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Forsmark site investigation

Drill hole KFM09A

Indirect tensile strength test

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This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the author and do not necessarily coincide with those of the client.

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Abstract

The density and the indirect tensile strength of 20 water saturated specimens of intact rock from borehole KFM09A at Forsmark have been determined. The specimens were collected at three depth levels ranging between 466–479, 563–564 and 592–593 m borehole length. Moreover, the rock types were metamorphic granodiorite (466–467 m and 592–595 m) respectively pegmatite and/or pegmatitic granite (479–480 m and 563–564 m). The specimens were photographed before and after the mechanical test.

The measured densities for the water saturated specimens were in the range 2,590–2,690 kg/m^3, which yields a mean value of 2,651 kg/m^3. The values for indirect tensile strength were in the range 6.6–18.8 MPa with a mean value of 14.0 MPa.

Sammanfattning

Densiteten och den indirekta draghållfastheten hos 20 vattenmättade prover av intakt homogent berg från borrhål KFM09A i Forsmark har bestämts. Proven har tagits från tre djupnivåer som ligger mellan 466–479, 563–564 och 592–593 m borrhålslängd. Bergarten vid dessa nivåer var metamorf granodiorit (466–467 m och 592–595 m) samt pegmatit och/eller pegmatitisk granit (479–480 m and 563–564 m). Provobjekten fotograferades före och efter de mekaniska proven.

Densiteten hos de vattenmättade proven var mellan 2 590–2 690 kg/m^3 vilket gav ett medelvärde på 2 651 kg/m^3. Värdena på den indirekta draghållfastheten var 6,6–18,8 MPa med ett medelvärde på 14,0 MPa.

Contents

1 Introduction

This document reports performance and results of indirect tensile strength tests on water-saturated specimens sampled from borehole KFM09A at Forsmark, see map in Figure 1-1. The tests were carried out in the material and rock mechanics laboratories at the Department of Building Technology and Mechanics at the Swedish National Testing and Research Institute (SP). The activity is part of the site investigation programme at Forsmark managed by SKB (The Swedish Nuclear Fuel and Waste Management Co).

The controlling documents for the activity are listed in Table 1-1. Both Activity Plan and Method Descriptions are SKB's internal controlling documents, whereas the Quality Plan referred to in the table is an SP internal controlling document.

Borehole KFM09A, see Figure 1-1, is a core drilled borehole inclined c 60° from the horizontal plane and with a total length of c 800 m.

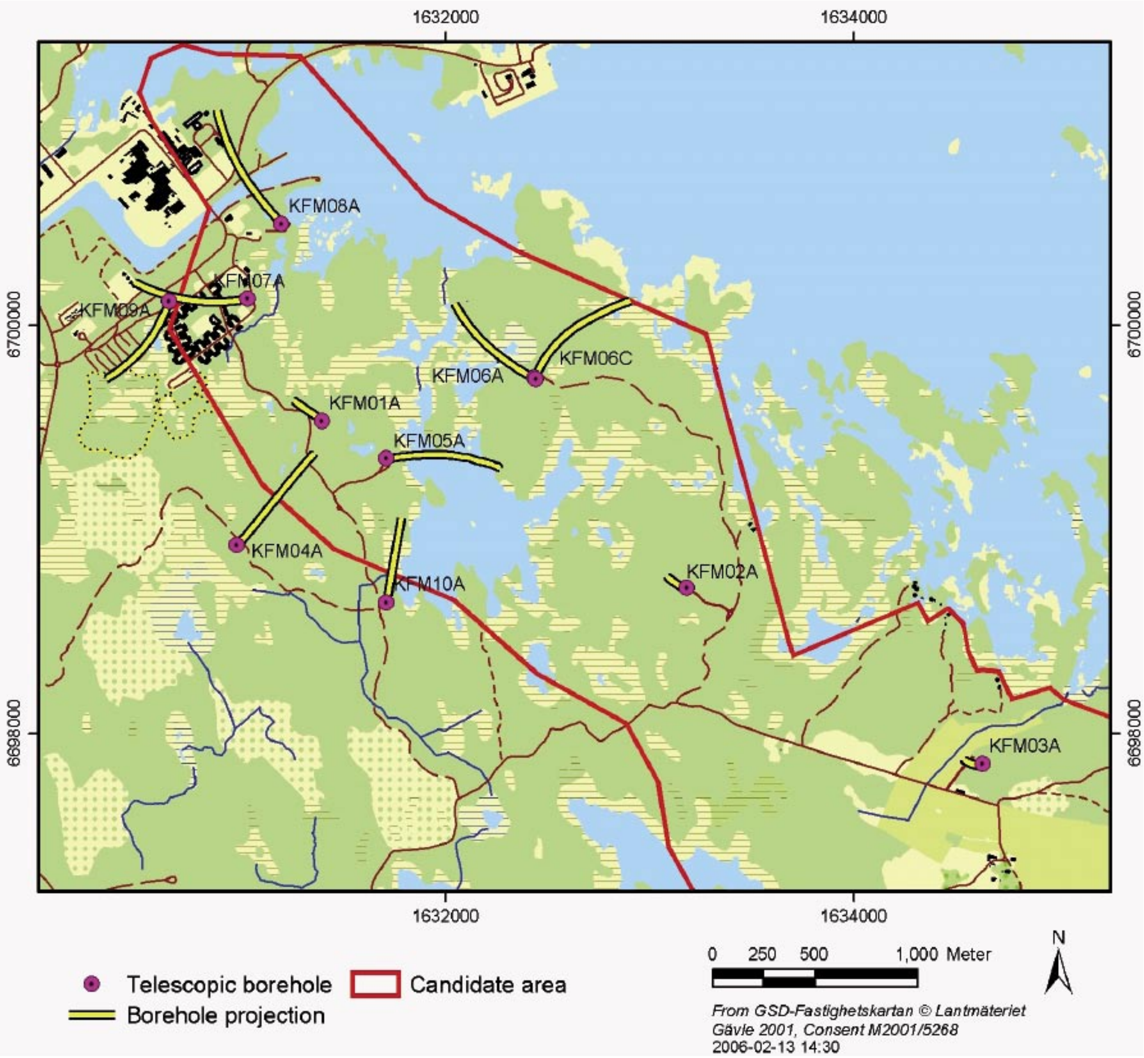

Figure 1-1. *Location of all deep core drilled boreholes completed up to February 2006 within or close to the Forsmark candidate area. The projection of each borehole on the horizontal plane at top of casing is also shown in the figure.*

Table 1-1. Controlling documents for performance of the activity.

Activity plan	Number	Version
KFM09A. Bergmekaniska och termiska laboratoriebestämningar	AP PF 400-05-111	1.0
Method description	**Number**	**Version**
Indirect test of tensile strength	SKB MD 190.004	2.0
Determining density and porosity of intact rock	SKB MD 160.002	2.0
Quality plan		
SP-QD 13.1		

SKB supplied SP with rock cores which arrived at SP in January 2006 and were tested during June 2006. The specimens, in form of cylindrical discs, were cut from the cores and selected based on the preliminary core logging with the strategy to primarily investigate the properties of the rock types metamorphic granodiorite (101056) respectively pegmatite and/or pegmatitic granite (101061). The method description SKB MD 190.004 was followed for the sampling and for the indirect tensile strength tests, whereas the method description SKB MD 160.002, was followed when the density was determined.

The specimens were put into water and stored in water with a minimum of 7 days, up to testing. This yields a water saturation, which is intended to resemble the in-situ moisture condition. The density was determined on each specimen and the indirect tensile tests were carried out at this moisture condition. The granodiorite specimens had a foliated material structure leading to anisotropic mechanical response whereas the pegmatitic specimens had a homogenous structure, which implies that the mechanical response is expected to be approximately isotropic. The direction of loading is displayed on the specimens by a drawn line on each specimen. The specimens were photographed before and after the mechanical testing.

2 Objective and scope

The purpose of the testing is to determine the density and the indirect tensile strength of a cylindrical intact rock core.

The results from the tests are going to be used in the site descriptive rock mechanics model, which will be established for the candidate area selected for site investigations at Forsmark.

3 Equipment

A circular saw with a diamond blade was used to cut the specimens to their final lengths. Specimens with a rough cutting surface were levelled in a grinding machine. The measurements of the dimensions were made with a sliding calliper. Furthermore, the tolerances were made checked by means of a dial indicator and a stone face plate.

The specimens and the water were weighed using a weighing scale. A thermometer was used for the water temperature measurement. The calculated wet density was determined with an uncertainty of ± 4 kg/m^3.

The mechanical testing was carried out in a load frame where the crossbar is mechanically driven by screws and has a maximum load capacity of 100 kN in compression. The axial compressive load was measured by an external 100 kN load cell. The uncertainty of the load measurement is less than 1%.

The frame was equipped with a pair of curved bearing blocks, radius 39 mm and width 29 mm, with pins for guiding the vertical deformation, see Figure 3-1. The top platen includes a spherical seating in order to have a fully centred loading position. The specimens were photographed with a 4.0 Mega pixel digital camera at highest resolution and the photographs were stored in a jpeg-format.

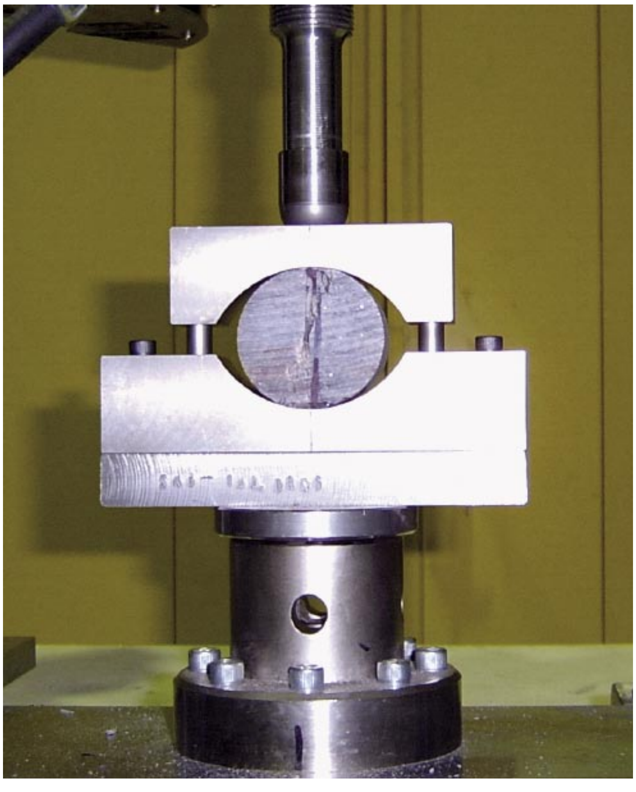

Figure 3-1. *Curved bearing blocks for indirect tensile test. The specimen in the picture does not belong to the tests in this report.*

4 Execution

The water saturation and determination of the density of the wet specimens were made in accordance with the method description SKB MD 160.002 (SKB internal controlling document). This includes determination of density in accordance to ISRM /1/ and water saturation by SS EN 13755 /2/. The determination of the indirect tensile strength was carried out in compliance with the method description SKB 190.004 (SKB internal controlling document). The test method follows ASTM D3967-95a /3/.

4.1 Description of the specimens

The rock type characterisation was made according to Stråhle /4/ using the SKB mapping system (Boremap). The identification marks, upper and lower sampling depth (Secup and Seclow) and the rock type are shown in Table 4-1.

Table 4-1. Specimen identification, sampling level and rock type for all specimens (based on the Boremap overview mapping).

Identification	Adj secup (m)	Adj seclow (m)	Rock type/occurrence
KFM09A-110-1	466.89	466.92	Granodiorite, metamorphic (101056)
KFM09A-110-2	466.92	466.95	Granodiorite, metamorphic (101056)
KFM09A-110-3	466.95	466.98	Granodiorite, metamorphic (101056)
KFM09A-110-4	466.98	467.02	Granodiorite, metamorphic (101056)
KFM09A-110-5	479.96	479.99	Pegmatite, pegmatitic granite (101061)
KFM09A-110-6	479.99	480.03	Pegmatite, pegmatitic granite (101061)
KFM09A-110-7	592.99	593.03	Granodiorite, metamorphic (101056)
KFM09A-110-8	593.03	593.06	Granodiorite, metamorphic (101056)
KFM09A-110-9	594.79	594.83	Granodiorite, metamorphic (101056)
KFM09A-110-10	594.83	594.86	Granodiorite, metamorphic (101056)
KFM09A-110-11	594.94	594.97	Granodiorite, metamorphic (101056)
KFM09A-110-12	594.97	595.00	Granodiorite, metamorphic (101056)
KFM09A-110-13	595.00	595.04	Granodiorite, metamorphic (101056)
KFM09A-110-14	595.04	595.07	Granodiorite, metamorphic (101056)
KFM09A-110-15	563.93	563.96	Pegmatite, pegmatitic granite (101061)
KFM09A-110-16	563.96	564.00	Pegmatite, pegmatitic granite (101061)
KFM09A-110-17	564.00	564.03	Pegmatite, pegmatitic granite (101061)
KFM09A-110-18	564.04	564.07	Pegmatite, pegmatitic granite (101061)
KFM09A-110-19	564.07	564.10	Pegmatite, pegmatitic granite (101061)
KFM09A-110-20	564.11	564.13	Pegmatite, pegmatitic granite (101061)

4.2 Testing

The temperature of the water was 20.8°C, which equals to a water density of 998.0 kg/m^3, when the density determination of the rock specimens was carried out. Further, the specimens had been stored 13 days in water when the density was determined and 21 days in water when the indirect tensile strength was determined.

An auto-calibration of the load frame was run prior to the mechanical test in order to check the system. Further, an individual check-list was filled in and checked for every specimen during all the steps in the execution. Moreover, comments were made during the mechanical testing upon observed phenomena that are relevant for the interpretation of the results. The check-list form is an SP internal quality document.

The diameter and thickness were entered into the test software which computed the indirect tensile strength together with the mean value and standard deviation for the whole test series. The results were then exported as text-files and stored in a file server on the SP computer network. The results were imported to the program MS Excel and rearranged to the SICADA database format. Moreover, the diagrams were produced using MS Excel.

An overview of the activities during the testing is shown in the step-by step description in Table 4-2.

4.3 Nonconformities

The testing was conducted according to the method description. The activity plan was followed with no departures.

Table 4-2. Activities during the mechanical testing.

Step	Activity
1	The geometrical tolerances were checked: parallel and perpendicular surfaces, smooth and straight circumferential surface.
2	The diameter and thickness were measured three times each. The respective mean value determines the dimensions that are reported.
3	The direction of compressive loading was marked as a line on one of the plane surfaces with a marker pen.
4	The specimens were then put into water and stored in water for minimum 7 days. The weight of water together with one specimen was determined. The specimen was taken out from the water and the weight of the water and rock specimen was determined separately, and by using the known density of the water, the wet density could be computed. This procedure was repeated for each specimen.
5	Digital photos were taken on each specimen.
6	The wet specimens were inserted into the loading device one by one, with the correct orientation given by the marked line. The strain gauges were connected to the sampling device and the signals were checked. The specimens were loaded up to failure during deformation control. The displacement rate was set to 0.3 mm/min during loading. The maximum compressive load, which also defines the failure load, was registered.
7	Digital photos were taken on each specimen after the mechanical testing.

5 Results

The results of the individual specimens are presented in Section 5.1 and a summary of the results is given in Section 5.2. The original results, unprocessed raw data obtained from the testing, were reported to the SICADA database. These data together with the digital photographs of the individual specimens were handed over to SKB. The handling of the results follows SDP-508 (SKB internal controlling document) in general.

5.1 Description and presentation of the specimen

The results for the individual specimens are as follows:

Specimen ID: KFM09A-110-1

Before mechanical test

After mechanical test

Diameter (mm)	Height (mm)	Density (kg/m³)	Tensile strength (MPa)
50.8	25.4	2,680	13.6

Comments: None

Specimen ID: KFM09A-110-2

Before mechanical test	**After mechanical test**
	

Diameter (mm)	**Height (mm)**	**Density (kg/m³)**	**Tensile strength (MPa)**
50.8	25.4	2,680	18.8

Comments: None

Specimen ID: KFM09A-110-3

Before mechanical test	**After mechanical test**
	

Diameter (mm)	**Height (mm)**	**Density (kg/m³)**	**Tensile strength (MPa)**
50.8	25.3	2,680	14.4

Comments: None

Specimen ID: KFM09A-110-4

Before mechanical test

After mechanical test

Diameter (mm)	**Height (mm)**	**Density (kg/m³)**	**Tensile strength (MPa)**
50.8	26.4	2,670	17.3

Comments: None

Specimen ID: KFM09A-110-5

Before mechanical test

After mechanical test

Diameter (mm)	**Height (mm)**	**Density (kg/m³)**	**Tensile strength (MPa)**
50.8	25.5	2,640	16.7

Comments: None

Specimen ID: KFM09A-110-6

Before mechanical test	**After mechanical test**
	

Diameter (mm)	**Height (mm)**	**Density (kg/m³)**	**Tensile strength (MPa)**
50.8	25.6	2,630	16.1

Comments: None

Specimen ID: KFM09A-110-7

Before mechanical test	**After mechanical test**
	

Diameter (mm)	**Height (mm)**	**Density (kg/m³)**	**Tensile strength (MPa)**
50.8	25.4	2,690	15.2

Comments: None

Specimen ID: KFM09A-110-8

Before mechanical test

After mechanical test

Diameter (mm)	**Height (mm)**	**Density (kg/m³)**	**Tensile strength (MPa)**
50.8	25.5	2,680	15.3

Comments: None

Specimen ID: KFM09A-110-9

Before mechanical test

After mechanical test

Diameter (mm)	**Height (mm)**	**Density (kg/m³)**	**Tensile strength (MPa)**
50.8	25.7	2,680	14.6

Comments: None

Specimen ID: KFM09A-110-10

Before mechanical test	After mechanical test
	

Diameter (mm)	Height (mm)	Density (kg/m^3)	Tensile strength (MPa)
50.8	25.6	2,680	16.0

Comments: None

Specimen ID: KFM09A-110-11

Before mechanical test	After mechanical test
	

Diameter (mm)	Height (mm)	Density (kg/m^3)	Tensile strength (MPa)
50.8	26.4	2,680	14.0

Comments: None

Specimen ID: KFM09A-110-12

Before mechanical test

After mechanical test

Diameter (mm)	Height (mm)	Density (kg/m³)	Tensile strength (MPa)
50.8	26.2	2,680	16.8

Comments: None

Specimen ID: KFM09A-110-13

Before mechanical test

After mechanical test

Diameter (mm)	Height (mm)	Density (kg/m³)	Tensile strength (MPa)
50.8	25.9	2,680	15.3

Comments: None

Specimen ID: KFM09A-110-14

Before mechanical test

After mechanical test

Diameter (mm)	**Height (mm)**	**Density (kg/m³)**	**Tensile strength (MPa)**
50.8	26.0	2,680	17.7

Comments: None

Specimen ID: KFM09A-110-15

Before mechanical test

After mechanical test

Diameter (mm)	**Height (mm)**	**Density (kg/m³)**	**Tensile strength (MPa)**
50.7	25.3	2,590	10.3

Comments: None

Specimen ID: KFM09A-110-16

Before mechanical test

After mechanical test

Diameter (mm)	Height (mm)	Density (kg/m^3)	Tensile strength (MPa)
50.7	26.8	2,610	10.0

Comments: None

Specimen ID: KFM09A-110-17

Before mechanical test

After mechanical test

Diameter (mm)	Height (mm)	Density (kg/m^3)	Tensile strength (MPa)
50.7	26.6	2,590	9.9

Comments: None

Specimen ID: KFM09A-110-18

Before mechanical test	**After mechanical test**
	

Diameter (mm)	**Height (mm)**	**Density (kg/m³)**	**Tensile strength (MPa)**
50.7	26.5	2,590	12.1

Comments: None

Specimen ID: KFM09A-110-19

Before mechanical test	**After mechanical test**
	

Diameter (mm)	**Height (mm)**	**Density (kg/m³)**	**Tensile strength (MPa)**
50.6	25.6	2,590	8.7

Comments: The anticipated vertical fracture is displaced sideways indicating that the fracture has been controlled by the material structure. The circumferential surface had some irregularities from the drilling.

Specimen ID: KFM09A-110-20

Before mechanical test	After mechanical test
	

Diameter (mm)	Height (mm)	Density (kg/m³)	Tensile strength (MPa)
50.4	26.0	2,620	6.6

Comments: The failure is parallel to the loading line and is seen as a thin line about one linewidth to the right of the loading line.

5.2 Results for the entire test series

A summary of the test results is shown in Tables 5-1 and 5-2. The densities and tensile strength versus sampling depth are shown in Figures 5-1 and 5-2.

Table 5-1. Summary of results.

Identification	Density (kg/m³)	Tensile strength (MPa)	Comments
KFM09A-110-1	2,680	13.6 (‖)	
KFM09A-110-2	2,680	18.8 (⊥)	
KFM09A-110-3	2,680	14.4 (‖)	
KFM09A-110-4	2,670	17.3 (⊥)	
KFM09A-110-5	2,640	16.7	
KFM09A-110-6	2,630	16.1	
KFM09A-110-7	2,690	15.2 (‖)	
KFM09A-110-8	2,680	15.3 (⊥)	
KFM09A-110-9	2,680	14.6 (‖)	
KFM09A-110-10	2,680	16.0 (⊥)	
KFM09A-110-11	2,680	14.0 (‖)	
KFM09A-110-12	2,680	16.8 (⊥)	
KFM09A-110-13	2,680	15.3 (‖)	
KFM09A-110-14	2,680	17.7 (⊥)	
KFM09A-110-15	2,590	10.3	
KFM09A-110-16	2,610	10.0	
KFM09A-110-17	2,590	9.9	
KFM09A-110-18	2,590	12.1	
KFM09A-110-19	2,590	8.7	
KFM09A-110-20	2,620	6.6	

(‖) loading along foliation, (⊥) loading across foliation.

Table 5-2. Calculated mean values (Mean val) and standard deviation (Std dev) of wet density and tensile strength at the different sampling levels and for all specimens.

	Density (kg/m³)	Tensile strength (MPa)
Mean value (All specimens)	2,651	14.0
Mean value (466–467 m)	2,678	16.0
Mean value (479–564 m)	2,608	11.3
Mean value (592–595 m)	2,681	15.6
Std dev (All specimens)	38.6	3.3
Std dev (466–467 m)	5.0	2.4
Std dev (479–564 m)	20.5	3.5
Std dev (592–595 m)	3.5	1.2

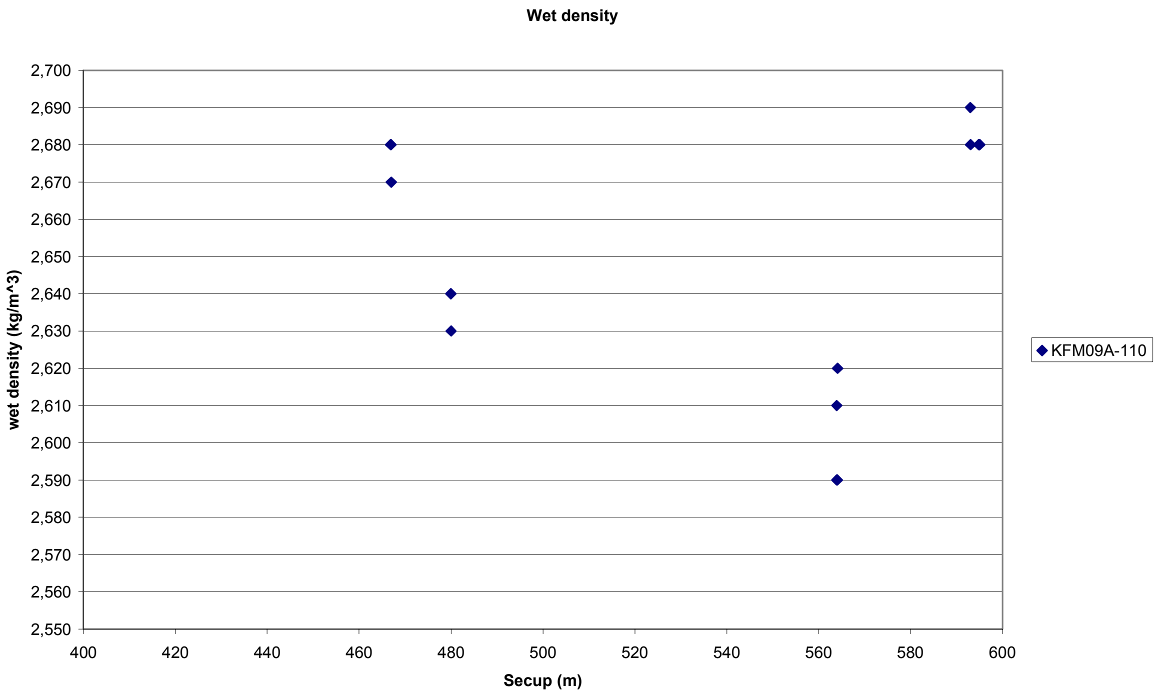

Figure 5-1. Density versus sampling depth in the borehole.

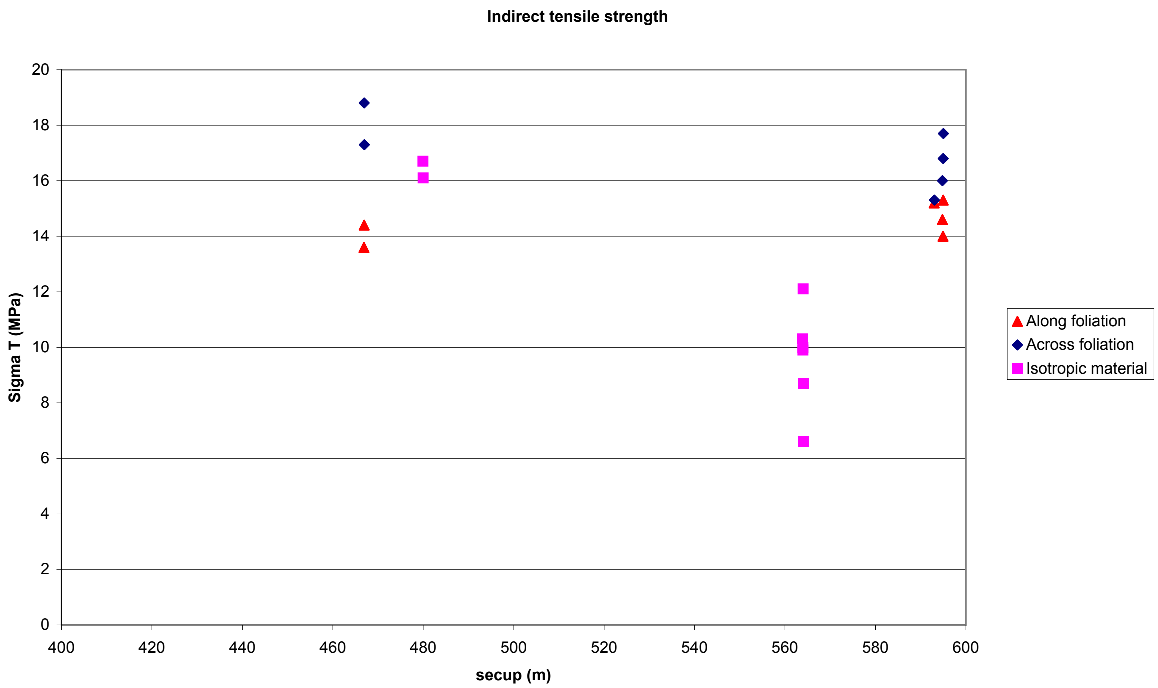

Figure 5-2. Tensile strength versus sampling depth in the borehole.

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/3/ **ASTM D3967-95a, 1996.** Standard test method for splitting tensile strength of intact rock core specimens.

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