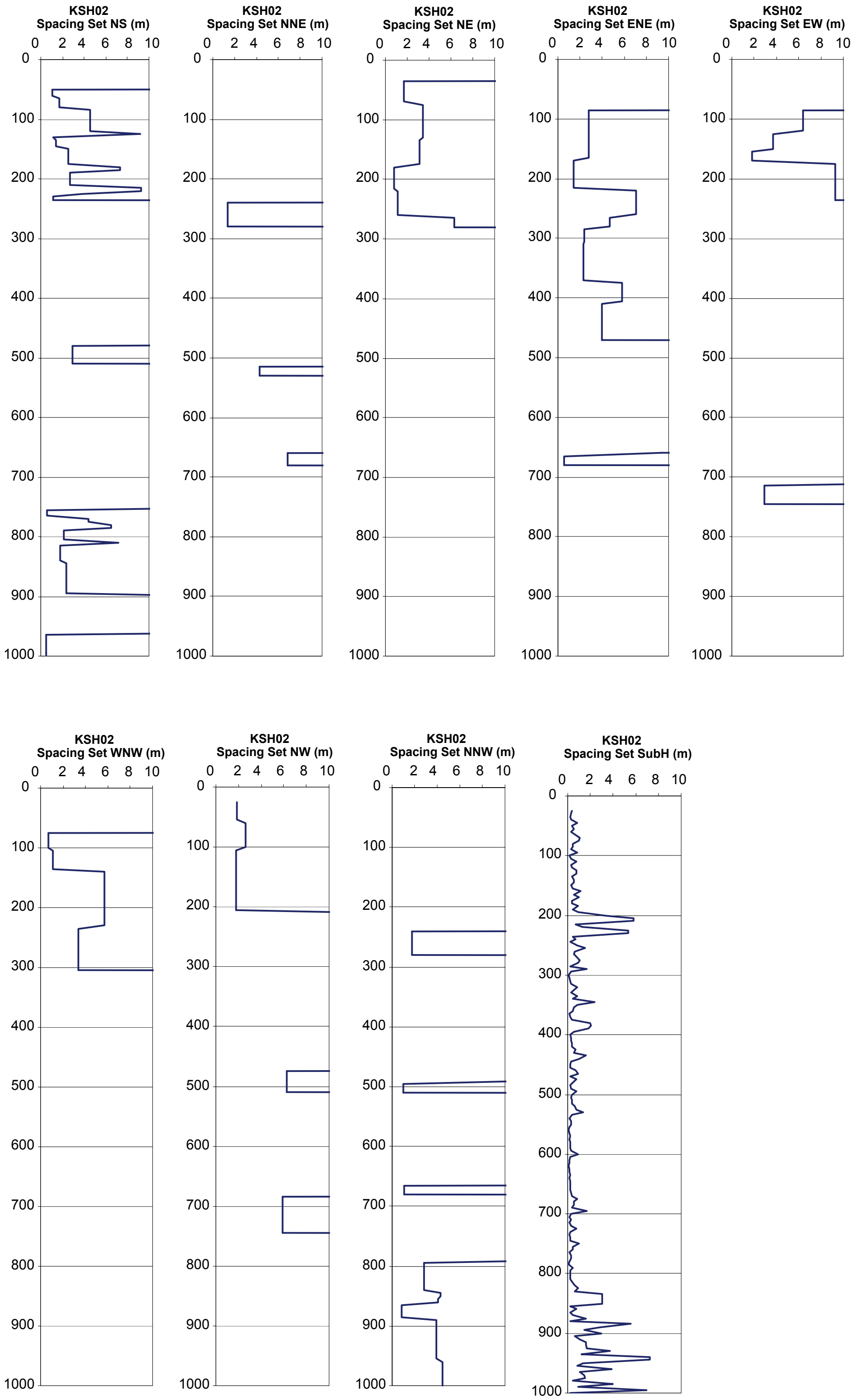
Set identification from the fracture orientation mapped for borehole KSH02 (based on SICADA data received on 07/05/2004). The orientations are given as strike/dip (right-hand rule).

Depth (m)	No of fract	NS	NNE	NE	ENE	EW	WNW	NW	NNW	SubH
20–80	228	174/71		055/76			118/74	326/65		082/07
80–234	477	007/77		036/89	258/71	093/61	122/80	325/72		116/11
234–281	123		013/73	220/76	253/68		291/81		341/71	059/03
281–304	137				258/73		112/71			005/09
304–470	585				250/66					022/07
470–511	218	179/65				093/75		124/73	331/59	346/04
511–532	151		024/46							097/01
532–654	828									354/05
654–681	193		205/55		074/44		305/65		342/58	353/06
681–743	276					097/65		312/61		286/14
743–1,007	571	178/62							334/55	160/06

Fisher's constant of the fracture sets identified for borehole KSH02 (based on SICADA data delivered on 07/05/2004).

Depth (m)	No of fract	NS	NNE	NE	ENE	EW	WNW	NW	NNW	SubH
20–80	228	89		50			126	94		10
80–234	477	102		21	46	102	73	61		11
234–281	123		60	533	118		15		10,217	10
281–304	137				188		287			9
304–470	585				66					11
470–511	218	125				122		63	42	11
511–532	151		27							53
532–654	828									9
654–681	193		27		46		48		115	21
681–743	276					65		87		14
743–1,007	571	36							37	11

Fracture spacing with depth for the five facture sets in borehole KSH02. The values are averaged for each 5 m length of borehole.

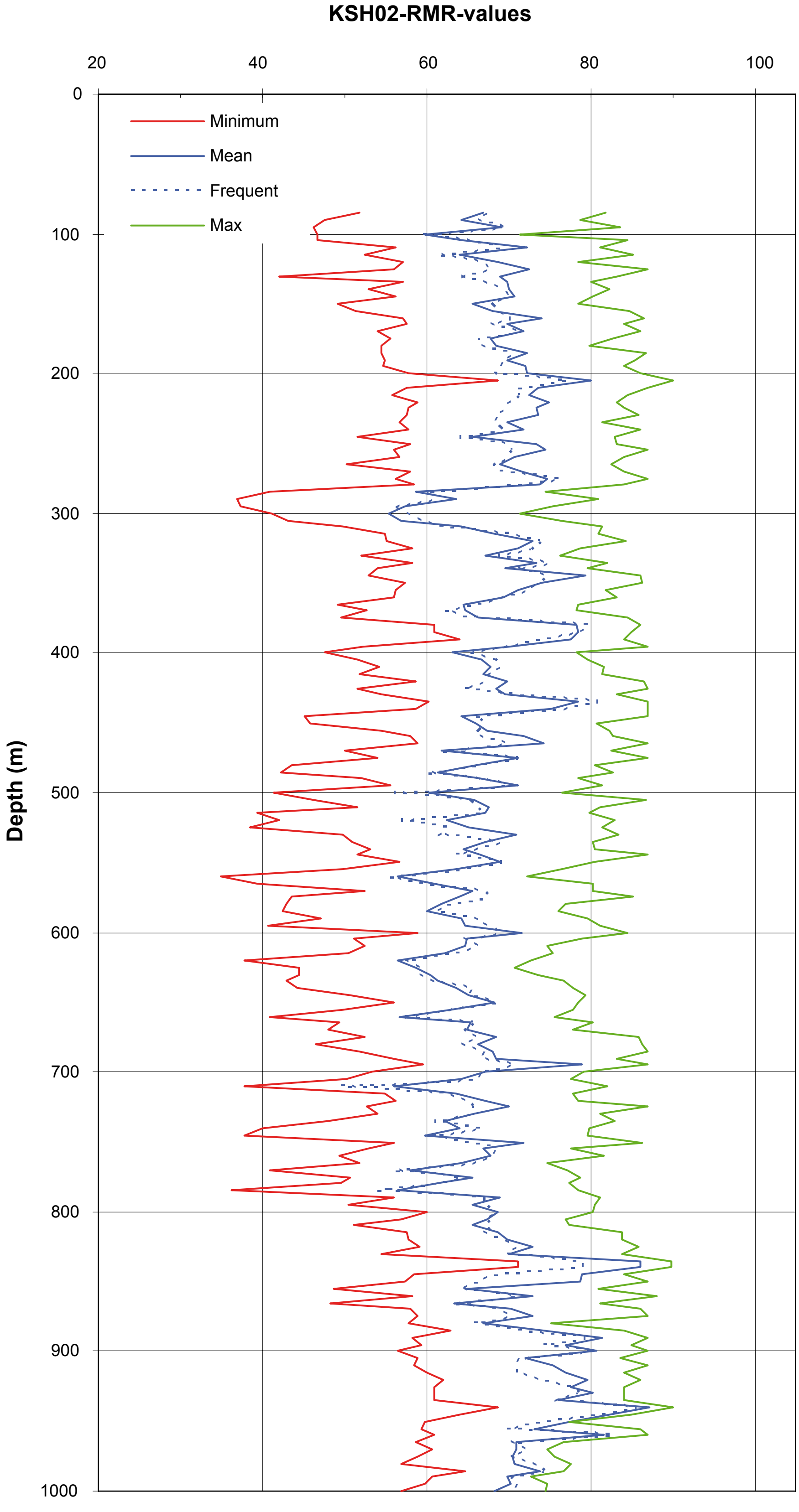


A2.2 RMR

RMR values along borehole KSH02 (core sections of 5 m).

Rock Unit	Minimum RMR	Average RMR	Frequent RMR	Maximum RMR	Standard deviation	Min possible RMR	Max possible RMR
80–235	59.7	70.1	69.9	80.2	4.0	42.0	90.0
235–280 DZ 1a	65.6	71.7	71.8	74.7	2.9	50.3	87.0
280–305 DZ 1b	55.4	58.4	57.4	63.5	3.1	36.9	81.0
305–470	61.8	70.1	69.7	79.5	4.9	45.2	87.0
470–510	60.3	66.3	66.2	71.3	3.9	41.3	87.0
510–530 DZ 2	62.4	66.4	66.1	71.0	3.6	38.6	83.4
530–655	56.4	63.6	64.1	71.5	3.6	34.9	87.0
655–680 DZ 3	56.6	64.4	65.4	68.6	4.6	41.0	86.2
680–745	56.0	65.8	65.8	79.0	5.5	37.8	87.0
745–1,000	56.4	72.4	70.9	87.2	6.9	36.2	90.0
RU1	55.4	69.5	69.8	80.2	5.1	36.9	90.0
RU2	56.0	64.8	64.9	79.0	4.3	34.9	87.0
RU3	56.4	72.4	70.9	87.2	6.9	36.2	90.0
Competent rock	56.0	69.3	68.8	87.2	6.1	34.9	90.0
Fractured rock	55.4	66.3	66.3	74.7	6.1	36.9	90.0
Whole borehole	55.4	68.9	68.7	87.2	6.2	34.9	90.0

Variation of RMR of the rock mass with depth for borehole KSH02. The values are given every 5 m.

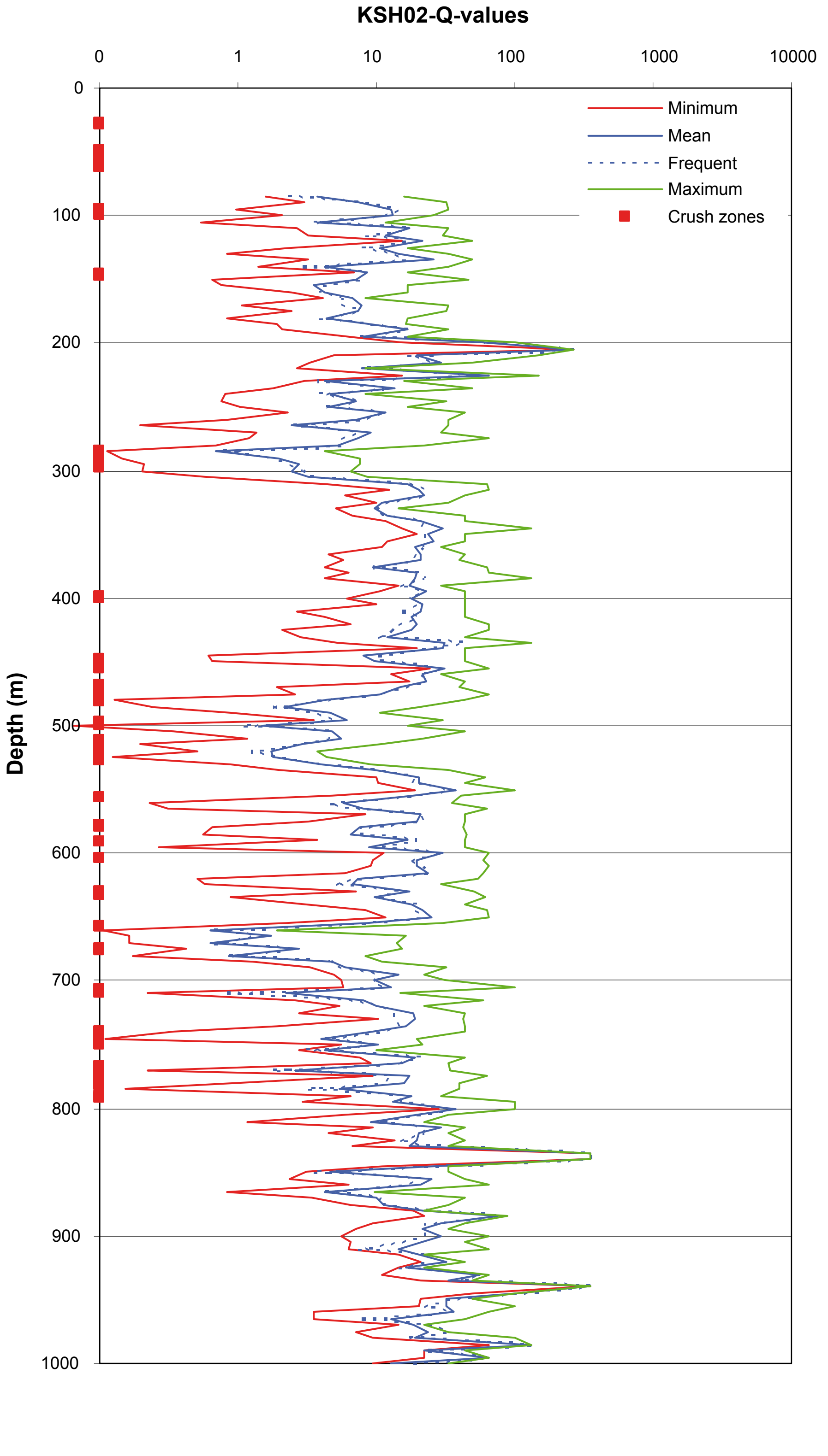


A2.3 Q

Q values along borehole KSH02 (core sections of 5 m).

Rock Unit	Minimum Q	Average Q	Frequent Q	Maximum Q	Min possible Q	Max possible Q
80–235	3.5	22.4	8.7	266.7	0.5	266.7
235–280 DZ 1a	2.5	6.6	7.0	11.6	0.2	66.0
280–305 DZ 1b	0.7	2.2	2.5	3.2	0.11	8.4
305–470	8.2	19.4	19.4	31.6	0.6	132.0
470–510	1.5	5.0	4.7	10.6	0.1	66.0
510–530 DZ 2	1.8	2.6	2.4	4.0	0.12	11.0
530–655	5.7	16.3	17.9	37.7	0.2	99.0
655–680 DZ 3	0.6	1.3	0.9	2.8	0.1	16.3
680–745	2.3	10.4	9.6	19.0	0.11	99.0
745–1,000	2.6	45.3	20.2	352.0	0.2	352.0
RU1	0.7	18.0	12.5	266.7	0.11	266.7
RU2	0.6	10.9	8.6	37.7	0.06	99.0
RU3	2.6	45.3	20.2	352.0	0.2	352.0
Competent rock	1.5	26.2	17.5	352.0	0.06	352.0
Fractured rock	0.6	3.8	2.8	11.6	0.11	66.0
Whole borehole	0.6	23.4	14.6	352.0	0.06	352.0

Variation of Q of the rock mass with depth for borehole KSH02. The values are given every 5 m.



Rock mass properties

A2.4 Deformation modulus

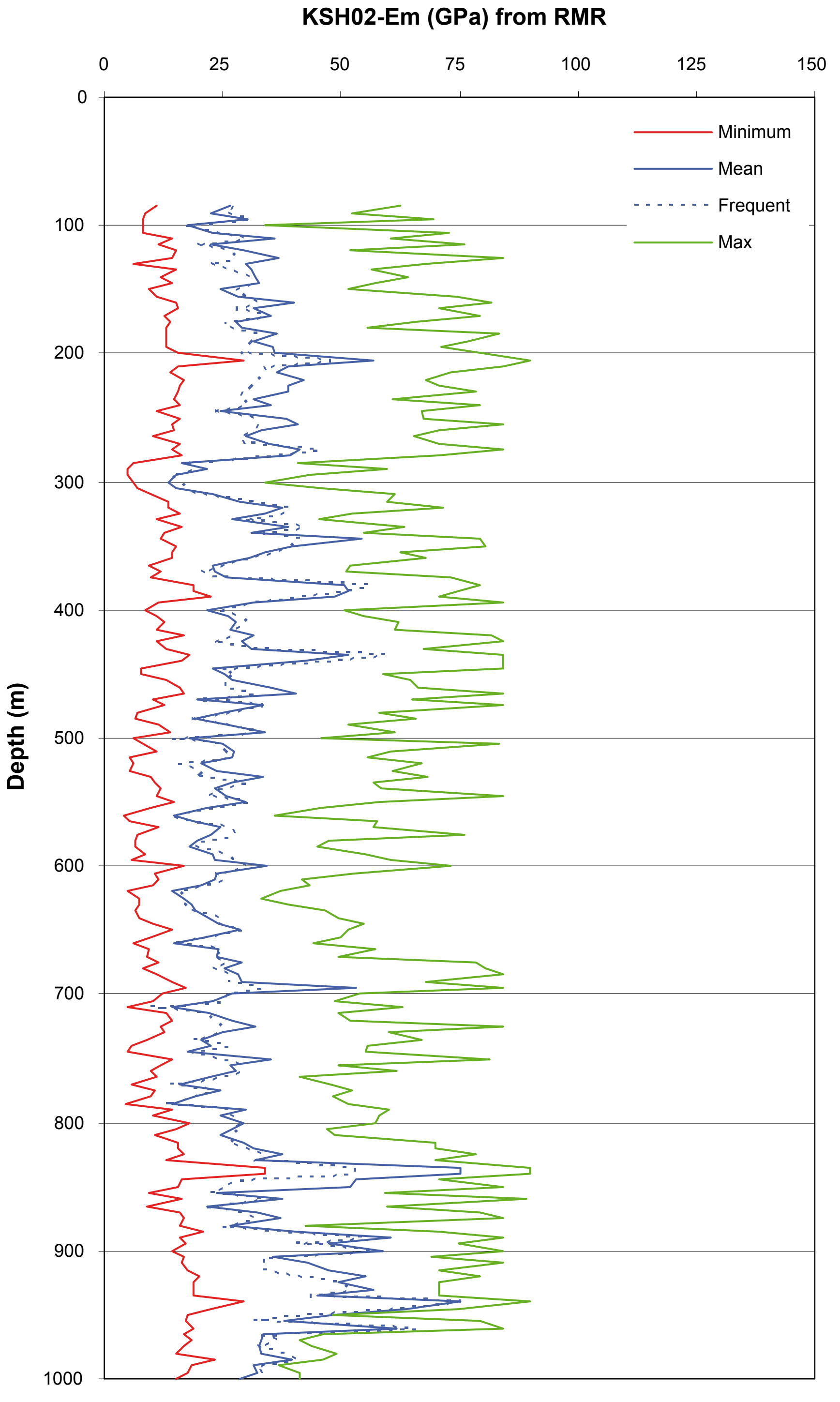
A2.4.1 RMR

Deformation modulus Em derived from RMR along for borehole KSH02 (core sections of 5 m).

Rock Unit	Minimum Em (GPa)	Average Em (GPa)	Frequent Em (GPa)	Maximum Em (GPa)	Standard deviation Em (GPa)	Min possible Em (GPa)	Max possible Em (GPa)
80–235	17.5	32.5	31.5	56.8	7.4	6.3	90.0
235–280 DZ 1a	24.5	35.3	35.1	41.4	5.5	10.2	84.1
280–305 DZ 1b	13.6	16.4	15.3	21.8	3.2	4.7	59.6
305–470	19.8	33.0	31.0	54.5	9.7	7.6	84.1
470–510	18.1	26.1	25.4	34.0	5.8	6.1	84.1
510–530 DZ 2	20.4	26.2	25.4	33.6	5.6	5.2	68.4
530–655	14.4	22.3	22.5	34.5	4.6	4.2	84.1
655–680 DZ 3	14.6	23.4	24.2	29.1	5.4	6.0	80.5
680–745	14.1	26.2	24.8	53.0	9.4	5.0	84.1
745–1,000	14.4	38.8	33.4	75.0	15.2	4.5	90.0
RU1	13.6	32.0	31.3	56.8	9.0	4.7	90.0
RU2	14.1	24.1	23.6	53.0	6.4	4.2	84.1
RU3	14.4	38.8	33.4	75.0	15.2	4.5	90.0
Competent rock	14.1	32.2	29.5	75.0	12.1	4.2	90.0
Fractured rock	13.6	27.0	25.5	41.4	8.9	4.7	84.1
Whole borehole	13.6	31.5	29.3	75.0	11.9	4.2	90.0

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 KSH02. The values are given every 5 m.



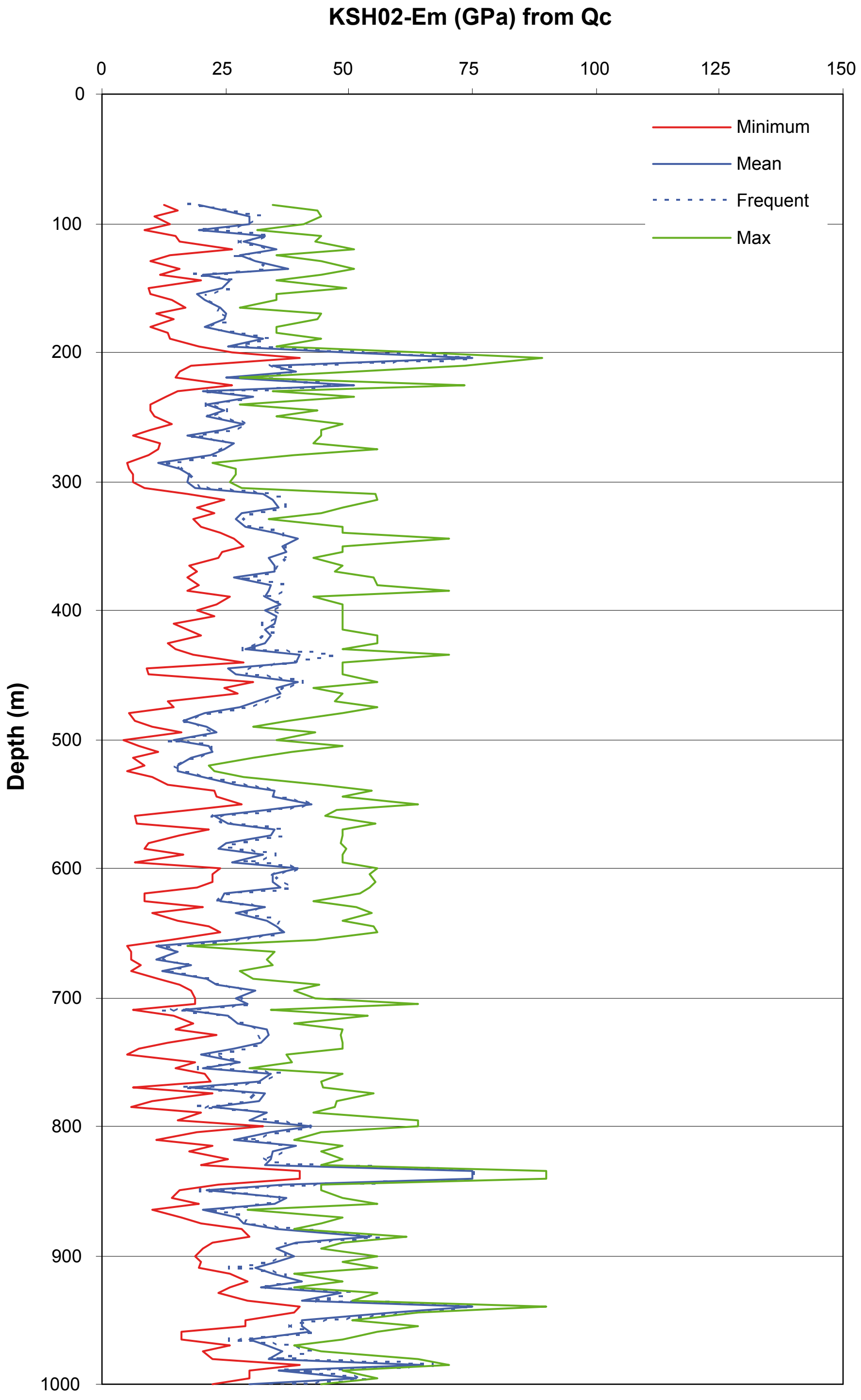
A2.4.2 Q

Deformation modulus Em derived from Q along borehole KSH02 (core sections of 5 m).

Rock Unit	Minimum Em (GPa)	Average Em (GPa)	Frequent Em (GPa)	Maximum Em (GPa)	Standard deviation Em (GPa)	Min possible Em (GPa)	Max possible Em (GPa)
80–235	19.4	30.1	26.1	75.0	11.5	8.7	89.1
235–280 DZ 1a	17.1	23.3	24.3	28.8	3.4	6.2	55.9
280–305 DZ 1b	11.2	16.1	17.2	18.7	3.0	5.1	28.2
305–470	25.6	33.7	34.2	40.2	3.9	9.0	70.5
470–510	14.5	21.0	21.3	27.9	4.1	4.3	55.9
510–530 DZ 2	15.3	17.3	16.9	20.2	2.4	5.3	30.8
530–655	22.7	31.3	33.2	42.6	5.5	6.5	64.0
655–680 DZ 3	10.8	13.4	12.1	17.9	3.1	5.0	35.1
680–745	16.7	26.8	27.0	33.9	5.4	5.1	64.0
745–1,000	17.5	37.7	34.6	75.0	13.0	5.7	90.0
RU1	11.2	29.9	29.4	75.0	9.1	5.1	89.1
RU2	10.8	26.1	26.1	42.6	7.8	4.3	64.0
RU3	17.5	37.7	34.6	75.0	13.0	5.7	90.0
Competent rock	14.5	32.7	33.0	75.0	10.4	4.3	90.0
Fractured rock	10.8	18.6	17.9	28.8	5.0	5.0	55.9
Whole borehole	10.8	30.9	31.0	75.0	10.9	4.3	90.0

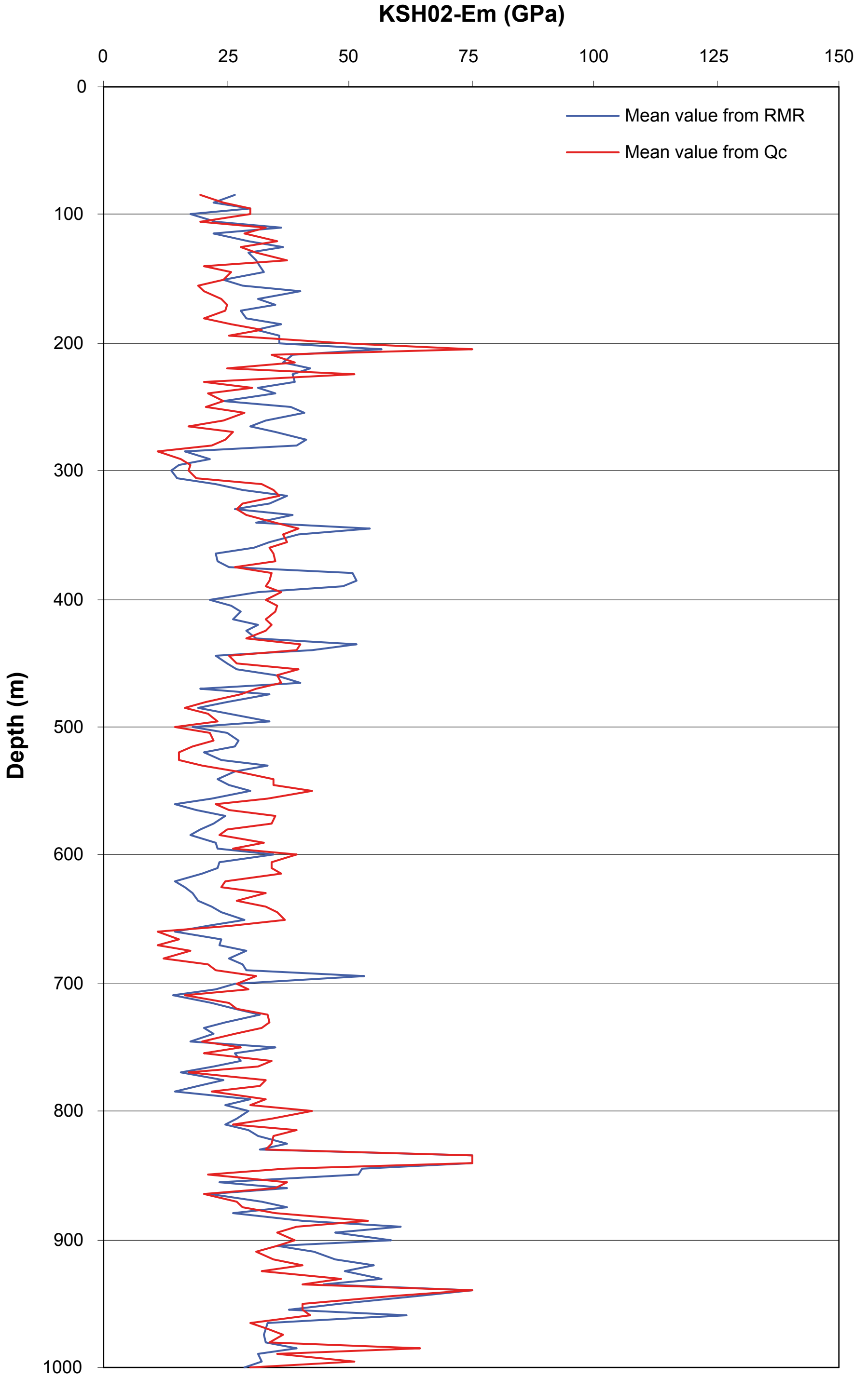
The maximum mean Em and the maximum confidence Em have a physical threshold in the Young's modulus of the intact rock, which is 75 and 90 GPa, respectively.

Variation of the deformation modulus of the rock mass obtained from Q_c with depth for borehole KSH02. The values are given every 5 m.



A2.4.3 Comparison

Comparison between the mean values of the deformation modulus E_m obtained from RMR and Qc for different depths for borehole KSH02.



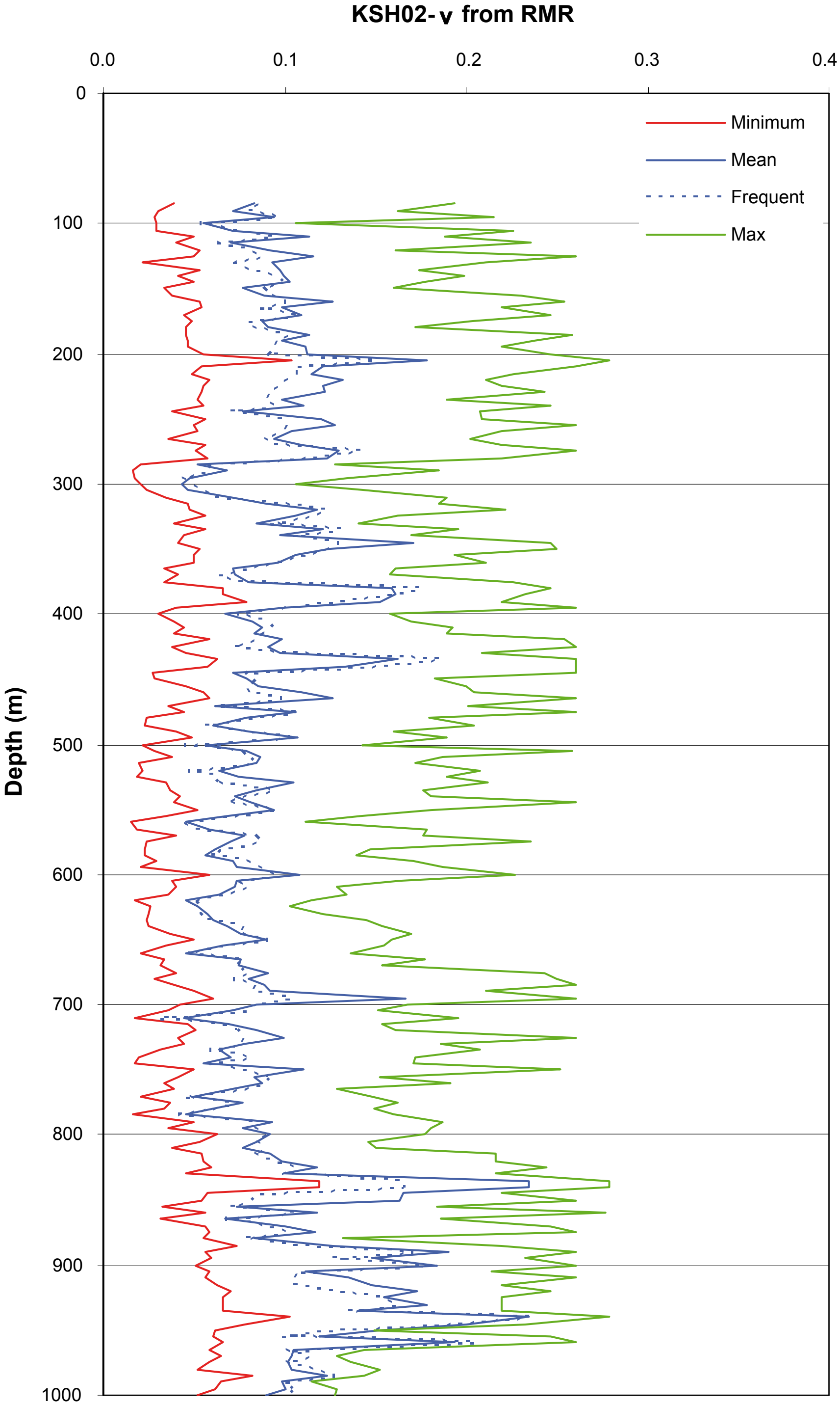
A2.5 Poisson's ratio

A2.5.1 RMR

Summary of Poisson's ratio (ν) derived from RMR for borehole KSH02 (core sections of 5 m, Hoek and Brown's a = 0.5).

Rock Unit	Minimum ν	Average ν	Frequent ν	Maximum ν	Standard deviation	Min possible ν	Max possible ν
80–235	0.05	0.10	0.10	0.18	0.02	0.02	0.23
235–280 DZ 1a	0.08	0.11	0.11	0.13	0.02	0.04	0.26
280–305 DZ 1b	0.04	0.05	0.05	0.07	0.01	0.02	0.18
305–470	0.06	0.10	0.10	0.17	0.03	0.03	0.26
470–510	0.06	0.08	0.08	0.11	0.02	0.02	0.26
510–530 DZ 2	0.06	0.08	0.08	0.11	0.02	0.02	0.21
530–655	0.05	0.07	0.07	0.11	0.01	0.01	0.26
655–680 DZ 3	0.05	0.07	0.08	0.09	0.02	0.02	0.25
680–745	0.04	0.08	0.08	0.17	0.03	0.02	0.26
745–1,000	0.05	0.12	0.10	0.23	0.05	0.02	0.28
RU1	0.04	0.10	0.10	0.18	0.03	0.02	0.28
RU2	0.04	0.08	0.07	0.17	0.02	0.01	0.26
RU3	0.05	0.12	0.10	0.23	0.05	0.02	0.28
Competent rock	0.04	0.10	0.09	0.23	0.04	0.01	0.28
Fractured rock	0.04	0.08	0.08	0.13	0.03	0.02	0.26
Whole borehole	0.04	0.10	0.09	0.23	0.04	0.01	0.28

Variation of Poisson's ratio (ν) with depth for borehole KSH02 (Hoek and Brown's a = 0.5). The values are given every 5 m.



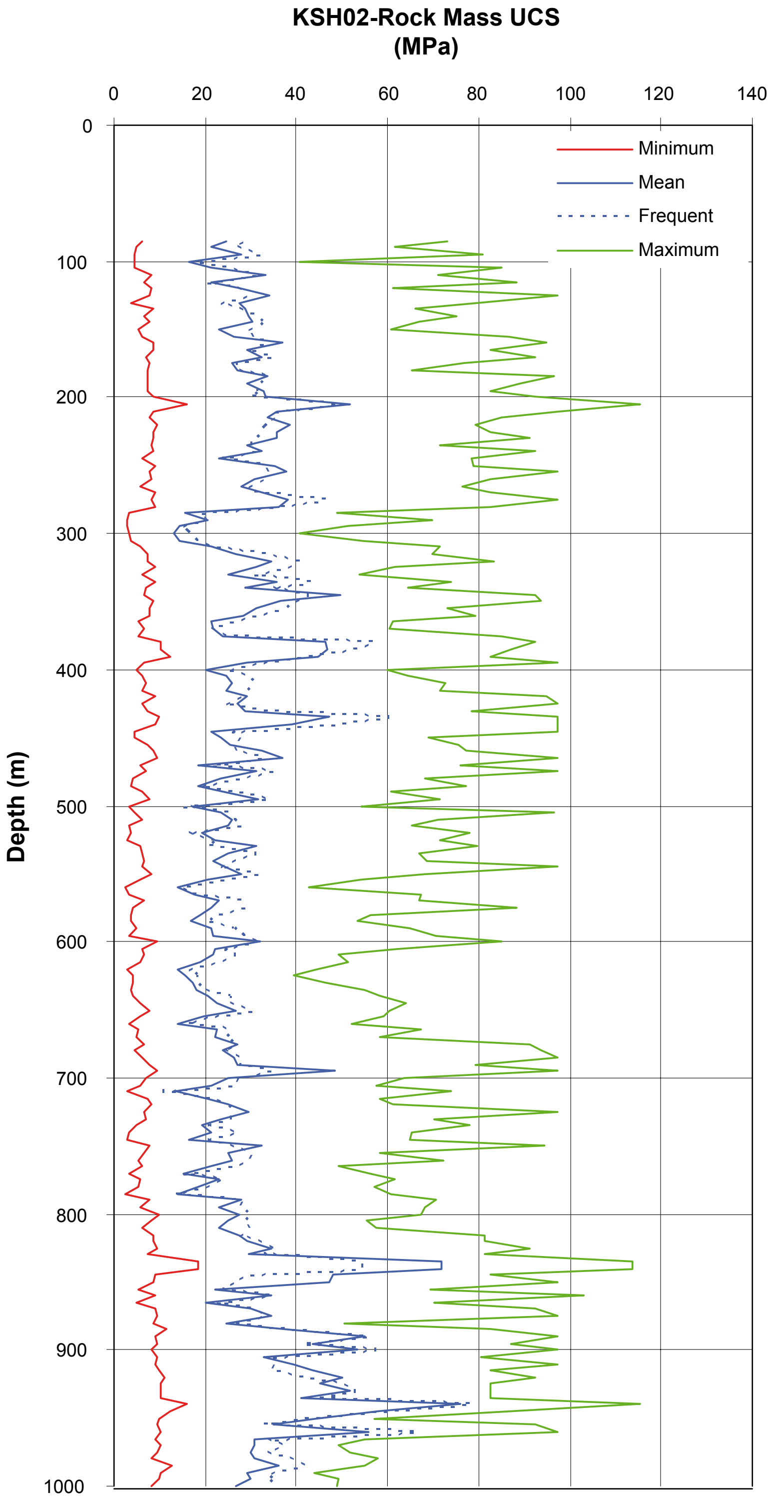
A2.6 Uniaxial compressive strength

A2.6.1 RMR

Summary of the uniaxial compressive strength of the rock mass derived from RMR for borehole KSH02 (core sections of 5 m, Hoek and Brown's a = 0.5).

Rock Unit	Minimum UCS	Average UCS	Frequent UCS	Maximum UCS	Standard deviation	Min possible UCS	Max possible UCS
80–235	16.6	30.1	29.2	51.6	6.6	3.6	115.2
235–280 DZ 1a	22.9	32.6	32.4	38.0	5.0	5.8	97.5
280–305 DZ 1b	13.0	15.6	14.5	20.5	2.9	2.7	69.9
305–470	18.6	30.5	28.8	49.6	8.7	4.3	97.5
470–510	17.1	24.3	23.7	31.5	5.2	3.5	97.5
510–530 DZ 2	19.2	24.4	23.7	31.1	5.0	3.0	79.8
530–655	13.8	20.9	21.2	31.9	4.2	2.4	97.5
655–680 DZ 3	13.9	22.0	22.7	27.1	4.9	3.4	93.4
680–745	13.5	24.4	23.2	48.3	8.4	2.9	97.5
745–1,000	13.8	35.9	30.9	76.1	14.4	2.6	115.2
RU1	13.0	29.7	29.0	51.6	8.1	2.7	115.2
RU2	13.5	22.6	22.1	48.3	5.7	2.4	97.5
RU3	13.8	35.9	30.9	76.1	14.4	2.6	115.2
Competent rock	13.5	29.9	27.4	76.1	11.2	2.4	115.2
Fractured rock	13.0	25.2	23.8	38.0	8.0	2.7	97.5
Whole borehole	13.0	29.3	27.2	76.1	10.9	2.4	115.2

Variation of the uniaxial compressive strength of the rock mass with depth for borehole KSH02 (Hoek and Brown's a = 0.5). The values are given every 5 m.

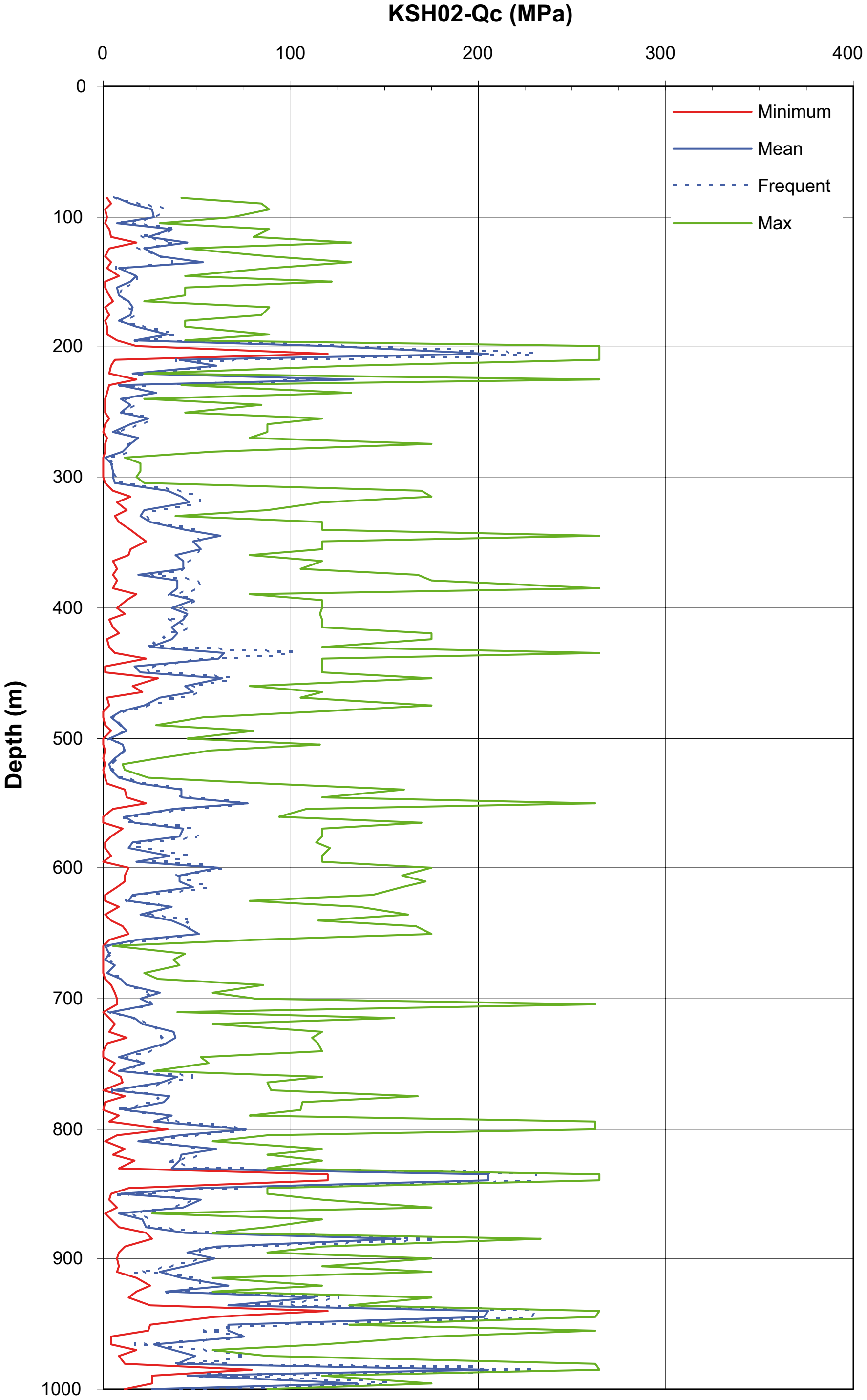


A2.6.2 Q

Summary of Qc derived from Q for borehole KSH02 (core sections of 5 m).

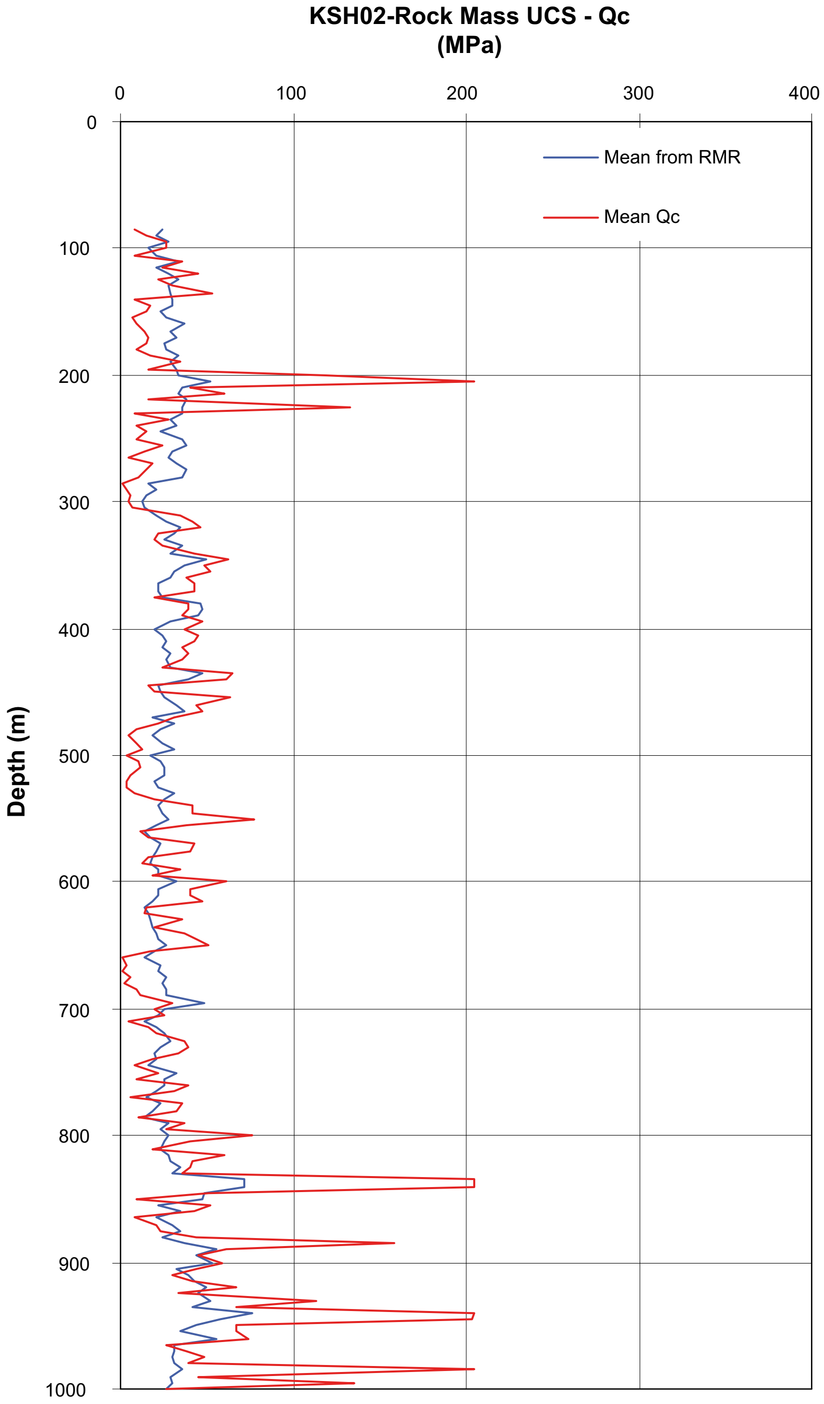
Rock Unit	Minimum Qc	Average Qc	Frequent Qc	Maximum Qc	Standard deviation	Min possible Qc	Max possible Qc
80–235	7.3	34.9	17.9	205.0	43.1	0.7	265.0
235–280 DZ 1a	5.0	13.4	14.4	23.8	5.6	0.2	174.9
280–305 DZ 1b	1.4	4.5	5.1	6.6	2.0	0.1	22.4
305–470	16.7	39.7	39.9	64.7	12.9	0.7	265.0
470–510	3.1	10.2	9.7	21.6	5.6	0.1	174.9
510–530 DZ 2	3.6	5.4	4.9	8.3	2.2	0.1	29.2
530–655	11.7	33.4	36.6	77.2	16.8	0.3	262.4
655–680 DZ 3	1.3	2.7	1.8	5.7	1.9	0.1	43.3
680–745	4.6	21.3	19.7	38.9	11.3	0.13	262.4
745–1,000	5.3	61.2	41.3	205.0	55.7	0.2	265.0
RU1	1.4	32.5	25.5	205.0	30.2	0.1	265.0
RU2	1.3	22.3	17.7	77.2	17.2	0.1	262.4
RU3	5.3	61.2	41.3	205.0	55.7	0.2	265.0
Competent rock	3.1	41.7	35.9	205.0	40.4	0.1	265.0
Fractured rock	1.3	7.8	5.7	23.8	6.0	0.1	174.9
Whole borehole	1.3	37.4	29.9	205.0	39.4	0.1	265.0

Variation of Q_c with depth for borehole KSH02. The values are given every 5 m.



A2.6.3 Comparison

Comparison of the rock mass compressive strength from RMR and Q for borehole KSH02 (Hoek and Brown's a = 0.5).



A2.7 Friction angle and cohesion and of the rock mass

A2.7.1 RMR

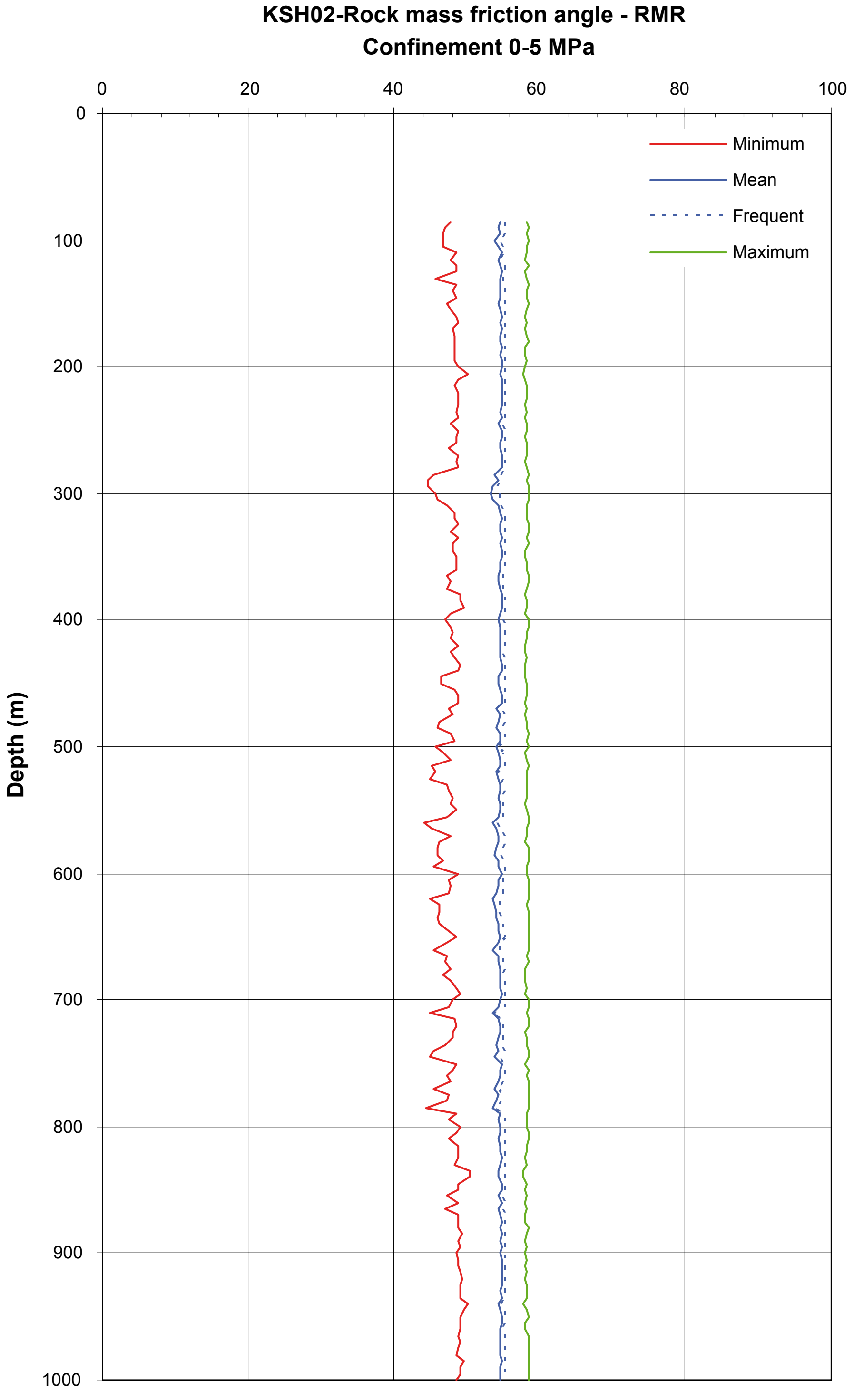
Summary of the friction angle (φ) of the rock mass derived from RMR for borehole KSH02 (10–30 MPa) (core sections of 5 m, Hoek and Brown's a = 0.5).

Rock Unit	Minimum φ'	Average φ'	Frequent φ'	Maximum φ'	Standard deviation	Min possible φ'	Max possible φ'
80–235	36.1	39.0	39.0	41.7	1.1	25.2	48.0
235–280 DZ 1a	37.8	39.5	39.5	40.3	0.8	27.5	47.4
280–305 DZ 1b	34.8	35.7	35.4	37.2	0.9	23.8	46.2
305–470	36.7	39.0	38.9	41.5	1.3	26.1	47.4
470–510	36.3	38.0	38.0	39.4	1.1	25.0	47.4
510–530 DZ 2	36.9	38.0	38.0	39.3	1.0	24.2	46.7
530–655	35.1	37.2	37.4	39.4	1.0	23.3	47.4
655–680 DZ 3	35.2	37.4	37.7	38.6	1.3	24.9	47.3
680–745	35.0	37.8	37.9	41.4	1.5	24.0	47.4
745–1,000	35.1	39.6	39.3	43.2	1.8	23.6	48.0
RU1	34.8	38.9	39.0	41.7	1.4	23.8	48.0
RU2	35.0	37.6	37.6	41.4	1.2	23.3	47.4
RU3	35.1	39.6	39.3	43.2	1.8	23.6	48.0
Competent rock	35.0	38.8	38.7	43.2	1.6	23.3	48.0
Fractured rock	34.8	38.0	38.0	40.3	1.7	23.8	47.4
Whole borehole	34.8	38.7	38.7	43.2	1.7	23.3	48.0

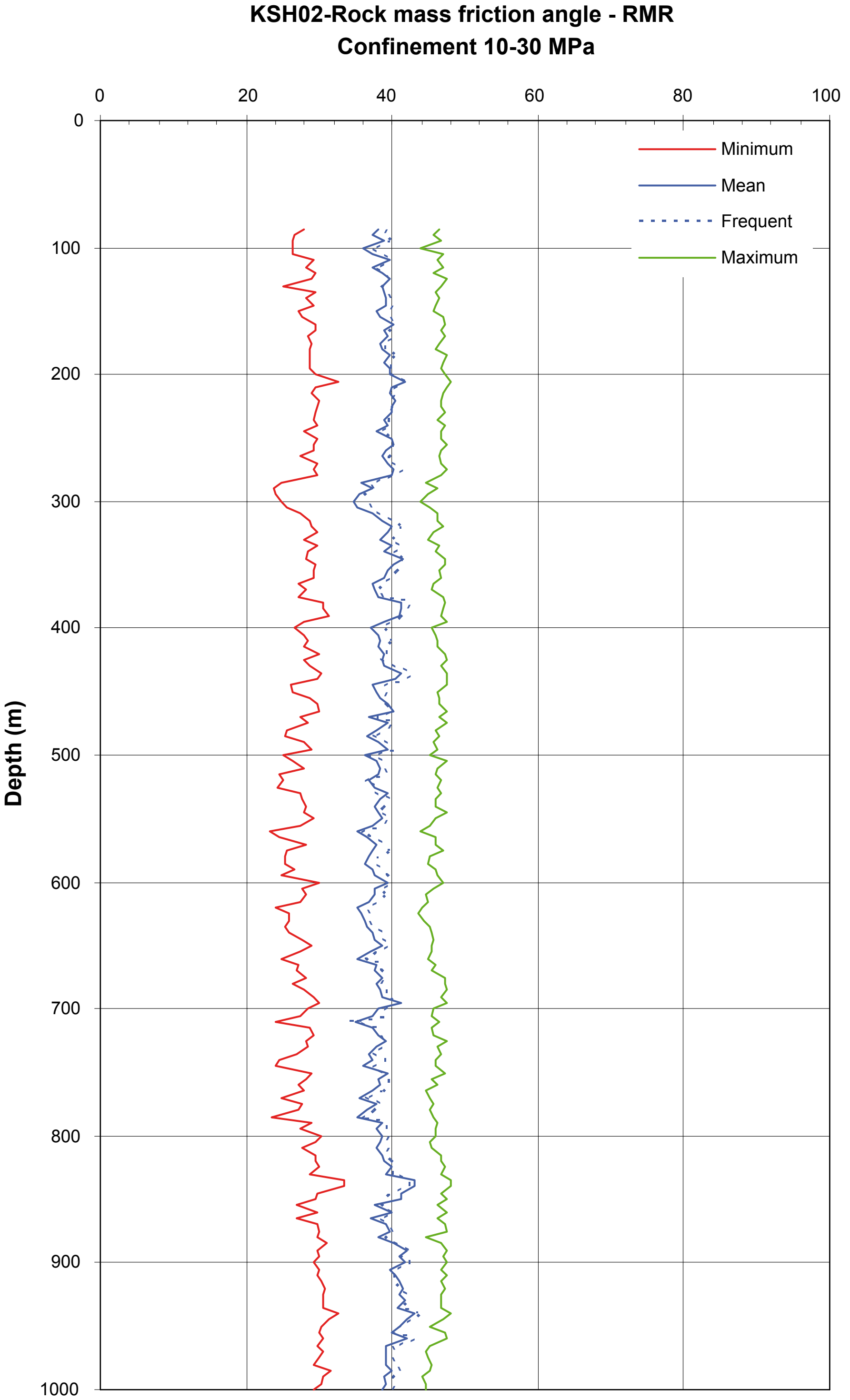
Summary of the cohesion of the rock mass derived from RMR for borehole KSH02 (10–30 MPa) (core sections of 5 m, Hoek and Brown's a = 0.5).

Rock Unit	Minimum c'	Average c'	Frequent c'	Maximum c'	Standard deviation	Min possible c'	Max possible c'
80–235	13.3	15.8	15.7	19.3	1.1	8.2	29.3
235–280 DZ 1a	14.6	16.2	16.2	17.1	0.8	9.2	26.8
280–305 DZ 1b	12.5	13.1	12.9	14.1	0.6	7.7	22.9
305–470	13.7	15.8	15.6	19.0	1.4	8.6	26.8
470–510	13.4	14.8	14.7	16.0	0.9	8.1	26.8
510–530 DZ 2	13.9	14.8	14.7	16.0	0.9	7.9	24.3
530–655	12.7	14.2	14.2	16.1	0.8	7.5	26.8
655–680 DZ 3	12.7	14.3	14.5	15.3	1.0	8.1	26.2
680–745	12.6	14.8	14.6	18.7	1.5	7.8	26.8
745–1,000	12.7	16.7	15.9	23.1	2.4	7.6	29.3
RU1	12.5	15.7	15.6	19.3	1.4	7.7	29.3
RU2	12.6	14.5	14.4	18.7	1.0	7.5	26.8
RU3	12.7	16.7	15.9	23.1	2.4	7.6	29.3
Competent rock	12.6	15.7	15.4	23.1	1.9	7.5	29.3
Fractured rock	12.5	14.9	14.7	17.1	1.5	7.7	26.8
Whole borehole	12.5	15.6	15.3	23.1	1.8	7.5	29.3

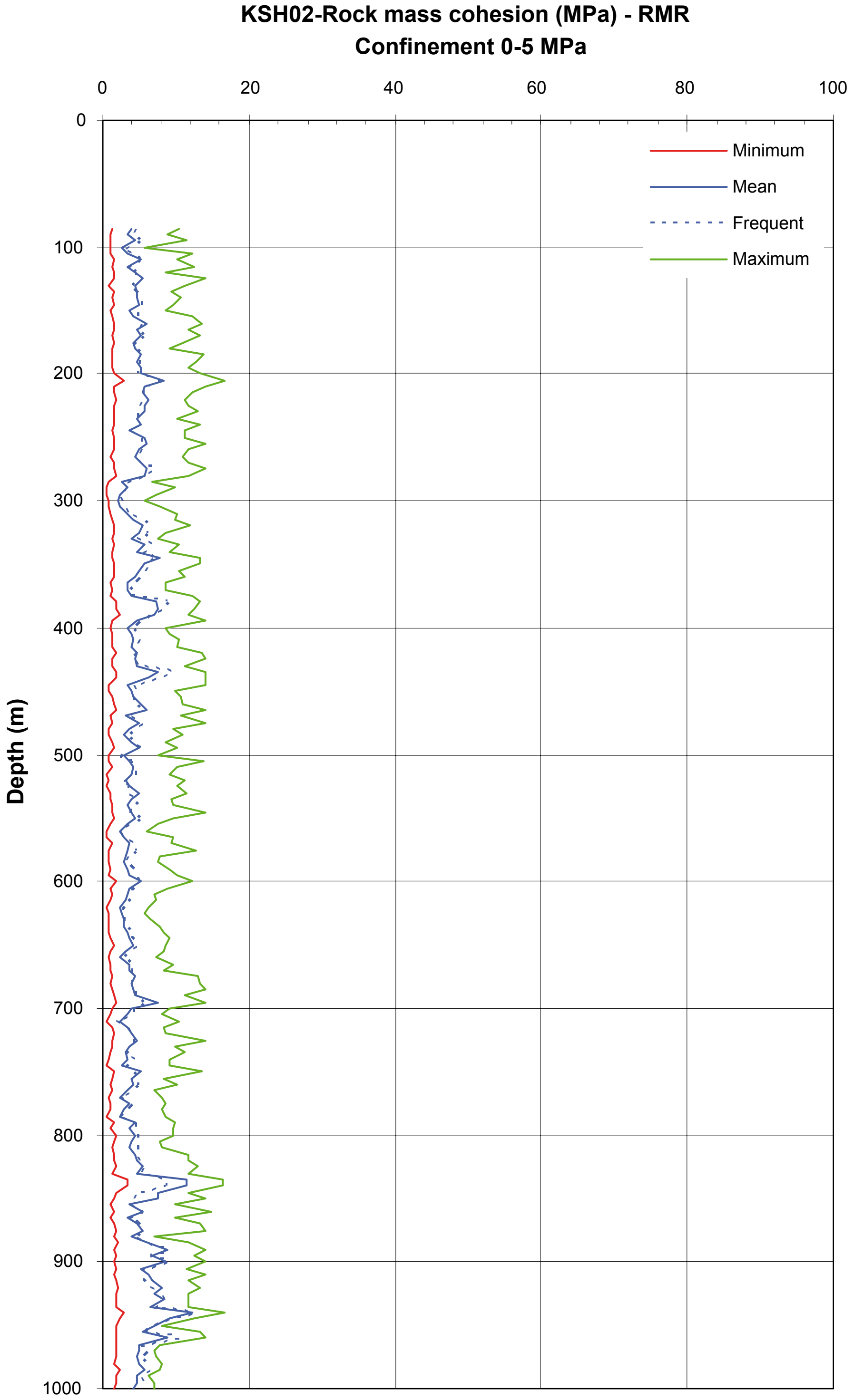
Variation of the rock mass friction angle from RMR for borehole KSH02 under stress confinement 0–5 MPa (Hoek and Brown's a = 0.5).



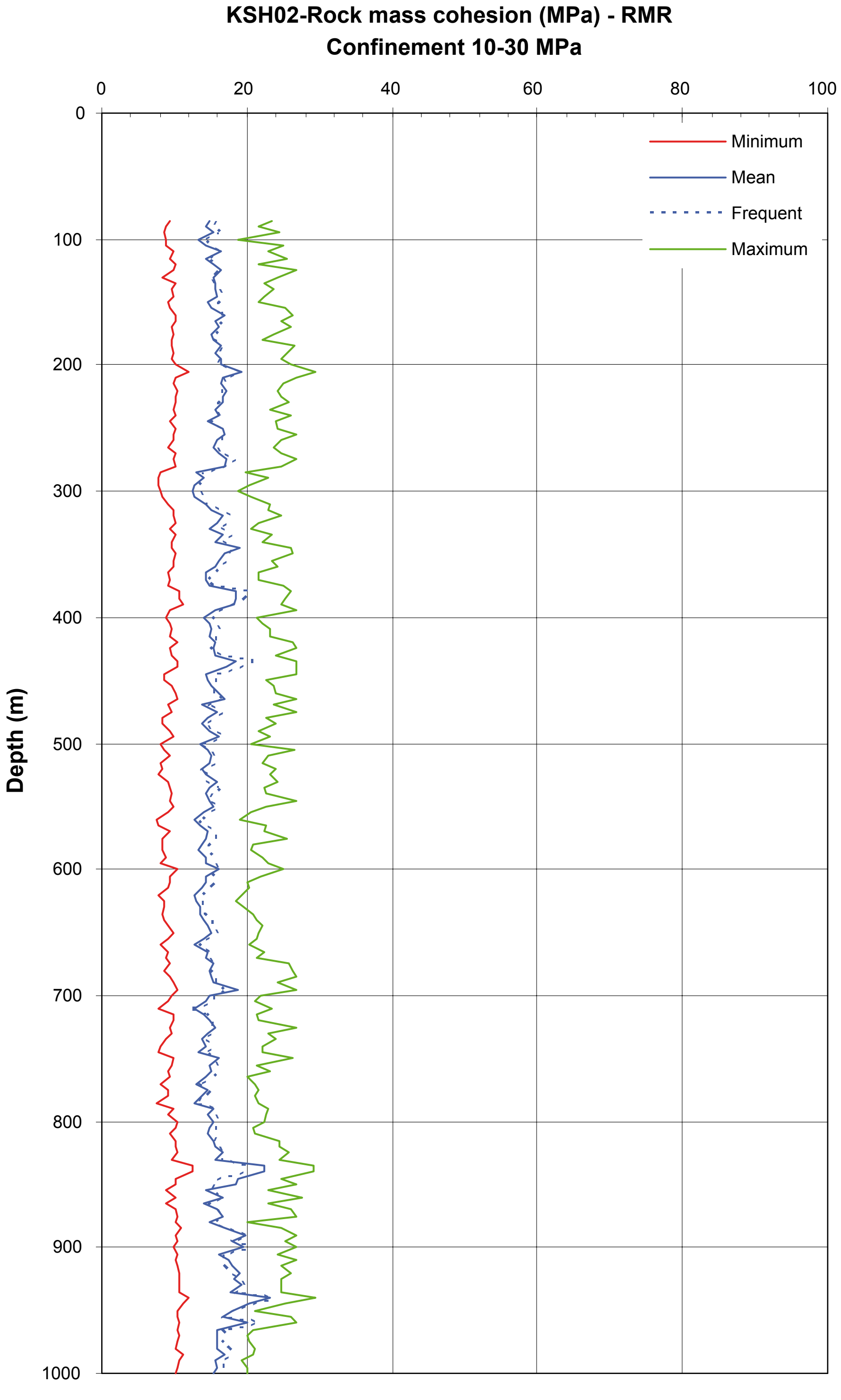
Variation of the rock mass friction angle from RMR for borehole KSH02 under stress confinement 10–30 MPa (Hoek and Brown's a = 0.5).



Variation of the rock mass cohesion from RMR for borehole KSH02 under stress confinement 0–5 MPa (Hoek and Brown's a = 0.5).



Variation of the rock mass cohesion from RMR for borehole KSH02 under stress confinement 10–30 MPa (Hoek and Brown's a = 0.5).



A2.7.2 Q

Summary of the frictional component FC of the rock mass derived from Qc for borehole KSH02 (core sections of 5 m).

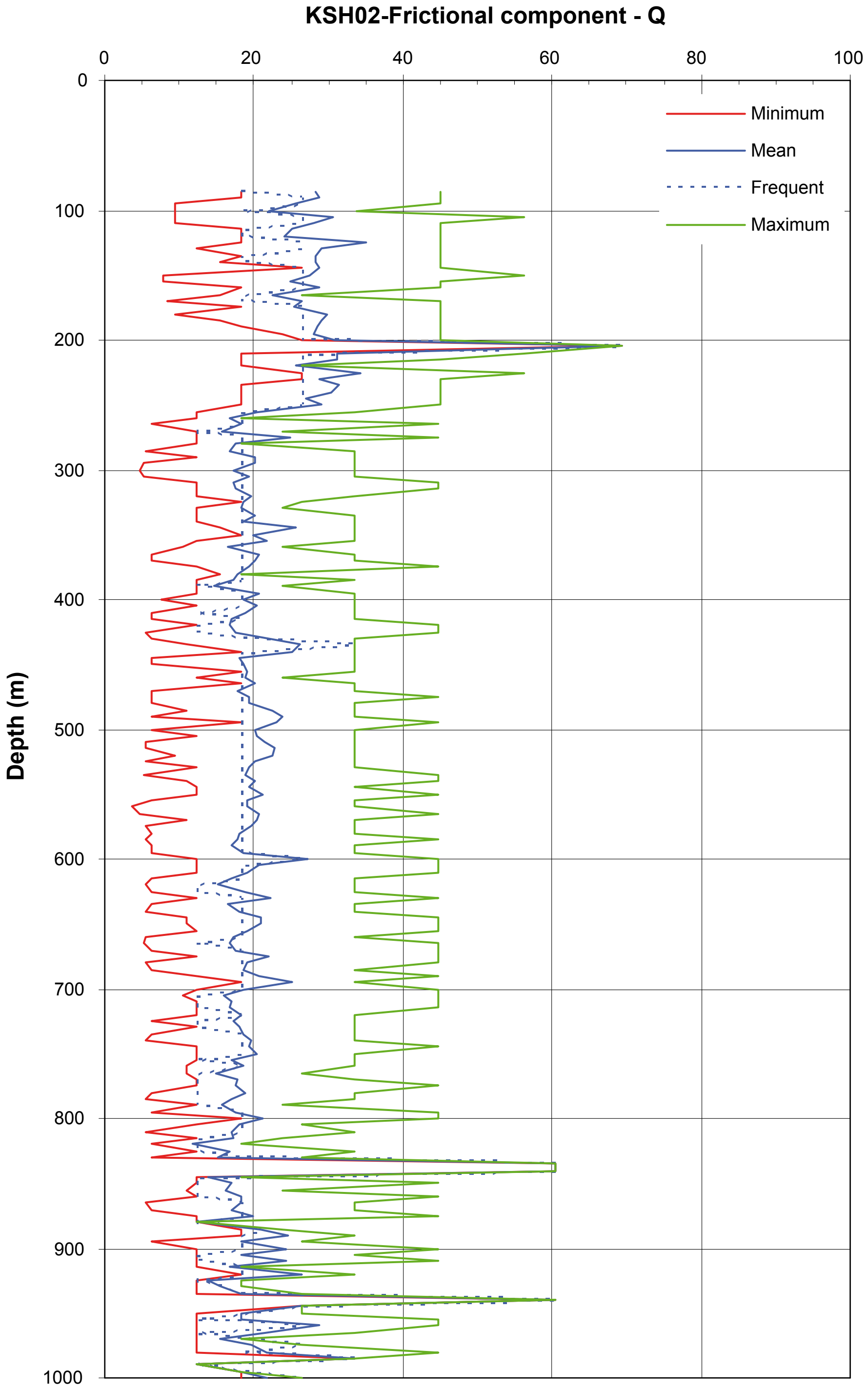
Rock Unit	Minimum mean FC	Average mean FC	Frequent mean FC	Maximum mean FC	Standard deviation	Min possible FC	Max possible FC
80–235	21.9	29.5	28.4	69.4	8.0	7.9	69.4
235–280 DZ 1a	15.7	22.2	20.4	30.3	5.6	6.3	45.0
280–305 DZ 1b	16.7	18.8	19.4	20.2	1.6	4.7	33.4
305–470	14.8	19.4	18.8	26.3	2.5	5.5	44.7
470–510	19.4	21.3	20.9	23.7	1.7	5.5	44.7
510–530 DZ 2	19.3	21.1	21.3	22.7	1.7	5.4	33.4
530–655	15.3	19.5	19.2	27.3	2.3	3.8	44.7
655–680 DZ 3	16.8	18.5	17.5	22.0	2.1	5.2	44.7
680–745	16.1	18.8	18.5	25.1	2.3	5.5	44.7
745–1,000	11.8	21.3	18.3	60.4	10.7	5.5	60.4
RU1	14.8	23.7	21.8	69.4	7.4	4.7	69.4
RU2	15.3	19.6	19.3	27.3	2.3	3.8	44.7
RU3	11.8	21.3	18.3	60.4	10.7	5.5	60.4
Competent rock	11.8	22.0	19.6	69.4	8.1	3.8	69.4
Fractured rock	15.7	20.5	19.4	30.3	4.0	4.7	45.0
Whole borehole	11.8	21.8	19.5	69.4	7.7	3.8	69.4

Summary of the cohesive component CC of the rock mass derived from Qc for bore-hole KSH02 (core sections of 5 m).

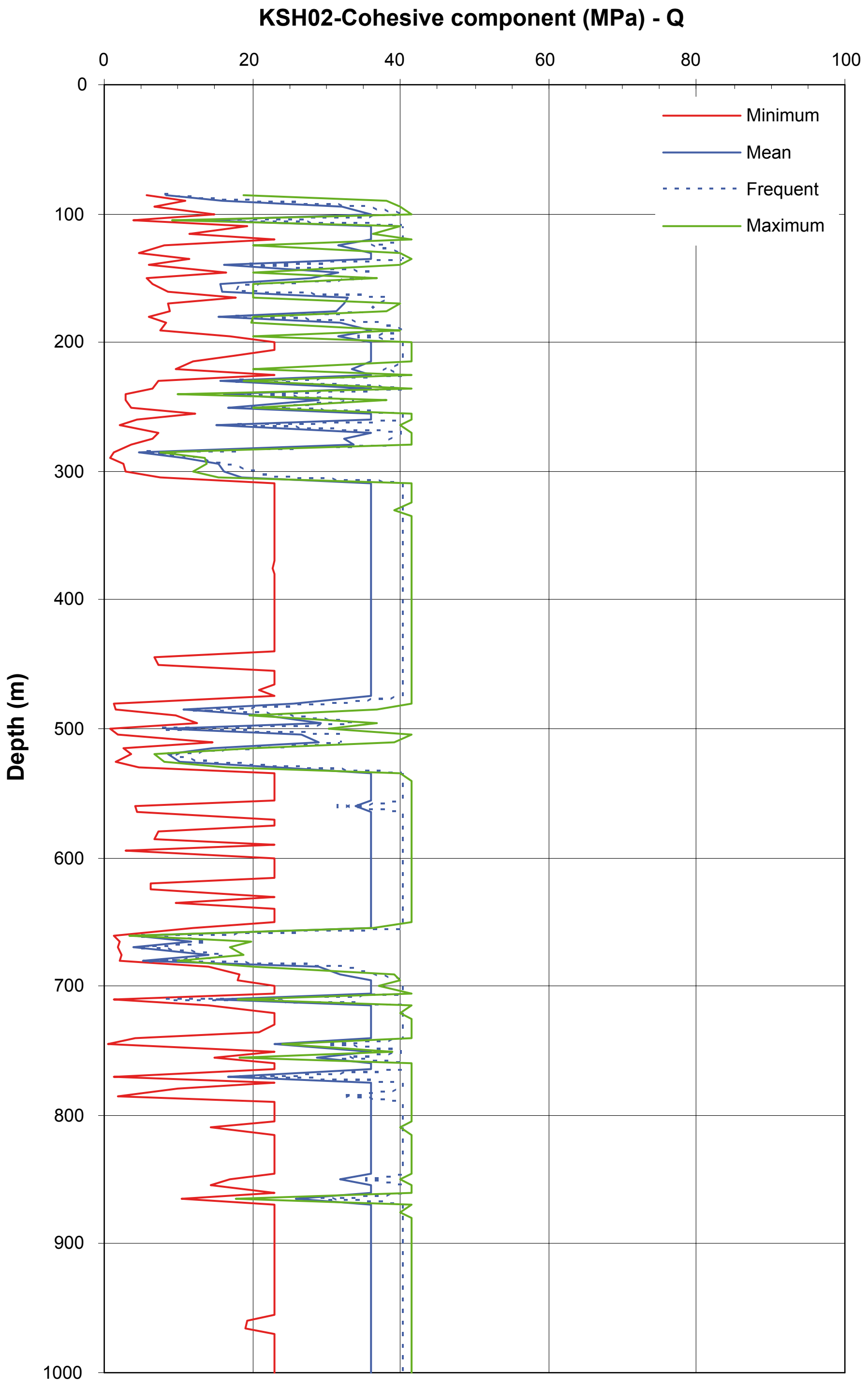
Rock Unit	Minimum CC	Average CC	Frequent CC	Maximum CC	Standard deviation	Min possible CC	Max possible CC
80–235	8.3	29.0	32.3	35.9	9.1	3.9	41.5
235–280 DZ 1a	15.3	27.9	32.3	35.9	9.1	2.2	41.5
280–305 DZ 1b	4.7	13.1	15.3	18.6	5.5	0.8	15.4
305–470	35.9	35.9	35.9	35.9	0.0	6.7	41.5
470–510	8.3	23.4	26.1	35.9	9.5	0.7	41.5
510–530 DZ 2	8.7	14.2	12.3	23.6*	6.7	1.5	20.0
530–655	34.0	35.9	35.9	35.9	0.4	2.9	41.5
655–680 DZ 3	4.0	7.9	5.1	14.2	4.8	1.3	19.8
680–745	15.1	32.5	35.9	35.9	6.6	0.6	41.5
745–1,000	16.7	35.1	35.9	35.9	3.2	1.2	41.5
RU1	4.7	30.8	35.9	35.9	8.7	0.8	41.5
RU2	4.0	29.1	35.9	35.9	10.6	0.6	41.5
RU3	16.7	35.1	35.9	35.9	3.2	1.2	41.5
Competent rock	8.3	33.4	35.9	35.9	6.1	0.6	41.5
Fractured rock	4.0	18.0	15.3	35.9	10.8	0.8	41.5
Whole borehole	4.0	31.5	35.9	35.9	8.6	0.6	41.5

*These values correspond to the minimum or maximum strength of the rock mass when combined with the corresponding Friction angles.

Variation of the frictional component FC from Q for borehole KSH02.

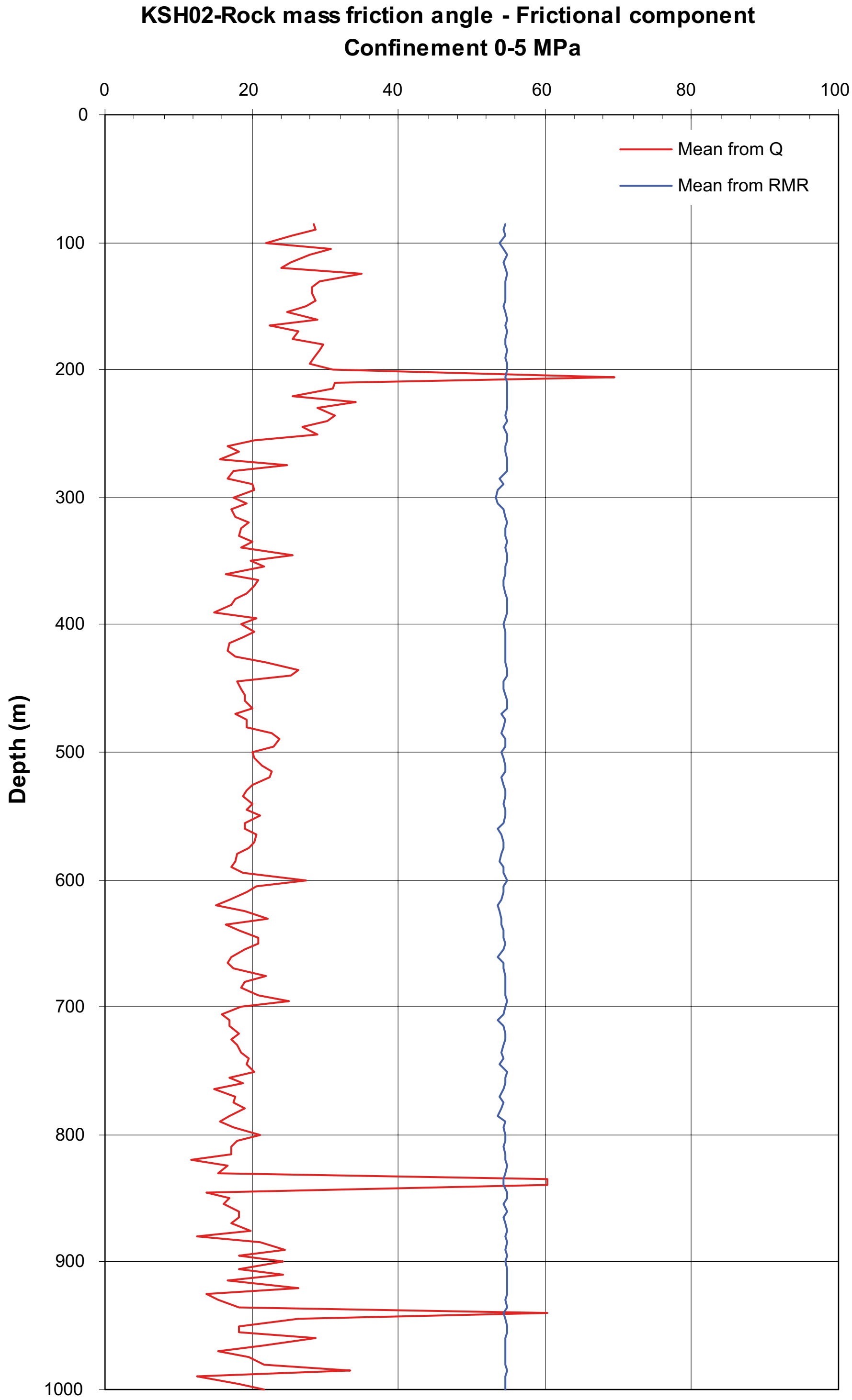


Variation of the cohesive component from Q for borehole KSH02.

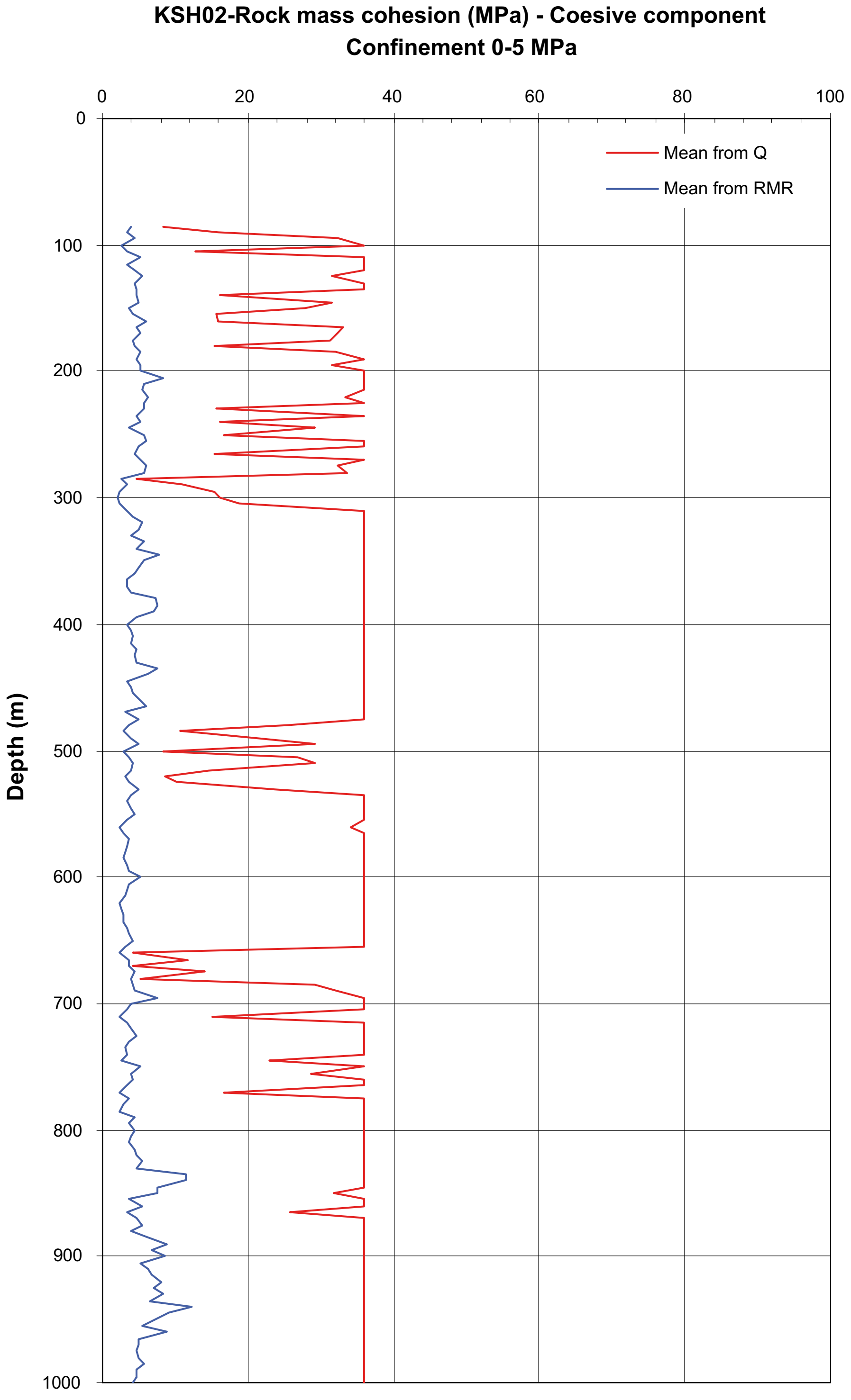


A2.7.3 Comparison

Comparison of the rock mass friction angle from RMR and Q for borehole KSH02 under stress confinement 0–5 MPa (Hoek and Brown's a = 0.5).



Comparison of the rock mass cohesion from RMR and Q for borehole KSH02 under stress confinement 0–5 MPa (Hoek and Brown's a = 0.5).



Appendix 3

KSH03A and B
Characterisation of the rock mass

A3.1 Fracture orientation

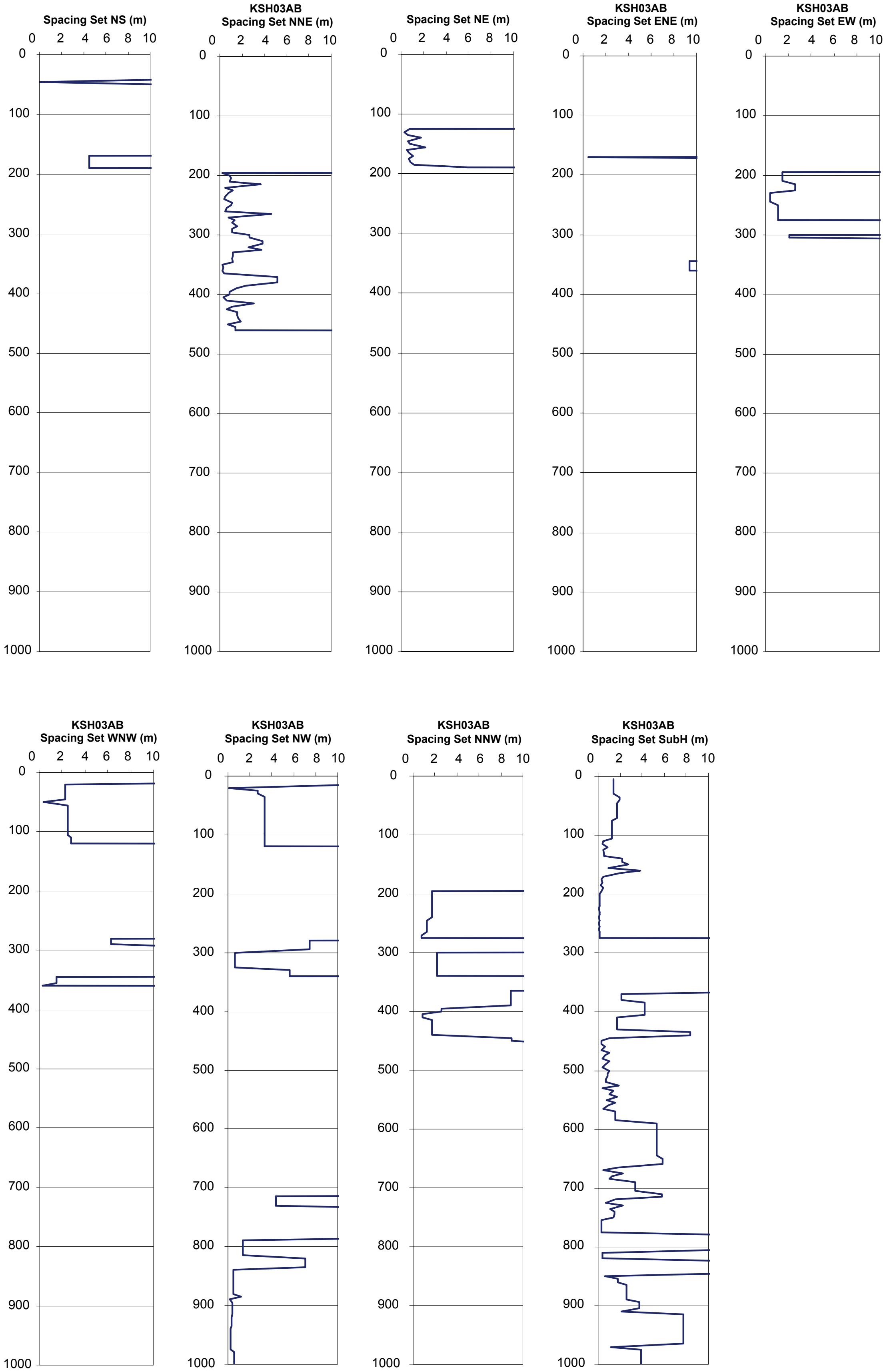
Set identification from the open fracture orientation mapped for borehole KSH03A and B (based on SICADA data received, 04-05-07). The orientations are given as strike/dip (right-hand rule).

Depth (m)	No of fract	NS	NNE	NE	ENE	EW	WNW	NW	NNW	SubH
0–120	178	006/84					283/61	138/70		143/03
120–165	105			230/39						108/28
165–190	110	181/55		224/69	250/80					100/07
190–275	718		214/82			262/76			170/79	171/10
275–295	58		196/44				118/58	143/83		
295–340	72		196/65			92/87		104/54	334/88	
340–360	115		197/78		080/85		101/46			
360–460	268		202/50						167/74	137/12
460–1,000	671							299/88		146/08

Fisher's constant of the open fracture sets identified for borehole KSH03A and B (SICADA, 04-05-07).

Depth (m)	No of fract	NS	NNE	NE	ENE	EW	WNW	NW	NNW	SubH
0–120	178	296.0					29.9	59.9		9.3
120–165	105			12.4						30.7
165–190	110	34.7		21.3	129.7					13.8
190–275	718		20.0			26.1			32.5	5.7
275–295	58		46.8				255.7	15.2		
295–340	72		49.5			265.7		43.3	26.7	
340–360	115		27.5		57.9		15.8			
360–460	268		31.4						45.7	20.0
460–1,000	671							26.1		15.2

Fracture spacing with depth for the five facture sets in borehole KSH03A and B. The values are averaged for each 5 m length of borehole.

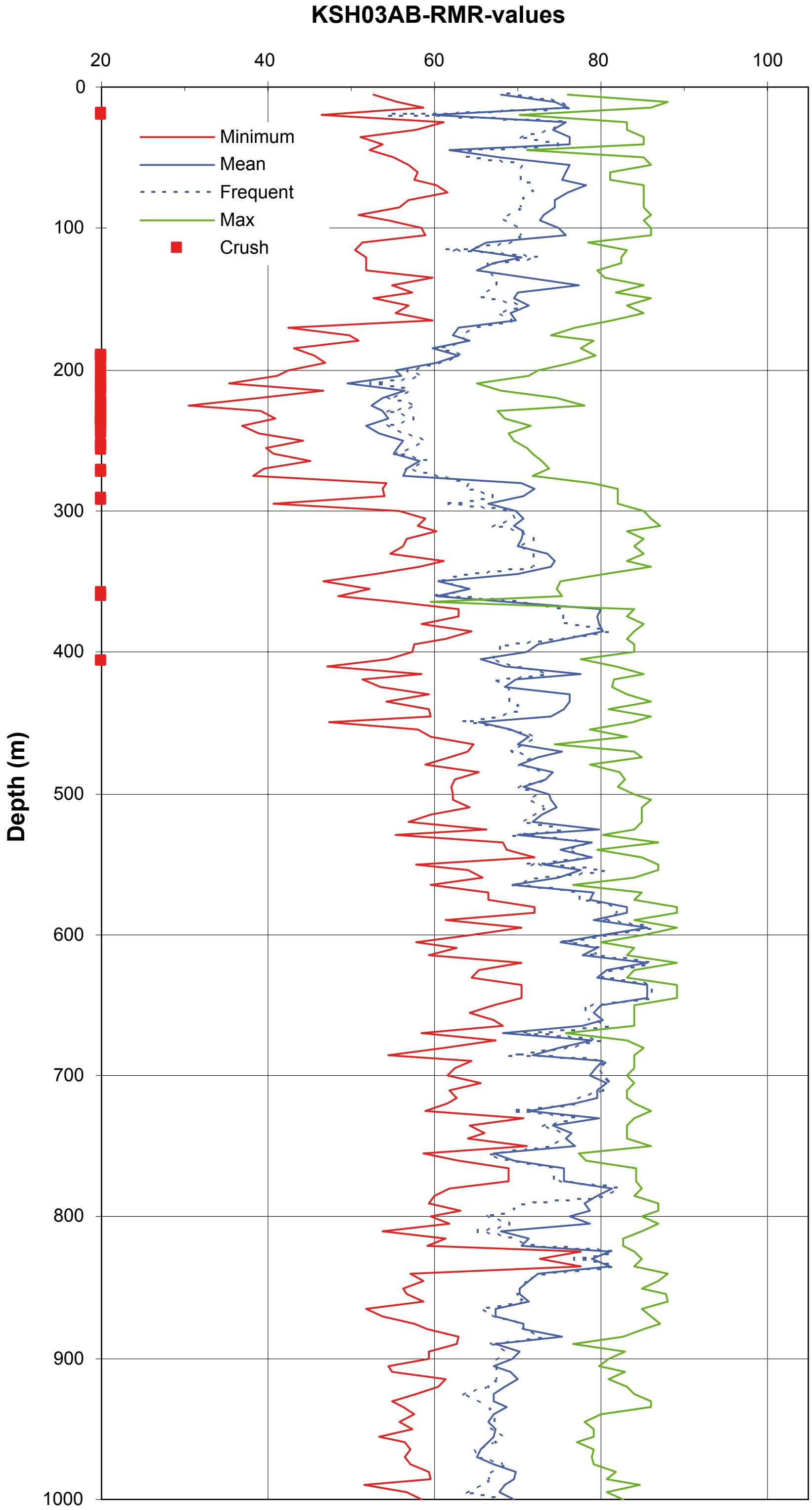


A3.2 RMR

RMR values along borehole KSH03A and B (core sections of 5 m).

Rock Unit	Minimum RMR	Average RMR	Frequent RMR	Maximum RMR	Standard deviation	Min possible RMR	Max possible RMR
0–160	59.9	71.9	73.7	78.3	4.8	46.6	88.1
160–270 DZ1	49.7	57.3	56.1	69.9	4.8	30.4	81.4
270–440	56.3	71.2	70.7	80.3	5.7	38.2	87.1
440–575	65.4	73.7	73.9	79.8	3.6	47.3	87.0
575–755	67.2	78.8	79.5	85.7	4.5	54.6	89.1
755–864	67.4	74.7	75.7	81.5	4.6	51.8	88.0
864–1,000	65.3	68.4	67.8	75.5	2.1	51.7	87.1
RU1	49.7	66.0	67.5	78.3	8.7	30.4	88.1
RU2	56.3	73.3	71.4	85.7	6.3	38.2	89.1
RU3	65.4	74.2	74.1	81.5	4.1	47.3	88.0
Competent rock	56.3	73.3	73.2	85.7	5.5	38.2	89.1
Fractured rock	49.7	57.3	56.2	69.9	4.8	30.4	81.4
Whole borehole	49.7	71.5	71.4	85.7	7.4	30.4	89.1

Variation of RMR with depth for borehole KSH03A and B. The values are given every 5 m.

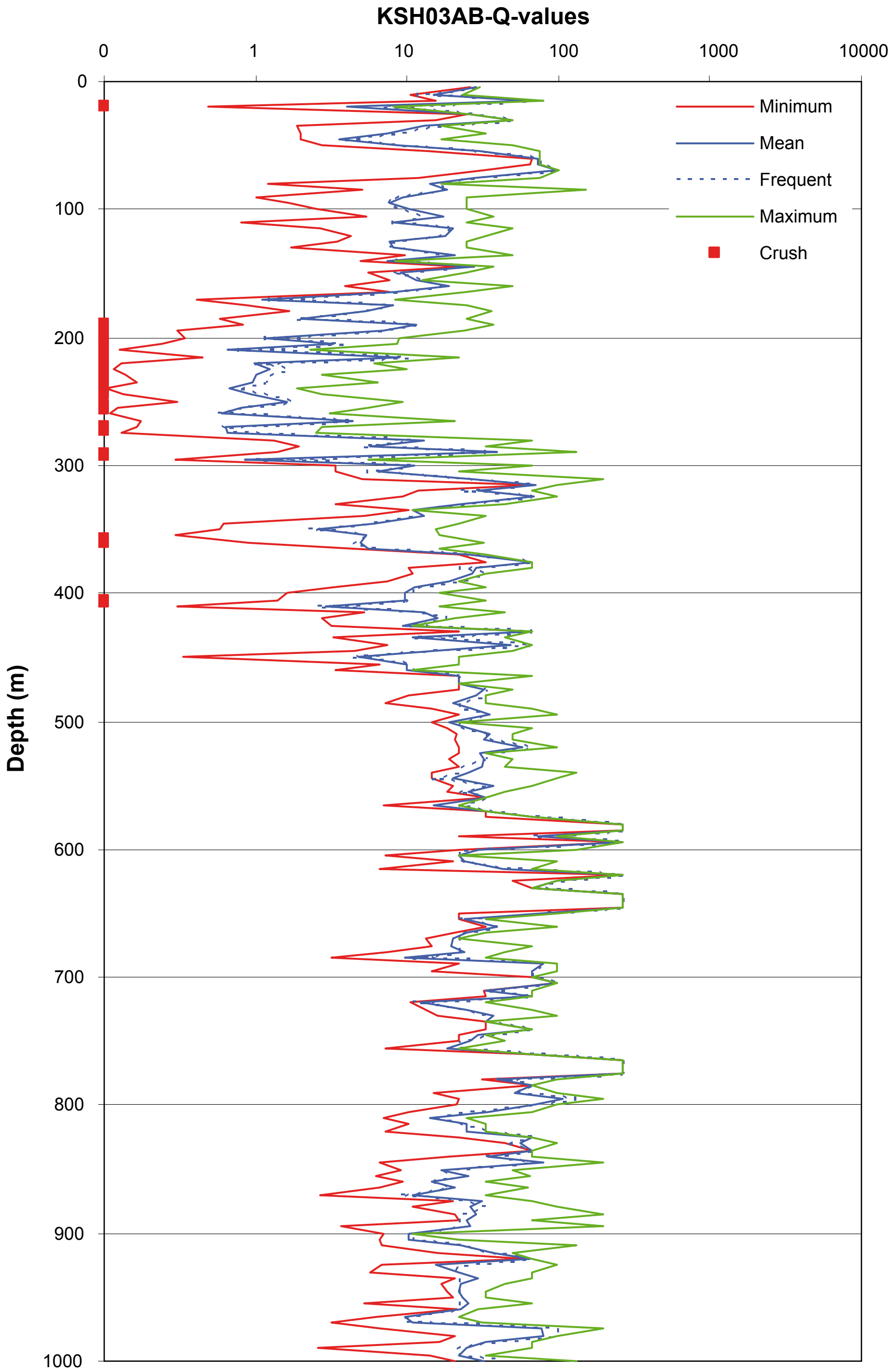


A3.3 Q

Q values along borehole KSH03A and B (core sections of 5 m).

Rock Unit	Minimum mean Q	Average mean Q	Frequent mean Q	Maximum mean Q	Confidence Min Q	Confidence Max Q
0–160	3.6	23.5	16.2	97.6	0.5	150.0
160–270 DZ1	0.6	3.2	1.2	11.6	0.1	37.5
270–440	0.6	20.8	12.1	70.7	0.1	37.5
440–575	4.8	27.6	27.1	66.0	0.3	132.0
575–755	9.7	86.0	41.4	264.0	3.2	264.0
755–864	13.9	76.0	54.2	264.0	6.2	264.0
864–1,000	9.6	28.3	24.3	79.7	2.6	198.0
RU1	0.6	15.2	8.2	97.6	0.1	150.0
RU2	0.6	47.1	24.9	264.0	0.1	264.0
RU3	4.8	49.3	31.7	264.0	0.3	264.0
Competent rock	0.6	43.5	25.6	264.0	0.1	264.0
Fractured rock	0.6	3.2	1.2	11.6	0.1	37.5
Whole borehole	0.6	39.0	23.4	264.0	0.1	264.0

Variation of Q with depth for borehole KSH03A and B. The values are given every 5 m.



Rock mass properties

A3.4 Deformation modulus

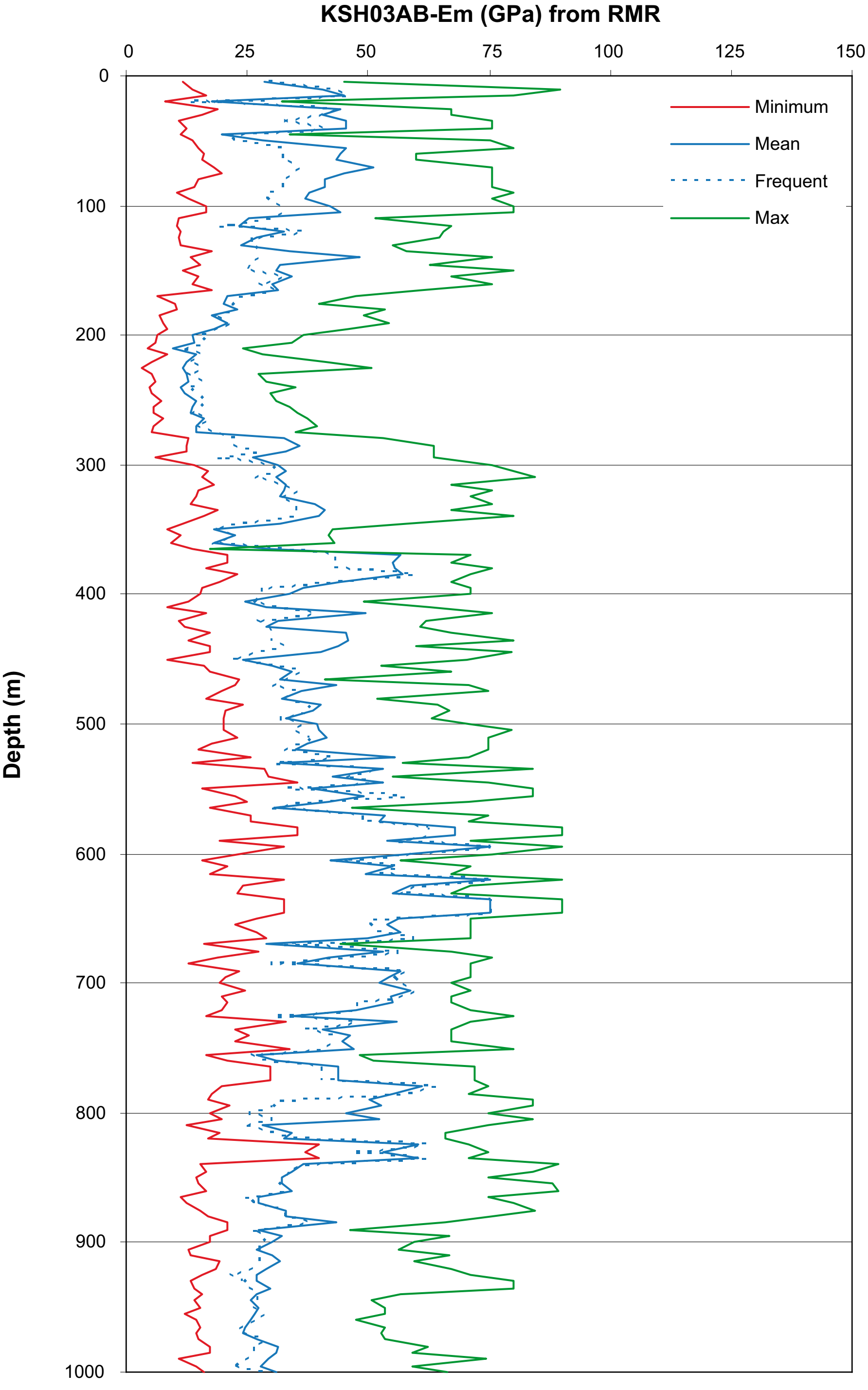
A3.4.1 RMR

Deformation modulus Em derived from RMR along for borehole KSH03A and B (core sections of 5 m).

Rock Unit	Minimum Em (GPa)	Average Em (GPa)	Frequent Em (GPa)	Maximum Em (GPa)	Standard deviation Em (GPa)	Min possible Em (GPa)	Max possible Em (GPa)
0–160	17.7	36.5	39.2	50.9	9.0	8.2	89.6
160–270 DZ1	9.8	15.9	14.2	31.5	5.0	3.2	61.1
270–440	14.4	35.6	33.0	57.1	11.0	5.1	84.6
440–575	24.2	39.9	39.5	55.5	8.3	8.6	84.1
575–755	27.0	53.7	54.5	75.0	12.5	13.0	90.0
755–864	27.2	42.9	44.0	61.2	11.2	11.1	89.1
864–1,000	24.1	29.1	27.9	43.3	3.8	11.0	84.6
RU1	9.8	28.1	27.5	50.9	12.8	3.2	89.6
RU2	14.4	40.5	34.3	75.0	14.6	5.1	90.0
RU3	24.2	41.3	39.9	61.2	9.7	8.6	89.1
Competent rock	14.4	40.1	38.0	75.0	12.6	5.1	90.0
Fractured rock	9.8	15.9	14.2	31.5	5.0	3.2	61.1
Whole borehole	9.8	37.4	34.4	75.0	14.2	3.2	90.0

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 KSH03A and B. The values are given every 5 m.



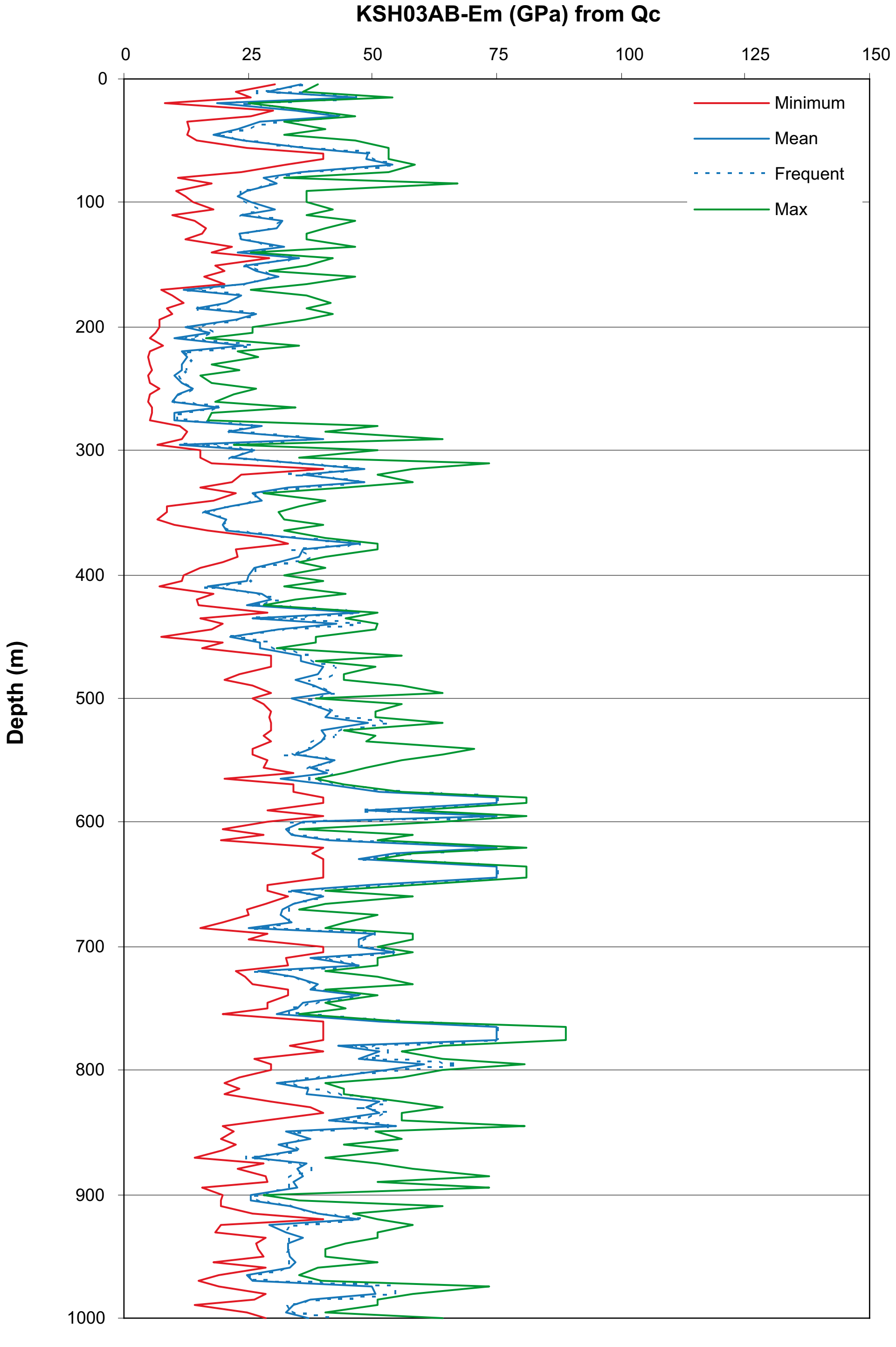
A3.4.2 Q

Deformation modulus Em derived from Q along borehole KSH03A and B (core sections of 5 m).

Rock Unit	Minimum Em (GPa)	Average Em (GPa)	Frequent Em (GPa)	Maximum Em (GPa)	Standard deviation Em (GPa)	Min possible Em (GPa)	Max possible Em (GPa)
0–160	18.0	31.0	29.6	54.0	9.1	8.1	66.9
160–270 DZ1	9.9	15.5	12.5	26.5	5.6	4.8	42.2
270–440	10.1	29.0	26.9	48.5	10.2	5.3	73.4
440–575	21.4	37.4	38.1	51.3	6.3	7.3	70.5
575–755	25.0	46.4	40.5	75.0	16.0	15.2	80.8
755–864	30.6	48.2	48.1	75.0	16.0	19.6	88.8
864–1,000	24.9	34.5	34.0	50.4	6.6	14.1	73.4
RU1	9.9	24.7	23.7	54.0	10.9	4.8	66.9
RU2	10.1	37.0	34.2	75.0	14.8	5.3	80.8
RU3	21.4	42.3	40.2	75.0	11.5	7.3	88.8
Competent rock	10.1	37.3	35.0	75.0	13.1	5.3	88.8
Fractured rock	9.9	15.5	12.5	26.5	5.6	4.8	42.2
Whole borehole	9.9	34.9	34.1	75.0	14.3	4.8	88.8

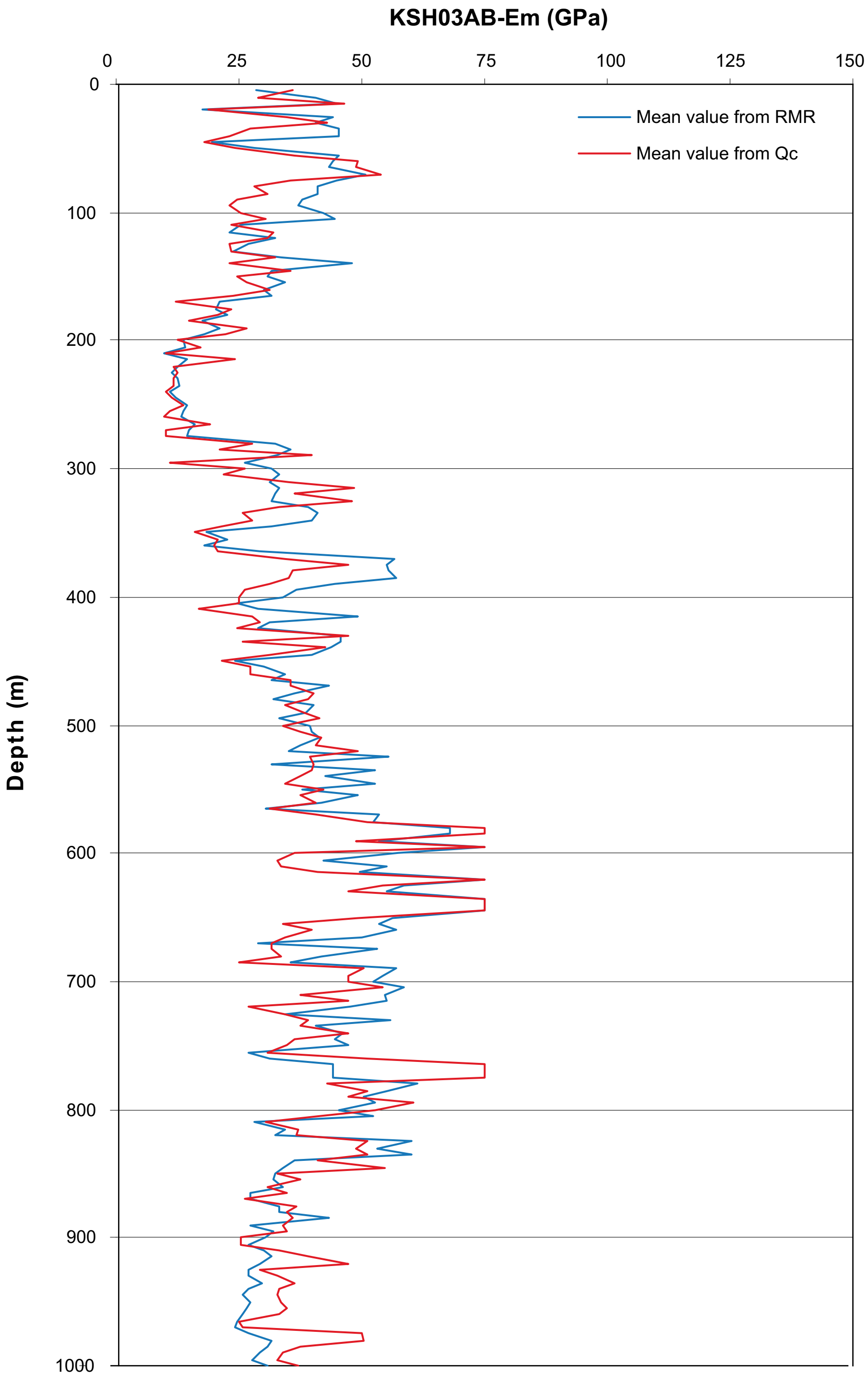
The maximum mean Em and the maximum confidence Em have a physical threshold in the Young's modulus of the intact rock, which is 75 and 90 GPa, respectively.

Variation of the deformation modulus of the rock mass obtained from Q_c with depth for borehole KSH03A and B. The values are given every 5 m.



A3.4.3 Comparison

Comparison between the mean values of the deformation modulus E_m obtained from RMR and Qc for different depths for borehole KSH03A and B.



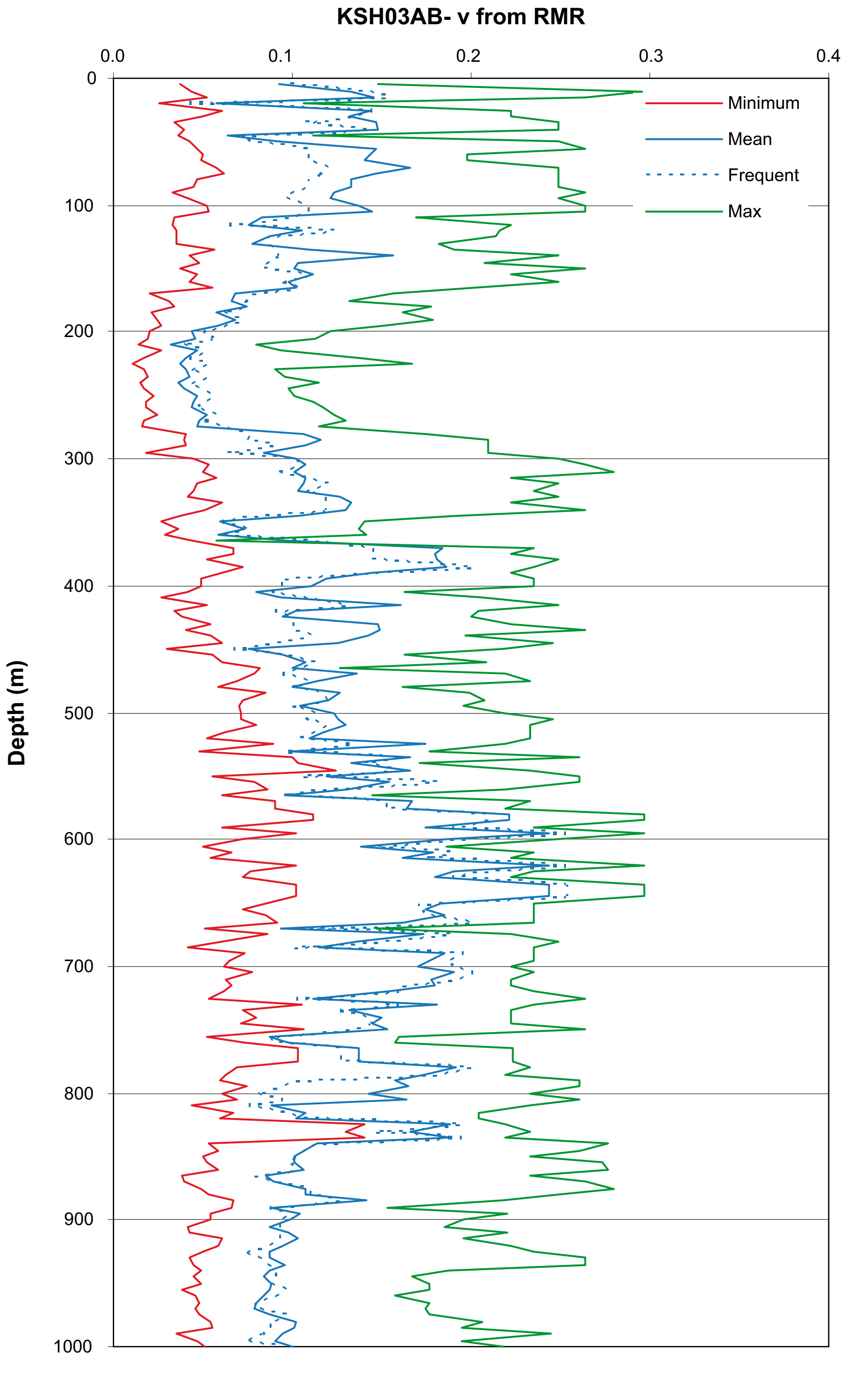
A3.5 Poisson's ratio

A3.5.1 RMR

Summary of Poisson's ratio (ν) derived from RMR for borehole KSH03A and B (core sections of 5 m, Hoek and Brown's a = 0.5).

Rock Unit	Minimum ν	Average ν	Frequent ν	Maximum ν	Standard deviation	Min possible ν	Max possible ν
0–160	0.06	0.12	0.13	0.17	0.03	0.03	0.30
160–270 DZ1	0.03	0.05	0.05	0.10	0.02	0.01	0.20
270–440	0.05	0.12	0.11	0.19	0.04	0.02	0.28
440–575	0.08	0.13	0.12	0.17	0.03	0.03	0.26
575–755	0.09	0.17	0.18	0.24	0.04	0.04	0.30
755–864	0.09	0.13	0.14	0.19	0.04	0.04	0.28
864–1,000	0.08	0.09	0.09	0.14	0.01	0.03	0.28
RU1	0.03	0.09	0.09	0.17	0.04	0.01	0.30
RU2	0.05	0.13	0.11	0.24	0.05	0.02	0.30
RU3	0.08	0.13	0.13	0.19	0.03	0.03	0.28
Competent rock	0.05	0.13	0.12	0.24	0.04	0.02	0.30
Fractured rock	0.03	0.05	0.05	0.10	0.02	0.01	0.20
Whole borehole	0.03	0.12	0.11	0.24	0.05	0.01	0.30

Variation of Poisson's ratio (ν) with depth for borehole KSH03A and B (Hoek and Brown's a = 0.5). The values are given every 5 m.



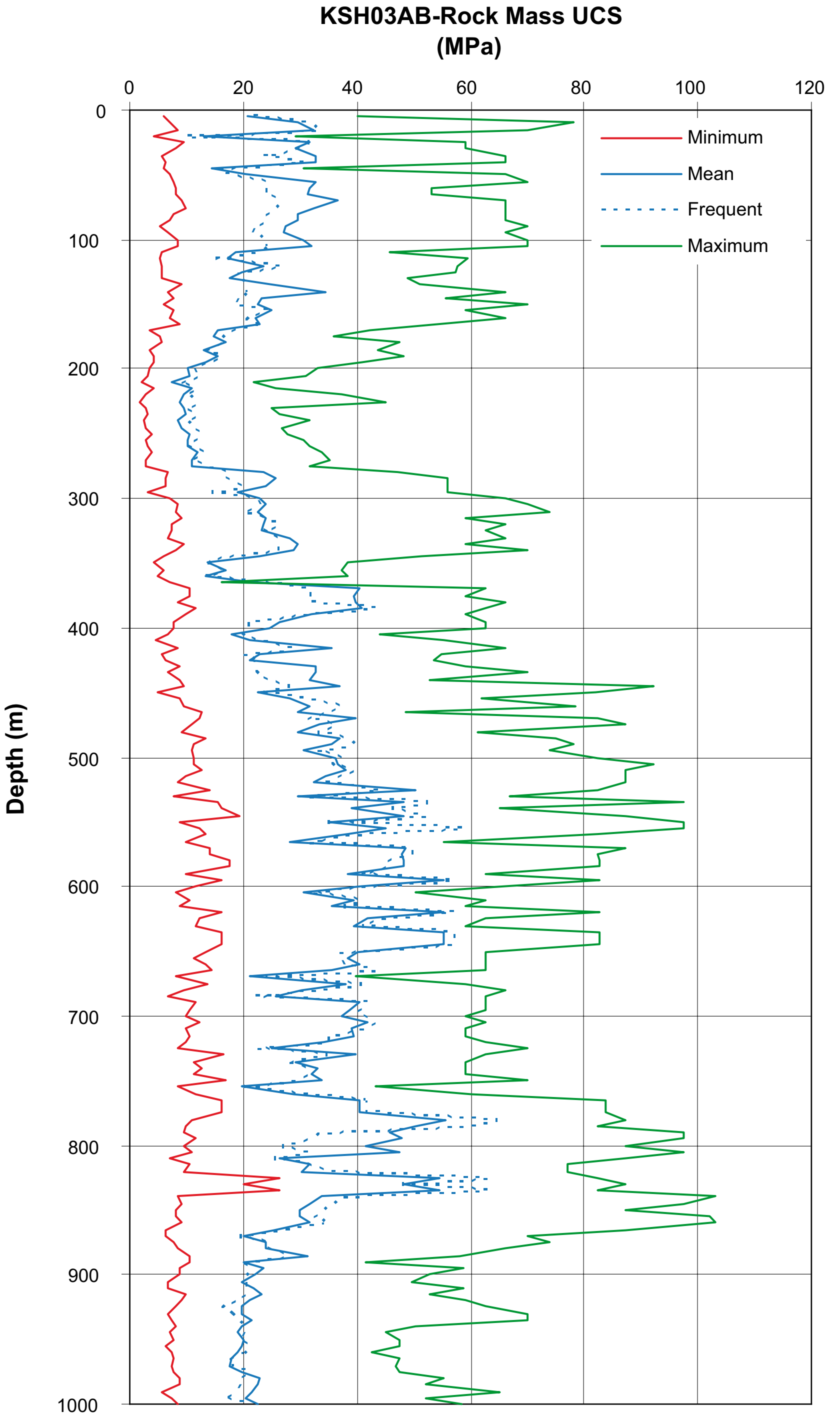
A3.6 Uniaxial compressive strength

A3.6.1 RMR

Summary of the uniaxial compressive strength of the rock mass derived from RMR for borehole KSH03A and B (core sections of 5 m, Hoek and Brown's a = 0.5).

Rock Unit	Minimum UCS	Average UCS	Frequent UCS	Maximum UCS	Standard deviation	Min possible UCS	Max possible UCS
0–160	13.1	26.4	28.4	36.5	6.3	4.3	78.2
160–270 DZ1	7.5	11.8	10.7	22.9	3.6	1.7	54.0
270–440	10.8	25.8	24.0	40.7	7.7	2.7	74.0
440–575	17.8	28.8	28.5	39.7	5.8	4.5	73.6
575–755	19.7	38.7	38.9	55.1	9.2	6.7	82.7
755–864	19.9	30.9	31.7	43.5	7.8	5.7	77.8
864–1,000	19.9	30.9	31.7	43.5	7.8	5.7	74.0
RU1	7.5	20.5	20.1	36.5	9.0	1.7	78.2
RU2	10.8	29.3	24.9	55.1	10.4	2.7	82.7
RU3	17.8	29.8	28.9	43.5	6.8	4.5	77.8
Competent rock	10.8	28.9	27.5	55.1	8.9	2.7	82.7
Fractured rock	7.5	11.8	10.7	22.9	3.6	1.7	54.0
Whole borehole	7.5	27.0	24.9	55.1	10.0	1.7	82.7

Variation of the uniaxial compressive strength of the rock mass with depth for borehole KSH03A and B (Hoek and Brown's a = 0.5). The values are given every 5 m.

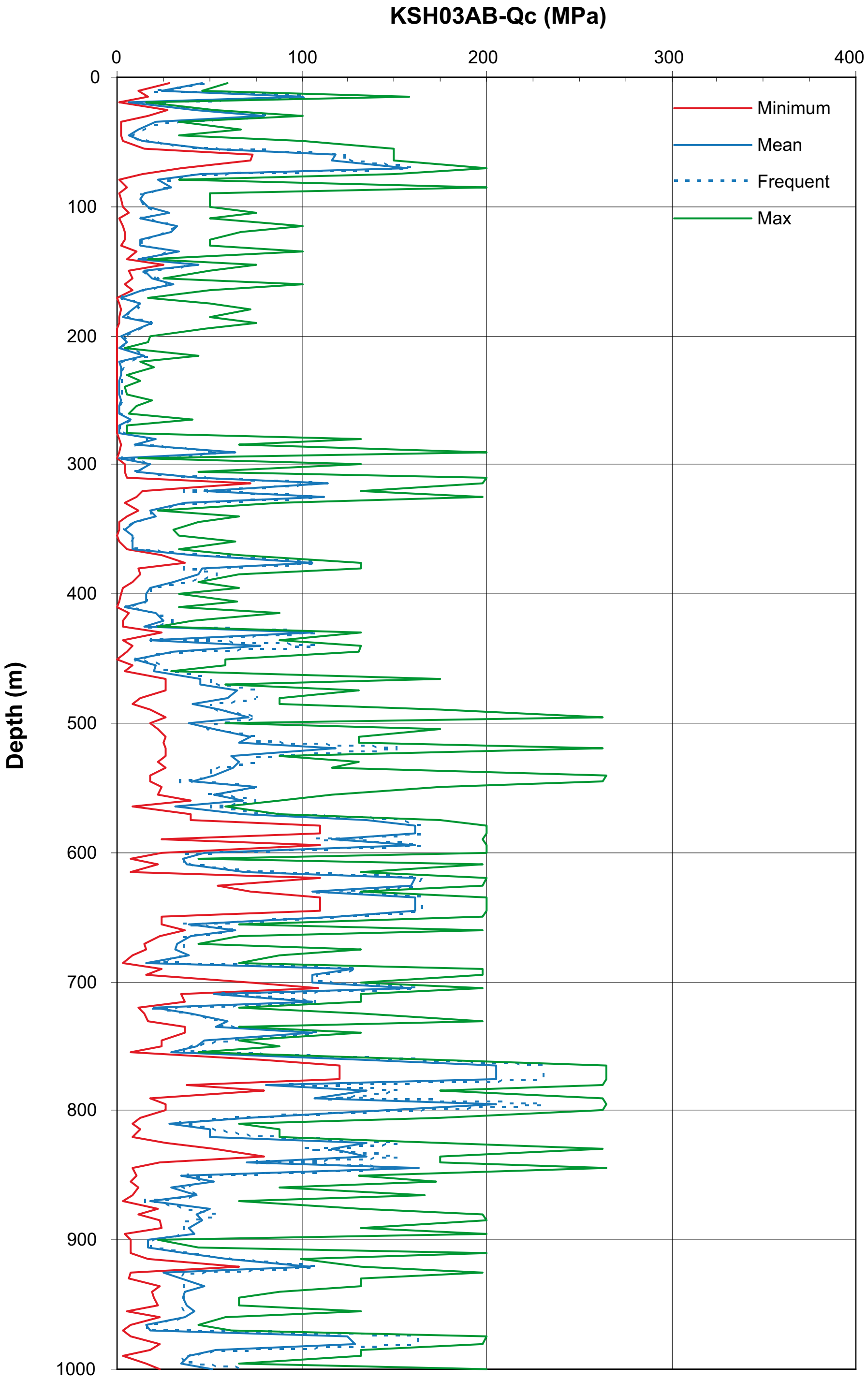


A3.6.2 Q

Summary of Qc derived from Q for borehole KSH03A and B (core sections of 5 m).

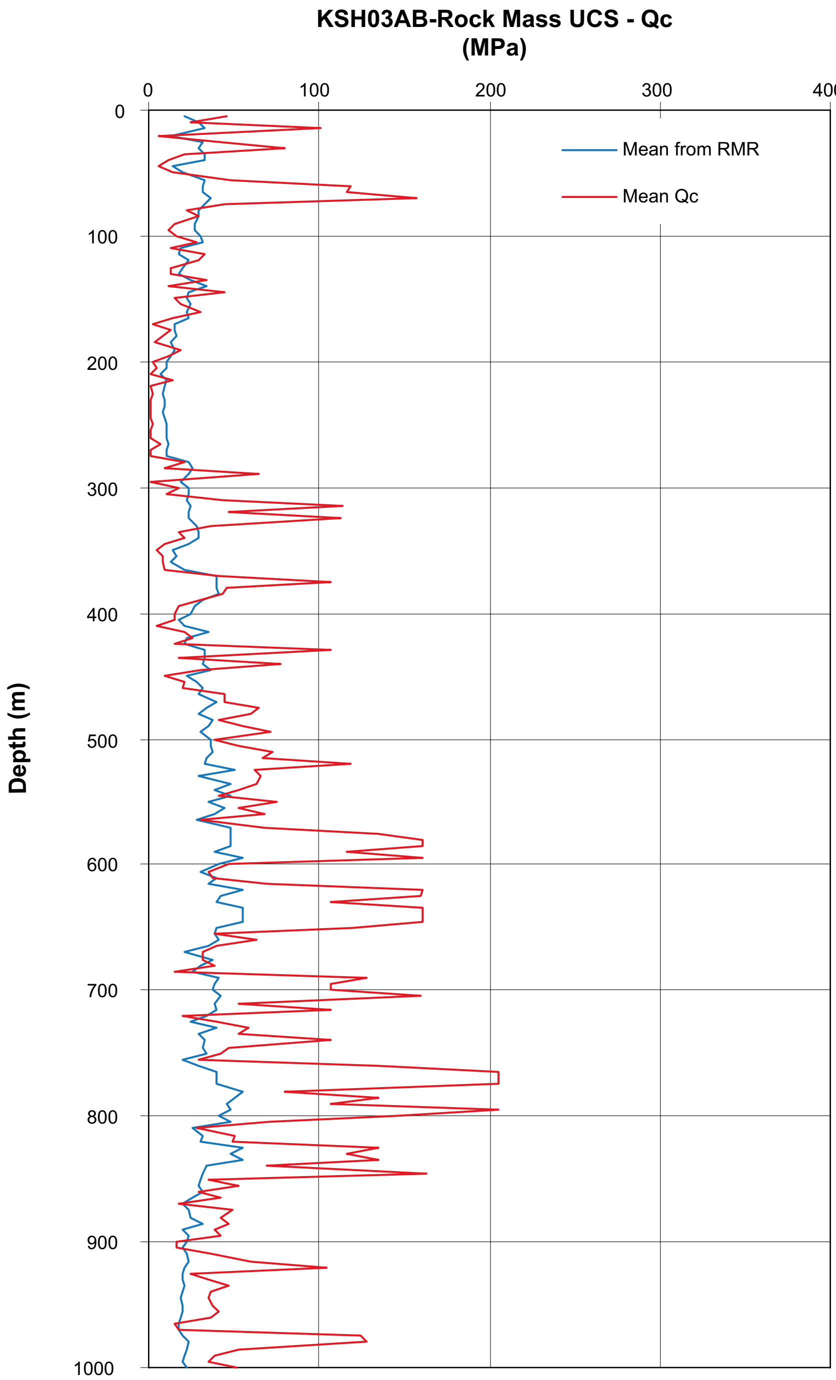
Rock Unit	Minimum Qc	Average Qc	Frequent Qc	Maximum Qc	Standard deviation	Min possible Qc	Max possible Qc
0–160	5.8	37.9	26.1	157.1	36.8	0.5	200.0
160–270 DZ1	1.0	5.2	2.0	18.6	5.4	0.1	75.0
270–440	1.0	33.6	19.5	113.9	33.3	0.1	200.0
440–575	9.9	56.5	55.5	135.3	26.8	0.4	265.0
575–755	15.6	87.0	66.6	161.0	52.5	3.5	200.0
755–864	28.6	109.3	111.1	205.0	62.0	7.5	265.0
864–1,000	15.4	45.6	39.1	128.4	29.2	2.8	200.0
RU1	1.0	24.6	13.3	157.1	32.7	0.1	200.0
RU2	1.0	56.7	40.1	161.0	46.8	0.1	200.0
RU3	9.9	80.2	64.9	205.0	52.6	0.4	265.0
Competent rock	1.0	59.8	43.1	205.0	48.8	0.1	265.0
Fractured rock	1.0	5.2	2.0	18.6	5.4	0.1	75.0
Whole borehole	1.0	53.8	39.6	205.0	49.2	0.1	265.0

Variation of Q_c with depth for borehole KSH03A and B. The values are given every 5 m.



A3.6.3 Comparison

Comparison of the rock mass compressive strength from RMR and Q for borehole KSH03A and B (Hoek and Brown's a = 0.5).



A3.7 Friction angle and cohesion and of the rock mass

A3.7.1 RMR

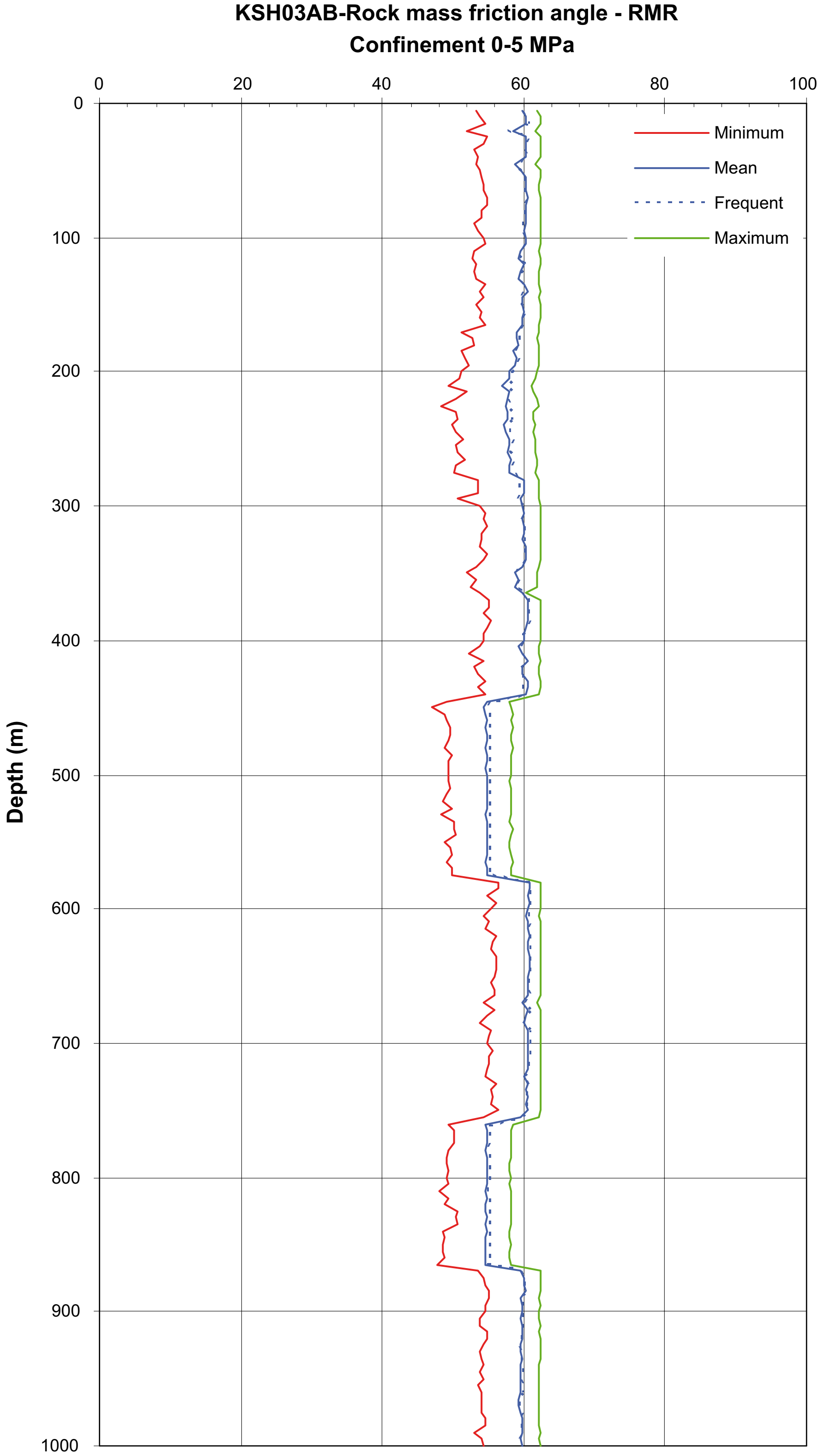
Summary of the friction angle (φ) of the rock mass derived from RMR for borehole KSH03A and B (10–30 MPa) (core sections of 5 m, Hoek and Brown's a = 0.5).

Rock Unit	Minimum φ'	Average φ'	Frequent φ'	Maximum φ'	Standard deviation	Min possible φ'	Max possible φ'
0–160	40.1	43.6	44.1	45.4	1.4	31.1	50.2
160–270 DZ1	37.0	39.3	38.9	43.0	1.4	26.4	48.6
270–440	39.0	43.4	43.3	45.9	1.6	28.6	50.0
440–575	37.7	40.0	40.1	41.6	0.9	26.6	47.4
575–755	42.2	45.5	45.7	47.4	1.2	33.5	50.4
755–864	38.3	40.3	40.6	42.0	1.2	27.9	47.6
864–1,000	41.7	42.6	42.4	44.6	0.6	32.6	50.0
RU1	37.0	41.8	42.3	45.4	2.5	26.4	50.2
RU2	39.0	44.0	43.5	47.4	1.8	28.6	50.4
RU3	37.7	40.1	40.1	42.0	1.1	26.6	47.6
Competent rock	37.7	42.8	42.9	47.4	2.3	26.6	50.4
Fractured rock	37.0	39.3	38.9	43.0	1.4	26.4	48.6
Whole borehole	37.0	42.2	42.6	47.4	2.5	26.4	50.4

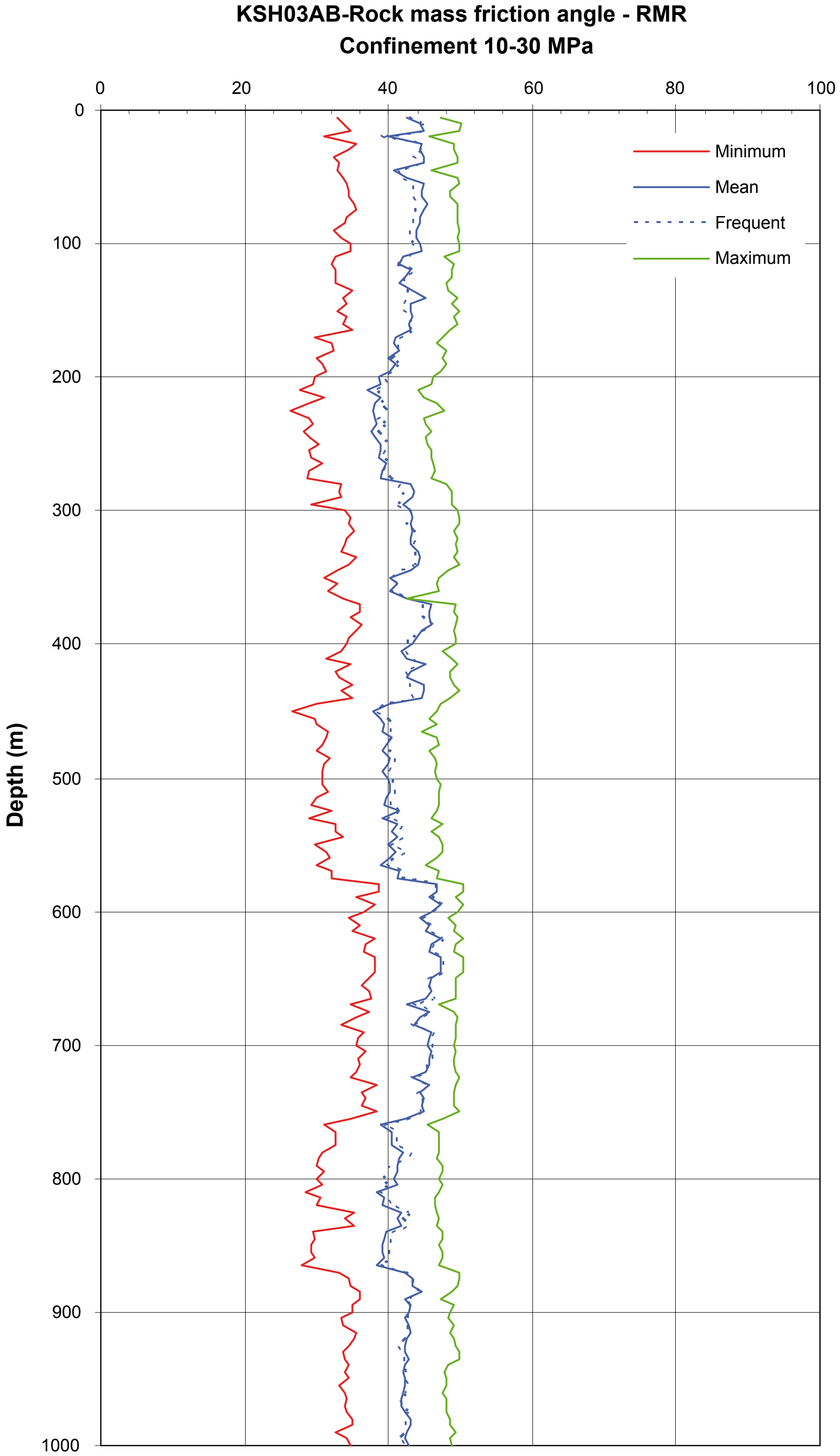
Summary of the cohesion of the rock mass derived from RMR for borehole KSH03A and B (10–30 MPa) (core sections of 5 m, Hoek and Brown's a = 0.5).

Rock Unit	Minimum c'	Average c'	Frequent c'	Maximum c'	Standard deviation	Min possible c'	Max possible c'
0–160	14.9	17.5	17.8	19.1	1.1	10.5	25.2
160–270 DZ1	13.2	14.5	14.2	16.9	0.9	8.6	22.1
270–440	14.2	17.3	17.1	19.7	1.3	9.5	24.6
440–575	14.5	16.9	16.8	19.1	1.2	8.8	26.8
575–755	16.3	19.4	19.4	21.7	1.4	11.6	25.7
755–864	15.0	17.3	17.5	19.9	1.6	9.4	27.6
864–1,000	15.9	16.6	16.4	18.3	0.5	11.2	24.6
RU1	13.2	16.2	16.4	19.1	1.8	8.6	25.2
RU2	14.2	17.9	17.3	21.7	1.6	9.5	25.7
RU3	14.5	17.1	16.9	19.9	1.4	8.8	27.9
Competent rock	14.2	17.6	17.2	21.7	1.5	8.8	27.6
Fractured rock	13.2	14.5	14.2	16.9	0.9	8.6	22.1
Whole borehole	13.2	17.2	17.0	21.7	1.8	8.6	27.6

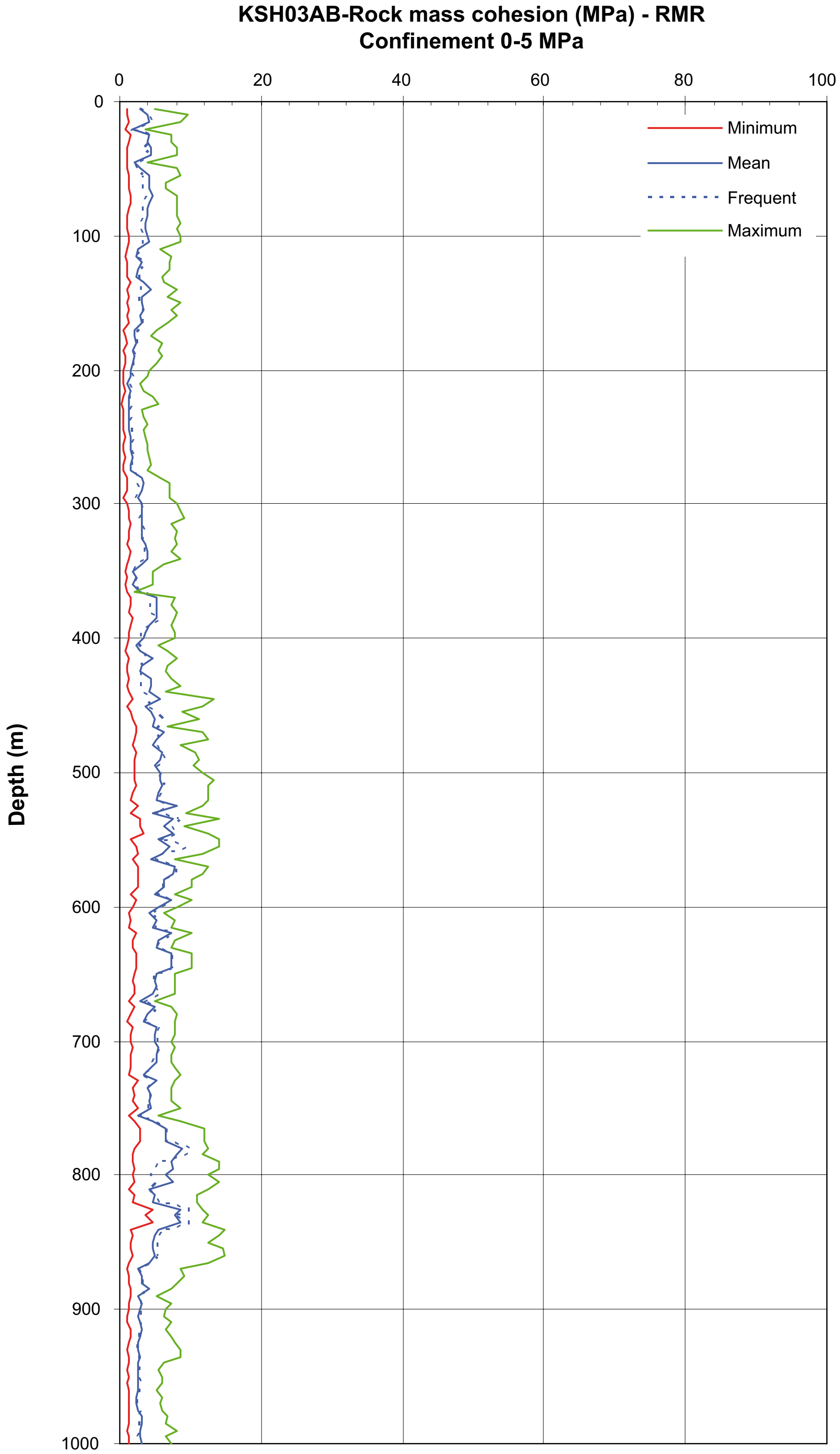
Variation of the rock mass friction angle from RMR for borehole KSH03A and B under stress confinement 0–5 MPa (Hoek and Brown's a = 0.5).



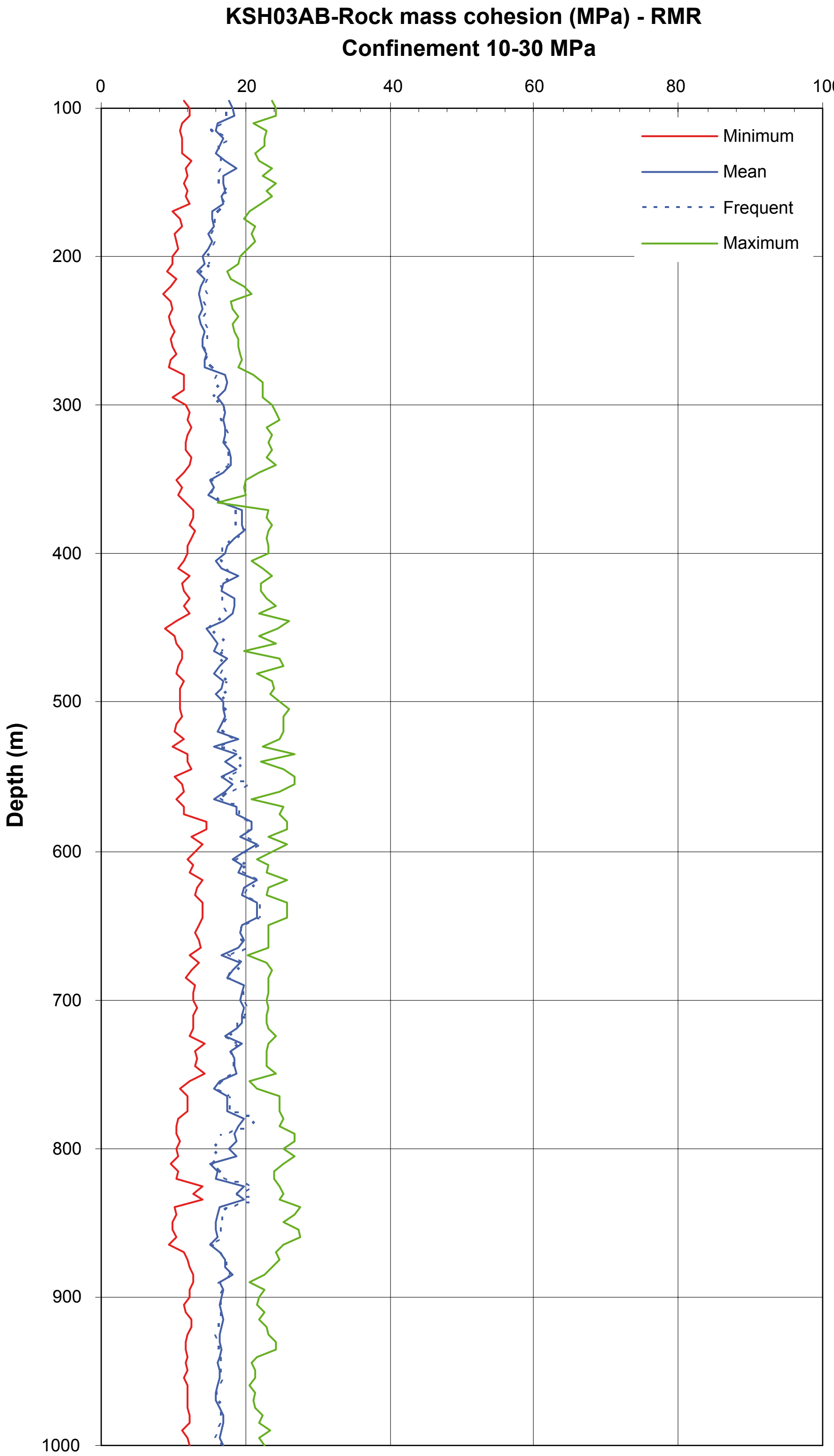
Variation of the rock mass friction angle from RMR for borehole KSH03A and B under stress confinement 10–30 MPa (Hoek and Brown's a = 0.5).



Variation of the rock mass cohesion from RMR for borehole KSH03A and B under stress confinement 0–5 MPa (Hoek and Brown's a = 0.5).



Variation of the rock mass cohesion from RMR for borehole KSH03A and B under stress confinement 10–30 MPa (Hoek and Brown's a = 0.5).



A3.7.2 Q

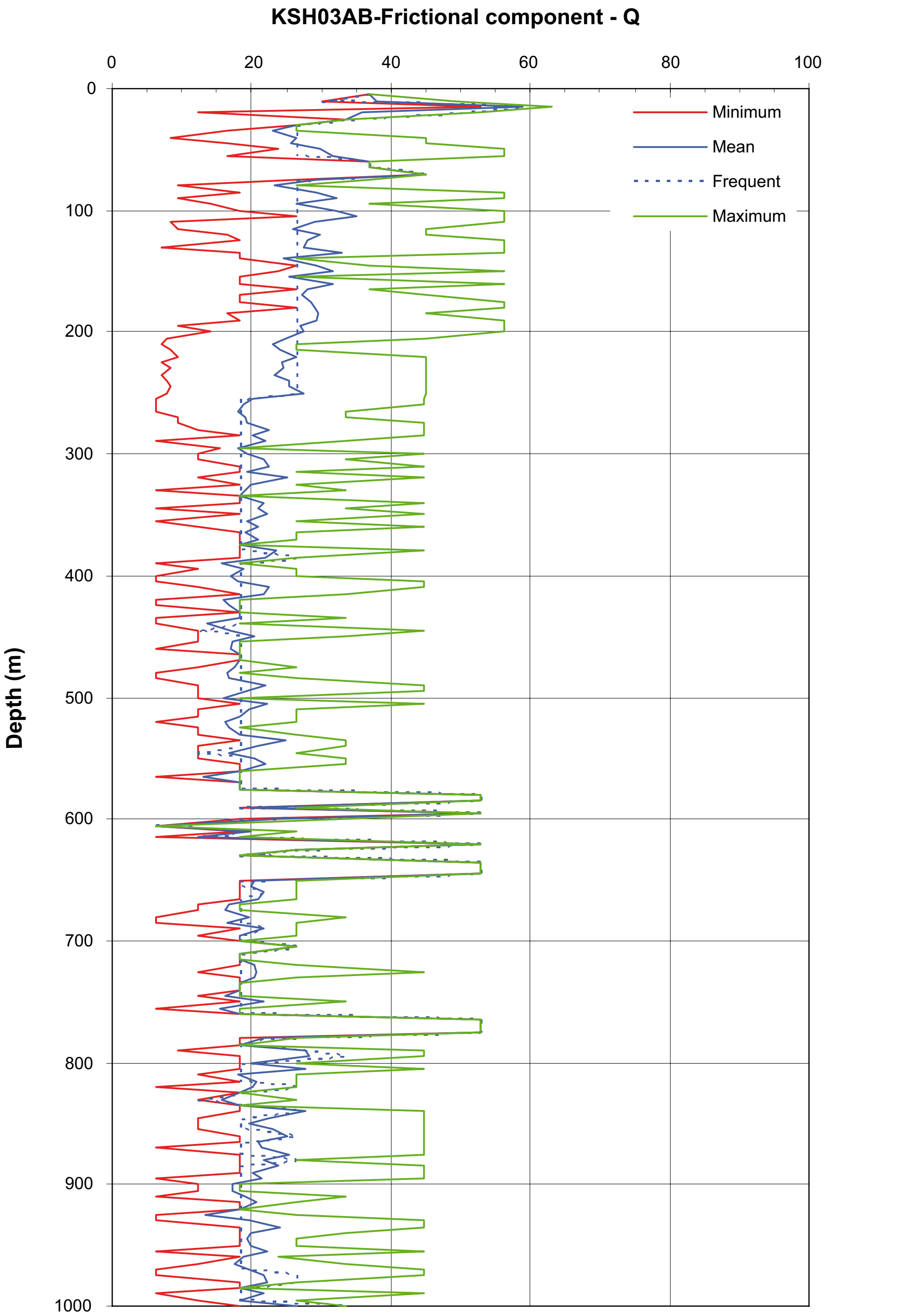
Summary of the frictional component FC of the rock mass derived from Qc for borehole KSH03A and B (core sections of 5 m).

Rock Unit	Minimum mean FC	Average mean FC	Frequent mean FC	Maximum mean FC	Standard deviation	Min possible FC	Max possible FC
0–160	23.2	31.5	29.9	58.8	7.0	7.1	63.2
160–270 DZ1	18.1	25.1	25.4	29.7	3.5	6.3	56.3
270–440	13.6	19.8	19.4	25.2	2.5	6.3	44.7
440–575	13.1	18.5	18.3	24.8	2.4	6.3	44.7
575–755	6.3	25.6	20.1	52.9	14.0	6.3	52.9
755–864	15.8	25.9	21.3	52.9	14.0	6.3	52.9
864–1,000	13.3	20.3	19.9	26.3	2.7	6.3	44.7
RU1	18.1	28.9	27.8	58.8	6.6	6.3	63.2
RU2	6.3	22.1	19.8	52.9	9.1	6.3	52.9
RU3	13.1	21.9	19.3	52.9	8.7	6.3	52.9
Competent rock	6.3	23.7	20.7	58.8	9.3	6.3	63.2
Fractured rock	18.1	25.1	25.4	29.7	3.5	6.3	56.3
Whole borehole	6.3	23.9	21.2	58.8	8.9	6.3	63.2

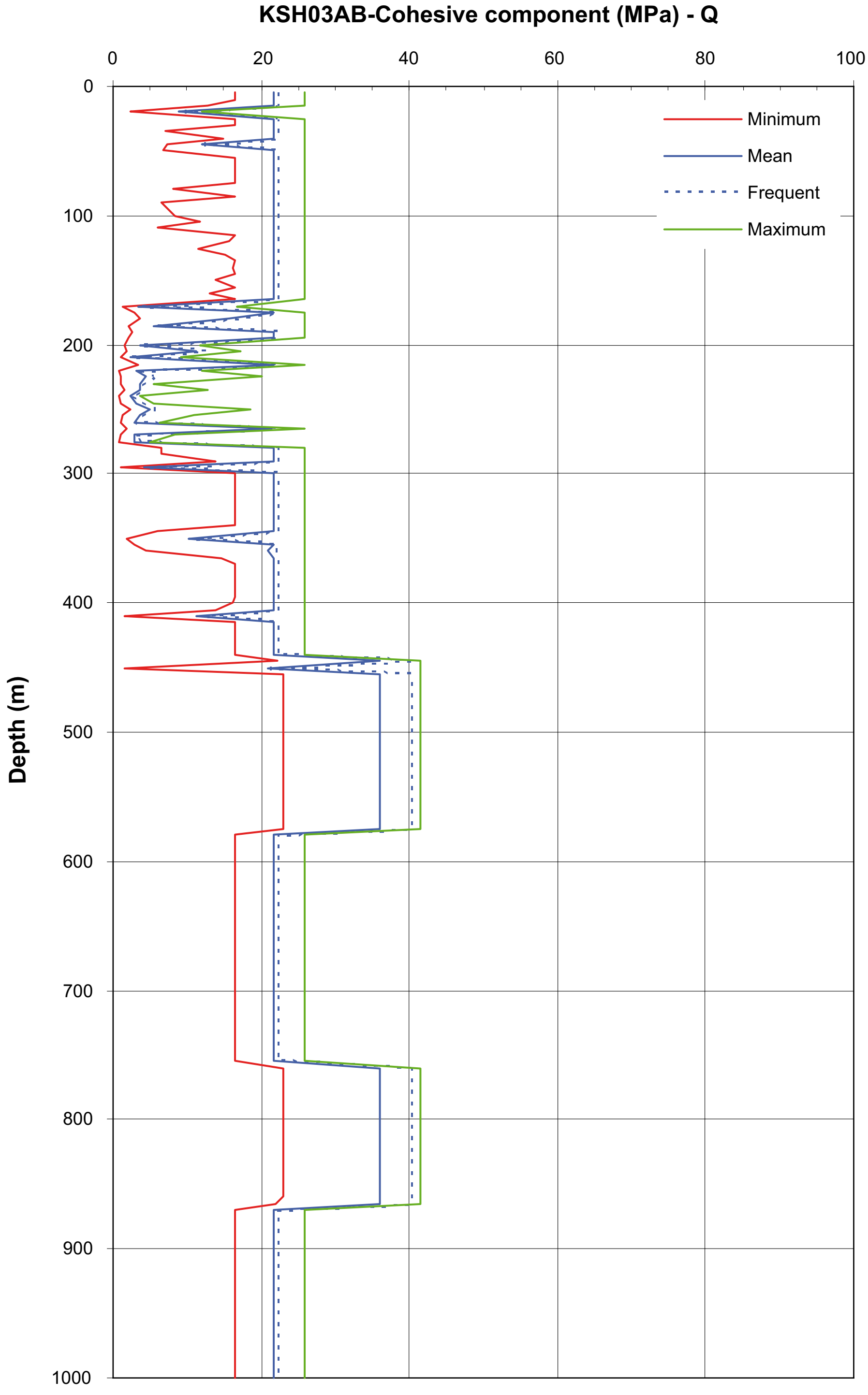
Summary of the cohesion of the rock mass derived from Qc for borehole KSH03A and B (core sections of 5 m).

Rock Unit	Minimum CC	Average CC	Frequent CC	Maximum CC	Standard deviation	Min possible CC	Max possible CC
0–160	8.8	21.0	21.7	21.7	2.8	2.4	25.8
160–270 DZ1	2.3	9.4	4.0	21.7	8.3	0.8	25.8
270–440	2.3	9.4	4.0	21.7	8.3	0.9	25.8
440–575	20.9	35.4	35.9	35.9	2.9	1.7	41.5
575–755	21.7	21.7	21.7	21.7	0.0	16.5	25.8
755–864	35.9	35.9	35.9	35.9	0.0	22.0	41.5
864–1,000	21.7	21.7	21.7	21.7	0.0	16.5	25.8
RU1	2.3	16.3	21.7	21.7	8.0	0.8	25.8
RU2	3.0	21.1	21.7	21.7	3.0	0.9	25.8
RU3	20.9	35.6	35.9	35.9	2.1	1.7	41.5
Competent rock	3.0	25.1	21.7	35.9	7.1	0.9	41.5
Fractured rock	2.3	9.4	4.0	21.7	8.3	0.8	25.8
Whole borehole	2.3	23.3	21.7	35.9	8.7	0.8	41.5

Variation of the frictional component FC from Q for borehole KSH03A and B.

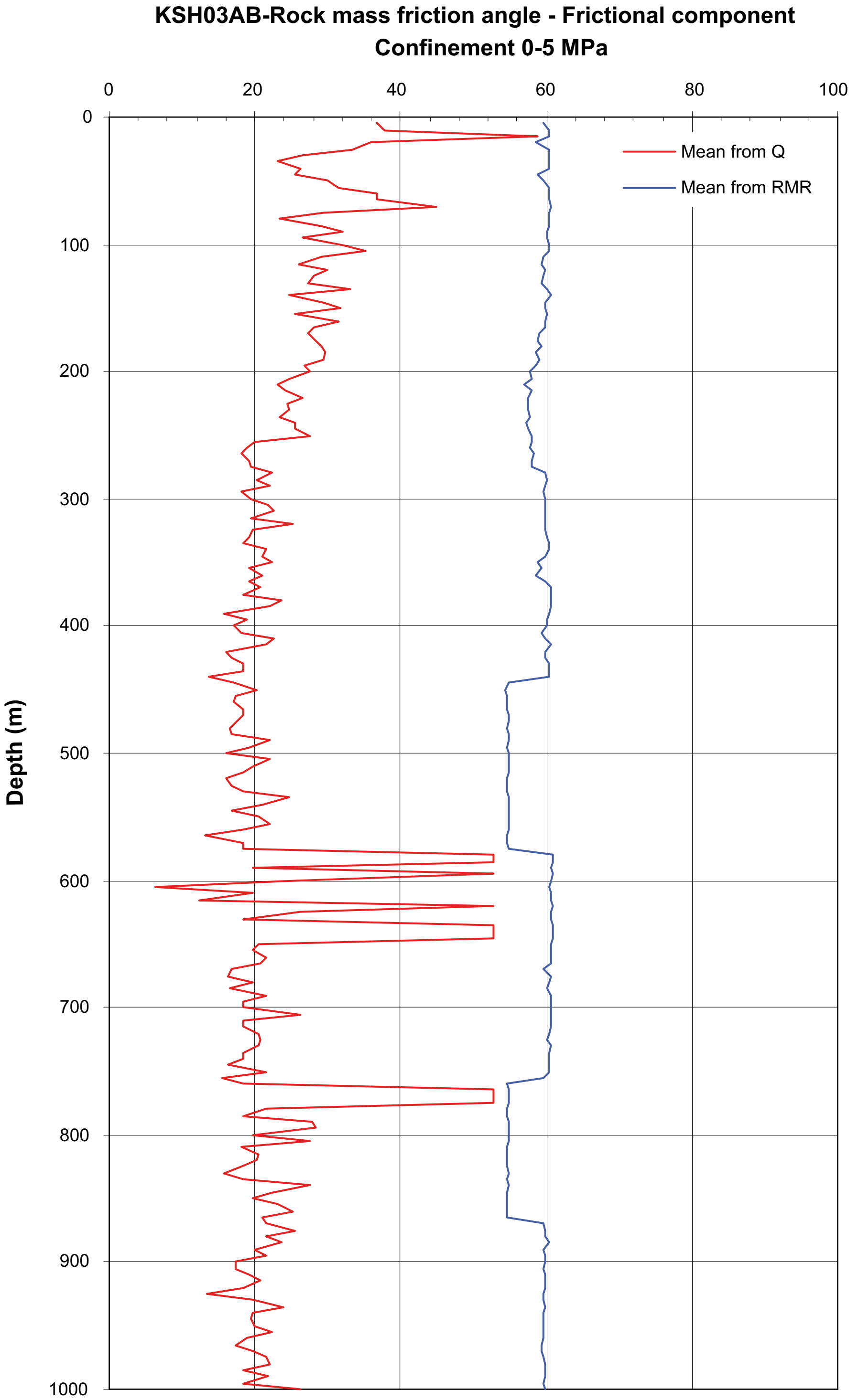


Variation of the cohesive component from Q for borehole KSH03A and B.

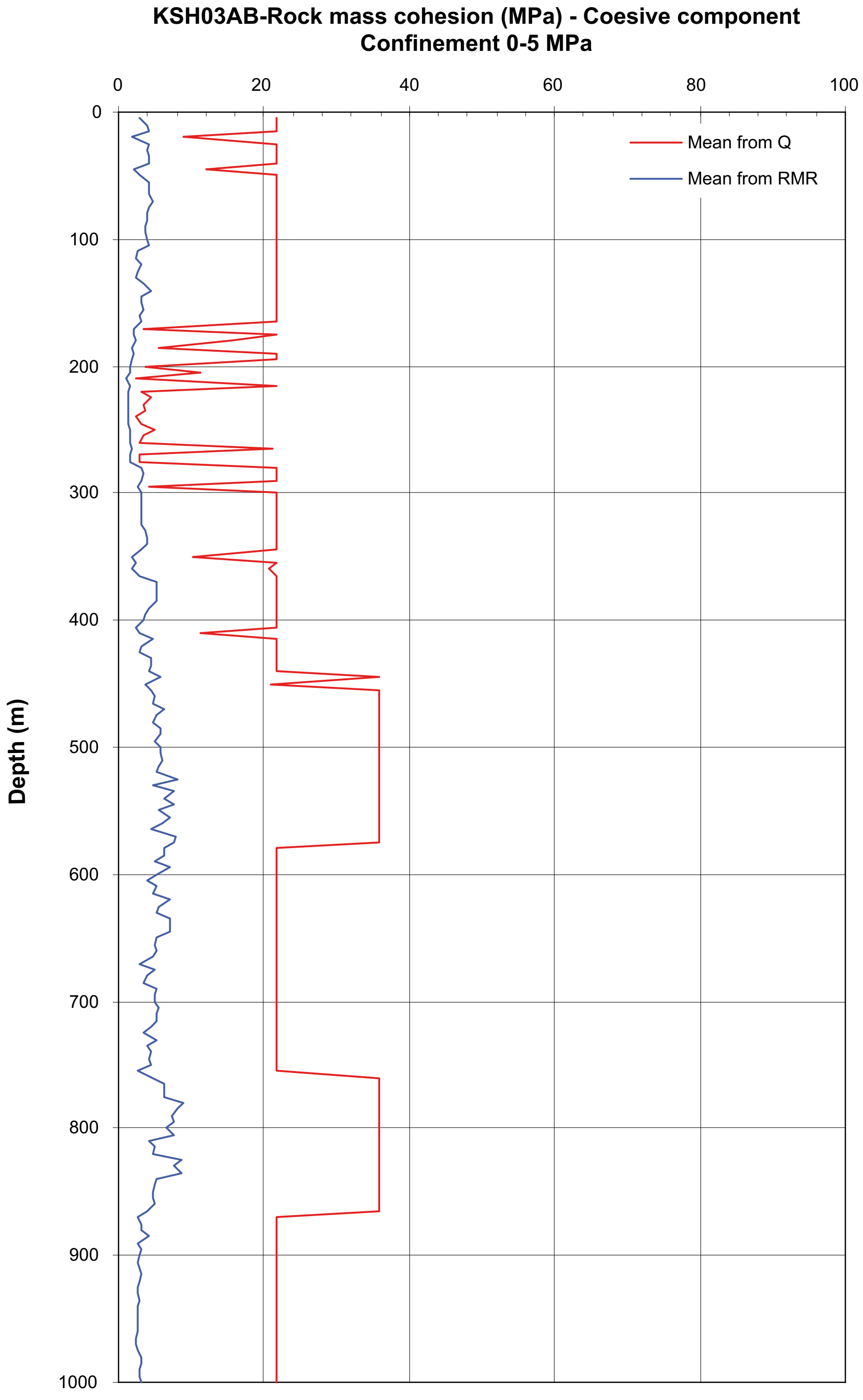


A3.7.3 Comparison

Comparison of the rock mass friction angle from RMR and Q for borehole KSH03A and B under stress confinement 0–5 MPa (Hoek and Brown's a = 0.5).



Comparison of the rock mass cohesion from RMR and Q for borehole KSH03A and B under stress confinement 0–5 MPa (Hoek and Brown's a = 0.5).



KAV01
Characterisation of the rock mass

A4.1 Fracture orientation and Fisher's constant

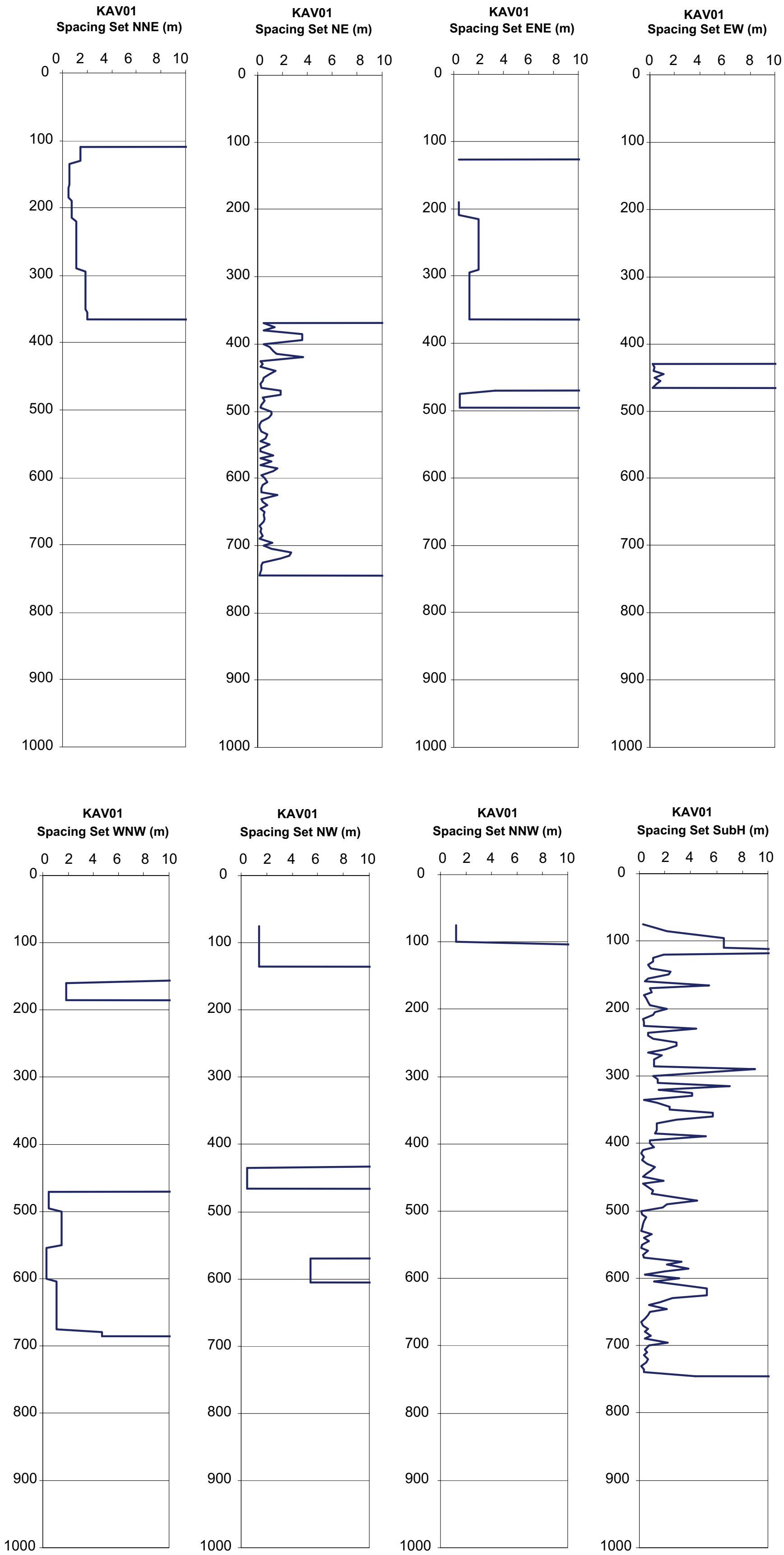
Set identification from the fracture orientation mapped for borehole KAV01 (based on SICADA data received on 25/04/2004). The orientations are given as strike/dip (right-hand rule).

Depth (m)	No of fract	NS	NNE	NE	ENE	EW	WNW	NW	NNW	SubH
20–70										
70–135	127		209/76					328/75	298/75	291/02
135–185	176		211/53				299/87			238/09
185–364	306		214/60		246/90					230/16
364–427	170			225/64						025/06
427–464	277			235/60		087/47		315/71		006/03
464–494	175			229/59	080/37		298/63			018/00
494–565	414			226/70			309/80			107/10
565–605	112			229/75			103/53	315/78		225/04
605–686	335			237/64			305/76			238/12
686–750	261			219/51						227/05

Fisher's constant of the fracture sets identified for borehole KAV01 (SICADA, 04-05-25).

Depth (m)	No of fract	NS	NNE	NE	ENE	EW	WNW	NW	NNW	SubH
20–70										
70–135	127		33					37	40	74
135–185	176		27				38			26
185–364	306		27		23					21
364–427	170			33						9
427–464	277			27		34		29		27
464–494	175			59	26		20			198
494–565	414			61			49			8
565–605	112			68			26	84		18
605–686	335			28			69			10
686–750	261			27						53

Fracture spacing with depth for the five facture sets in borehole KAV01. The values are averaged for each 5 m length of borehole.

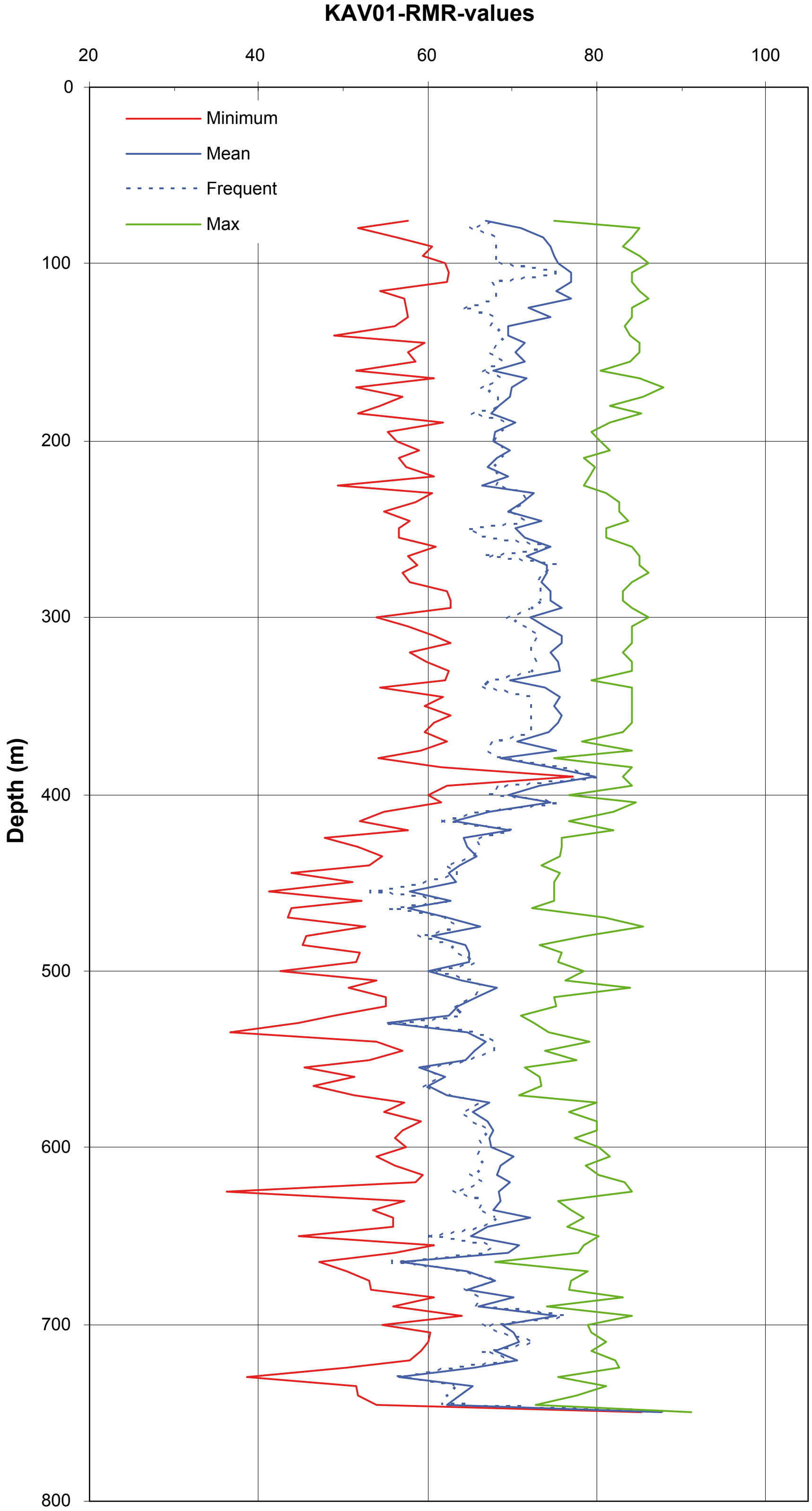


A4.2 RMR

RMR values along borehole KAV01 (core sections of 5 m).

Rock Unit	Minimum RMR	Average RMR	Frequent RMR	Maximum RMR	Standard deviation	Min possible RMR	Max possible RMR
70–135 RU1	66.9	73.8	74.6	77.1	3.1	51.9	86.1
135–185 RU2	67.5	69.8	69.8	71.7	1.5	48.9	88.0
185–365 RU3	66.4	72.6	73.7	76.0	2.9	48.9	86.1
365–425	63.2	70.9	70.1	79.7	4.8	47.9	84.7
425–440 DZ1	63.7	64.7	64.8	65.7	1.0	51.9	75.9
440–465 DZ2	57.7	60.8	62.4	63.5	2.8	41.4	75.7
465–565 DZ3	55.2	63.3	64.2	68.2	3.1	36.6	85.5
565–605	62.4	66.8	67.3	70.1	2.2	51.4	81.6
605–685 RU6	56.7	67.5	68.3	72.2	3.6	36.3	84.1
685–750 RU7	56.6	68.6	68.0	87.7	7.4	38.5	91.1
RU4	57.7	66.6	64.9	79.7	5.5	41.4	85.5
RU5	55.2	64.4	65.0	70.1	3.6	36.6	84.0
Competent rock	56.6	70.6	70.3	87.7	4.5	36.3	91.1
Fractured rock	55.2	63.0	63.7	68.2	3.0	36.6	85.5
Whole borehole	55.2	69.0	69.4	87.7	5.2	36.3	91.1

Variation of RMR with depth for borehole KAV01. The values are given every 5 m.

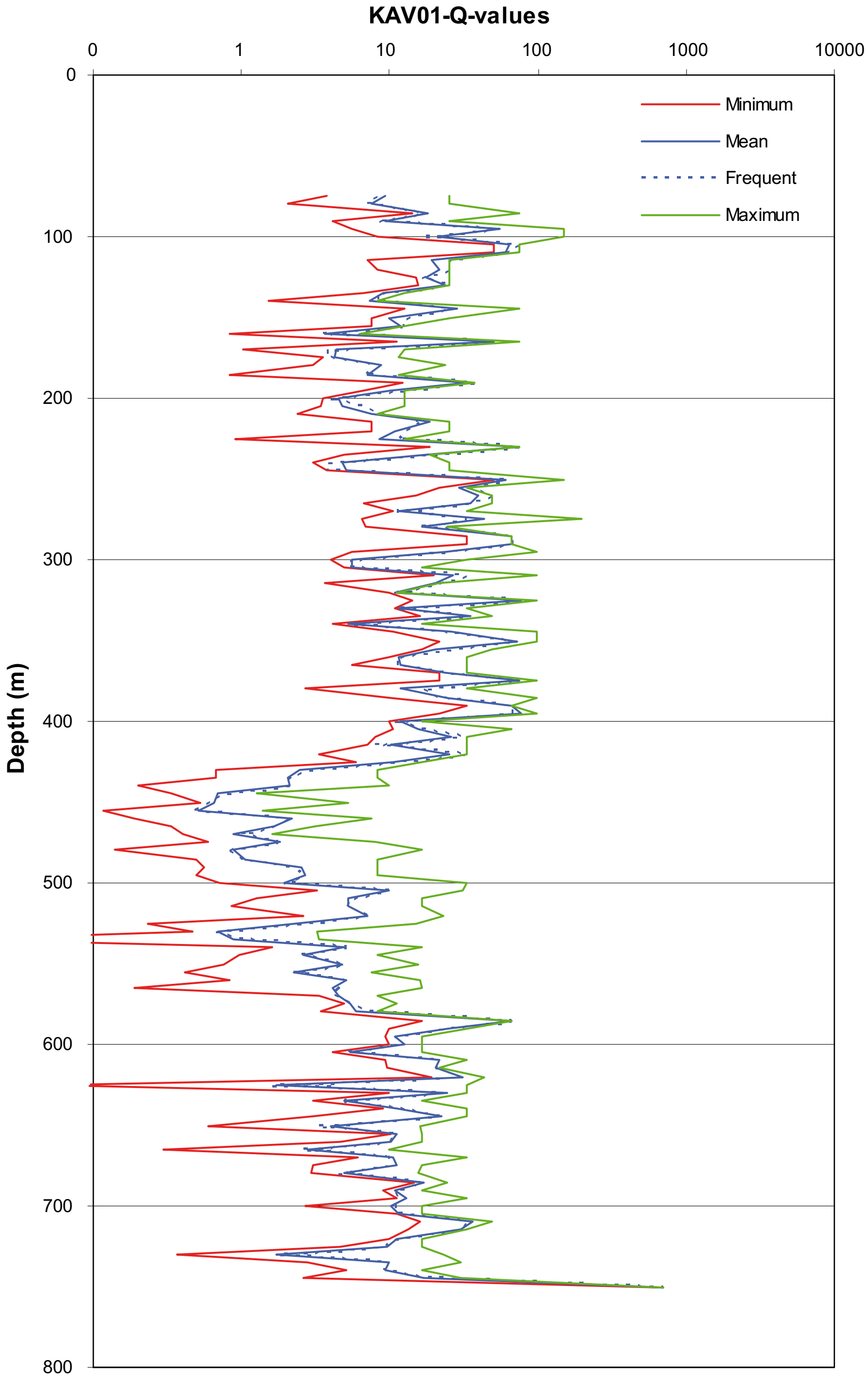


A4.3 Q

Q values along borehole KAV01 (core sections of 5 m).

Rock Unit	Minimum Q	Average Q	Frequent Q	Maximum Q	Min possible Q	Max possible Q
70–135 RU1	7.4	25.9	19.4	64.3	2.1	150.0
135–185 RU2	3.6	13.5	8.0	50.0	0.8	75.0
185–365 RU3	4.6	25.9	17.9	77.0	0.9	198.0
365–425	10.1	31.3	24.0	76.2	2.7	99.0
425–440 DZ1	2.1	2.2	2.1	2.4	0.2	10.0
440–465 DZ2	0.5	1.1	0.7	2.2	0.1	7.6
465–565 DZ3	0.7	3.4	2.6	9.9	0.01	33.0
565–605	4.6	16.9	8.3	66.0	3.3	66.0
605–685 RU6	1.7	13.1	11.1	31.2	0.06	44.0
685–750 RU7	1.7	67.3	11.2	704.0	0.4	704.0
RU4	0.5	15.3	2.6	76.2	0.1	99.0
RU5	0.7	8.8	5.2	66.0	0.01	66.0
Competent rock	1.7	27.8	12.0	704.0	0.1	704.0
Fractured rock	0.5	2.8	2.2	9.9	0.01	33.0
Whole borehole	0.5	22.6	10.8	704.0	0.01	704.0

Variation of Q with depth for borehole KAV01. The values are given every 5 m.



Rock mass properties

A4.4 Deformation modulus

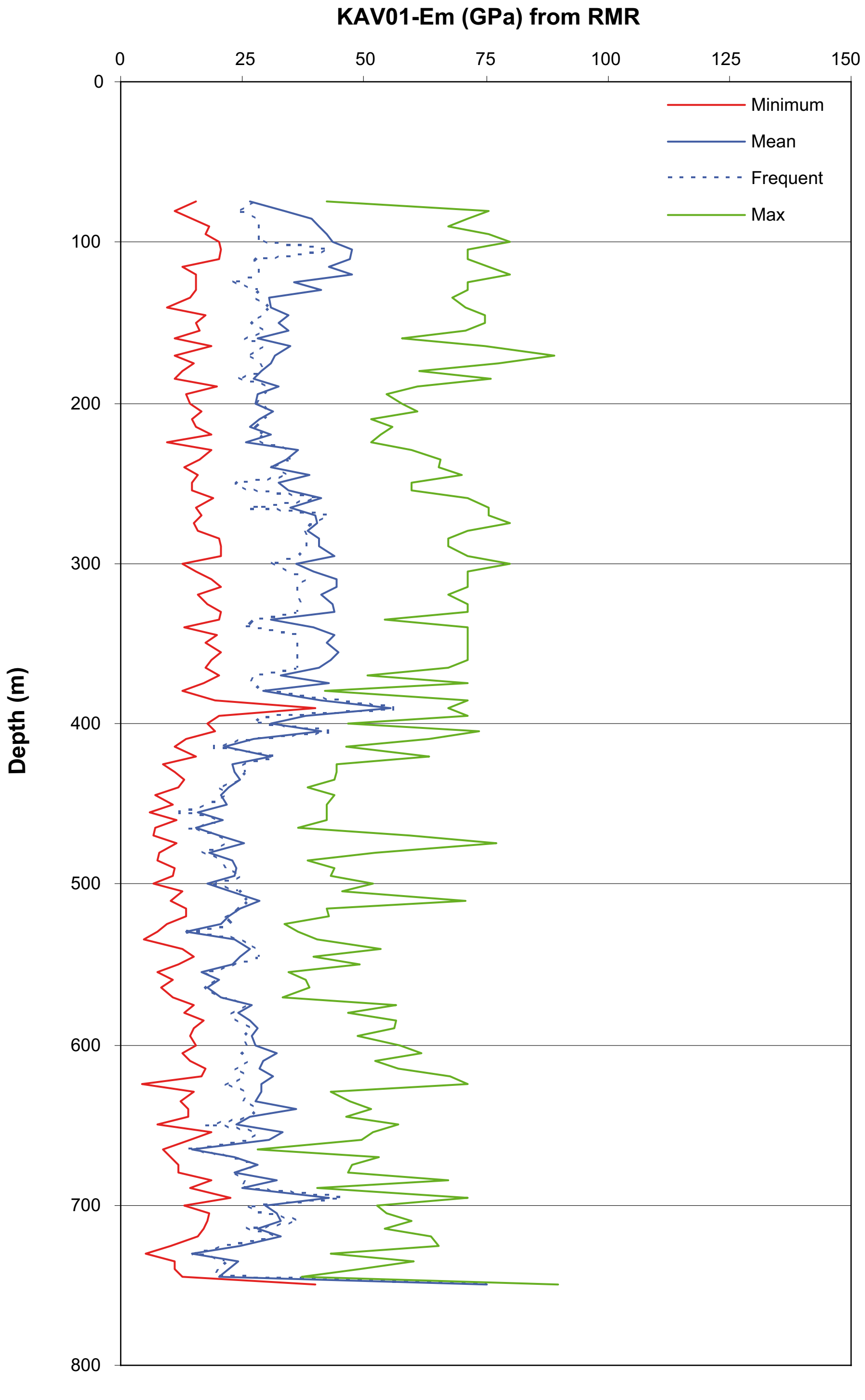
A4.4.1 RMR

Deformation modulus Em derived from RMR along for borehole KAV01 (core sections of 5 m).

Rock Unit	Minimum Em (GPa)	Average Em (GPa)	Frequent Em (GPa)	Maximum Em (GPa)	Standard deviation Em (GPa)	Min possible Em (GPa)	Max possible Em (GPa)
70–135 RU1	26.5	39.8	41.2	47.5	6.5	11.1	79.9
135–185 RU2	27.4	31.4	31.3	34.9	2.8	9.4	89.1
185–365 RU3	25.8	37.1	39.1	44.6	5.9	9.7	79.9
365–425	21.4	34.5	31.9	55.3	9.6	8.9	73.8
425–440 DZ1	22.0	23.4	23.4	24.7	1.4	11.1	44.5
440–465 DZ2	15.6	18.9	20.5	21.7	3.0	6.1	43.8
465–565 DZ3	13.5	21.8	22.7	28.5	3.6	4.6	77.2
565–605	20.4	26.6	27.0	31.9	3.3	10.9	61.5
605–685 RU6	14.7	27.9	28.7	36.0	4.9	4.5	71.2
685–750 RU7	14.7	31.1	28.1	75.0	14.9	5.2	90.0
RU4	15.6	27.4	23.6	55.3	9.5	6.1	77.2
RU5	13.5	23.4	23.7	31.9	4.5	4.6	70.9
Competent rock	14.7	33.8	32.3	75.0	8.6	4.5	90.0
Fractured rock	13.5	21.4	22.0	28.5	3.5	4.6	77.2
Whole borehole	13.5	31.2	30.6	75.0	9.3	4.5	90.0

The maximum Em and the maximum possible 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 KAV01. The values are given every 5 m.



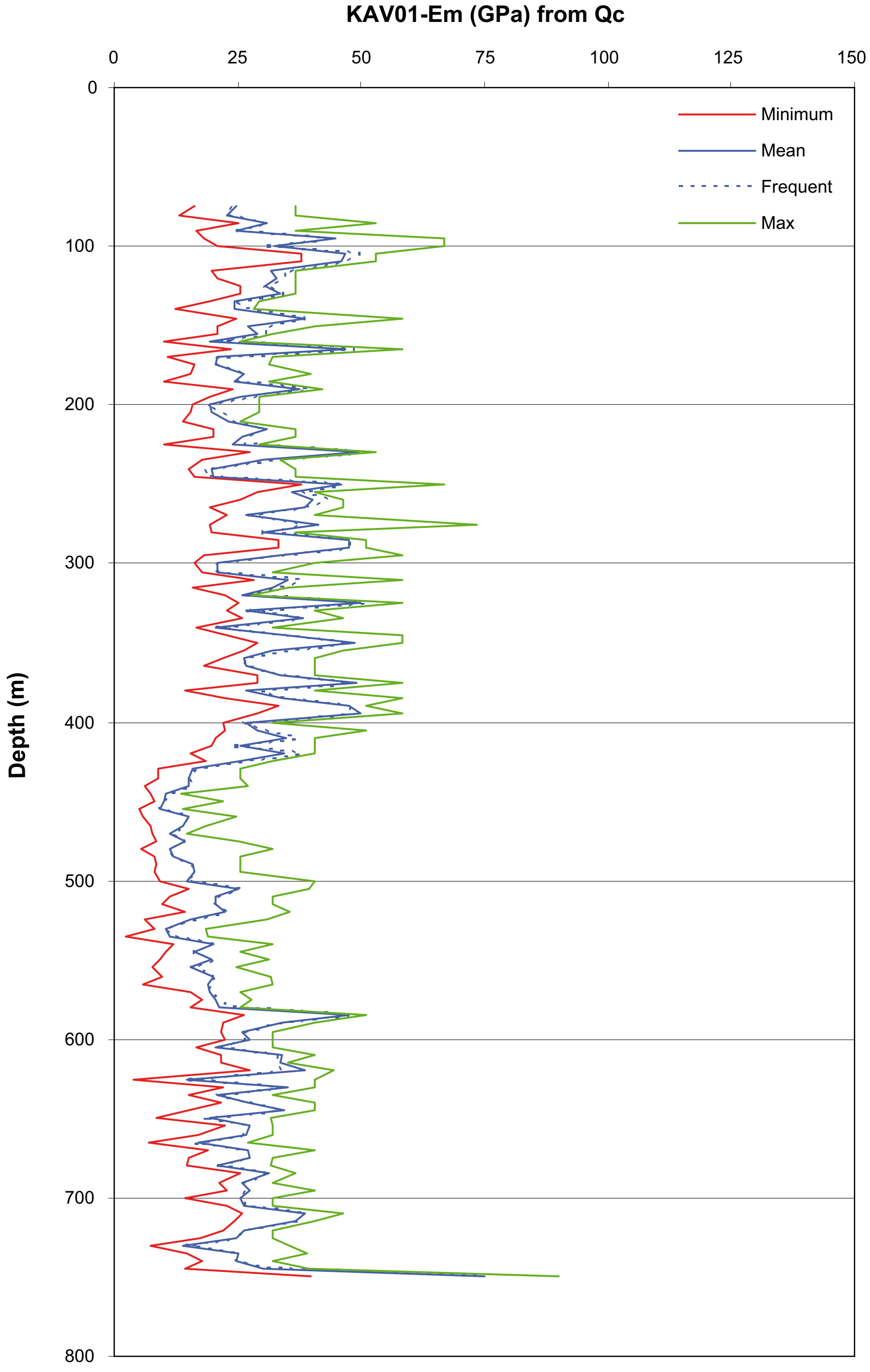
A4.4.2 Q

Deformation modulus Em derived from Q along borehole KAV01 (core sections of 5 m).

Rock Unit	Minimum Em (GPa)	Average Em (GPa)	Frequent Em (GPa)	Maximum Em (GPa)	Standard deviation Em (GPa)	Min possible Em (GPa)	Max possible Em (GPa)
70–135 RU1	22.9	32.7	31.5	47.0	8.3	13.1	66.9
135–185 RU2	19.5	27.7	25.3	46.8	8.7	9.9	58.4
185–365 RU3	19.4	32.0	30.6	49.9	9.6	10.0	73.4
365–425	25.3	34.7	33.8	49.7	9.2	14.4	58.3
425–440 DZ1	15.0	15.2	15.0	15.8	0.4	6.0	27.2
440–465 DZ2	9.3	11.8	10.4	15.2	2.6	5.1	24.8
465–565 DZ3	10.4	16.6	16.1	25.2	4.2	2.3	40.4
565–605	19.4	27.0	23.6	47.4	9.6	15.4	50.9
605–685 RU6	14.6	27.2	27.3	38.5	7.1	3.9	44.5
685–750 RU7	14.0	30.8	26.2	75.0	14.6	7.4	90.0
RU4	9.3	23.2	16.2	49.7	12.6	5.1	58.3
RU5	10.4	21.2	20.3	47.4	7.9	2.3	50.9
Competent rock	14.0	30.8	27.3	75.0	9.8	3.9	90.0
Fractured rock	9.3	15.6	15.3	25.2	4.1	2.3	40.4
Whole borehole	9.3	27.6	26.2	75.0	10.9	2.3	90.0

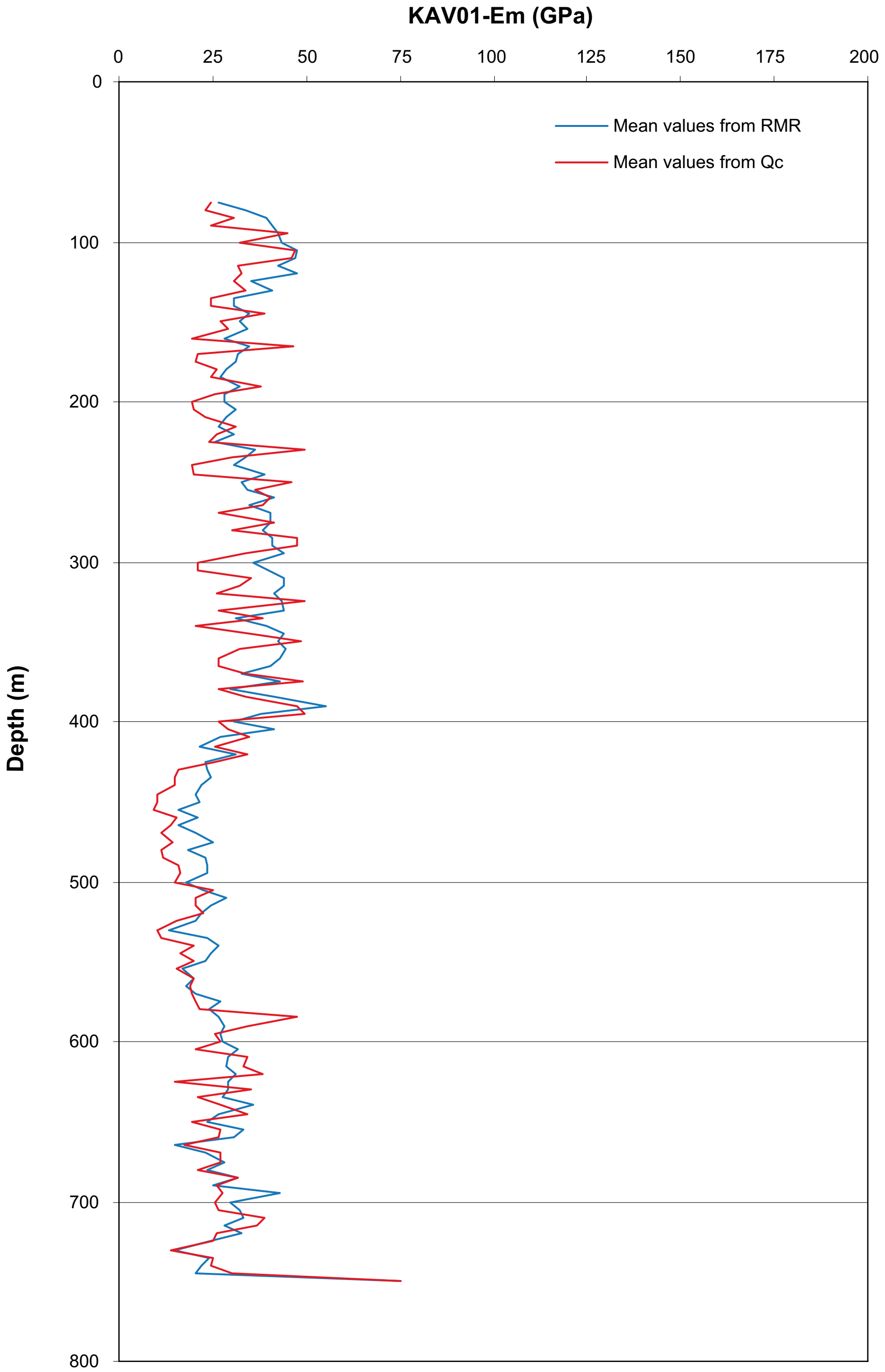
The maximum mean Em and the maximum confidence Em have a physical threshold in the Young's modulus of the intact rock, which is 75 and 90 GPa, respectively.

Variation of the deformation modulus of the rock mass obtained from Q_c with depth for borehole KAV01. The values are given every 5 m.



A4.4.3 Comparison

Comparison between the mean values of the deformation modulus E_m obtained from RMR and Qc for different depths for borehole KAV01.



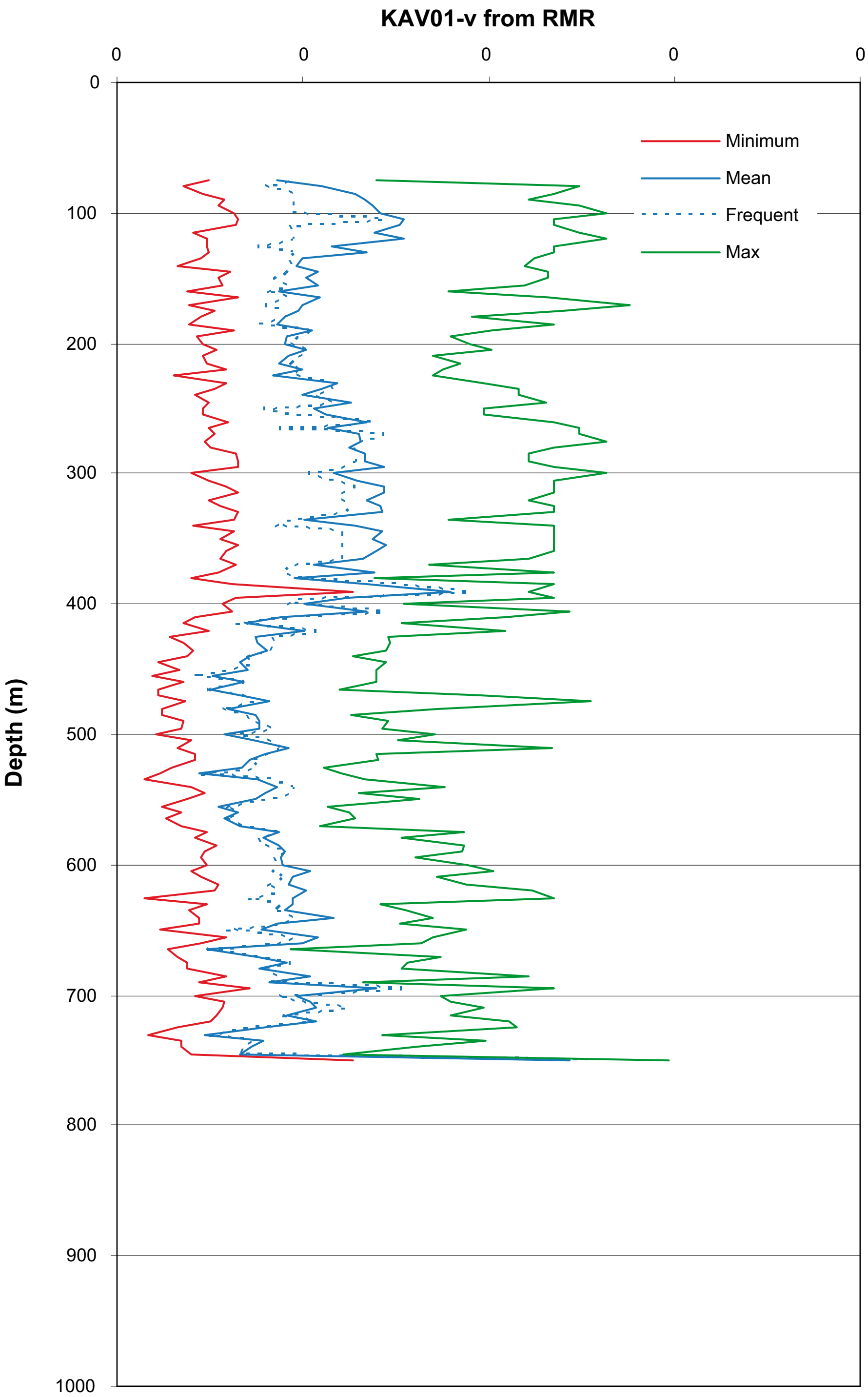
A4.5 Poisson's ratio

A4.5.1 RMR

Summary of Poisson's ratio (ν) derived from RMR for borehole KAV01 (core sections of 5 m, Hoek and Brown's a = 0.5).

Rock Unit	Minimum ν	Average ν	Frequent ν	Maximum ν	Standard deviation	Min possible ν	Max possible ν
70–135 RU1	0.09	0.13	0.13	0.15	0.02	0.04	0.26
135–185 RU2	0.09	0.10	0.10	0.11	0.01	0.03	0.28
185–365 RU3	0.08	0.12	0.13	0.15	0.02	0.03	0.26
365–425	0.07	0.11	0.10	0.18	0.03	0.03	0.24
425–440 DZ1	0.07	0.08	0.08	0.08	0.004	0.04	0.15
440–465 DZ2	0.05	0.06	0.07	0.07	0.01	0.02	0.14
465–565 DZ3	0.04	0.07	0.07	0.09	0.01	0.02	0.25
565–605	0.07	0.09	0.09	0.10	0.01	0.03	0.20
605–685 RU6	0.05	0.09	0.09	0.12	0.02	0.01	0.23
685–750 RU7	0.05	0.10	0.09	0.24	0.05	0.02	0.30
RU4	0.05	0.09	0.08	0.18	0.03	0.02	0.25
RU5	0.04	0.08	0.08	0.10	0.02	0.02	0.23
Competent rock	0.05	0.11	0.10	0.24	0.03	0.01	0.30
Fractured rock	0.04	0.07	0.97	0.09	0.01	0.01	0.25
Whole borehole	0.04	0.10	0.10	0.24	0.03	0.01	0.30

Variation of Poisson's ratio (ν) with depth for borehole KAV01 (Hoek and Brown's a = 0.5). The values are given every 5 m.



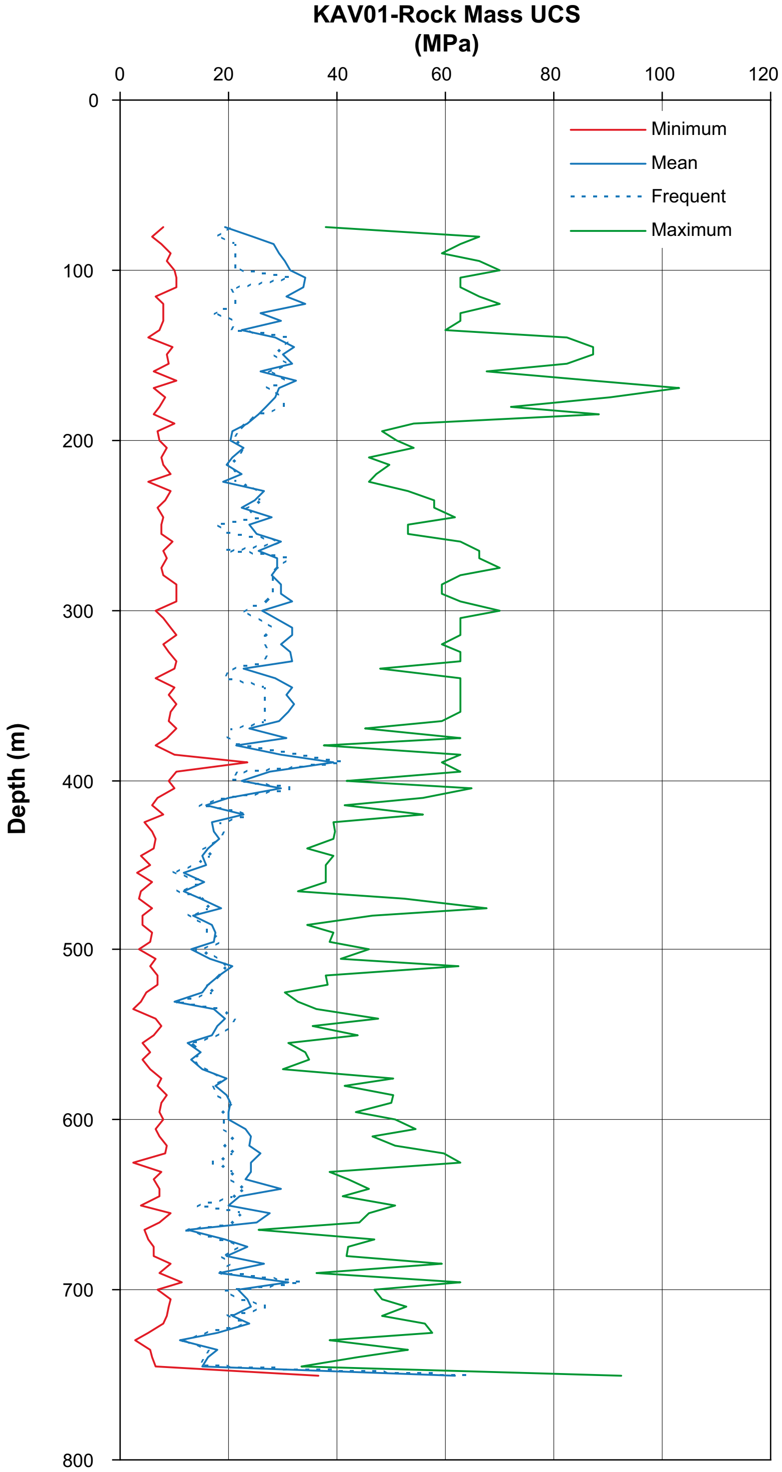
A4.6 Uniaxial compressive strength

A4.6.1 RMR

Summary of the uniaxial compressive strength of the rock mass derived from RMR for borehole KAV01 (core sections of 5 m, Hoek and Brown's a = 0.5).

Rock Unit	Minimum UCS	Average UCS	Frequent UCS	Maximum UCS	Standard deviation	Min possible UCS	Max possible UCS
70–135 RU1	19.4	28.8	29.7	34.1	4.6	5.7	70.0
135–185 RU2	25.5	29.1	29.1	32.3	2.5	5.3	103.1
185–365 RU3	18.9	26.9	28.3	32.1	4.1	5.0	70.0
365–425	15.8	25.0	23.2	39.5	6.7	4.6	64.8
425–440 DZ1	16.2	17.2	17.2	18.2	1.0	5.7	39.8
440–465 DZ2	11.6	14.0	15.1	16.0	2.1	3.2	39.2
465–565 DZ3	10.1	16.1	16.7	20.8	2.6	2.5	67.7
565–605	15.1	19.5	19.8	23.2	2.3	5.6	54.4
605–685 RU6	12.5	23.2	23.8	29.7	4.0	2.4	62.6
685–750 RU7	11.0	23.3	20.6	61.6	12.5	2.7	92.4
RU4	11.6	20.0	17.4	39.5	6.7	3.2	67.7
RU5	10.1	17.2	17.4	23.2	3.2	2.5	62.4
Competent rock	11.0	25.6	25.4	61.6	6.4	2.4	103.1
Fractured rock	10.1	15.8	16.2	20.8	2.5	2.5	67.7
Whole borehole	10.1	23.6	23.4	61.6	7.0	2.4	103.1

Variation of the uniaxial compressive strength of the rock mass with depth for borehole KAV01 (Hoek and Brown's a = 0.5). The values are given every 5 m.

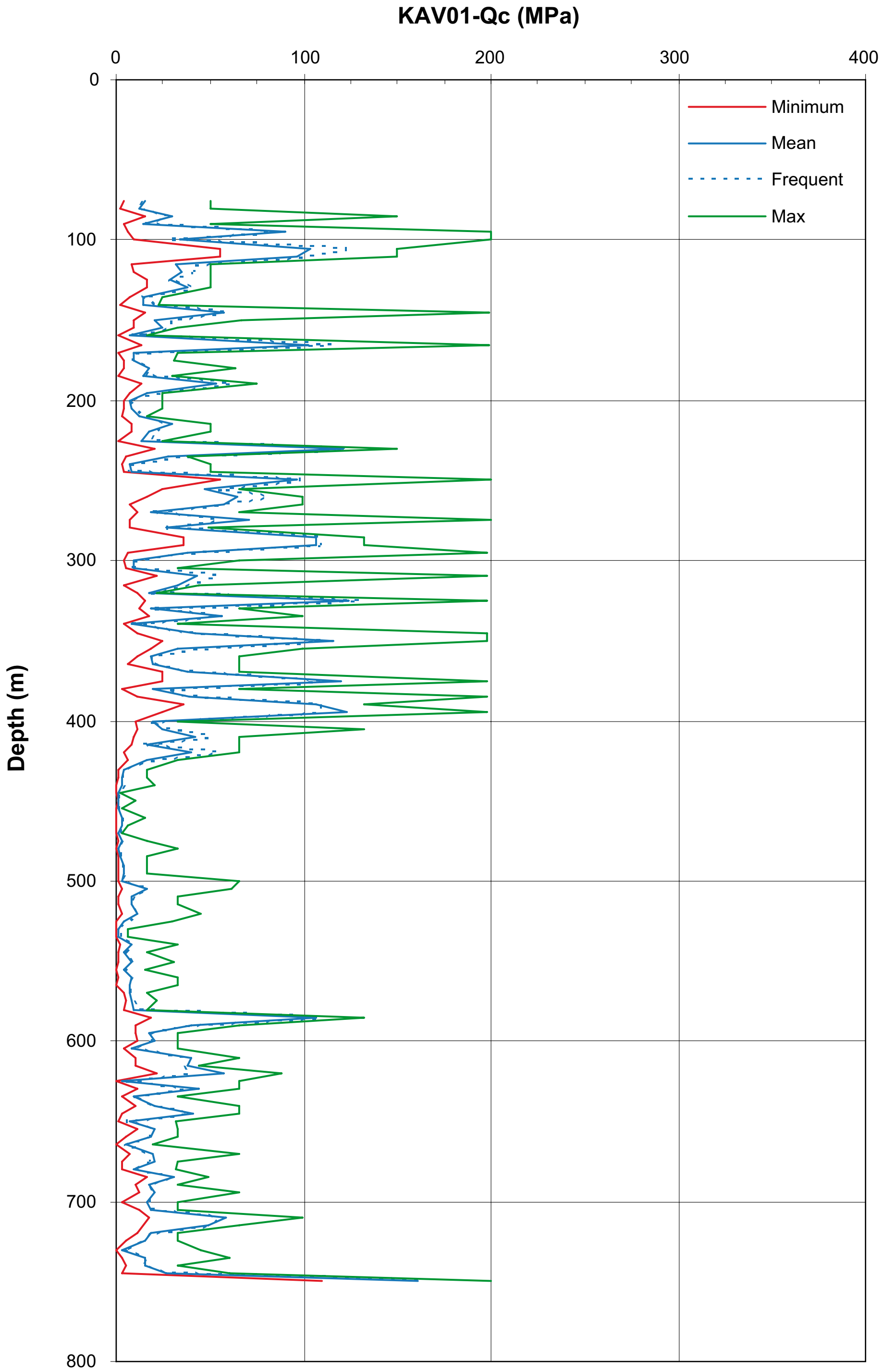


A4.6.2 Q

Summary of Qc derived from Q for borehole KAV01 (core sections of 5 m).

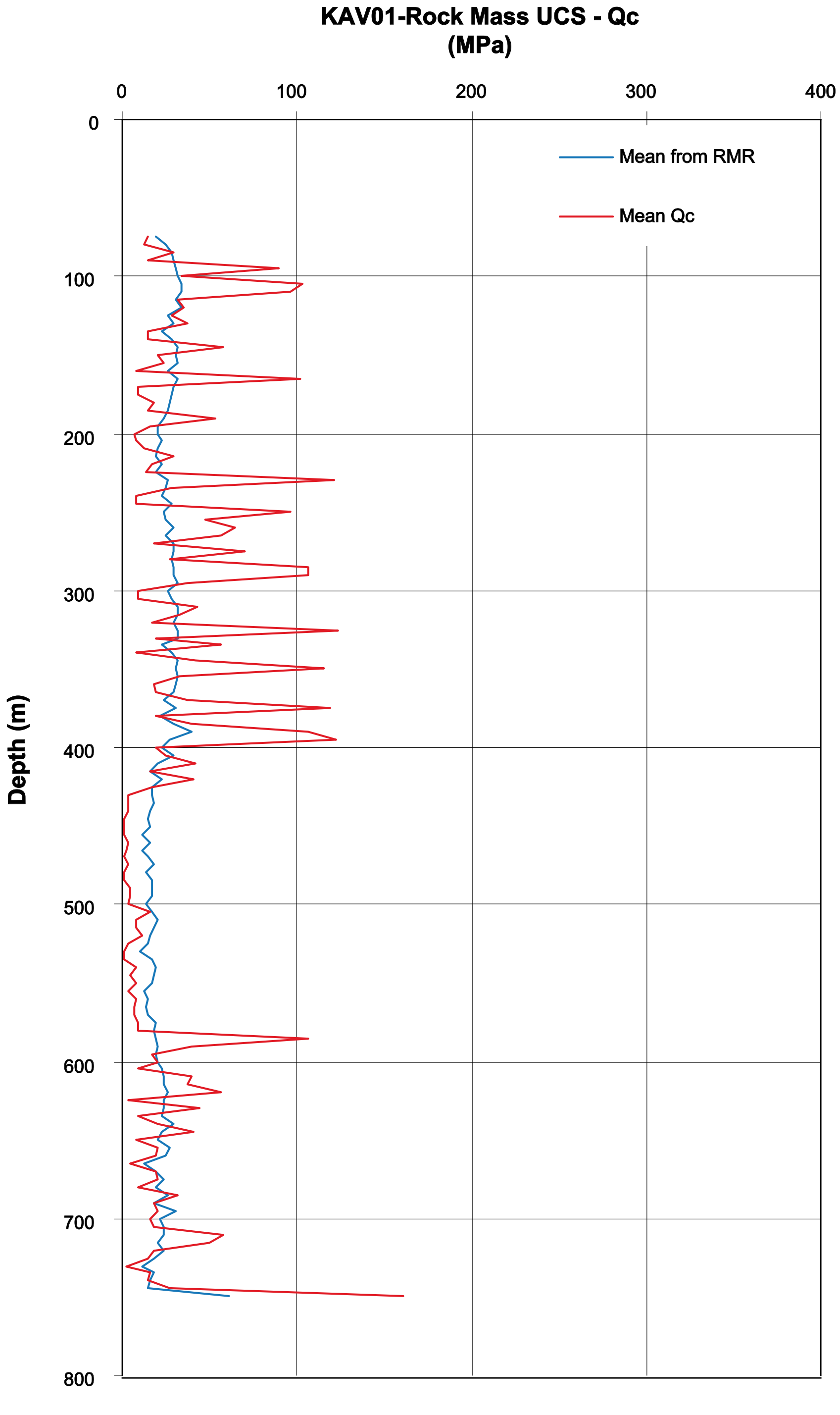
Rock Unit	Minimum Qc	Average Qc	Frequent Qc	Maximum Qc	Standard deviation	Min possible Qc	Max possible Qc
70–135 RU1	12.0	41.7	31.3	103.5	32.7	2.3	200.0
135–185 RU2	7.4	27.7	16.3	102.5	30.0	1.0	198.8
185–365 RU3	7.3	41.7	28.8	123.9	36.3	1.0	200.0
365–425	16.3	50.4	38.6	122.6	41.0	4.0	198.0
425–440 DZ1	3.4	3.6	3.4	3.9	0.3	0.2	20.0
440–465 DZ2	0.8	1.8	1.1	3.5	1.2	0.1	15.2
465–565 DZ3	1.1	5.4	4.2	16.0	3.9	0.01	66.0
565–605	7.3	27.2	13.4	106.3	33.7	3.7	132.0
605–685 RU6	3.1	24.0	20.2	57.0	16.1	0.1	88.0
685–750 RU7	2.7	33.5	18.0	161.0	41.1	0.4	200.0
RU4	0.8	24.6	4.2	122.6	36.5	0.1	198.0
RU5	1.1	14.1	8.3	106.3	22.2	0.01	132.0
Competent rock	2.7	36.7	20.4	161.0	34.2	0.1	200.0
Fractured rock	0.8	4.6	3.6	16.0	3.6	0.01	66.0
Whole borehole	0.8	30.1	17.9	161.0	33.2	0.01	66.0

Variation of Q_c with depth for borehole KAV01. The values are given every 5 m.



A4.6.3 Comparison

Comparison of the rock mass compressive strength from RMR and Q for borehole KAV01 (Hoek and Brown's a = 0.5).



A4.7 Friction angle and cohesion and of the rock mass

A4.7.1 RMR

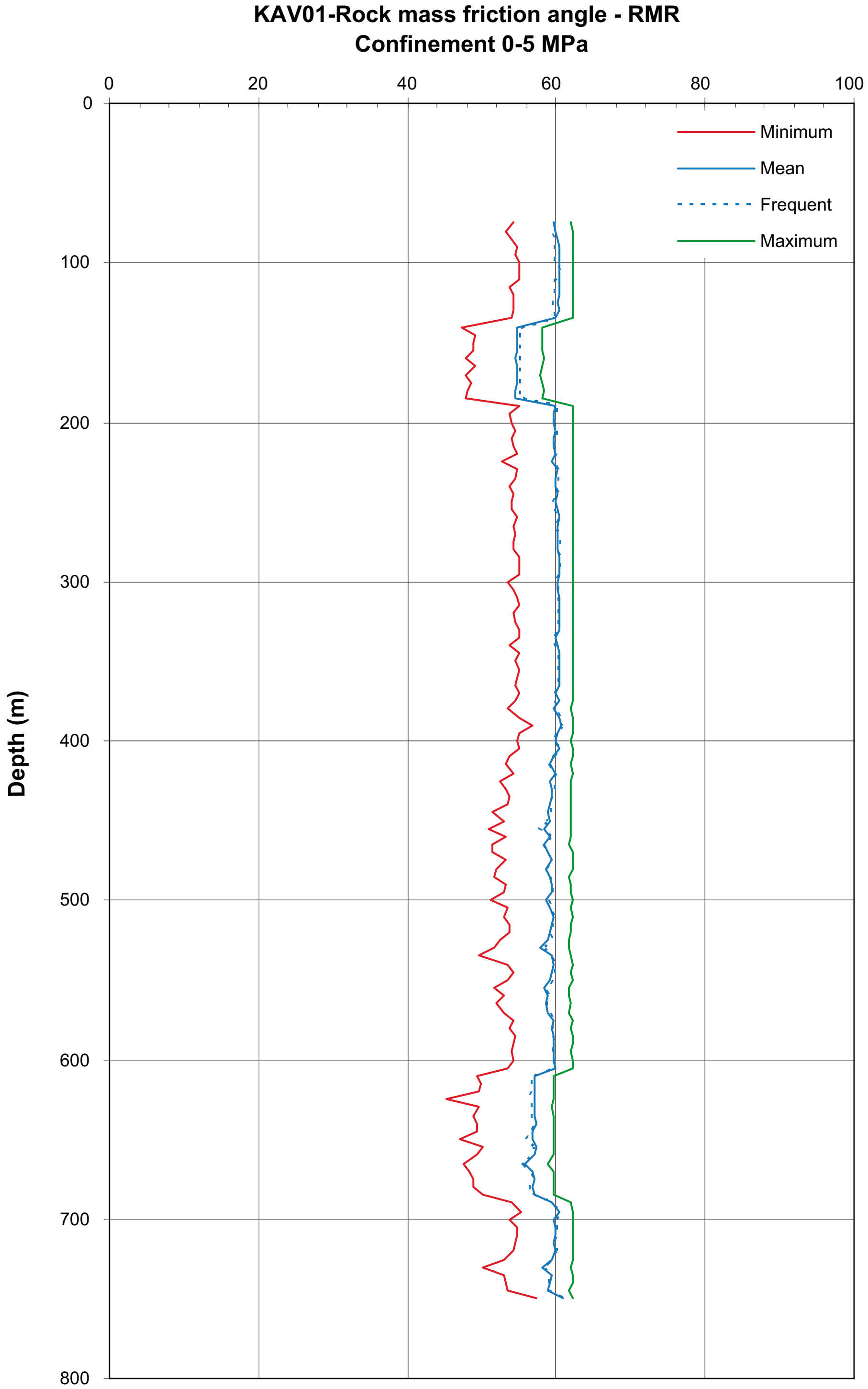
Summary of the friction angle (φ) of the rock mass derived from RMR for borehole KAV01 (10–30 MPa) (core sections of 5 m, Hoek and Brown's a = 0.5).

Rock Unit	Minimum φ'	Average φ'	Frequent φ'	Maximum φ'	Standard deviation	Min possible φ'	Max possible φ'
70–135 RU1	42.1	44.1	44.4	45.1	0.9	32.7	49.7
135–185 RU2	38.3	39.0	39.0	39.5	0.4	27.1	47.6
185–365 RU3	42.0	43.8	44.1	44.8	0.8	31.9	49.7
365–425	41.1	43.3	43.1	45.8	1.4	31.5	49.4
425–440 DZ1	41.2	41.5	41.5	41.8	0.3	32.7	47.1
440–465 DZ2	39.4	40.3	40.8	41.1	0.8	29.5	47.1
465–565 DZ3	38.7	41.1	41.4	42.5	0.9	28.2	49.6
565–605	40.8	42.1	42.3	43.1	0.7	32.5	48.6
605–685 RU6	37.0	40.1	40.4	41.5	1.0	24.1	46.8
685–750 RU7	39.1	42.6	42.5	47.9	2.1	28.7	50.9
RU4	39.4	42.0	41.6	45.8	1.6	29.5	49.6
RU5	38.7	41.4	41.6	43.1	1.1	28.2	49.2
Competent rock	37.0	42.5	42.9	47.9	2.0	24.1	50.9
Fractured rock	38.7	41.0	41.2	42.5	0.9	28.2	49.6
Whole borehole	37.0	42.2	42.3	47.9	2.0	24.1	50.9

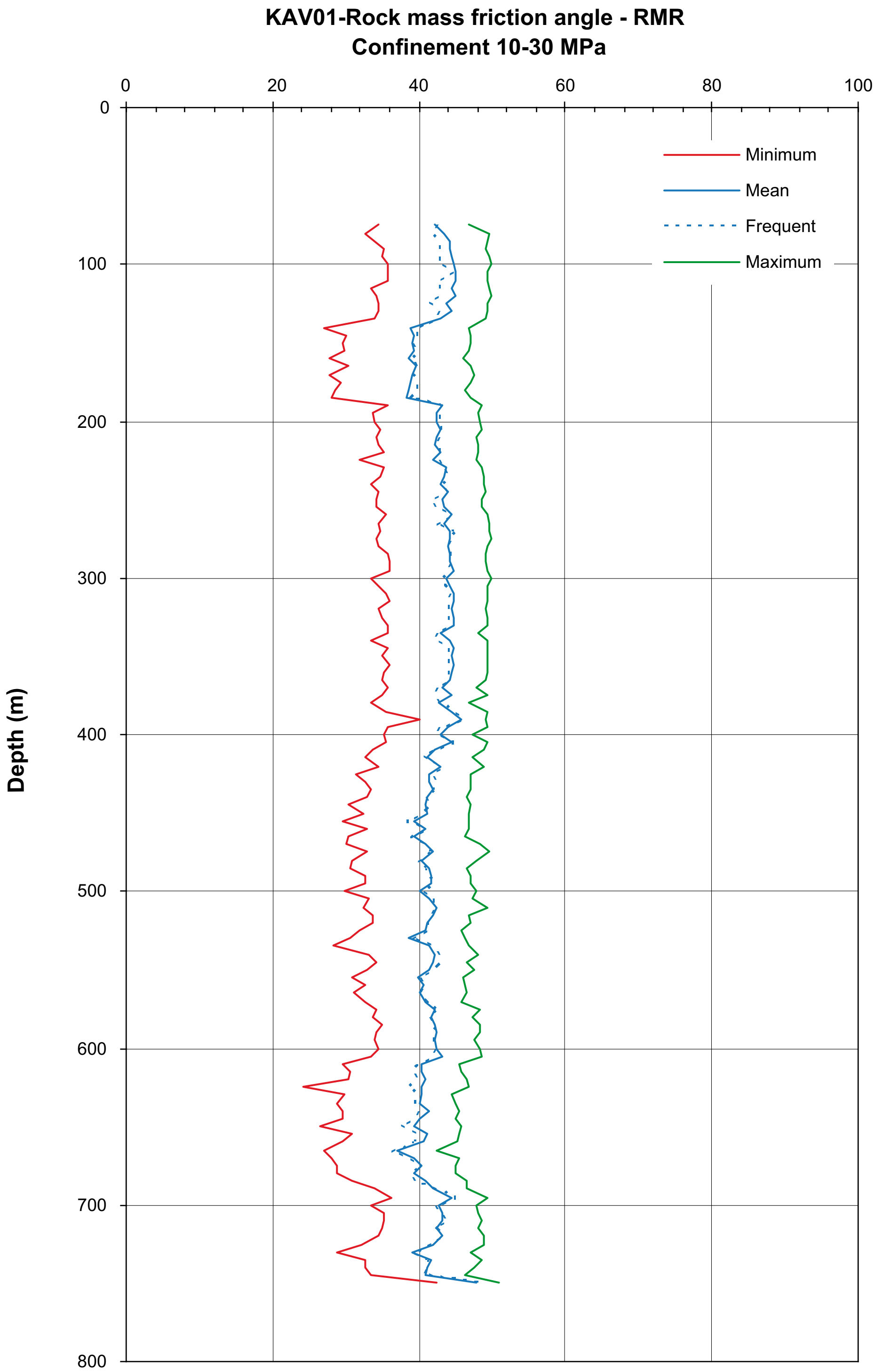
Summary of the cohesion of the rock mass derived from RMR for borehole KAV01 (10–30 MPa) (core sections of 5 m, Hoek and Brown's a = 0.5).

Rock Unit	Minimum c'	Average c'	Frequent c'	Maximum c'	Standard deviation	Min possible c'	Max possible c'
70–135 RU1	16.3	17.9	18.1	18.7	0.8	11.2	24.1
135–185 RU2	15.0	15.6	15.6	16.2	0.4	9.0	27.6
185–365 RU3	16.2	17.6	17.8	18.4	0.7	10.9	24.1
365–425	15.5	17.2	17.0	19.5	1.1	10.7	23.5
425–440 DZ1	15.6	15.8	15.8	16.0	0.2	11.2	20.2
440–465 DZ2	14.5	15.1	15.4	15.6	0.5	9.9	20.1
465–565 DZ3	14.1	15.5	15.7	16.5	0.6	9.3	23.9
565–605	15.3	16.3	16.3	17.0	0.5	11.2	22.2
605–685 RU6	13.4	15.6	15.7	16.7	0.8	7.8	22.2
685–750 RU7	14.3	16.8	16.5	22.5	2.0	9.5	26.9
RU4	14.5	16.3	15.8	19.5	1.2	9.9	23.9
RU5	14.1	15.8	15.9	17.0	0.7	9.3	23.2
Competent rock	13.4	16.9	16.8	22.5	1.3	7.8	27.6
Fractured rock	14.1	15.5	15.6	16.5	0.6	9.3	23.9
Whole borehole	13.4	16.6	16.4	22.5	1.3	7.8	27.6

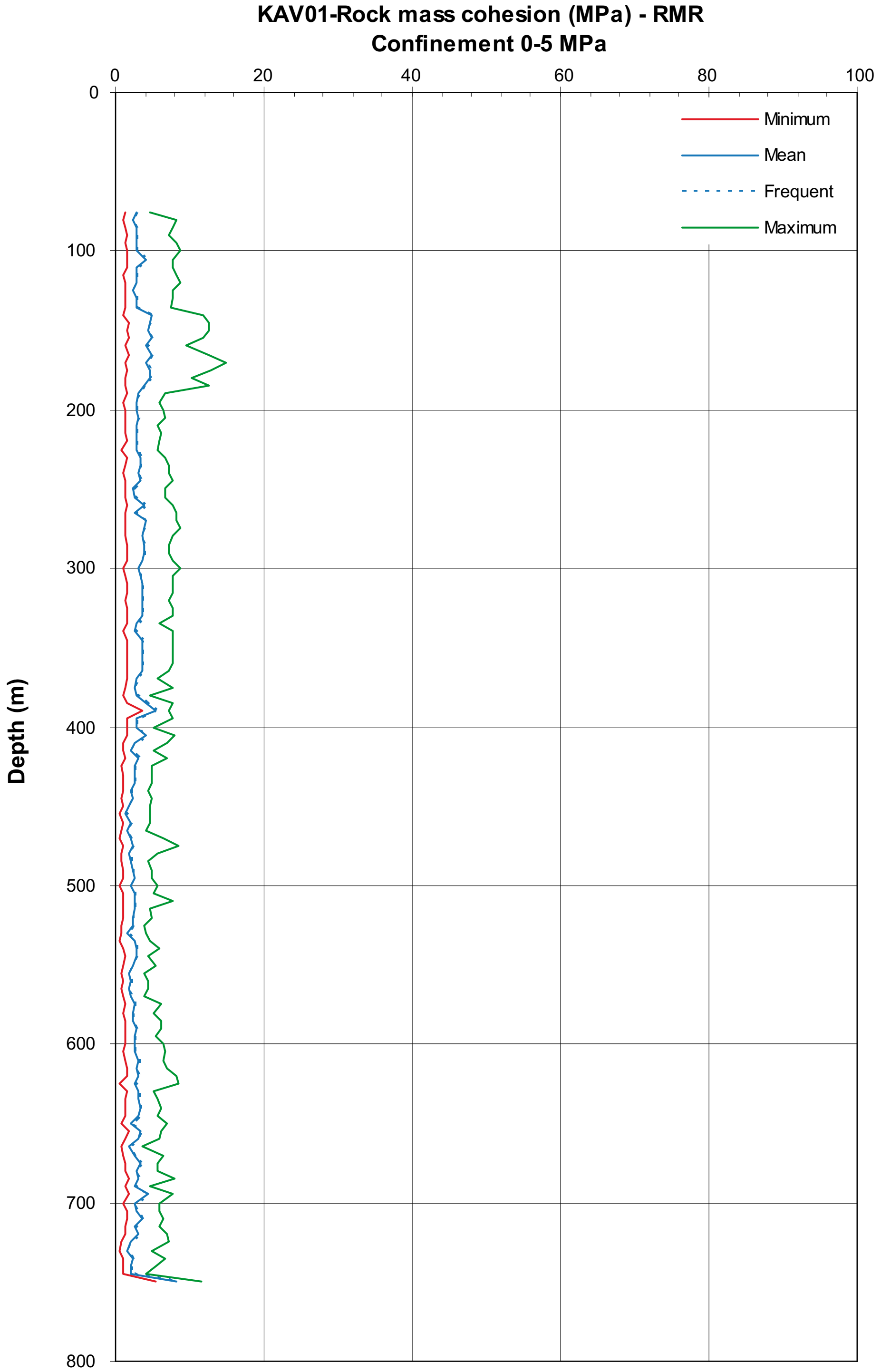
Variation of the rock mass friction angle from RMR for borehole KAV01 under stress confinement 0–5 MPa (Hoek and Brown's a = 0.5).



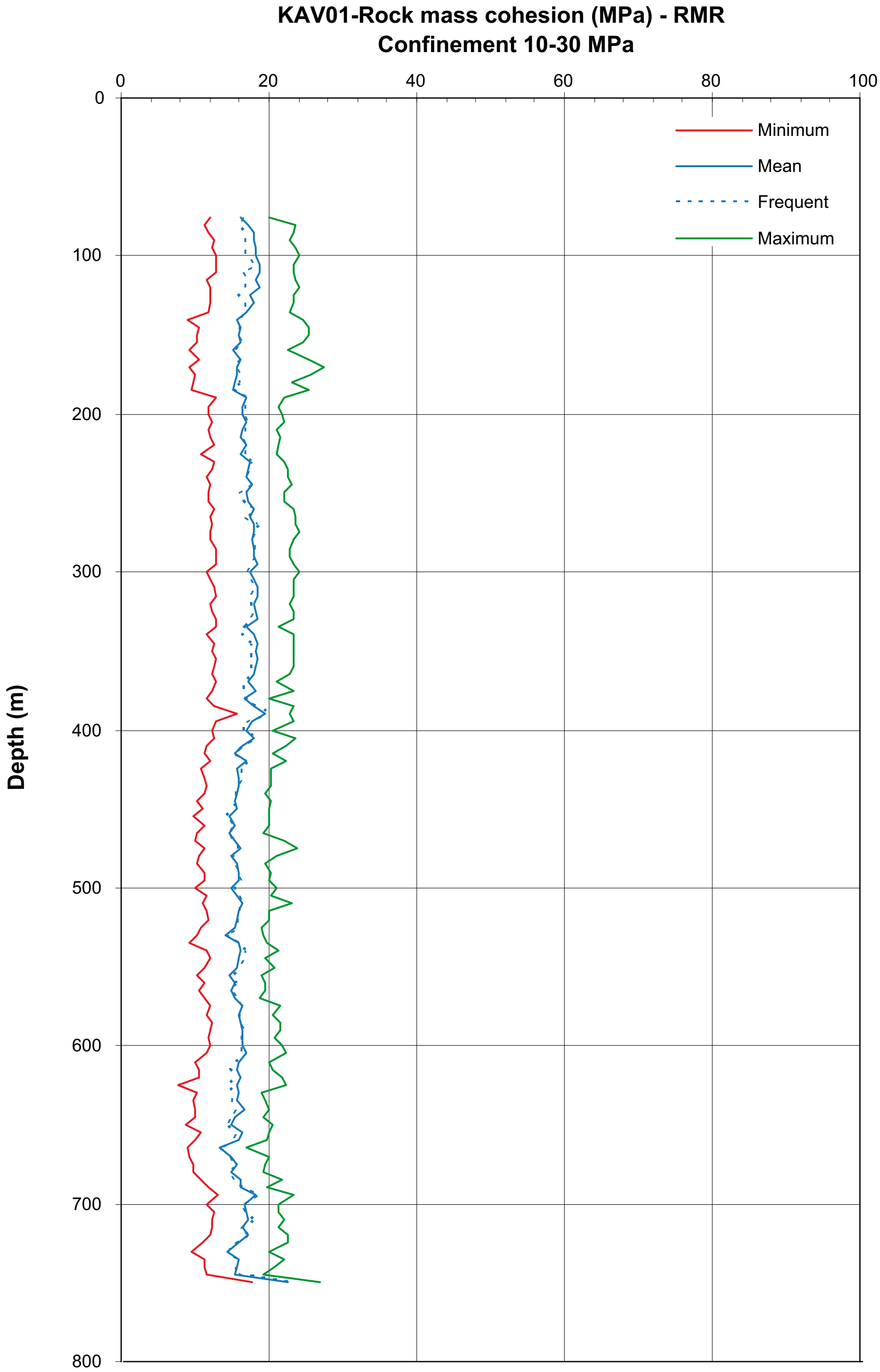
Variation of the rock mass friction angle from RMR for borehole KAV01 under stress confinement 10–30 MPa (Hoek and Brown's a = 0.5).



Variation of the rock mass cohesion from RMR for borehole KAV01 under stress confinement 0–5 MPa (Hoek and Brown's a = 0.5).



Variation of the rock mass cohesion from RMR for borehole KAV01 under stress confinement 10–30 MPa (Hoek and Brown's a = 0.5).



A4.7.2 Q

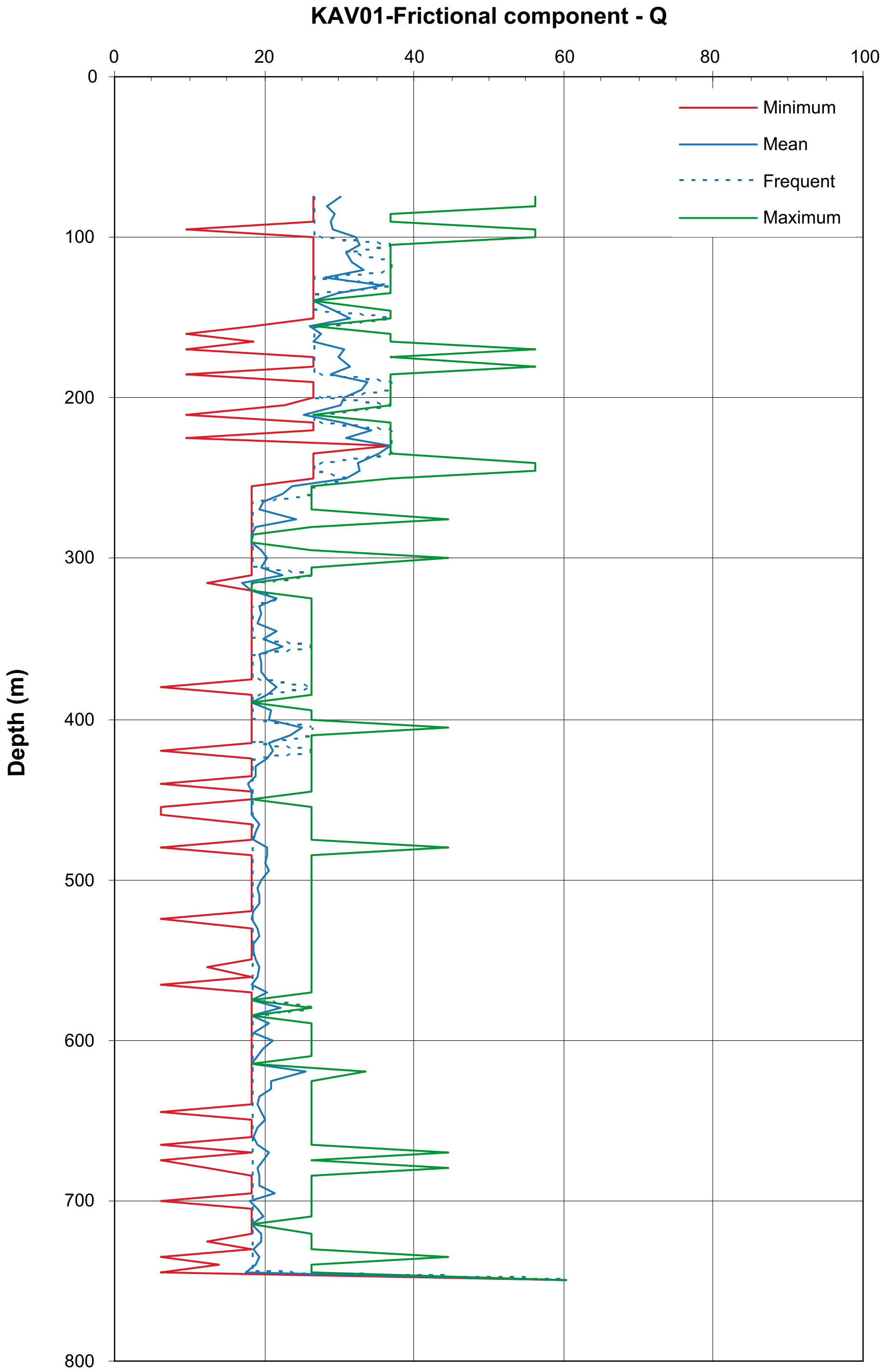
Summary of the frictional component FC of the rock mass derived from Qc for borehole KAV01 (core sections of 5 m).

Rock Unit	Minimum FC	Average FC	Frequent FC	Maximum FC	Standard deviation	Min possible FC	Max possible FC
70–135 RU1	28.2	30.8	30.1	35.8	2.2	9.5	56.3
135–185 RU2	26.1	28.8	29.1	31.5	2.0	9.5	56.3
185–365 RU3	17.1	24.5	22.0	36.9	6.2	9.5	56.3
365–425	18.3	21.0	20.6	25.0	1.8	6.3	44.7
425–440 DZ1	17.8	18.5	18.7	18.8	0.6	6.3	26.3
440–465 DZ2	18.3	18.6	18.4	19.4	0.5	6.3	26.3
465–565 DZ3	18.3	19.2	19.1	20.6	0.7	6.3	44.7
565–605	18.3	19.9	20.2	22.2	1.5	18.3	26.3
605–685 RU6	18.3	19.9	19.3	25.6	1.7	6.3	44.7
685–750 RU7	17.6	22.3	19.3	60.4	11.5	6.3	60.4
RU4	17.8	20.0	20.3	25.0	1.7	6.3	44.7
RU5	18.3	19.3	19.1	22.2	1.0	6.3	26.3
Competent rock	17.1	24.0	20.8	60.4	6.5	6.3	60.4
Fractured rock	17.8	19.0	18.9	20.6	0.7	6.3	44.7
Whole borehole	17.1	22.9	20.2	60.4	6.1	6.3	60.4

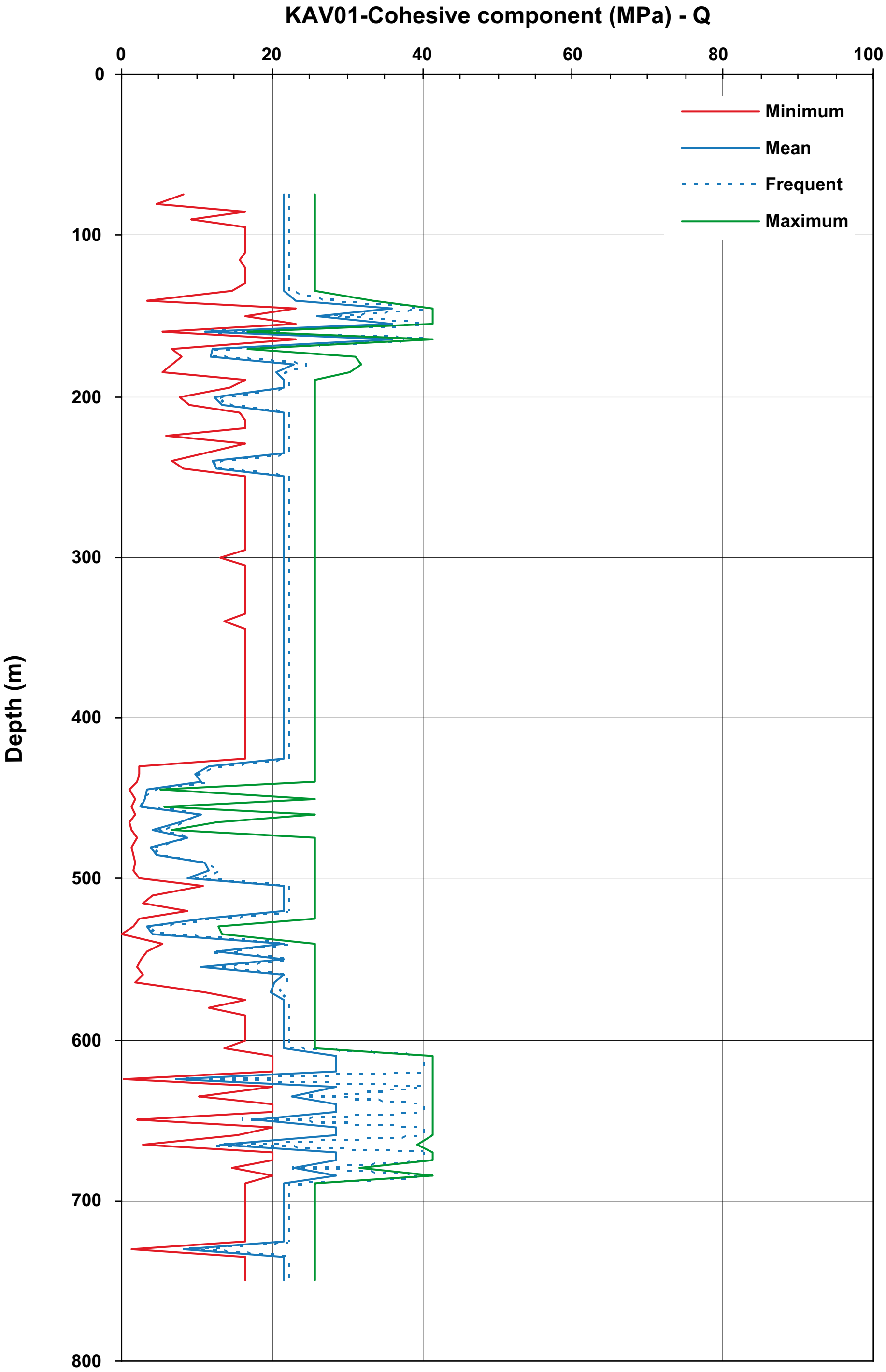
Summary of the cohesion of the rock mass derived from Qc for borehole KAV01 (core sections of 5 m).

Rock Unit	Minimum CC	Average CC	Frequent CC	Maximum CC	Standard deviation	Min possible CC	Max possible CC
RU1 70–135	21.7	21.7	21.7	21.7	0	4.5	25.8
RU2 135–185	11.1	23.5	23.0	35.9	10.0	3.4	41.5
RU3 185–365	12.0	20.7	21.7	21.7	2.9	6.0	25.8
365–425	21.7	21.7	21.7	21.7	0	16.5	25.8
425–440 DZ1	9.8	10.6	10.5	11.5	0.9	2.0	25.8
440–465 DZ2	2.5	5.4	3.3	10.5	3.5	1.1	25.8
465–565 DZ3	3.2	13.3	11.4	21.7	7.4	0.04	25.8
565–605	19.8	21.5	21.7	21.7	0.7	11.1	25.8
RU6 605–685	7.2	24.8	28.4	28.4	6.6	0.2	41.5
RU7 685–750	8.2	20.7	21.7	21.7	3.7	1.2	25.8
RU4	2.5	14.0	11.6	21.7	7.7	1.1	25.8
RU5	3.2	17.9	21.7	21.7	6.3	0.04	25.8
Competent rock	7.2	21.8	21.7	35.9	4.6	0.2	41.5
Fractured rock	2.5	11.6	10.5	21.7	7.1	0.04	25.8
Whole borehole	2.5	19.7	21.7	35.9	6.6	0.04	41.5

Variation of the frictional component FC from Q for borehole KAV01.

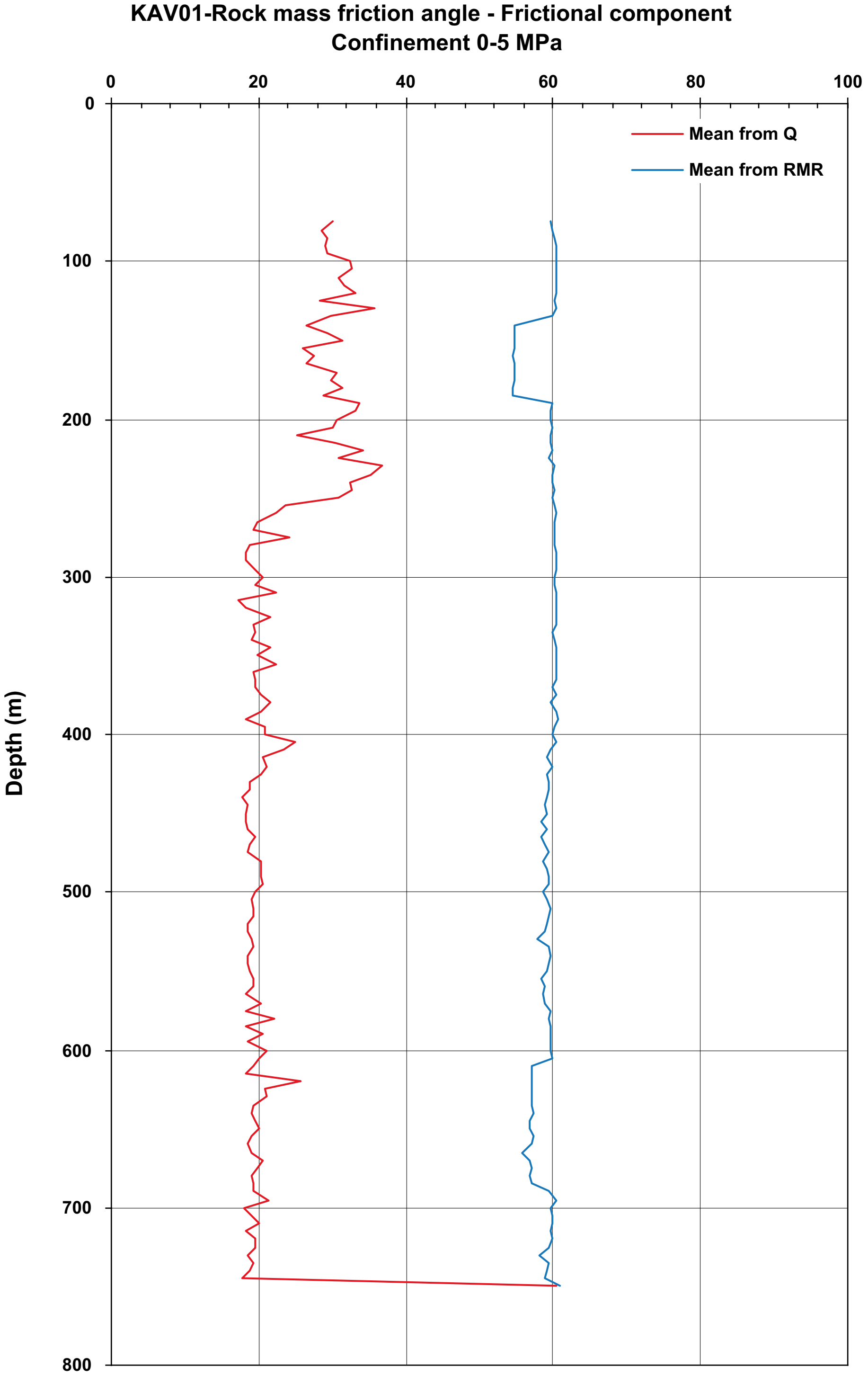


Variation of the cohesive component from Q for borehole KAV01.

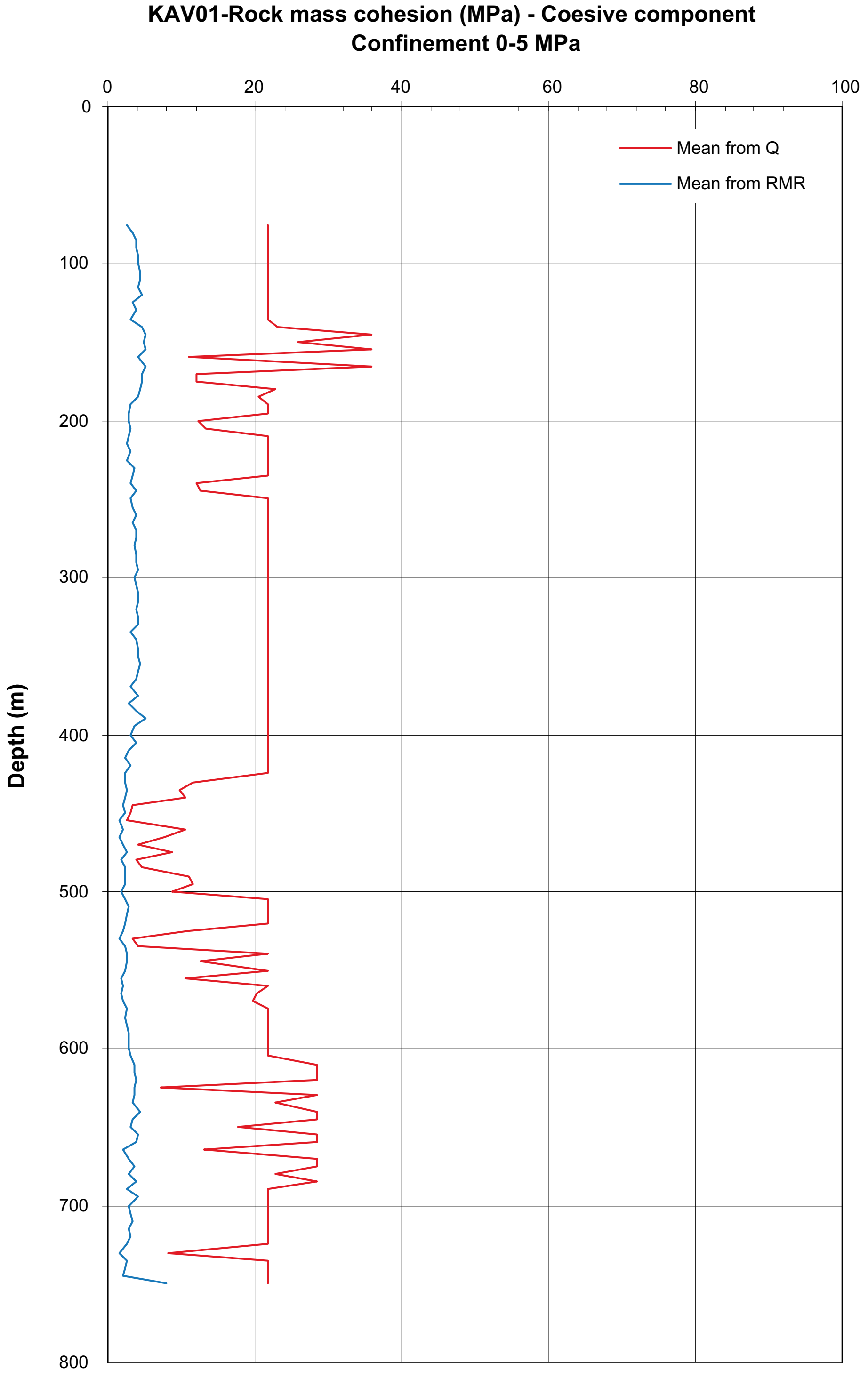


A4.7.3 Comparison

Comparison of the rock mass friction angle from RMR and Q for borehole KAV01 under stress confinement 0–5 MPa (Hoek and Brown's a = 0.5).



Comparison of the rock mass cohesion from RMR and Q for borehole KAV01 under stress confinement 0–5 MPa (Hoek and Brown's a = 0.5).



Appendix 5

KLX02
Characterisation of the rock mass

A5.1 Fracture orientation

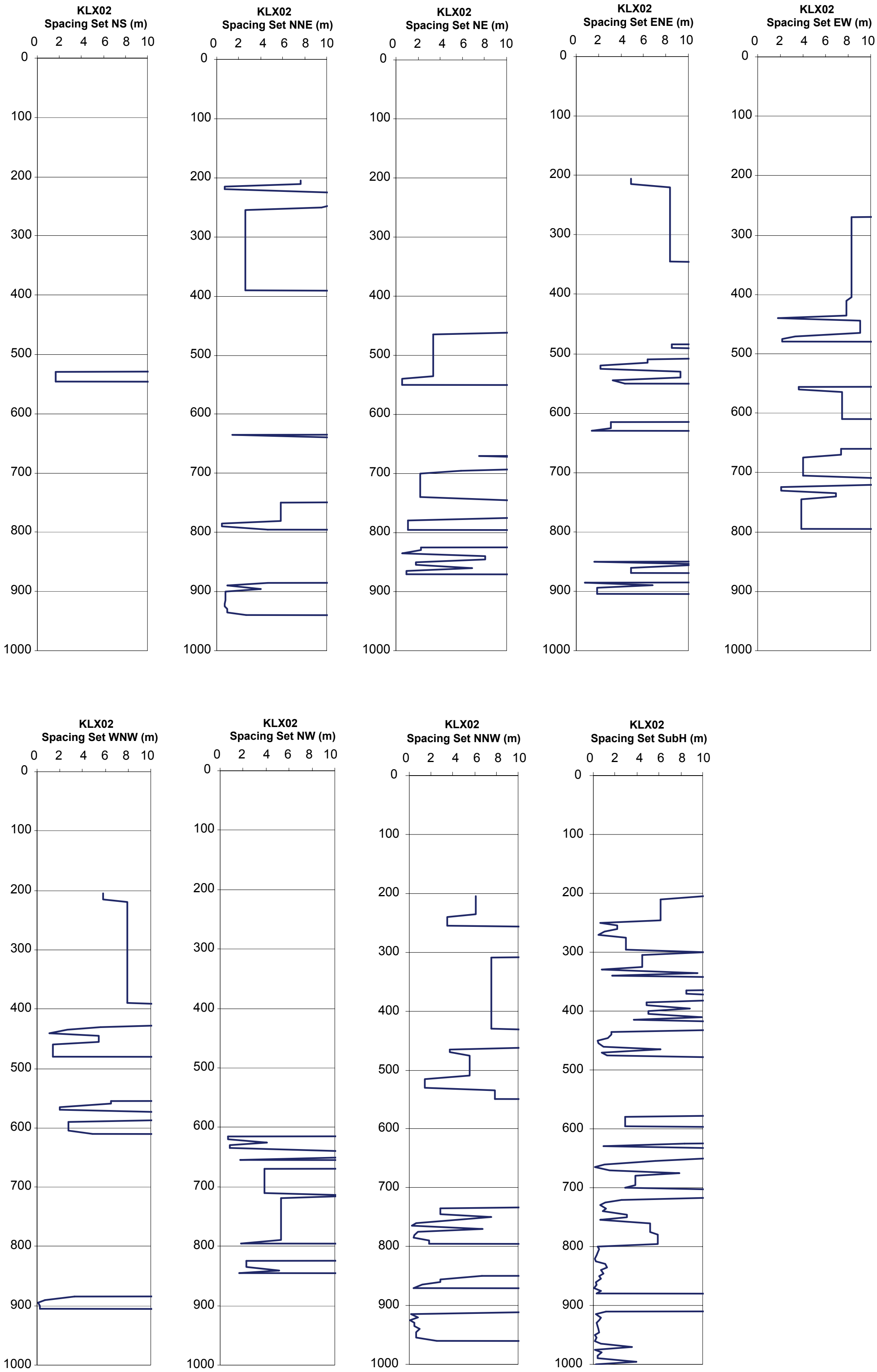
Set identification from the open fracture orientation mapped for borehole KLX02 (based on SICADA data received on 07/05/2004). The orientations are given as strike/dip (right-hand rule).

Depth (m)	No of fract	NS	NNE	NE	ENE	EW	WNW	NW	NNW	SubH
200–420	183		024/79		074/80	269/63	116/86		339/79	282/05
420–480	119			043/80		269/89	300/74		333/61	111/04
480–550	94	009/79		214/87	235/52				155/79	
550–610	65					268/65	128/54			280/02
610–630	49				011/79			318/53		287/03
630–655	27		024/59					294/47		091/06
655–665	41									100/14
665–725	84			231/80		275/80		312/53		333/11
725–795	218		193/52	030/75		260/75		136/82	331/48	066/02
795–820	152									095/06
820–845	98			038/65			103/62	319/55		088/08
845–870	257			210/41	238/71				158/66	102/04
870–880	24									265/11
880–905	180		193/48		074/60		293/42			
905–940	219		195/57						337/68	218/10
940–960	183								327/80	111/06
960–1,000	215	007/77								006/03

Fisher's constant of the open fracture sets identified for borehole KLX02 (SICADA, 04-05-07).

Depth (m)	No of fract	NS	NNE	NE	ENE	EW	WNW	NW	NNW	SubH
200–420	183		29.2		76.0	83.4	37.6		24.4	15.8
420–480	119			202.8		28.2	17.3		91.2	9.3
480–550	94	47.6		21.6	57.3				61.8	
550–610	65					55.5	23.5			14.2
610–630	49				39.9			18.8		45.6
630–655	27		24.0					16.3		10,000
655–665	41									6.3
665–725	84			11.2		8.2		66.0		10.5
725–795	218		17.8	44.0		16.6		79.7	11.9	27.2
795–820	152									27.4
820–845	98			27.4			34.8	48.3		11.5
845–870	257			70.2	90.4				32.2	22.0
870–880	24									6.2
880–905	180		46.7		27.9		12.4			
905–940	219		41.8						17.4	8.4
940–960	183								27.9	21.0
960–1,000	215	36.9								12.1

Fracture spacing with depth for the five facture sets in borehole KLX02. The values are averaged for each 5 m length of borehole.

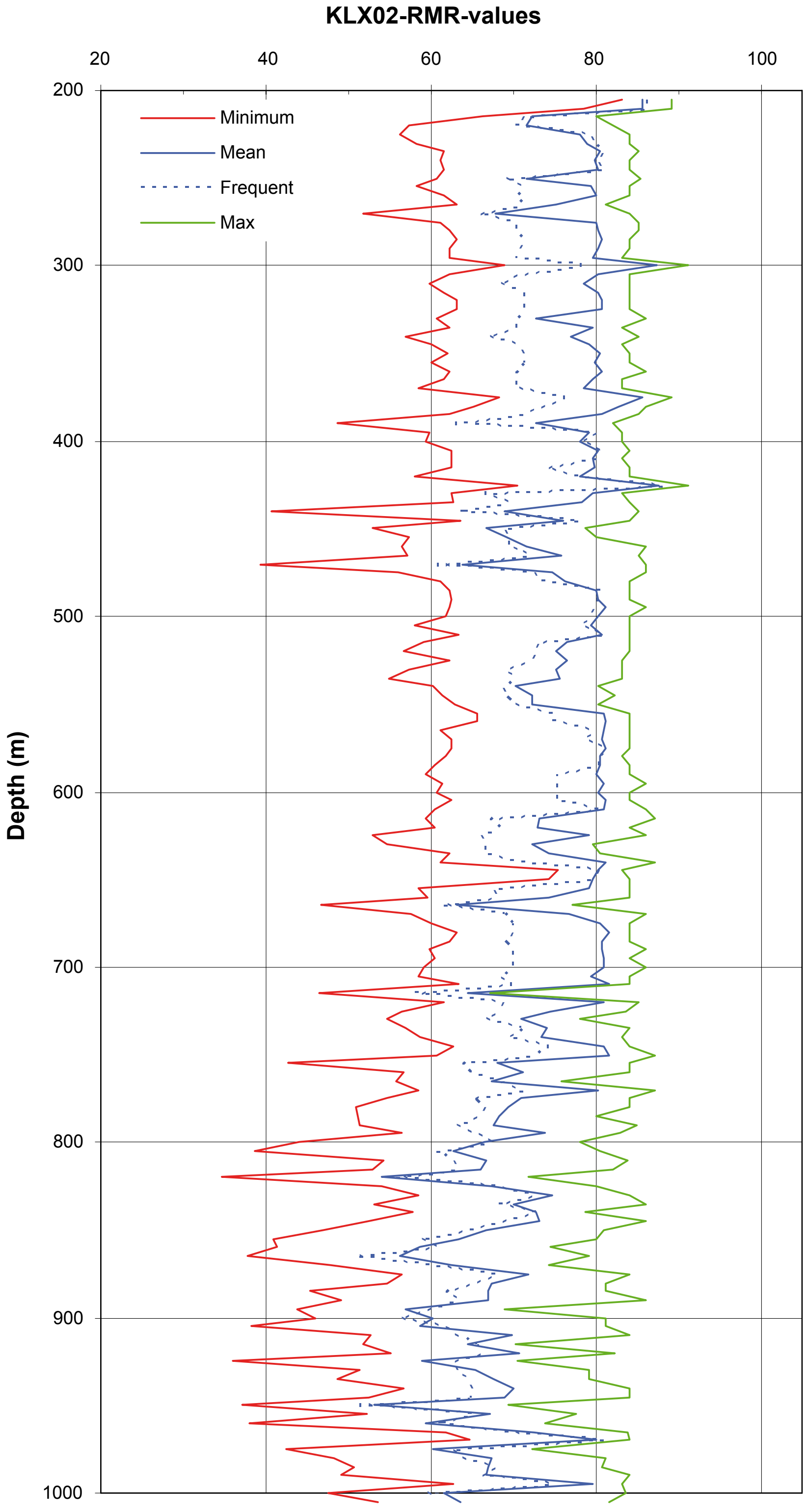


A5.2 RMR

RMR values along borehole KLX02 (core sections of 5 m).

Rock Unit	Minimum RMR	Average RMR	Frequent RMR	Maximum RMR	Standard deviation	Min possible RMR	Max possible RMR
200–540	63.8	78.0	79.5	87.7	4.7	39.3	91.1
540–770	63.1	77.3	80.3	81.7	5.0	42.7	87.1
770–960 DZ1	53.3	65.7	66.9	74.7	5.6	34.7	86.1
960–1,005	60.2	68.8	67.0	80.2	7.3	42.5	84.1
RU1	60.2	76.9	79.3	87.7	5.8	39.3	91.1
RU2	53.3	72.0	72.3	81.7	7.8	34.7	87.1
Competent rock	60.2	77.0	79.6	87.7	5.5	39.3	91.1
Fractured rock	53.3	65.7	66.9	74.7	5.6	34.7	86.1
Whole borehole	53.3	74.4	76.3	87.7	7.3	34.7	91.1

Variation of RMR with depth for borehole KLX02. The values are given every 5 m.

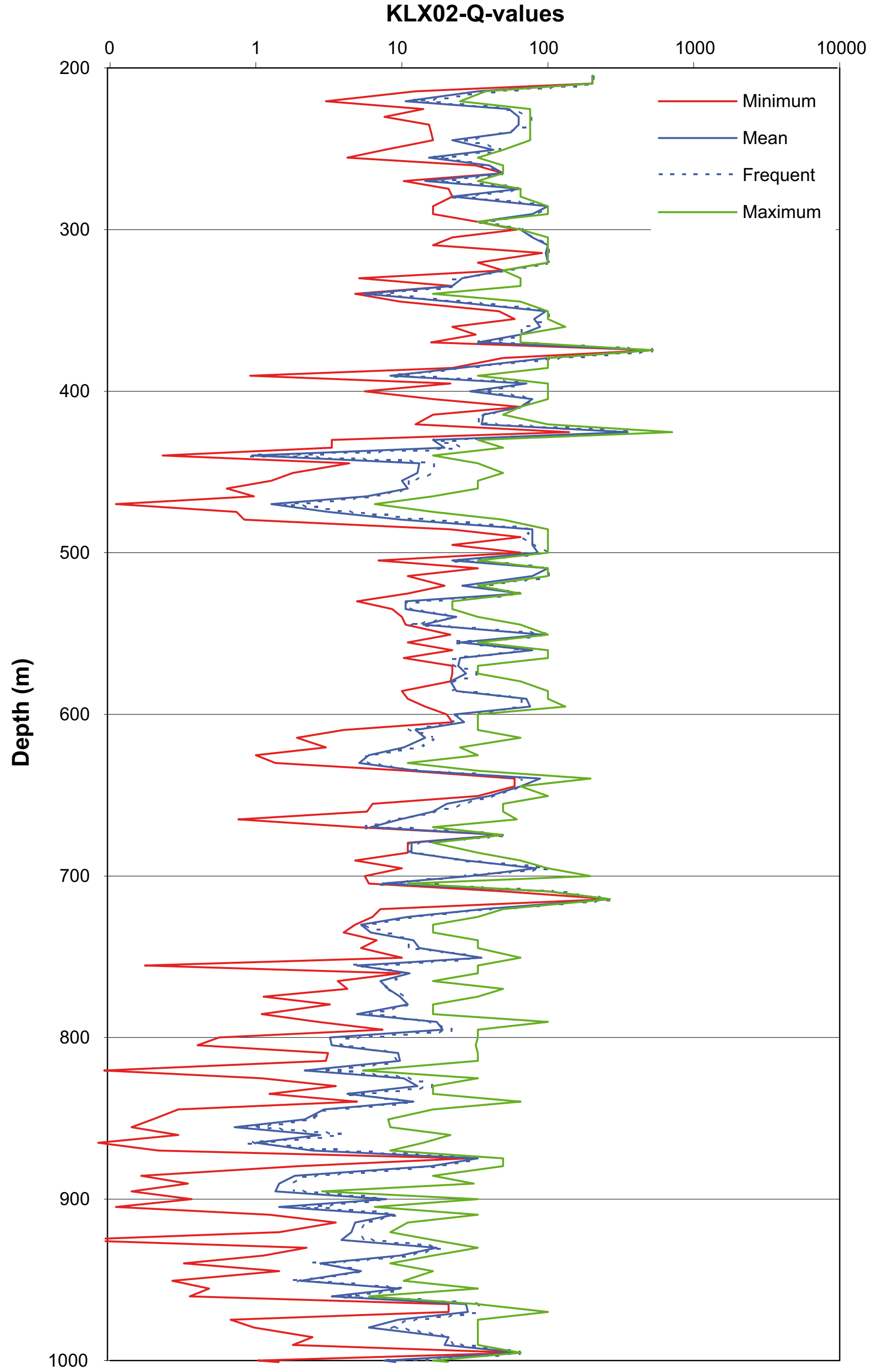


A5.3 Q

Q values along borehole KLX02 (core sections of 5 m).

Rock Unit	Minimum Q	Average Q	Frequent Q	Maximum Q	Standard deviation	Min possible Q	Max possible Q
200–540	0.9	61.5	40.6	528.0	79.3	0.1	704.0
540–770	4.9	34.1	21.2	264.0	43.8	0.2	264.0
770–960 DZ1	0.7	7.3	4.7	33.2	6.7	0.1	99.0
960–1,005	5.9	22.6	19.5	66.0	18.2	0.7	99.0
RU1	0.9	57.0	33.3	528.0	75.7	0.1	704.0
RU2	0.7	22.0	10.9	264.0	35.2	0.1	264.0
Competent rock	0.9	48.4	26.3	528.0	66.4	0.1	704.0
Fractured rock	0.7	7.3	4.7	33.2	6.7	0.1	99.0
Whole borehole	0.7	38.7	19.5	528.0	60.6	0.1	704.0

Variation of Q with depth for borehole KLX02. The values are given every 5 m.



Rock mass properties

A5.4 Deformation modulus

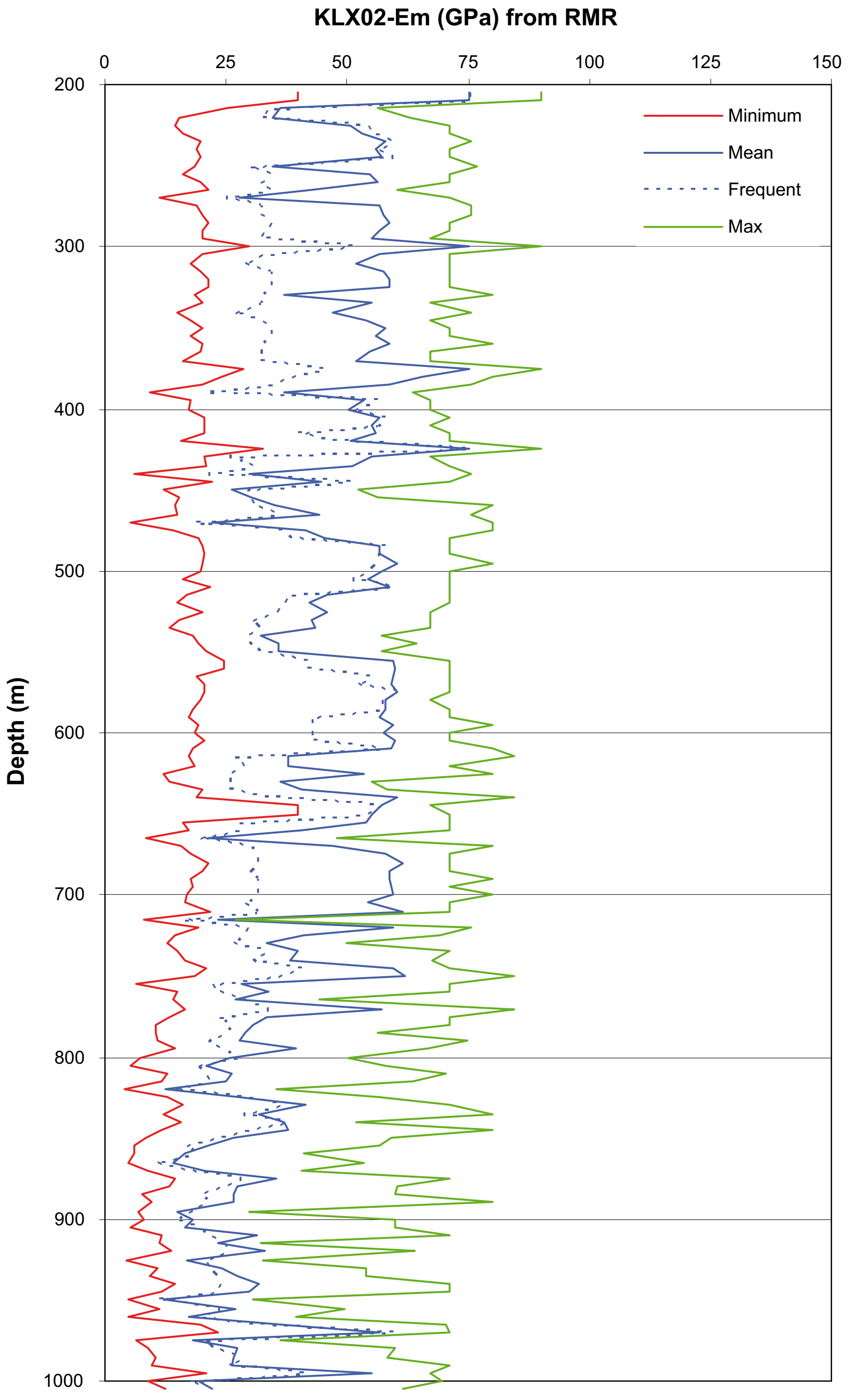
A5.4.1 RMR

Deformation modulus Em derived from RMR along for borehole KLX02 (core sections of 5 m).

Rock Unit	Minimum Em (GPa)	Average Em (GPa)	Frequent Em (GPa)	Maximum Em (GPa)	Standard deviation Em (GPa)	Min possible Em (GPa)	Max possible Em (GPa)
200–540	22.2	51.2	54.8	75.0	11.8	5.4	90.0
540–770	21.2	49.9	57.2	61.9	12.2	6.6	84.6
770–960 DZ1	12.1	25.9	26.5	41.5	7.6	4.1	79.9
960–1,005	18.0	32.0	26.7	56.8	14.7	6.5	71.2
RU1	18.0	49.0	53.9	75.0	13.6	5.4	90.0
RU2	12.1	39.0	36.0	61.9	15.8	4.1	84.6
Competent rock	18.0	49.3	54.9	75.0	13.0	5.4	90.0
Fractured rock	12.1	25.9	26.5	41.5	7.6	4.1	79.9
Whole borehole	12.1	43.8	45.5	75.0	15.6	4.1	90.0

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 KLX02. The values are given every 5 m.



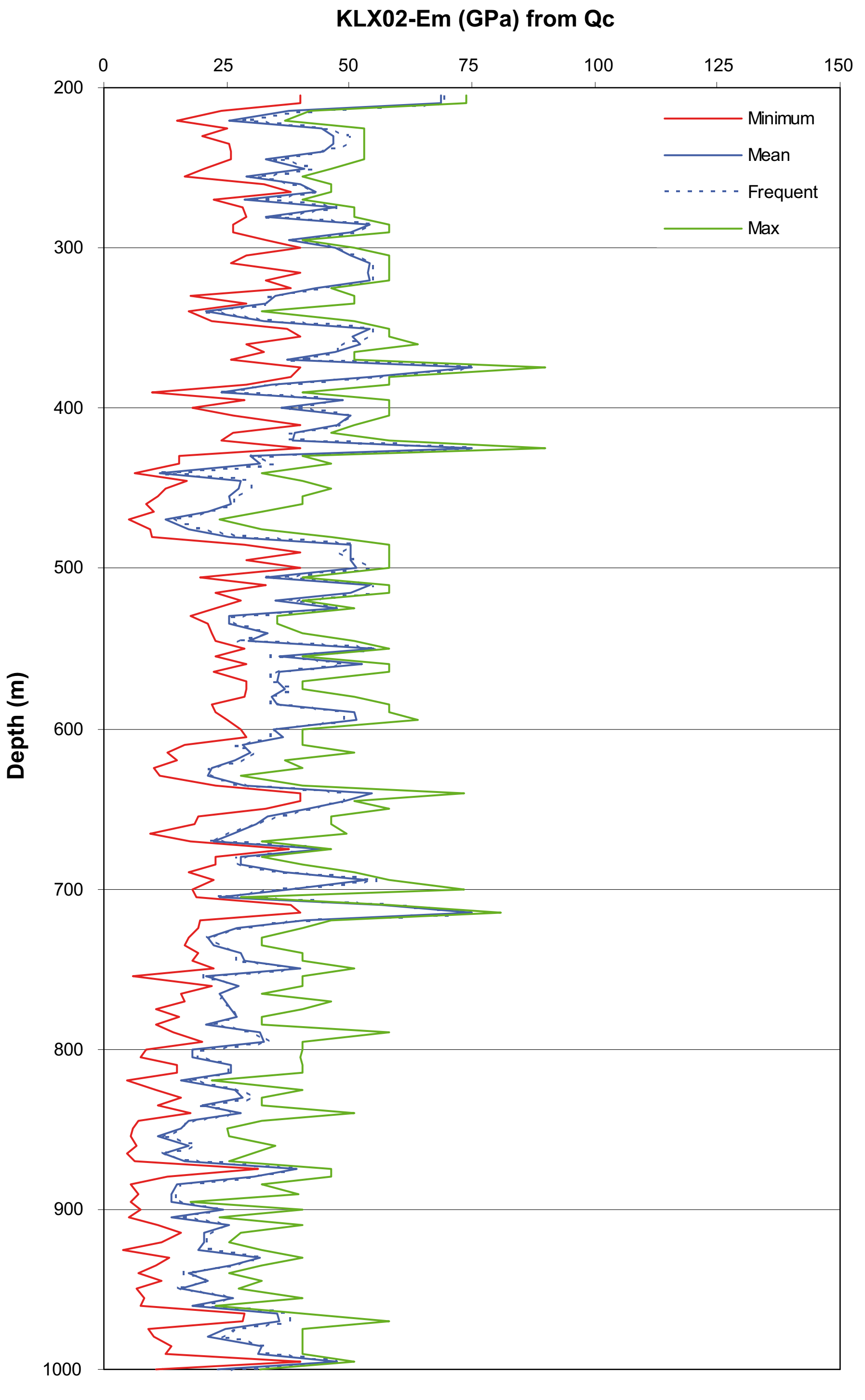
A5.4.2 Q

Deformation modulus Em derived from Q along borehole KLX02 (core sections of 5 m).

Rock Unit	Minimum Em (GPa)	Average Em (GPa)	Frequent Em (GPa)	Maximum Em (GPa)	Standard deviation Em (GPa)	Min possible Em (GPa)	Max possible Em (GPa)
200–540	11.4	40.7	40.3	75.0	13.7	4.9	90.0
540–770	20.7	35.4	33.8	75.0	12.0	5.7	80.8
770–960 DZ1	10.9	21.8	20.4	39.3	6.7	3.8	58.3
960–1,005	21.1	31.4	31.5	47.4	8.0	9.1	58.3
RU1	11.4	39.6	37.7	75.0	13.4	4.9	90.0
RU2	10.9	29.2	27.1	75.0	12.0	3.8	80.8
Competent rock	11.4	38.0	35.6	75.0	13.0	4.9	90.0
Fractured rock	10.9	21.8	20.4	39.3	6.7	3.8	58.3
Whole borehole	10.9	34.2	31.8	75.0	13.7	3.8	90.0

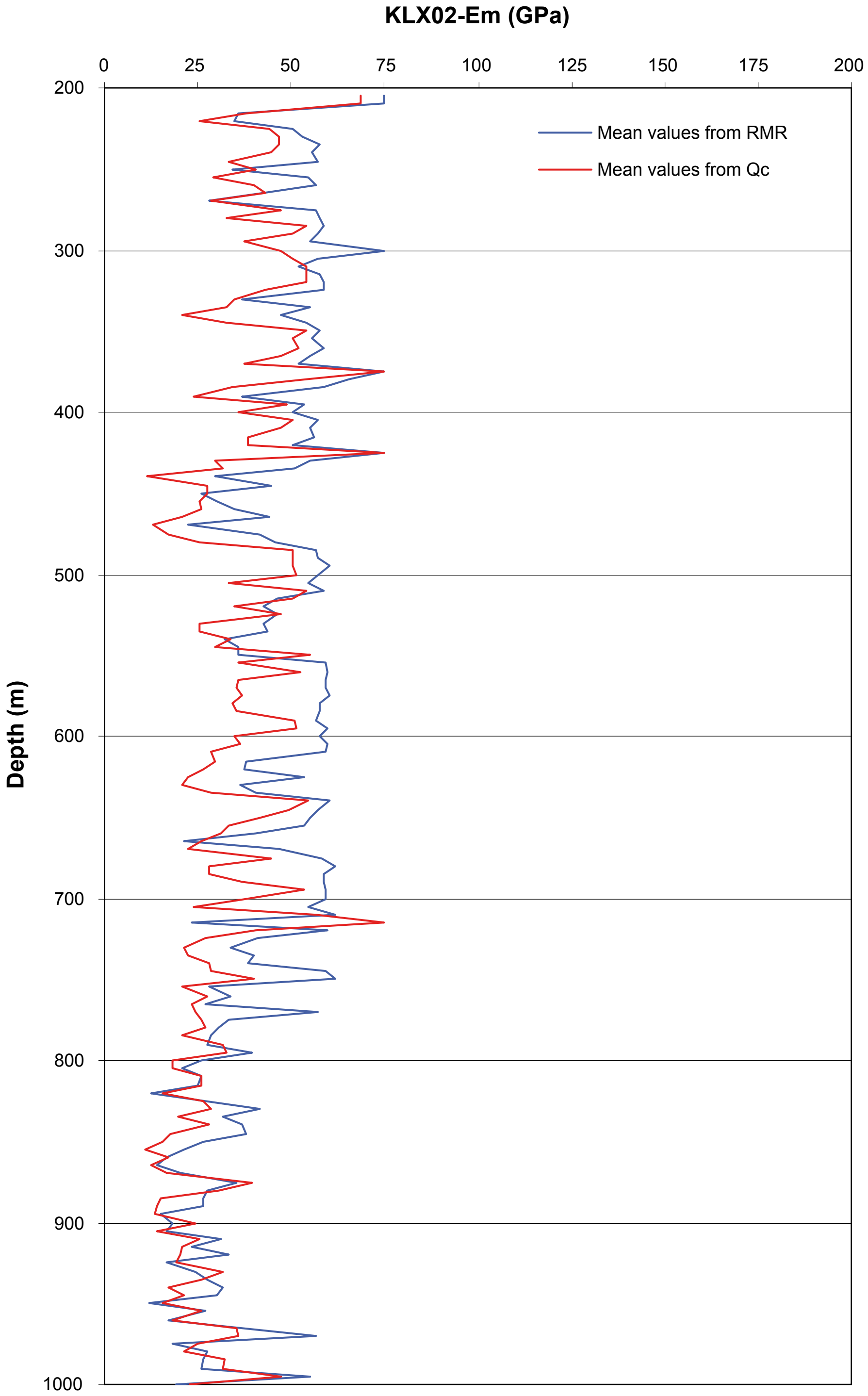
The maximum mean Em and the maximum confidence Em have a physical threshold in the Young's modulus of the intact rock, which is 75 and 90 GPa, respectively.

Variation of the deformation modulus of the rock mass obtained from Q_c with depth for borehole KLX02. The values are given every 5 m.



A5.4.3 Comparison

Comparison between the mean values of the deformation modulus E_m obtained from RMR and Qc for different depths for borehole KLX02.



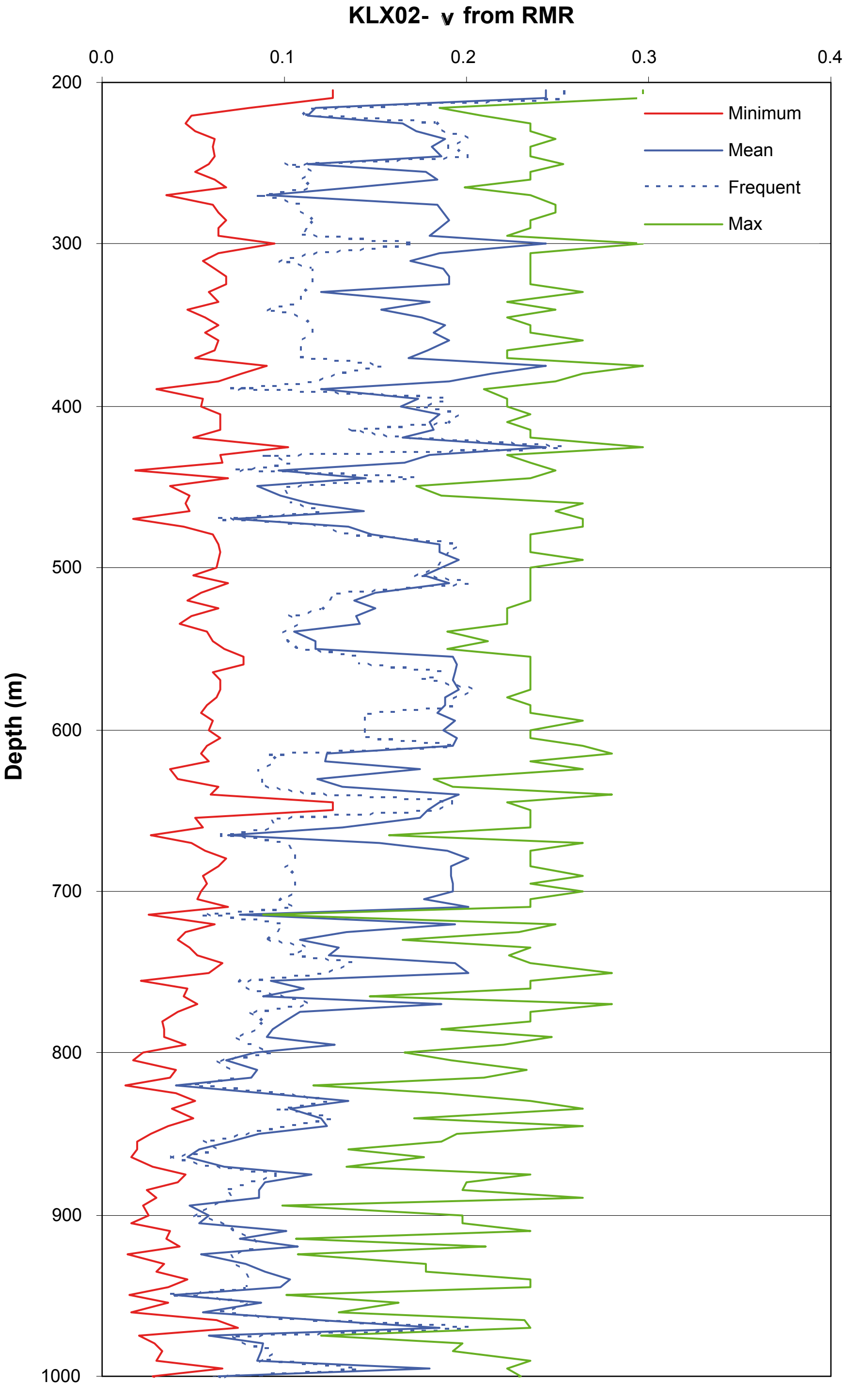
A5.5 Poisson's ratio

A5.5.1 RMR

Summary of Poisson's ratio (ν) derived from RMR for borehole KLX02 (core sections of 5 m, Hoek and Brown's a = 0.5).

Rock Unit	Minimum ν	Average ν	Frequent ν	Maximum ν	Standard deviation	Min possible ν	Max possible ν
200–540	0.07	0.17	0.18	0.24	0.04	0.02	0.30
540–770	0.07	0.16	0.19	0.20	0.04	0.02	0.28
770–960 DZ1	0.04	0.08	0.09	0.14	0.02	0.01	0.26
960–1,005	0.06	0.10	0.09	0.18	0.05	0.02	0.23
RU1	0.06	0.16	0.18	0.24	0.04	0.02	0.30
RU2	0.04	0.13	0.12	0.20	0.05	0.01	0.28
Competent rock	0.06	0.16	0.18	0.24	0.04	0.02	0.30
Fractured rock	0.04	0.08	0.09	0.14	0.02	0.01	0.26
Whole borehole	0.04	0.14	0.15	0.24	0.05	0.01	0.30

Variation of Poisson's ratio (ν) with depth for borehole KLX02 (Hoek and Brown's a = 0.5). The values are given every 5 m.



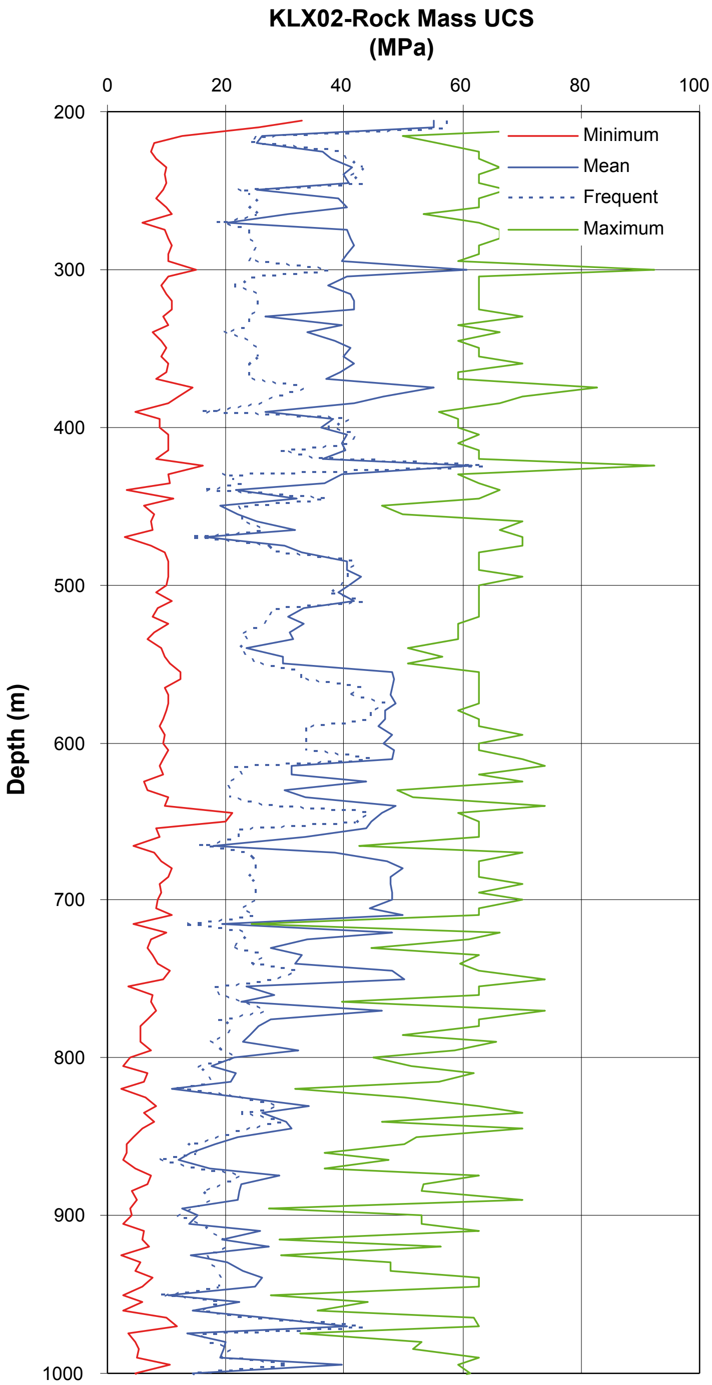
A5.6 Uniaxial compressive strength

A5.6.1 RMR

Summary of the uniaxial compressive strength of the rock mass derived from RMR for borehole KLX02 (core sections of 5 m, Hoek and Brown's a = 0.5).

Rock Unit	Minimum UCS	Average UCS	Frequent UCS	Maximum UCS	Standard deviation	Min possible UCS	Max possible UCS
200–540	16.3	37.0	39.1	61.6	9.0	3.8	80.8
540–770	17.8	40.6	46.3	50.1	9.6	5.1	75.1
770–960 DZ1	10.3	21.5	22.1	34.1	6.1	3.3	71.0
960–1,005	13.4	23.3	19.5	40.5	10.2	4.5	54.8
RU1	13.4	35.4	38.5	61.6	10.1	3.8	80.8
RU2	10.3	32.0	29.7	50.1	12.6	3.3	75.1
Competent rock	13.4	37.3	39.5	61.6	10.2	3.8	80.8
Fractured rock	10.3	21.5	22.1	34.1	6.1	3.3	71.0
Whole borehole	10.3	33.6	33.4	61.6	11.5	3.3	80.8

Variation of the uniaxial compressive strength of the rock mass with depth for borehole KLX02 (Hoek and Brown's a = 0.5). The values are given every 5 m.

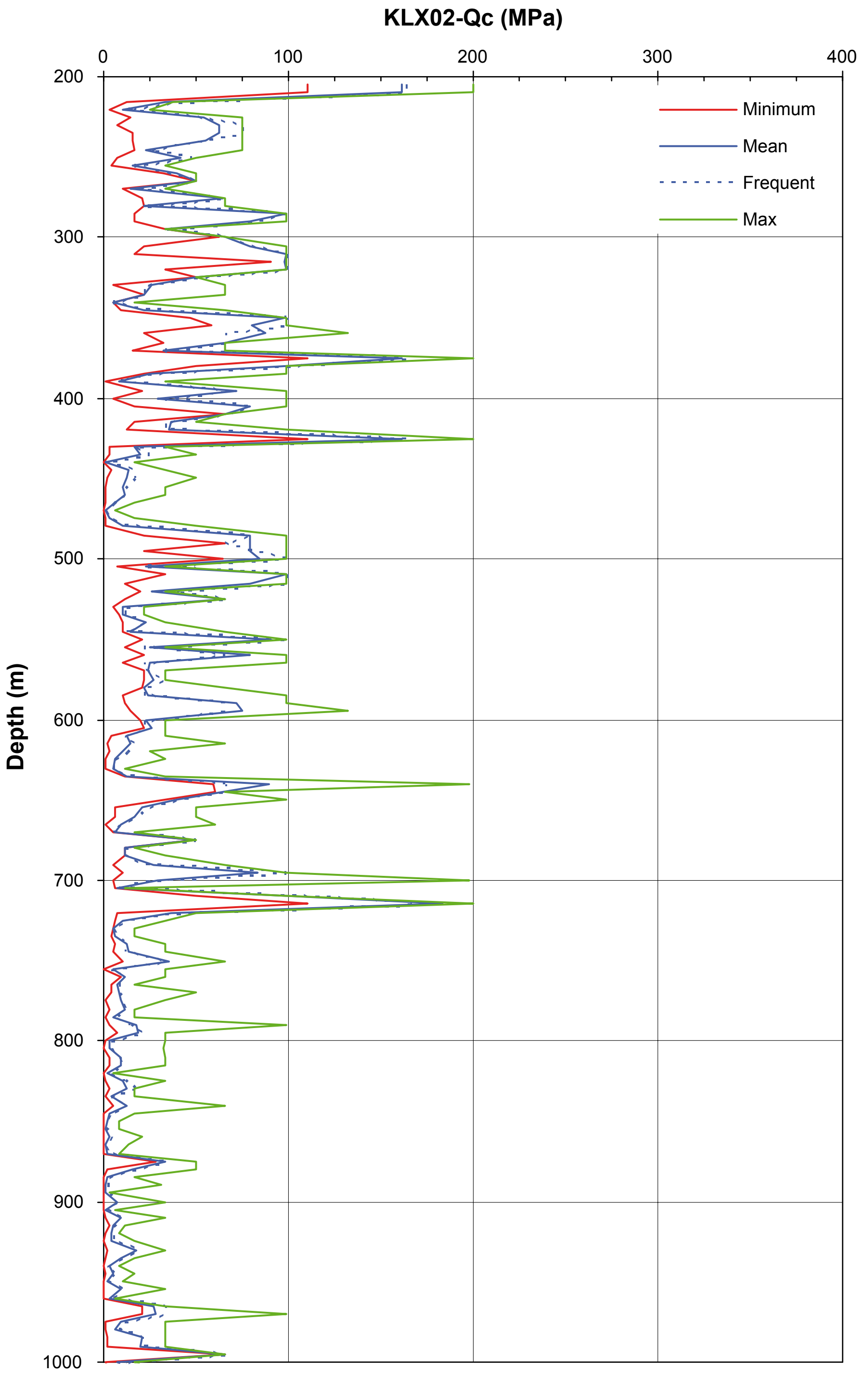


A5.6.2 Q

Summary of Qc derived from Q for borehole KLX02 (core sections of 5 m).

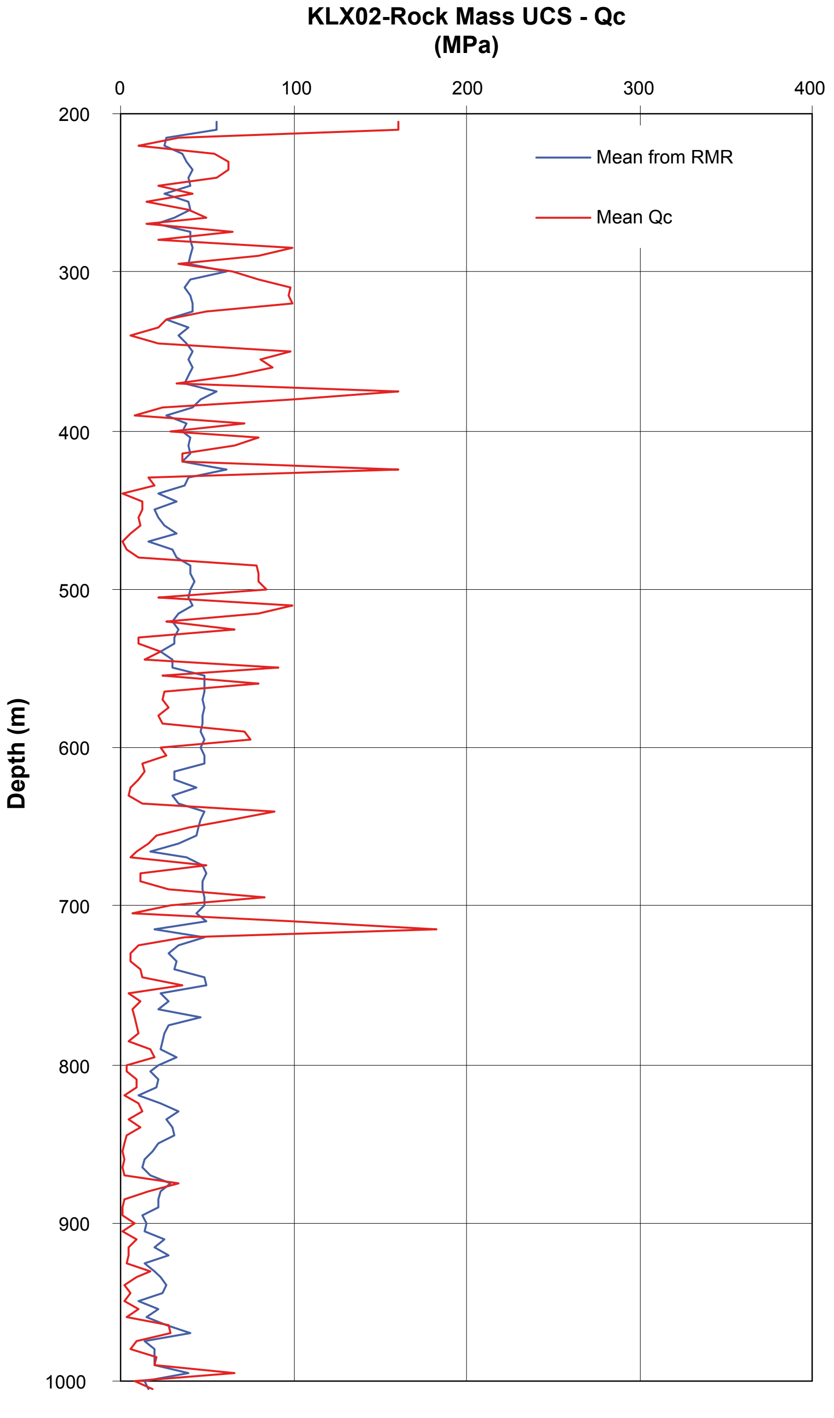
Rock Unit	Minimum Qc	Average Qc	Frequent Qc	Maximum Qc	Standard deviation	Min possible Qc	Max possible Qc
200–540	0.9	52.2	40.6	161.0	41.4	0.1	200.0
540–770	4.9	32.4	21.2	183.0	35.1	0.2	200.0
770–960 DZ1	0.7	7.3	4.7	33.2	6.7	0.1	99.0
960–1,005	5.9	22.6	19.5	66.0	18.2	0.7	99.0
RU1	0.9	48.7	33.3	161.0	40.4	0.1	200.0
RU2	0.7	21.0	10.9	183.0	29.1	0.1	200.0
Competent rock	0.9	42.6	26.3	183.0	39.2	0.1	200.0
Fractured rock	0.7	7.3	4.7	33.2	6.7	0.1	99.0
Whole borehole	0.7	34.3	19.5	183.0	37.5	0.1	200.0

Variation of Q_c with depth for borehole KLX02. The values are given every 5 m.



A5.6.3 Comparison

Comparison of the rock mass compressive strength from RMR and Q for borehole KLX02 (Hoek and Brown's a = 0.5).



A5.7 Friction angle and cohesion and of the rock mass

A5.7.1 RMR

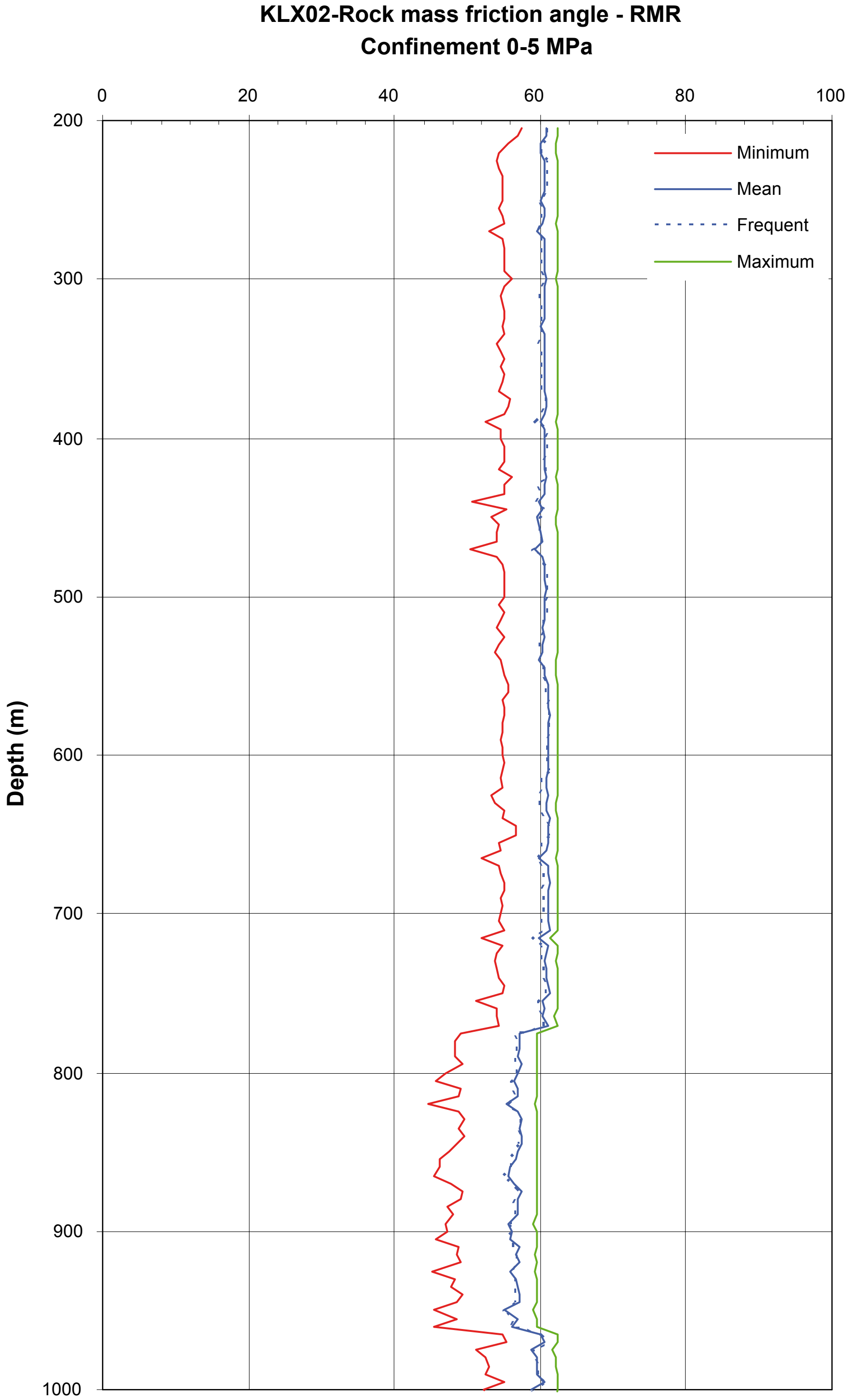
Summary of the friction angle (φ) of the rock mass derived from RMR for borehole KLX02 (10–30 MPa) (core sections of 5 m, Hoek and Brown's a = 0.5).

Rock Unit	Minimum φ'	Average φ'	Frequent φ'	Maximum φ'	Standard deviation	Min possible φ'	Max possible φ'
200–540	41.2	45.3	45.7	47.9	1.3	28.9	50.9
540–770	42.1	46.1	46.9	47.3	1.4	29.9	50.0
770–960 DZ1	35.9	39.6	40.0	42.2	1.6	23.6	47.3
960–1,005	40.2	42.7	42.2	45.9	2.1	29.9	49.3
RU1	40.2	45.0	45.7	47.9	1.6	28.9	50.9
RU2	35.9	43.2	44.0	47.3	3.6	23.6	50.0
Competent rock	40.2	45.4	45.8	47.9	1.6	28.9	50.9
Fractured rock	35.9	39.6	40.0	42.2	1.6	23.6	47.3
Whole borehole	35.9	44.0	45.2	47.9	3.0	23.6	50.9

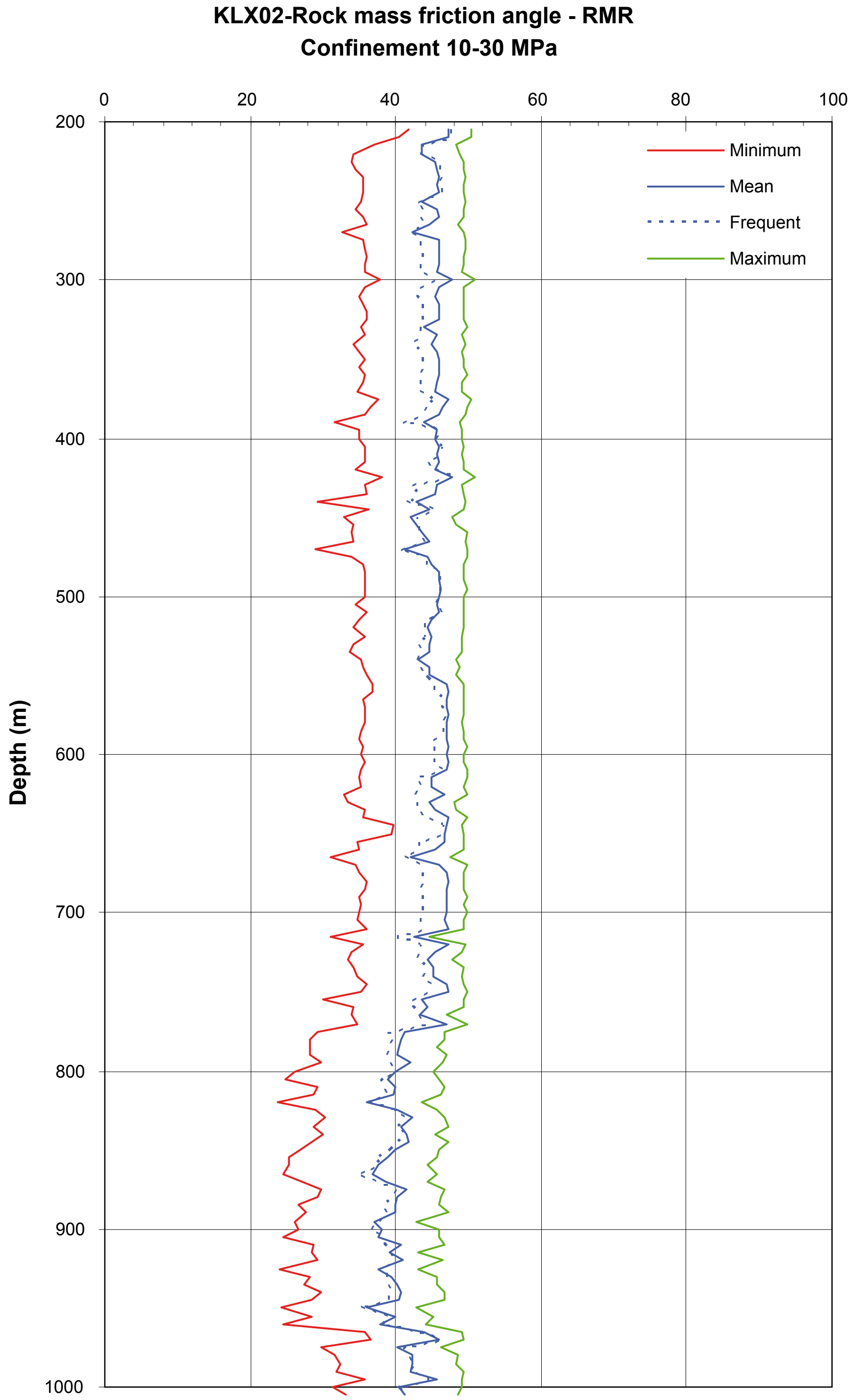
Summary of the cohesion of the rock mass derived from RMR for borehole KLX02 (10–30 MPa) (core sections of 5 m, Hoek and Brown's a = 0.5).

Rock Unit	Minimum c'	Average c'	Frequent c'	Maximum c'	Standard deviation	Min possible c'	Max possible c'
200–540	15.6	19.1	19.5	22.5	1.3	9.6	26.9
540–770	16.1	19.8	20.7	21.2	1.4	10.0	24.6
770–960 DZ1	12.8	15.2	15.4	17.4	1.2	7.6	23.2
960–1,005	14.9	16.8	16.3	19.7	1.7	10.0	23.2
RU1	14.9	18.8	19.4	22.5	1.6	9.6	26.9
RU2	12.8	17.7	17.7	21.2	2.6	7.6	24.6
Competent rock	14.9	19.2	19.5	22.5	1.6	9.6	26.9
Fractured rock	12.8	15.2	15.4	17.4	1.2	7.6	23.2
Whole borehole	12.8	18.3	18.7	22.5	2.3	7.6	26.9

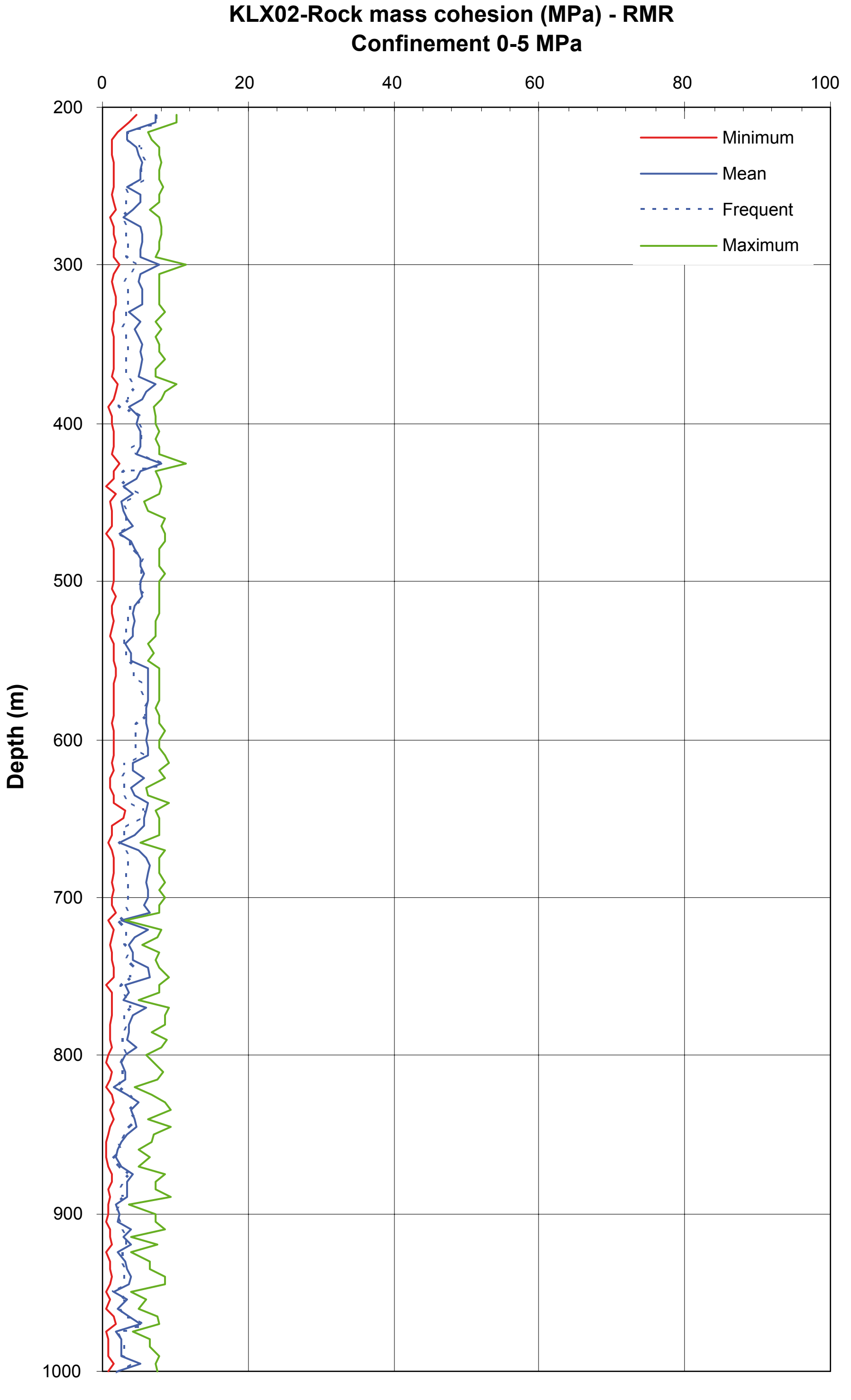
Variation of the rock mass friction angle from RMR for borehole KLX02 under stress confinement 0–5 MPa (Hoek and Brown's a = 0.5).



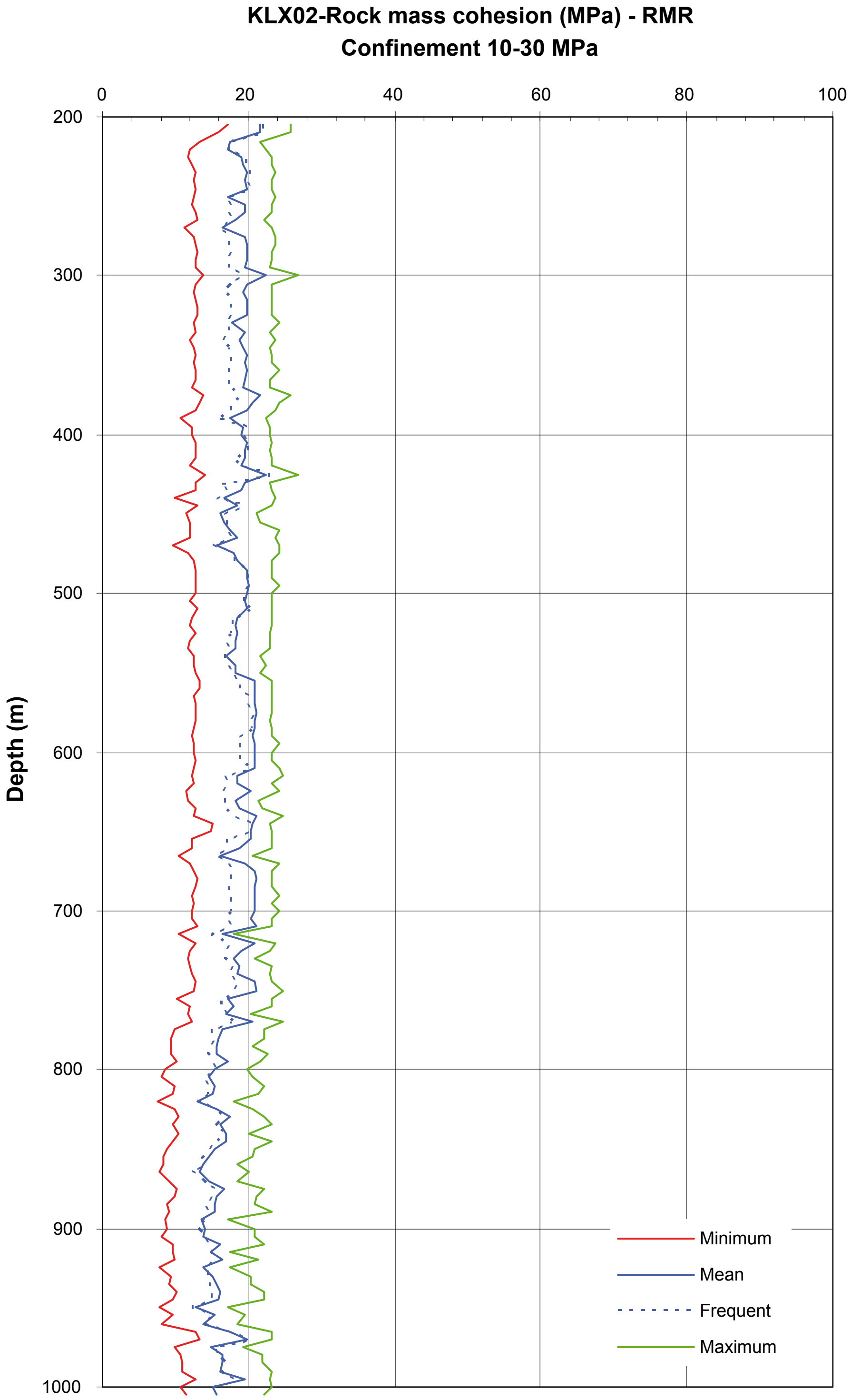
Variation of the rock mass friction angle from RMR for borehole KLX02 under stress confinement 10–30 MPa (Hoek and Brown's a = 0.5).



Variation of the rock mass cohesion from RMR for borehole KLX02 under stress confinement 0–5 MPa (Hoek and Brown's a = 0.5).



Variation of the rock mass cohesion from RMR for borehole KLX02 under stress confinement 10–30 MPa (Hoek and Brown's a = 0.5).



A5.7.2 Q

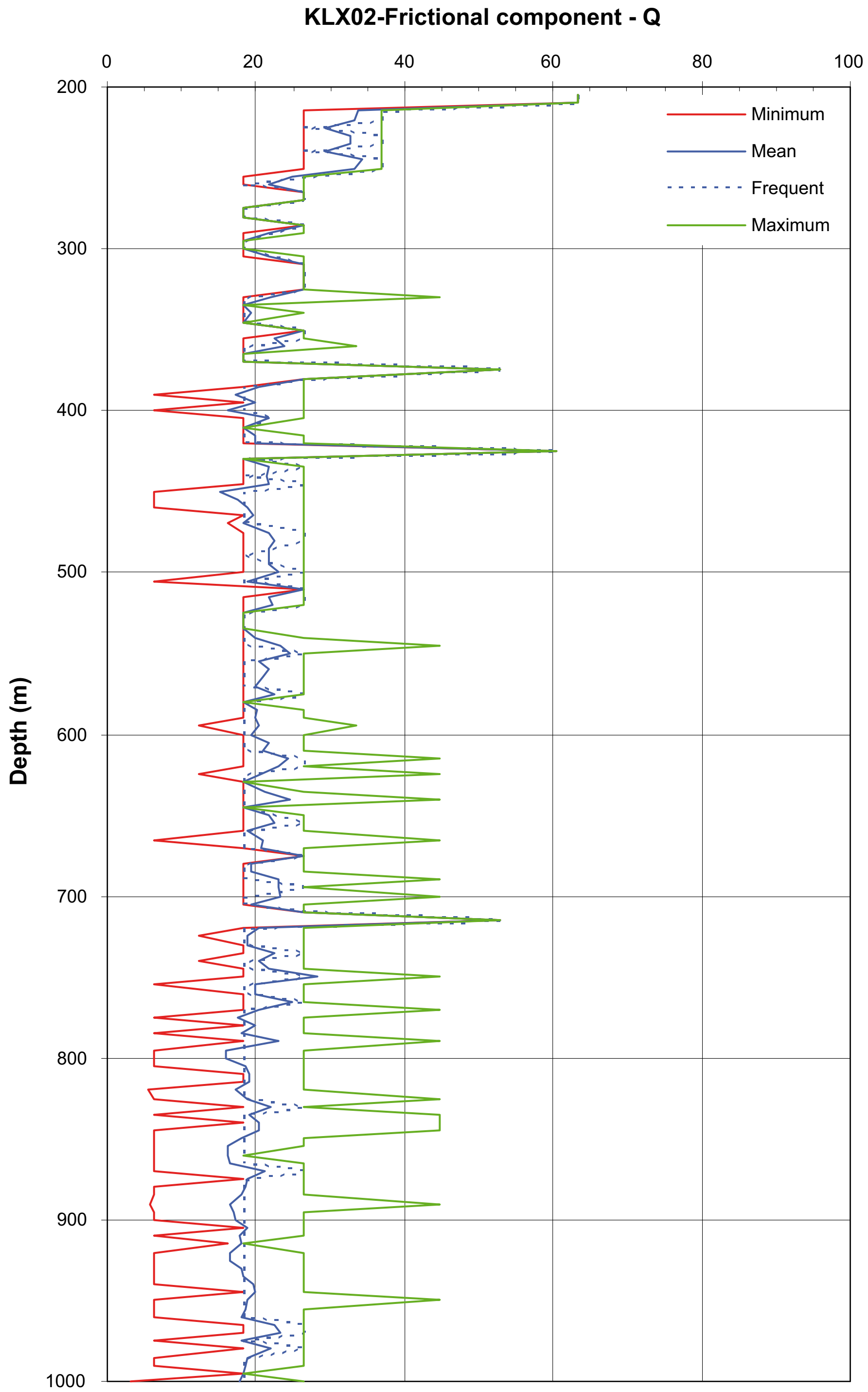
Summary of the frictional component FC of the rock mass derived from Qc for borehole KLX02 (core sections of 5 m).

Rock Unit	Minimum FC	Average FC	Frequent FC	Maximum FC	Standard deviation	Min possible FC	Max possible FC
200–540	15.2	24.7	21.6	63.4	10.1	6.3	63.4
540–770	18.3	22.1	20.9	52.9	5.2	6.3	52.9
770–960 DZ1	16.1	18.4	18.2	23.0	1.6	5.5	44.7
960–1,005	17.7	19.8	18.5	23.4	2.3	3.1	44.7
RU1	15.2	24.1	21.6	63.4	9.6	3.1	63.4
RU2	16.1	20.4	19.8	52.9	4.4	5.5	52.9
Competent rock	15.2	23.4	21.6	63.4	8.3	3.1	63.4
Fractured rock	16.1	18.4	18.2	23.0	1.6	5.5	44.7
Whole borehole	15.2	22.2	20.4	63.4	7.6	3.1	63.4

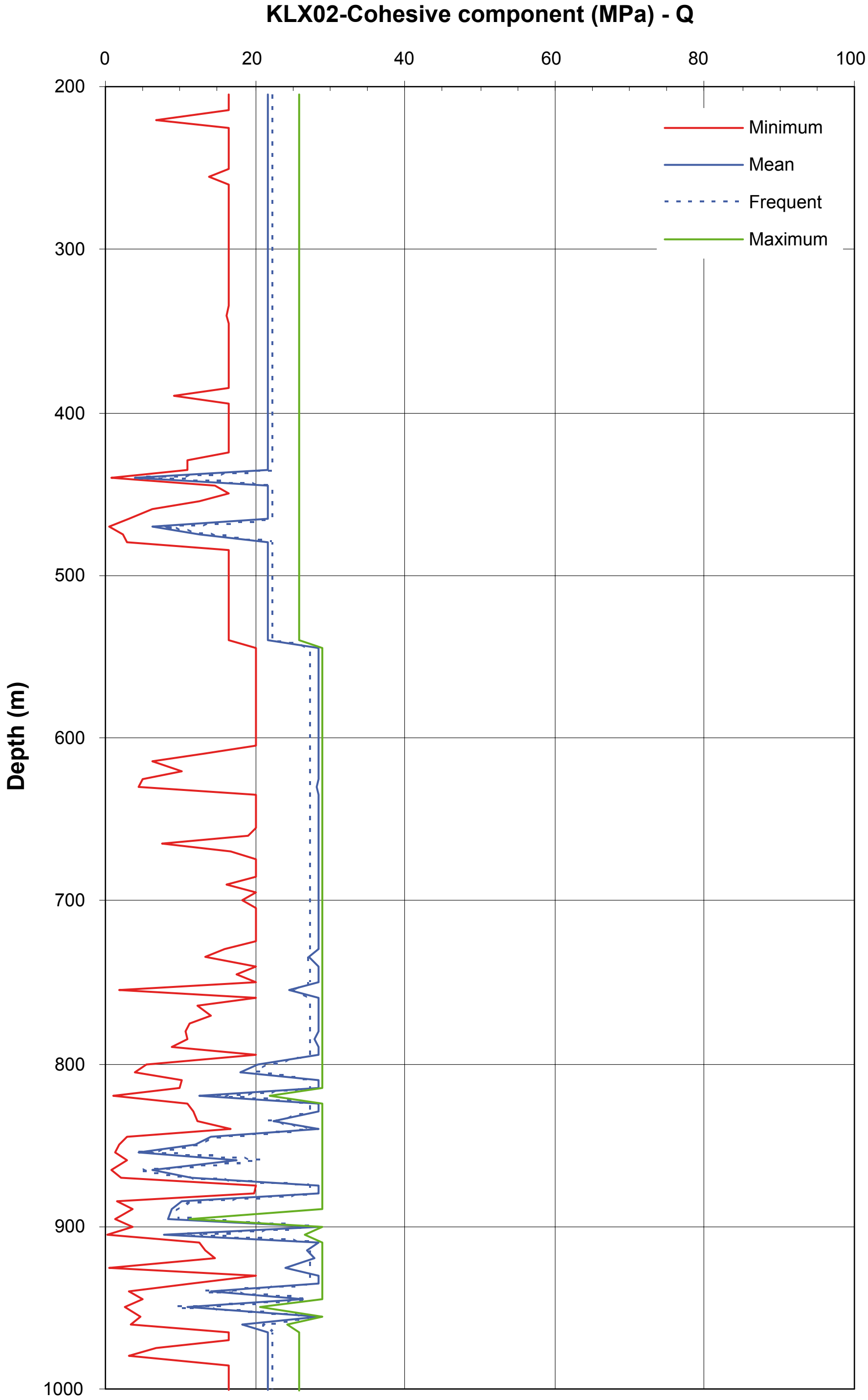
Summary of the cohesion of the rock mass derived from Qc for borehole KLX02 (core sections of 5 m).

Rock Unit	Minimum CC	Average CC	Frequent CC	Maximum CC	Standard deviation	Min possible CC	Max possible CC
200–540	3.8	21.1	21.7	21.7	3.0	0.4	25.8
540–770	24.6	28.3	28.4	28.4	0.6	1.7	28.9
770–960 DZ1	4.5	21.2	26.7	28.4	8.4	0.4	28.9
960–1,005	21.7	21.7	21.7	21.7	0.0	3.2	25.8
RU1	3.8	21.1	21.7	21.7	2.9	0.4	25.8
RU2	4.5	25.1	28.4	28.4	6.6	0.4	28.9
Competent rock	3.8	23.8	21.7	28.4	4.2	0.4	28.9
Fractured rock	4.5	21.2	26.7	28.4	8.4	0.4	28.9
Whole borehole	3.8	23.2	21.7	28.4	5.5	0.4	28.9

Variation of the frictional component FC from Q for borehole KLX02.

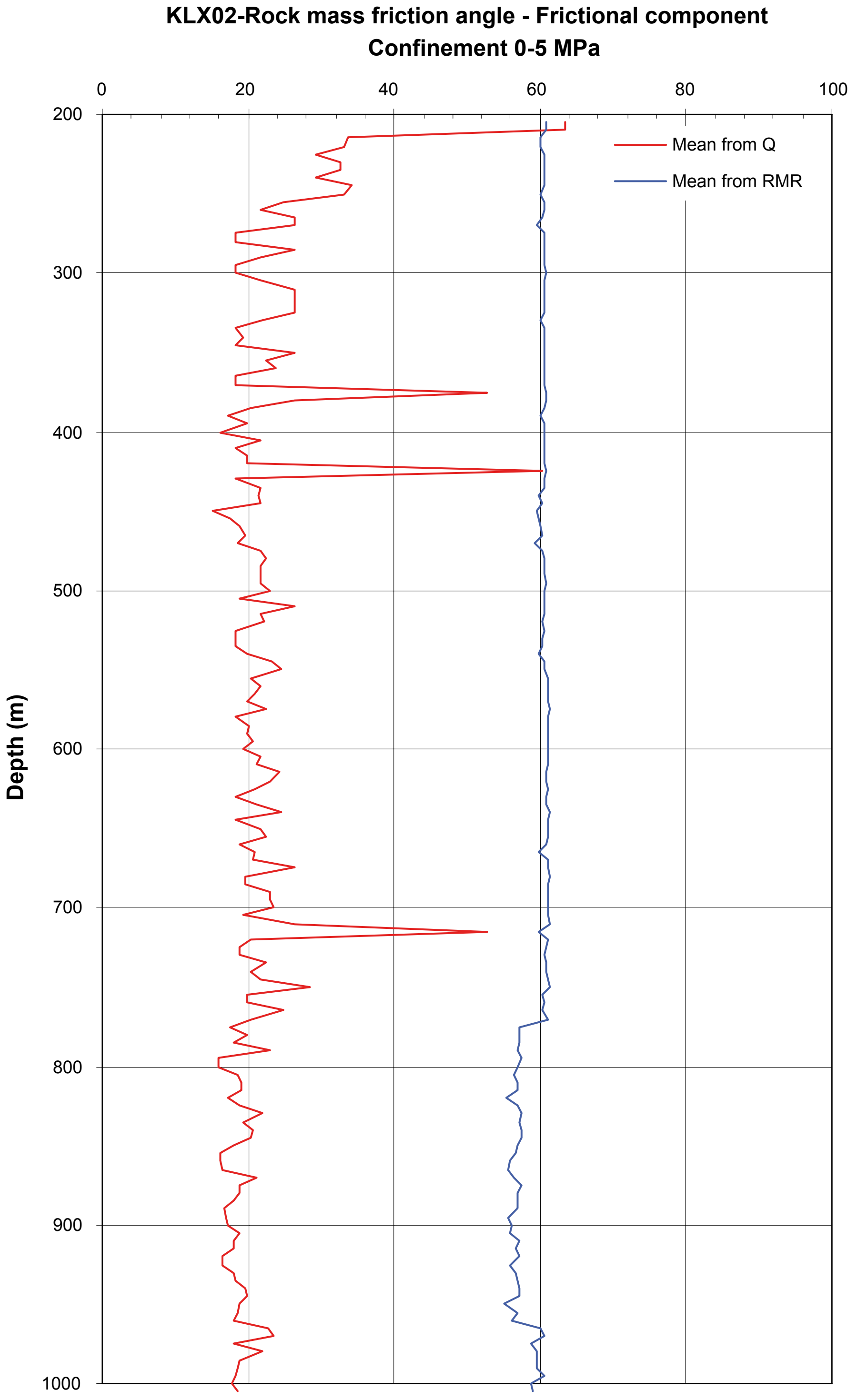


Variation of the cohesive component from Q for borehole KLX02.



A5.7.3 Comparison

Comparison of the rock mass friction angle from RMR and Q for borehole KLX02 under stress confinement 0–5 MPa (Hoek and Brown's a = 0.5).



Comparison of the rock mass cohesion from RMR and Q for borehole KLX02 under stress confinement 0–5 MPa (Hoek and Brown's a = 0.5).