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Oskarshamn site investigation

Drill hole KLX02

Indirect tensile strength test

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September 2004

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Keywords: Rock mechanics, Indirect tensile strength, Tension test.

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 30 water saturated specimens of intact rock from borehole KLX02 in Laxemar have been determined. The specimens were taken at three depth levels ranging between 312–318 m, 488–506 m and 743–746 m. Moreover, the rock type was Ävrö granite. The specimens were photographed before and after the mechanical test.

The measured density for the water saturated specimens were in the range 2,660–2,700 kg/m^3, which yields a mean value of 2,685 kg/m^3. The values for indirect tensile strength were in the range 12.3–15.2 MPa (312–318 m), 11.5–16.4 MPa (488–506 m) and 10.4–14.6 MPa (743–746 m).

Sammanfattning

Densiteten och den indirekta draghållfastheten hos 30 vattenmättade prover av intakt homogent berg från borrhål KLX02 i Laxemar har bestämts. Proven har tagits från tre djupnivåer 312–318 m, 488–506 m och 743–746 m. Bergtypen för samtliga nivåer var Ävrö granit. Proveobjekten fotograferades före och efter de mekaniska proven.

Densiteten hos de vattenmättade proven var mellan 2 660–2 700 kg/m^3, vilket gav ett medelvärde på 2 685 kg/m^3. Värdena på den indirekta draghållfastheten var 12.3–15.2 MPa (312–318 m), 11.5–16.4 MPa (488–506 m) och 10.4–14.6 MPa (743–746 m).

Contents

1 Introduction

Indirect tensile strength tests have been conducted on water-saturated specimens sampled from borehole KLX02 in Laxemar, see map in Figure 1-1. These tests belong to one of the activities performed as part of the site investigation in the Laxemar area lead by Swedish Nuclear Fuel and Waste Management Co (SKB). The tests were carried out in the material and rock mechanics laboratories at the department of Building Technology and Mechanics at Swedish National Testing and Research Institute (SP). All work is carried out in accordance with the activity plan AP PS 400-03-92 (SKB internal controlling document) and is controlled by SP-QD 13.1 (SP internal quality document).

SKB supplied SP with rock cores and they arrived at SP in February 2004 and were tested during September 2004. 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 dominant rock type. The specimens were put in 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 rock material had a homogenous structure, which implies that the mechanical response of 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.

The method description SKB MD 190.004e, version 2.0, (SKB internal controlling document) was followed for the sampling and for the indirect tensile strength tests and the method description SKB MD 160.002, version 2.0, (SKB internal controlling document) was followed when the density was determined.

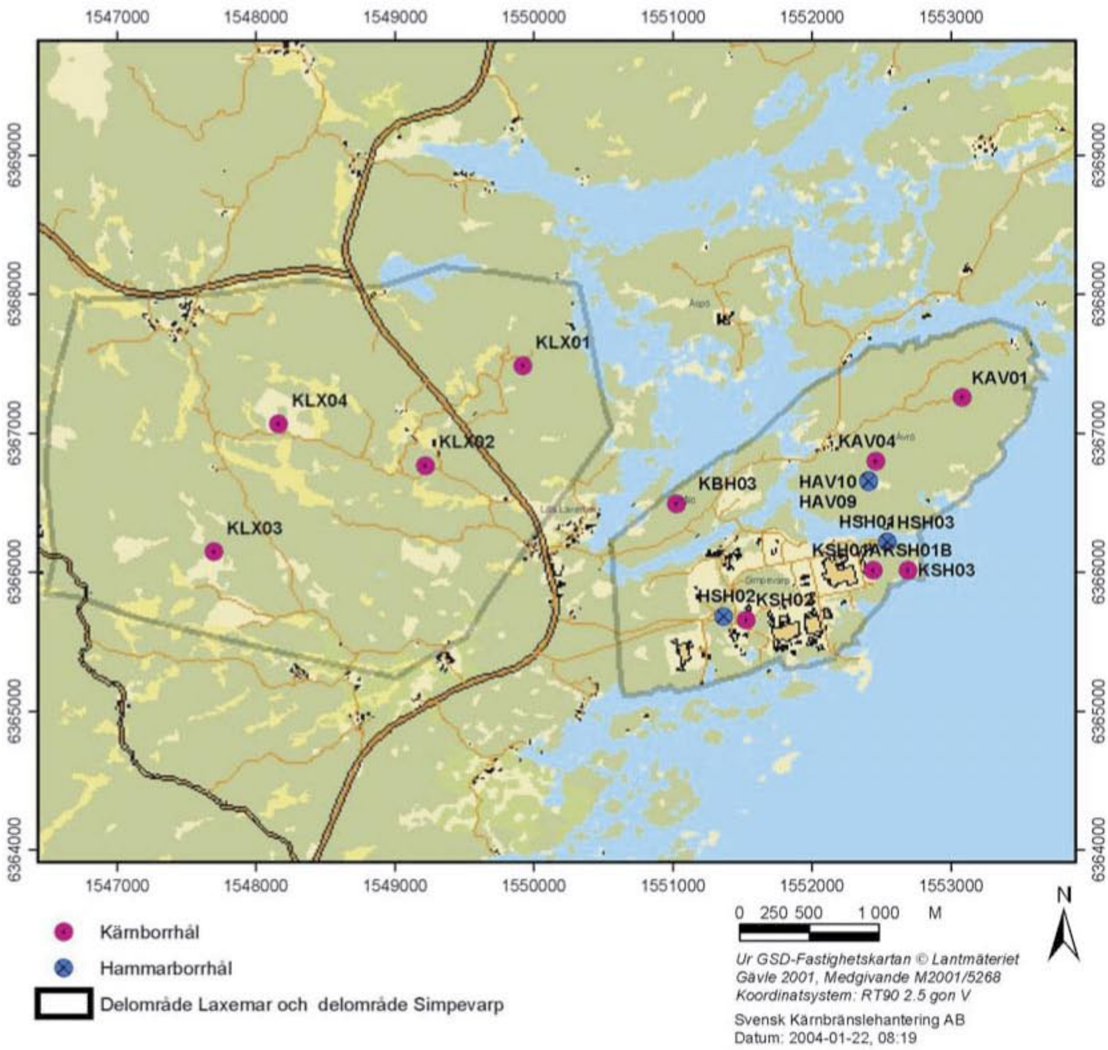


Figure 1-1. *Location of the drill hole KLX02 at the Laxemar site.*

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 specimens are from the borehole KLX02, which is an old borehole with a bore depth of 1,700 m.

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 Laxemar.

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 weighted using a scale for weight measurement. 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 maximum load capacity is 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.

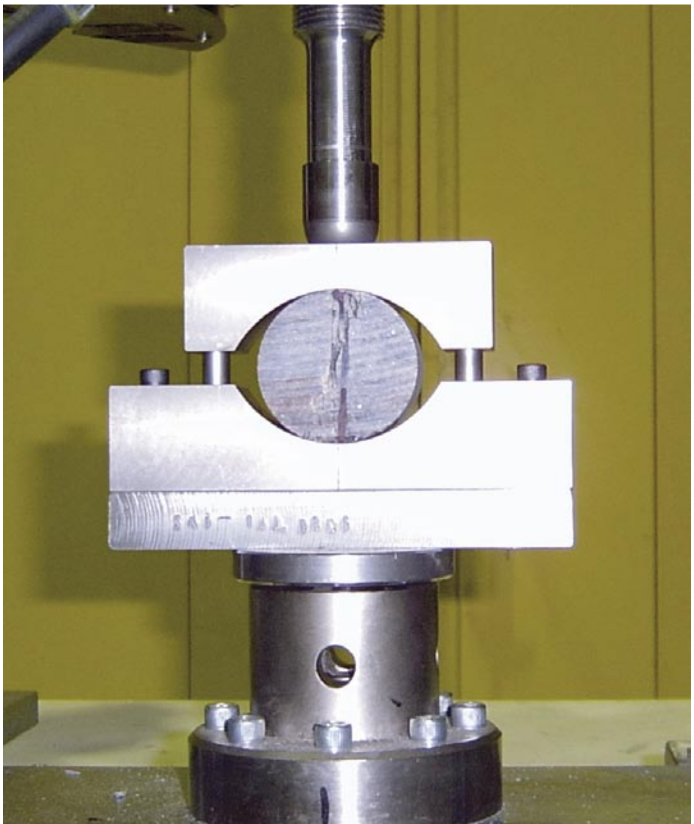


Figure 3-1. *Curved bearing blocks for the indirect tensile test. The specimen in the picture does not belong to the test series in this report.*

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, version 2.0, (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 according to the method description SKB 190.004e, version 2.0, (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 (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 depth and rock type for all specimens.

Identification	Secup (m)	Seclow (m)	Rock type
KLX02-110-1	312.84	312.88	Ävrö granite (All specimens)
KLX02-110-2	312.88	312.92	
KLX02-110-3	312.92	312.96	
KLX02-110-4	312.96	313.00	
KLX02-110-5	313.14	313.18	
KLX02-110-6	317.29	317.33	
KLX02-110-7	317.33	317.36	
KLX02-110-8	317.36	317.40	
KLX02-110-9	317.48	317.52	
KLX02-110-10	317.73	317.77	
KLX02-110-13	488.67	488.71	
KLX02-110-14	488.71	488.75	
KLX02-110-15	488.75	488.79	
KLX02-110-16	488.79	488.83	
KLX02-110-17	488.89	488.93	
KLX02-110-18	488.93	488.96	
KLX02-110-19	488.96	489.00	
KLX02-110-20	489.78	489.82	
KLX02-110-21	489.82	489.85	
KLX02-110-22	505.65	505.68	
KLX02-110-25	743.29	743.32	
KLX02-110-26	743.32	743.36	
KLX02-110-27	743.36	743.39	
KLX02-110-28	743.71	743.75	
KLX02-110-29	743.75	743.78	

Identification	Secup (m)	Seclow (m)	Rock type
KLX02-110-30	745.06	745.09	
KLX02-110-31	745.09	745.13	
KLX02-110-32	745.13	745.16	
KLX02-110-34	745.20	745.24	
KLX02-110-35	745.95	745.99	

4.2 Testing

A step-by step description of the full test procedure is as follows:

Step	Activity
1	The drill cores were marked where the specimens are to be taken.
2	The specimens were cut to the specified length according to markings. If the cutting surfaces were rough, they were slightly grinded.
3	The tolerances were checked: parallel and perpendicular surfaces, smooth and straight circumferential surface.
4	The diameter and thickness were measured three times each. The respectively mean value determines the dimensions that are reported.
5	The direction of compressive loading was marked as a line on one of the plane surfaces with a marker pen.
6	The specimens were then put in water and stored in water for minimum 7 days. The weight of water and one specimen together was determined. The specimen was taken out from the water and the weight of the water and rock specimen was determined separately and by knowing the density of the water the wet density could be computed. This was repeated for each specimen.
7	Digital photos were taken on each specimen.
8	The wet specimens were inserted in the loading device one by one, with the correct orientation given by the marked line, and loaded up to failure in deformation control. The load frame crossbar speed was set to 0.3 mm/min, which yielded a loading rate of approximately 9.5 MPa/min. The maximum compressive load, which also defines the failure load. was registered.
9	Digital photos were taken on each specimen after the mechanical testing.

The temperature of the water was 18.7°C, which equals to a water density of 998.4 kg/m^3, when the density determination of the rock specimens was carried out. Further, the specimens had been stored 7 days in water when the density was determined and 22–23 days in water when the indirect tensile strength was determined.

An auto-calibration of the load frame was run before 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 upon observations made during the mechanical testing that are relevant for the interpretation of the results. The check-list form is a SP internal quality document.

The diameter and thickness were entered into the test software whereby the test software 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 program MS Excel and rearranged to the SICADA data base format. Moreover, the diagrams were produced using MS Excel.

5 Results

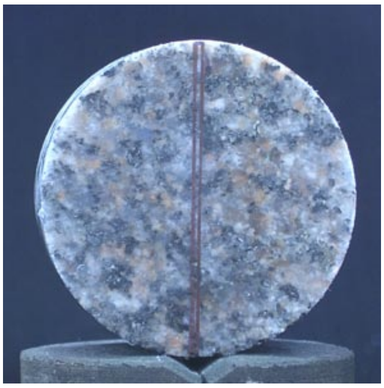
The results of the individual specimens are presented in Section 5.1 and a summary of the results is given in Section 5.2. The original results, unprocessed raw data obtained from the testing, were reported to the SICADA database FN 236. These data together with the digital photographs of the individual specimens were stored on a CD and 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

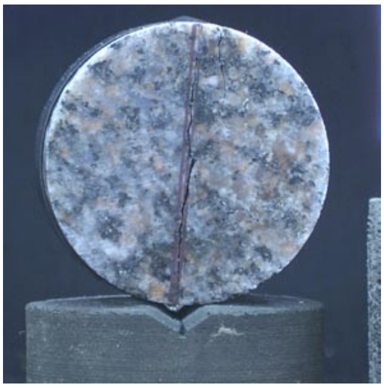
The results for the individual specimens are as follows:

Specimen ID: KLX02-110-1

Before mechanical test



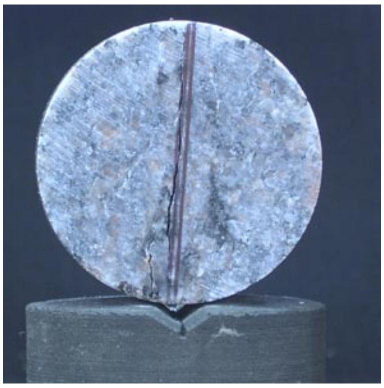
After mechanical test



Diameter (mm)	Height (mm)	Density (kg/m^3)	Tensile strength (MPa)
47.3	26.1	2,680	13.2

Comments: None

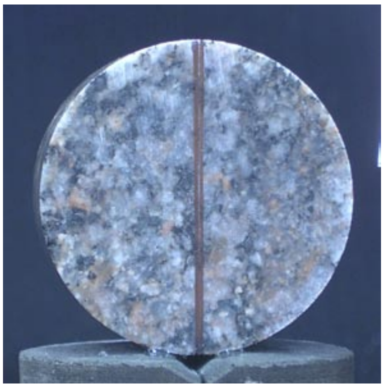
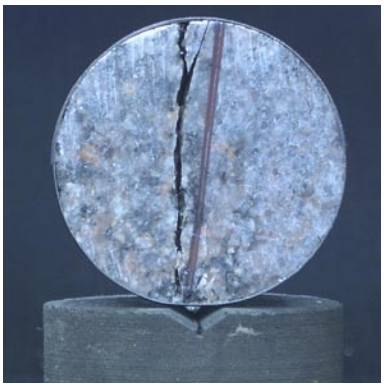
Specimen ID: KLX02-110-2

Before mechanical test	After mechanical test
	

Diameter (mm)	Height (mm)	Density (kg/m^3)	Tensile strength (MPa)
47.3	26.1	2,680	12.3

Comments: None

Specimen ID: KLX02-110-3

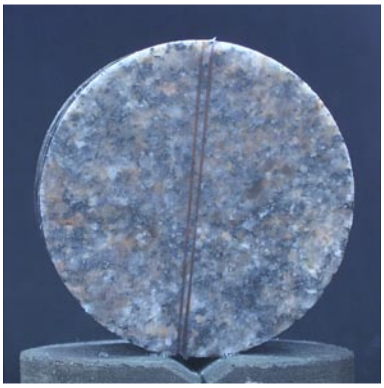
Before mechanical test	After mechanical test
	

Diameter (mm)	Height (mm)	Density (kg/m^3)	Tensile strength (MPa)
47.3	26.1	2,680	12.5

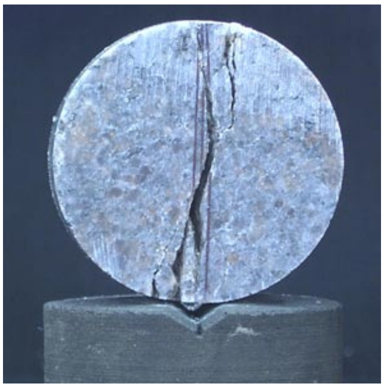
Comments: None

Specimen ID: KLX02-110-4

Before mechanical test



After mechanical test

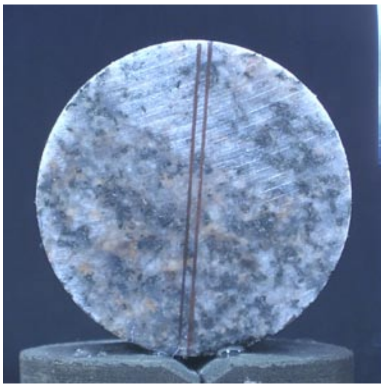


Diameter (mm)	**Height (mm)**	**Density (kg/m^3)**	**Tensile strength (MPa)**
47.3	26.2	2,660	14.9

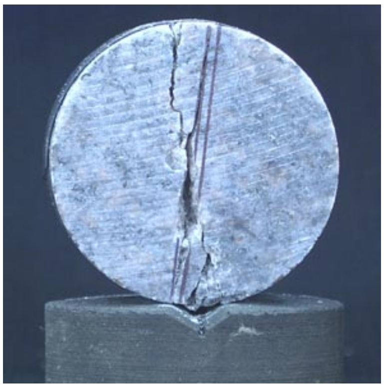
Comments: None

Specimen ID: KLX02-110-5

Before mechanical test



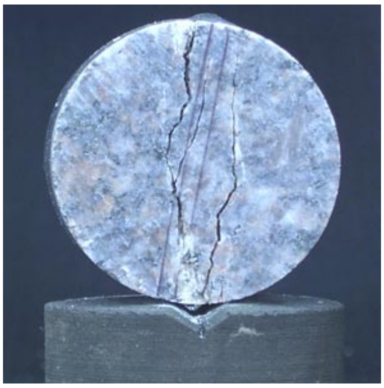
After mechanical test



Diameter (mm)	**Height (mm)**	**Density (kg/m^3)**	**Tensile strength (MPa)**
47.3	26.3	2,690	14.5

Comments: None

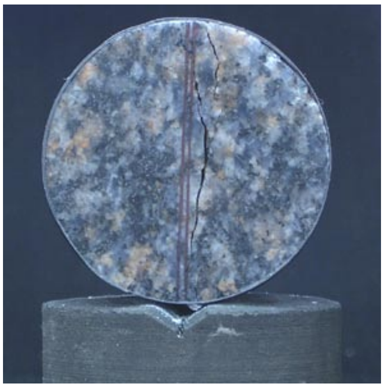
Specimen ID: KLX02-110-6

Before mechanical test	After mechanical test
	

Diameter (mm)	**Height (mm)**	**Density (kg/m³)**	**Tensile strength (MPa)**
47.3	26.2	2,680	15.2

Comments: None

Specimen ID: KLX02-110-7

Before mechanical test	After mechanical test
	

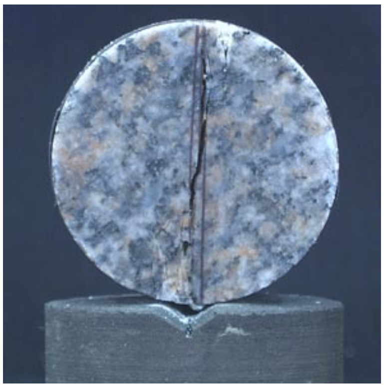
Diameter (mm)	**Height (mm)**	**Density (kg/m³)**	**Tensile strength (MPa)**
47.2	26.2	2,700	13.4

Comments: None

Specimen ID: KLX02-110-8

Before mechanical test

After mechanical test

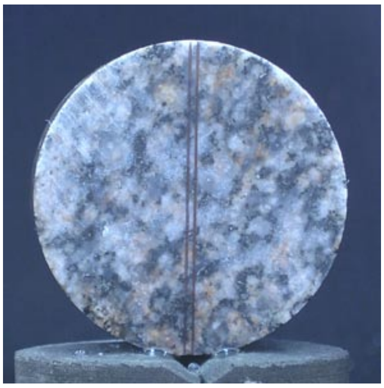


Diameter (mm)	**Height (mm)**	**Density (kg/m³)**	**Tensile strength (MPa)**
47.3	26.2	2,690	13.7

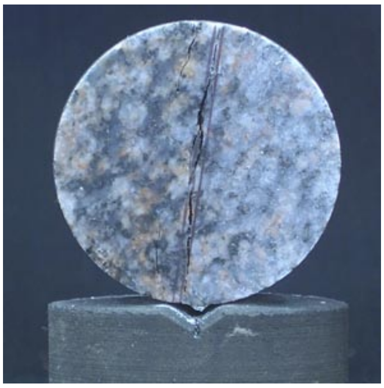
Comments: None

Specimen ID: KLX02-110-9

Before mechanical test



After mechanical test



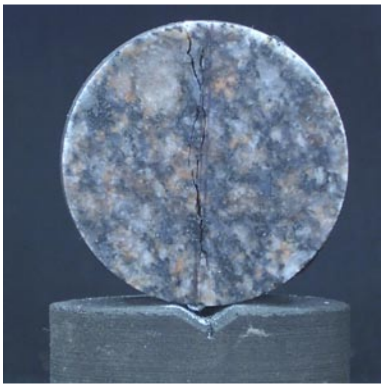
Diameter (mm)	**Height (mm)**	**Density (kg/m³)**	**Tensile strength (MPa)**
47.2	26.2	2,680	13.9

Comments: None

Specimen ID: KLX02-110-10

Before mechanical test

After mechanical test

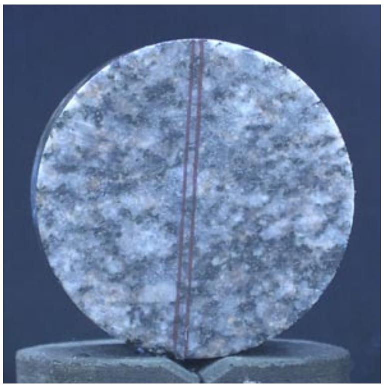


Diameter (mm)	**Height (mm)**	**Density (kg/m^3)**	**Tensile strength (MPa)**
47.2	26.1	2,670	13.1

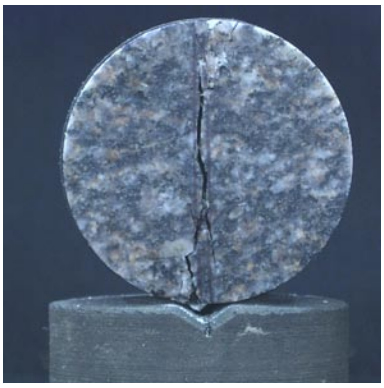
Comments: None

Specimen ID: KLX02-110-13

Before mechanical test



After mechanical test



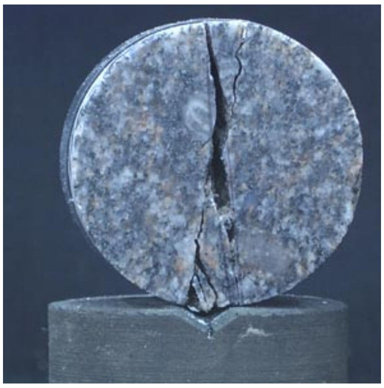
Diameter (mm)	**Height (mm)**	**Density (kg/m^3)**	**Tensile strength (MPa)**
47.4	26.1	2,690	14.5

Comments: None

Specimen ID: KLX02-110-14

Before mechanical test

After mechanical test

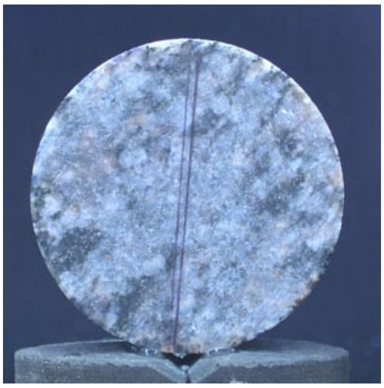


Diameter (mm)	Height (mm)	Density (kg/m^3)	Tensile strength (MPa)
47.4	26.1	2,690	14.1

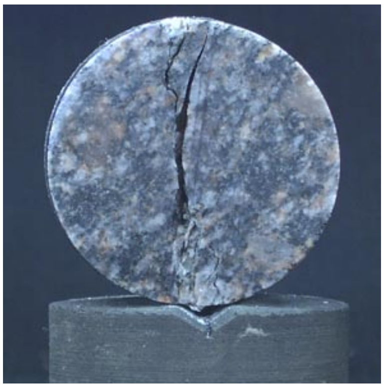
Comments: None

Specimen ID: KLX02-110-15

Before mechanical test



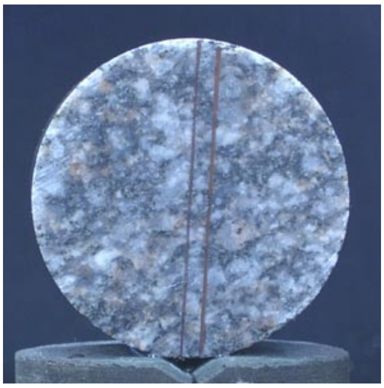
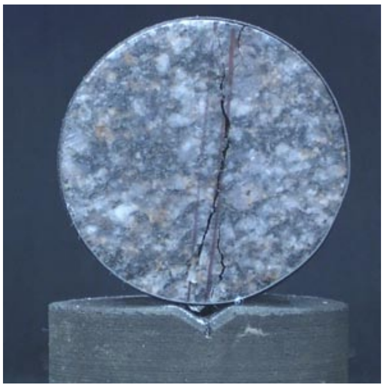
After mechanical test



Diameter (mm)	Height (mm)	Density (kg/m^3)	Tensile strength (MPa)
47.4	26.2	2,690	14.8

Comments: None

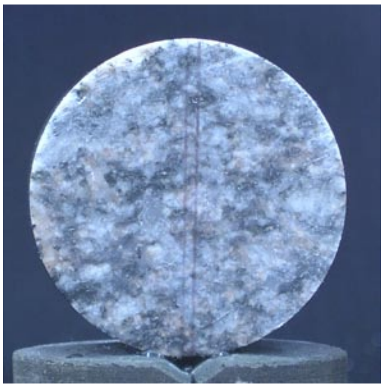
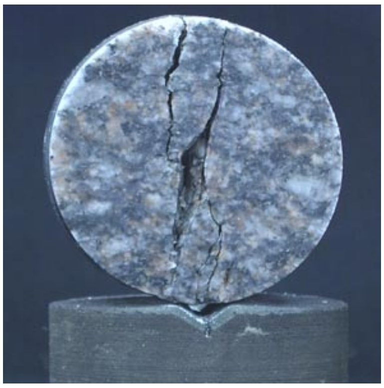
Specimen ID: KLX02-110-16

Before mechanical test	After mechanical test
	

Diameter (mm)	Height (mm)	Density (kg/m^3)	Tensile strength (MPa)
47.4	26.2	2,690	15.5

Comments: None

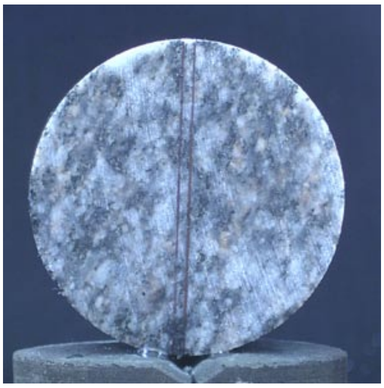
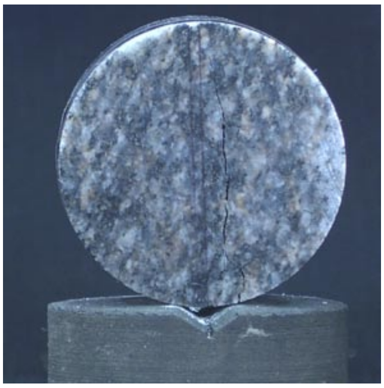
Specimen ID: KLX02-110-17

Before mechanical test	After mechanical test
	

Diameter (mm)	Height (mm)	Density (kg/m^3)	Tensile strength (MPa)
47.5	26.2	2,690	16.4

Comments: None

Specimen ID: KLX02-110-18

Before mechanical test	After mechanical test
	

Diameter (mm)	Height (mm)	Density (kg/m^3)	Tensile strength (MPa)
47.4	26.1	2,690	14.0

Comments: None

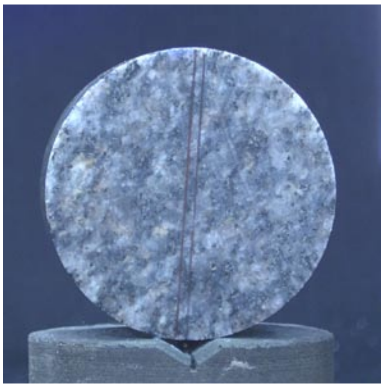
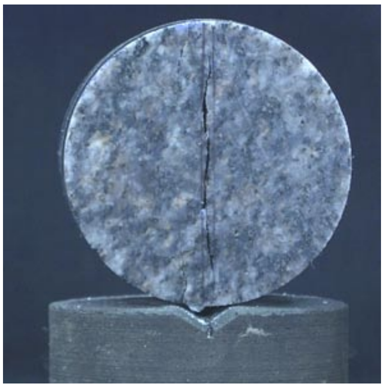
Specimen ID: KLX02-110-19

Before mechanical test	After mechanical test
	

Diameter (mm)	Height (mm)	Density (kg/m^3)	Tensile strength (MPa)
47.4	26.3	2,690	13.6

Comments: None

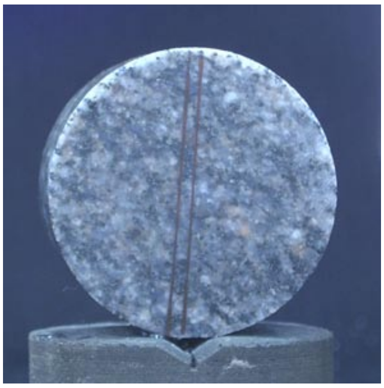
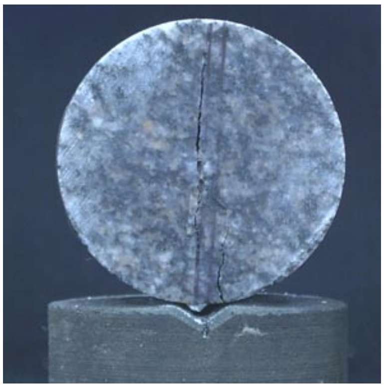
Specimen ID: KLX02-110-20

Before mechanical test	After mechanical test
	

Diameter (mm)	**Height (mm)**	**Density (kg/m^3)**	**Tensile strength (MPa)**
47.4	26.2	2,680	13.3

Comments: None

Specimen ID: KLX02-110-21

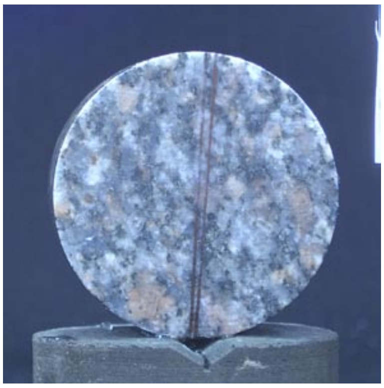
Before mechanical test	After mechanical test
	

Diameter (mm)	**Height (mm)**	**Density (kg/m^3)**	**Tensile strength (MPa)**
47.6	26.1	2,690	14.2

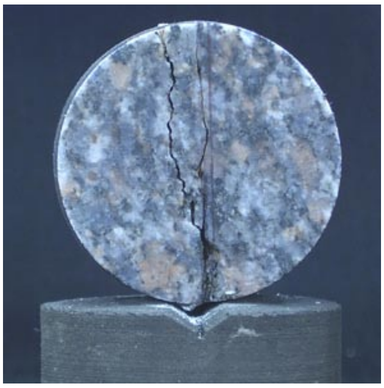
Comments: None

Specimen ID: KLX02-110-22

Before mechanical test



After mechanical test

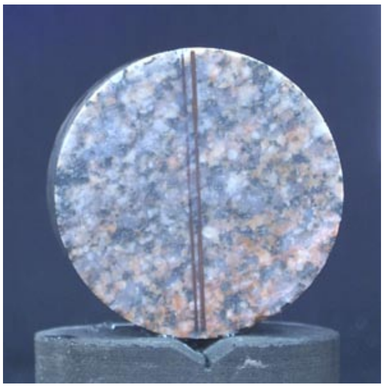


Diameter (mm)	**Height (mm)**	**Density (kg/m³)**	**Tensile strength (MPa)**
46.7	26.0	2,690	11.5

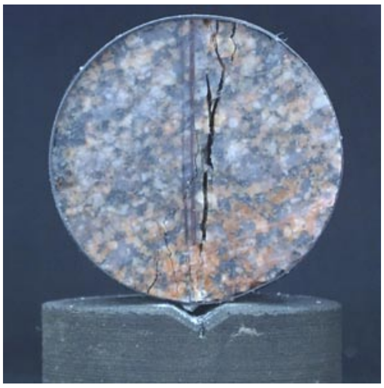
Comments: None

Specimen ID: KLX02-110-25

Before mechanical test



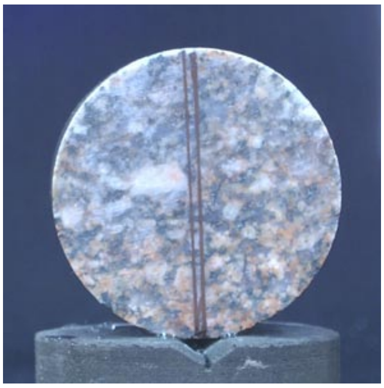
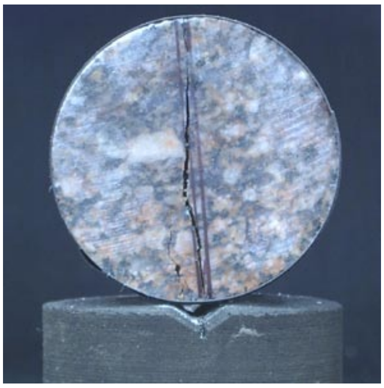
After mechanical test



Diameter (mm)	**Height (mm)**	**Density (kg/m³)**	**Tensile strength (MPa)**
47.4	26.2	2,680	13.8

Comments: None

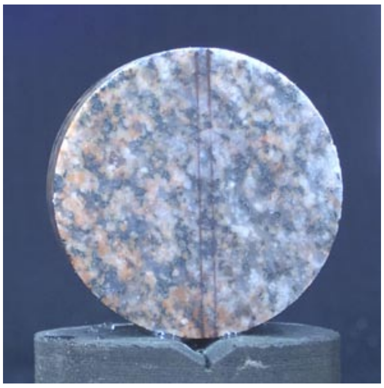
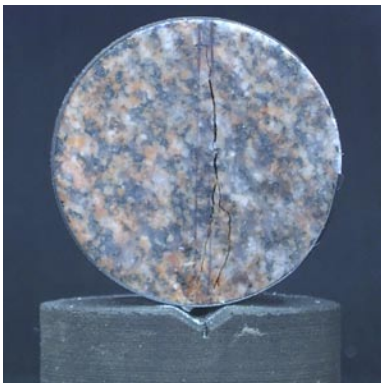
Specimen ID: KLX02-110-26

Before mechanical test	After mechanical test
	

Diameter (mm)	**Height (mm)**	**Density (kg/m^3)**	**Tensile strength (MPa)**
47.5	26.2	2,680	14.6

Comments: None

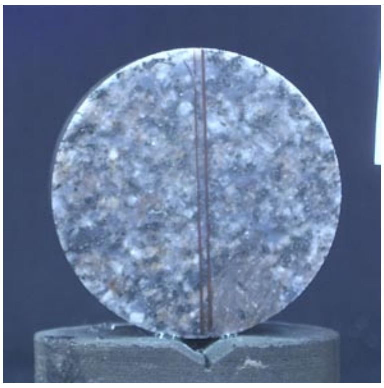
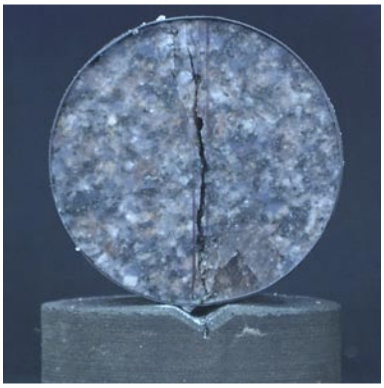
Specimen ID: KLX02-110-27

Before mechanical test	After mechanical test
	

Diameter (mm)	**Height (mm)**	**Density (kg/m^3)**	**Tensile strength (MPa)**
47.4	26.0	2,670	14.2

Comments: None

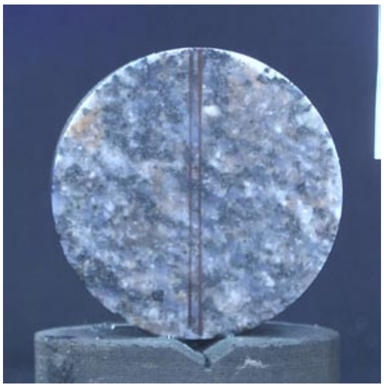
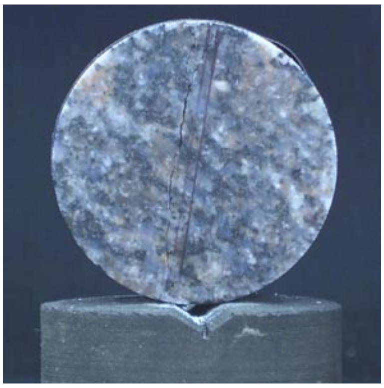
Specimen ID: KLX02-110-28

Before mechanical test	After mechanical test
	

Diameter (mm)	**Height (mm)**	**Density (kg/m^3)**	**Tensile strength (MPa)**
47.5	26.2	2,690	11.6

Comments: None

Specimen ID: KLX02-110-29

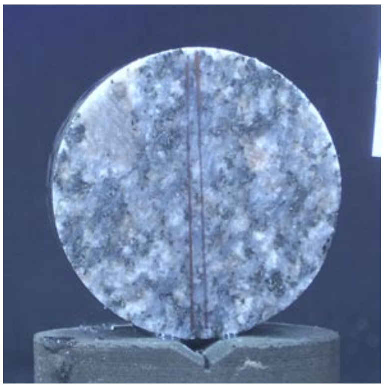
Before mechanical test	After mechanical test
	

Diameter (mm)	**Height (mm)**	**Density (kg/m^3)**	**Tensile strength (MPa)**
47.4	26.1	2,690	12.3

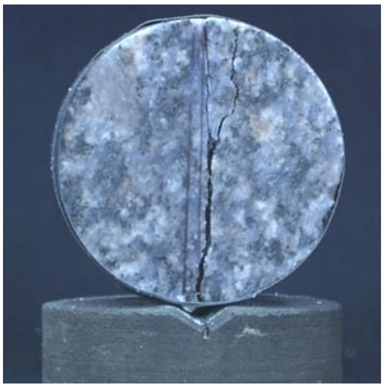
Comments: None

Specimen ID: KLX02-110-30

Before mechanical test



After mechanical test

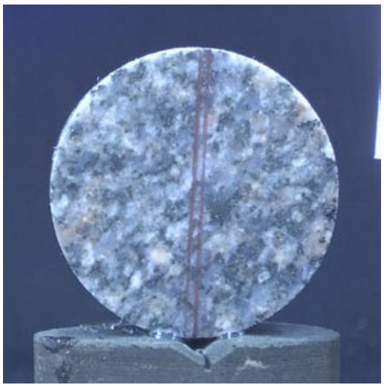


Diameter (mm)	Height (mm)	Density (kg/m^3)	Tensile strength (MPa)
47.5	26.4	2,690	10.4

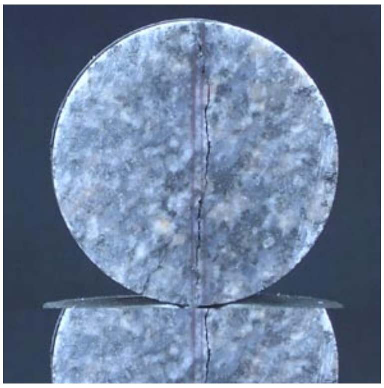
Comments: None

Specimen ID: KLX02-110-31

Before mechanical test



After mechanical test

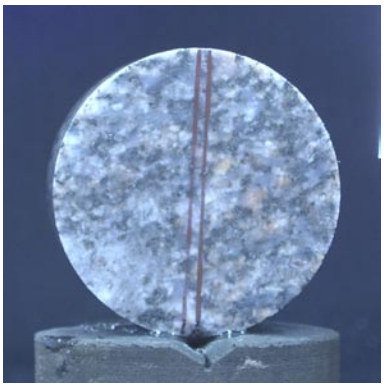


Diameter (mm)	Height (mm)	Density (kg/m^3)	Tensile strength (MPa)
47.5	26.0	2,690	11.2

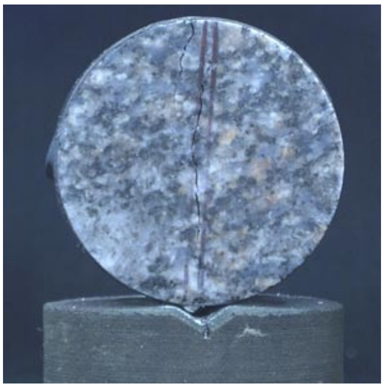
Comments: None

Specimen ID: KLX02-110-32

Before mechanical test



After mechanical test

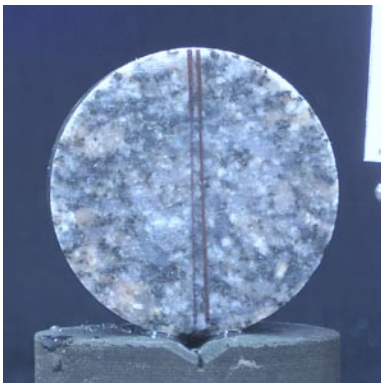


Diameter (mm)	**Height (mm)**	**Density (kg/m^3)**	**Tensile strength (MPa)**
47.5	26.1	2,690	12.8

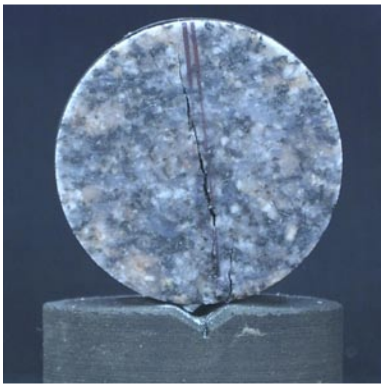
Comments: None

Specimen ID: KLX02-110-34

Before mechanical test



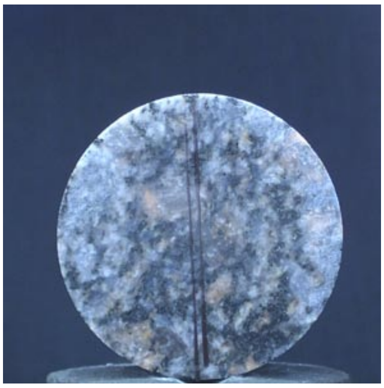
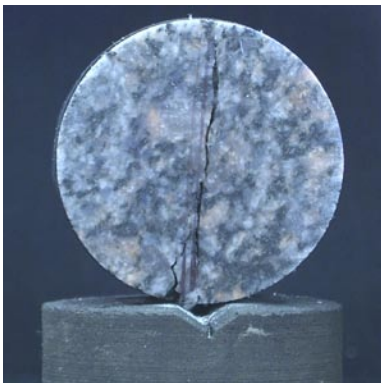
After mechanical test



Diameter (mm)	**Height (mm)**	**Density (kg/m^3)**	**Tensile strength (MPa)**
47.5	26.2	2,690	12.4

Comments: None

Specimen ID: KLX02-110-35

Before mechanical test	After mechanical test
	

Diameter (mm)	**Height (mm)**	**Density (kg/m^3)**	**Tensile strength (MPa)**
47.5	26.1	2,690	11.4

Comments: None

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 the depth, at which the specimens are taken, are shown in Figures 5-1 and 5-2.

Table 5-1. Summary of results.

Identification	Density (kg/m^3)	Tensile strength (MPa)	Comments, see section 5.1
KLX02-110-1	2,680	13.2	
KLX02-110-2	2,680	12.3	
KLX02-110-3	2,680	12.5	
KLX02-110-4	2,660	14.9	
KLX02-110-5	2,690	14.5	
KLX02-110-6	2,680	15.2	
KLX02-110-7	2,700	13.4	
KLX02-110-8	2,690	13.7	
KLX02-110-9	2,680	13.9	
KLX02-110-10	2,670	13.1	
KLX02-110-13	2,690	14.5	
KLX02-110-14	2,690	14.1	
KLX02-110-15	2,690	14.8	

Identification	Density (kg/m³)	Tensile strength (MPa)	Comments, see section 5.1
KLX02-110-16	2,690	15.5	
KLX02-110-17	2,690	16.4	
KLX02-110-18	2,690	14.0	
KLX02-110-19	2,690	13.6	
KLX02-110-20	2,680	13.3	
KLX02-110-21	2,690	14.2	
KLX02-110-22	2,690	11.5	
KLX02-110-25	2,680	13.8	
KLX02-110-26	2,680	14.6	
KLX02-110-27	2,670	14.2	
KLX02-110-28	2,690	11.6	
KLX02-110-29	2,690	12.3	
KLX02-110-30	2,690	10.4	
KLX02-110-31	2,690	11.2	
KLX02-110-32	2,690	12.8	
KLX02-110-34	2,690	12.4	
KLX02-110-35	2,690	11.4	

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 val Ävrö granite (312–318 m)	2,681	13.7
Mean val Ävrö granite (488–506 m)	2,689	14.2
Mean val Ävrö granite (743–746 m)	2,686	12.5
Mean val (All specimens)	2,885	13.4
Std dev Ävrö granite (312–318 m)	11.0	1.0
Std dev Ävrö granite (488–506 m)	3.2	1.3
Std dev Ävrö granite (743–746 m)	7.0	1.4
Std dev (All specimens)	8.2	1.4

5.3 Discussion

The testing was conducted according to the method description and the activity plan. Specimen KLX02-110-33 was replaced by specimen KLX02-110-35 as one small piece had been broken off from the cutting edge.

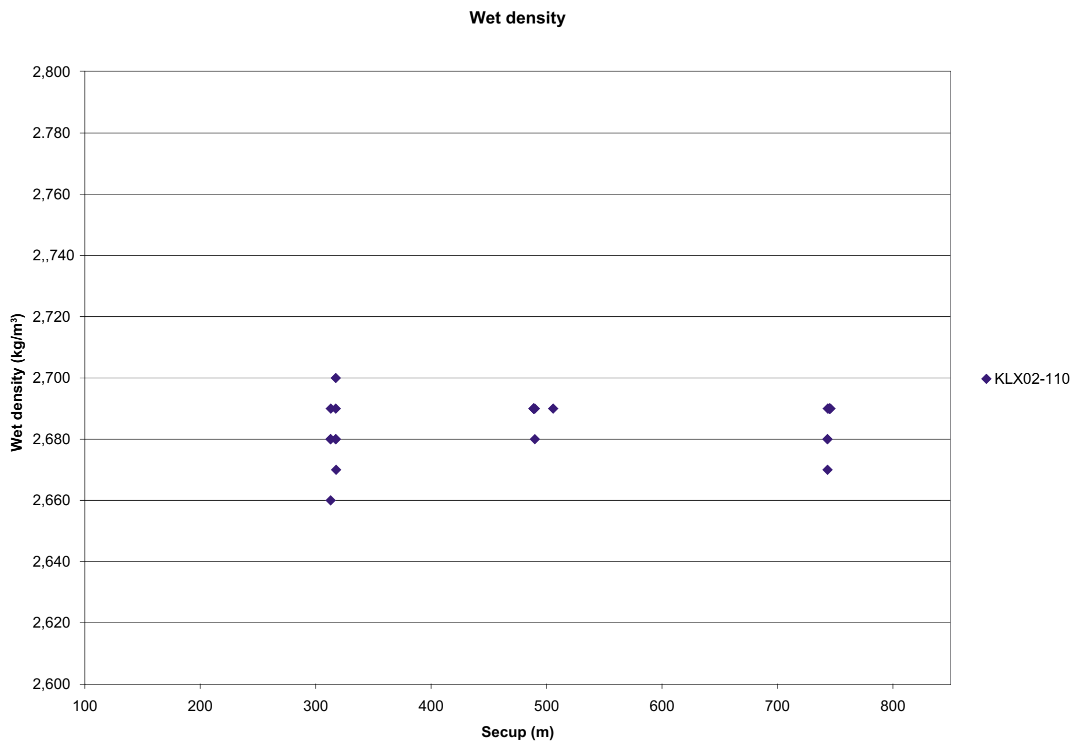


Figure 5-1. Density versus depth at which the specimens are taken in the borehole.

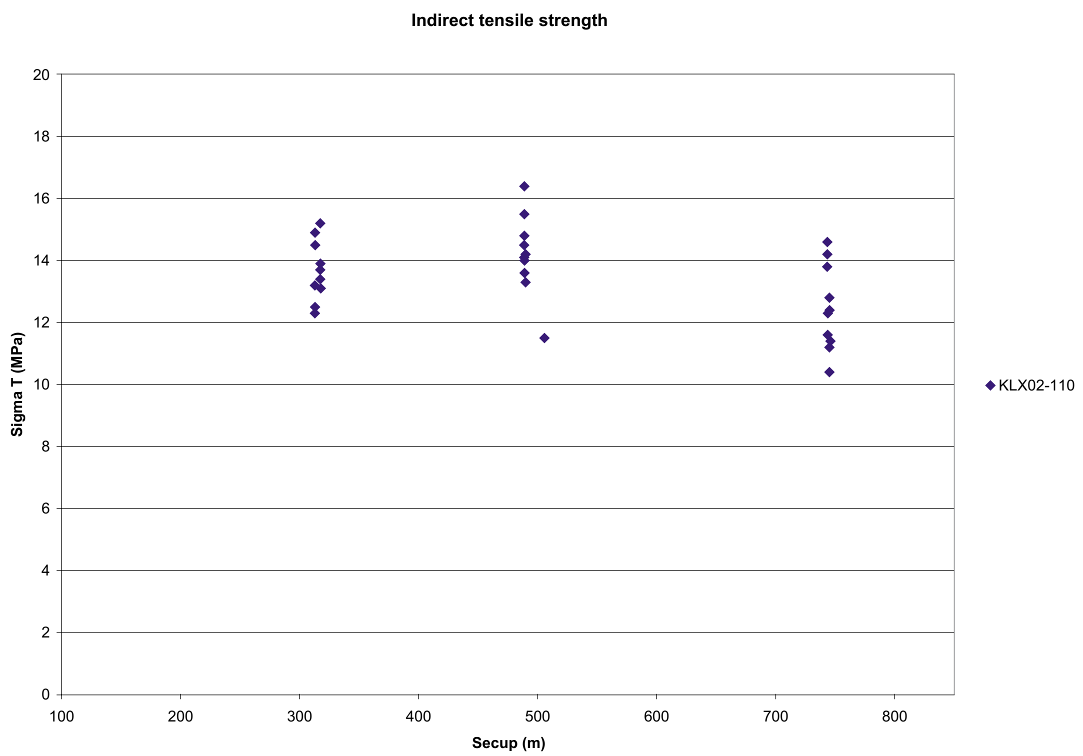


Figure 5-2. Tensile strength versus depth at which the specimens are taken in the borehole.

References

/1/ **ISRM, 1979.** Suggested Method for Determining Water Content, Porosity, Density, Absorption and Related Properties and Swelling and Slake-durability Index Properties. Int. J. Rock. Mech. Min. Sci. & Geomech. Abstr, 16(2), pp 141–156.

/2/ **SS-EN 13755.** Natural stone test methods – Determination of water absorption at atmospheric pressure.

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

/4/ **Stråhle A, 2001.** Definition och beskrivning av parametrar för geologisk, geofysisk och bergmekanisk kartering av berg. SKB R-01-19, Svensk Kärnbränslehantering AB. In Swedish.