Report

Brightwater
TREATMENT SYSTEM

Appendix 3F.4
Frozen Soil Testing

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King County
Department of Natural Resources and Parks
Wastewater Treatment Division

Brightwater Conveyance System
Ballinger Way Portal

Test Report

Laboratory investigations on soil samples in frozen condition

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Appendix 1 Overview of the received soil materials

1 GENERAL

1.1 Introduction

The Ballinger Way Portal (#5) will receive TBM's launched from Point Wells Portal and North Kenmore Portal. The finished inside diameter will be about 30 feet and the top of the invert slab will be at a depth of about 200 feet (elevation 206).

As one preliminary design concept ground freezing could be used for temporary support of Ballinger Way Portal. The system consists of a concrete slurry wall in the upper 50 feet of the excavation and frozen ground for the remainder of the excavation. All of the freeze pipes will be installed to a depth of about 235 to 255 feet.

The expected subsurface conditions are alternating sequences of sand, clay and silt from the surface down to approx. 260 feet.

For the purposes of this investigation, the soil behavior in frozen conditions is assumed to be consistent within each United Soil Classification System (USCS) classification. All samples were taken from boring P5-04, and are divided as follows:

- Layer ML: samples from 79.2 to 136.0 ft
- Layer SM: samples from 144.0 to 179.0 ft
- Layer CL: samples from 183.0 to 223.5 ft

1.2 Scope of work

In order to describe the stress and deformation behavior of the frozen soil the following tests were performed:

Uniaxial Compression Tests:	frozen (T = -10°C [14°F], T = -20°C [-4°F])
Triaxial Compression Tests:	frozen (T = -10°C [14°F])
Uniaxial Creep Tests:	frozen (T = -10°C [14°F])

For the classification of the soil material the testing includes the determination of:

grain size distribution
moisture contents and densities

To estimate the influence of salinity on the freezing temperature chemical investigations are proposed.

For the performance of the tests CDM Jessberger received undisturbed soil material from boring P5-04. Appendix 1 gives an overview of the soil material with the range of depth, specimen-No., the type of specimen and the conditions.

This report presents the results from CDM Jessberger's laboratory tests and the design parameters of frozen soil, which are estimated from the test results.

1.3 References and basis of information

The documents, data and other information which were used for this report are listed below. All documents, data and other information are numbered with an individual Reference No.:

[U1] North Creek Analytical Inc.: Results of chemical analyses, Seattle, January 2005

[U2] Vyalov, S.S.: The strength and creep of frozen soils and calculations for ice-soil retraining structures, Izdatel'stvo Akademii Nauk SSSr Moscow, 1962, USA CRREL Transl. 76, 1965

[U3] Ladanyi, B.: An engineering theory of creep of frozen soils. Can. Geotech. J., 1962, p. 63–80

[U4] Klein, J.: Nichtlineares Kriechen von künstlich gefrorenem Emschermergel. Schriftenreihe des Instituts für Grundbau, Wasserwesen und Verkehrswesen, Ruhr-Universität Bochum, Serie Grundbau, Heft 2, 1978

[U5] Odquist, F.K.G, Hult, J.: Kriechfestigkeit metallischer Werkstoffe, New York/Heidelberg/Berlin, Springer Verlag, 1962

[U6] Johansen, O., Frivik, P.E.: Thermal properties of soils and rock material. Reprint 2. ISGF 1980, Trondheim, S. 427 – 453

[U7] Naval Facilities Engineering Command: Soil Mechanics, 1986

1.4 Limitations

Our professional services were performed using a degree of care and skill ordinarily exercised, under similar circumstances, by reputable engineers and technicians practicing in the geotechnical fields in this or similar localities at this time. The laboratory tests were performed according to German "DIN-Norm" and recommendations of the International Symposium on Ground Freezing Working Group 2 (ISGF WG 2). No other warranty, expressed or implied, is made as to the professional advice included in this report. Although the King County WTD may share this report with other parties, this report has been prepared for the King County WTD to be used solely for their use and evaluation of this project.

The laboratory test results and design parameters are based on the soil samples that were delivered to CDM Jessberger. If subsurface conditions, data or other information are found to be different than presented in the report, the results contained in this report should be reevaluated by CDM Jessberger and confirmed in writing.

2 INVESTIGATIONS

2.1 General

In general our investigations are concentrated on:

index properties of the unfrozen material
strength and deformation behavior of the frozen material
chemical analysis to estimate the influence of salinity on the freezing temperature.

The tests concerning the stress-strain behavior of frozen material were mainly performed at a temperature of T = -10 °C (14°F). Only the uniaxial compression tests were performed at temperatures of T = -10 °C (14°F) and T = -20 °C (-4°F).

CDM Jessberger received soil samples of undisturbed material in tubes with a diameter of approx. 8.5 cm (3.3 in). Soil specimens with a diameter of 5 cm (2.0 in) are needed for the triaxial compression tests. The specimens were trimmed out of the undisturbed samples to a diameter of approx. 5 cm (2.0 in) and a height of approx. 11 cm (4.3 in).

Undisturbed samples were prepared in the following manner: The samples were carefully pushed out of the tubes in unfrozen condition and cut into pieces of approx. 15 to 18 cm (5.9 to 7.1 in) length. Then the specimens were covered with a plastic membrane and evacuated for storage in the cold room at the chosen test temperature.

Remolded samples were prepared by filling a steel cylinder with a diameter of 5 or 10 cm (2.0 or 3.9 in) with the soil and compacting it to the appropriate density. The appropriate density was chosen based on density tests conducted on undisturbed samples within the same soil layer. The specimens are frozen in the steel cylinder and pushed out in frozen condition.

The tests for the investigation of the stress-strain and the creep behavior are performed using enlarged and lubricated endplates in order to achieve uniform loading of the specimens.

The moisture content of each specimen is determined after completion of the strength test. This data is used to interpret the test results.

2.2 Determination of the physical soil parameters

2.2.1 Grain size distribution

Depending on the fines content (percentage of soil particles with $d < 0.063$ mm), the grain size distribution curve is determined by the sieving method, the hydrometer method or a combination of both methods. Soils with a low fines content is tested by sieving the dry material only. Soils with a high fines content are tested by the hydrometer method only. Soils that contain a significant content of grains larger and smaller than 0.063 mm are tested by a combination of the sieving and hydrometer methods.

The tests are performed in general accordance with DIN 18123. The result is plotted as a grain size distribution curve on a semilogarithmic scale. Attachments 1.1, 2.1 and 3.1 contain the content of the four main soil groups clay, silt, sand and gravel of the tested soil materials.

2.2.2 Moisture content and density

The moist and dry density and the moisture content are determined for each specimen.

The moisture content w is determined by drying at a temperature of 105 °C (221°F) according to DIN 18121.

The density ρ is the relation between weight m and volume V of the specimen:

$$\rho = \frac{m}{V}$$

In combination with the moisture content w the dry density ρ_d follows:

$$\rho_d = \frac{\rho}{1 + w}$$

The specific gravity ρ_S is determined by using a pycnometer according to DIN 18124.
It is the relation between dry weight m_d and volume V_S of the solid particles:

$$\rho_S = \frac{m_d}{V_S}$$

The porosity n is evaluated using the values of density, specific gravity and moisture content:

$$n = 1 - \frac{\rho}{\rho_s(1+w)} = 1 - \frac{\rho_d}{\rho_s}$$

The pore volume is used to determine the soil density under natural conditions.

The degree of water saturation S_r is expressed by the equation:

$$S_r = \frac{\rho_d \cdot w}{\rho_w \cdot n}$$

All parameters are listed in Attachment 1.1, 2.1 and 3.1, columns 11 to 16.

2.3 Salinity

The salinity of the groundwater is evaluated by chemical analysis of the amount of the cations sodium, potassium, calcium and magnesium and of the anions chloride, sulfate and hydrocarbonate. Based on the ion concentration, the salt compounds can be calculated and subsequently the content of water-soluble salts in the soil sample can be determined.

Salinity depends on many factors, and the evaluation of the salt formation based on ion concentration is only an approximation. The estimation of the sequence of salt formation is based on different criteria like solubility of the salts and the amount of the salts related to the total salt content. The recrystallizing salt compounds which are found if the solvent water is evaporated out of a brine, are evaluated based on the sequence of its solubility and according to the method of Palmer. Palmer assumes, that the geohydrochemical characteristics of waters are defined by the salinity (e.g. Cl, SO_4, HCO_3) and the alkalinity (Na, K, Ca, Mg).

Double salts which may be formed are not taken into account in the calculation. The chosen sequences of salt compounds are listed in Attachment 4.

2.4 Frozen soil behavior

Freezing will change the thermal and the strength properties of the soil. The thermal characteristics are important for the thermal analysis to predict the required freeze time and the freeze plant capacity.

The knowledge of the strength and deformation properties of frozen soils is basic to the structural design of frozen soil support structures, which are time- and temperature-dependent. In some cases, the complete stress-strain history, starting from its initial loading, should be taken into consideration.

The behavior of frozen soil under quasi-static loading usually differs significantly from that of unfrozen soil due to the presence of ice and unfrozen water films. Frozen soils are sensitive to creep and relaxation effects and their behavior is strongly affected by temperature changes.

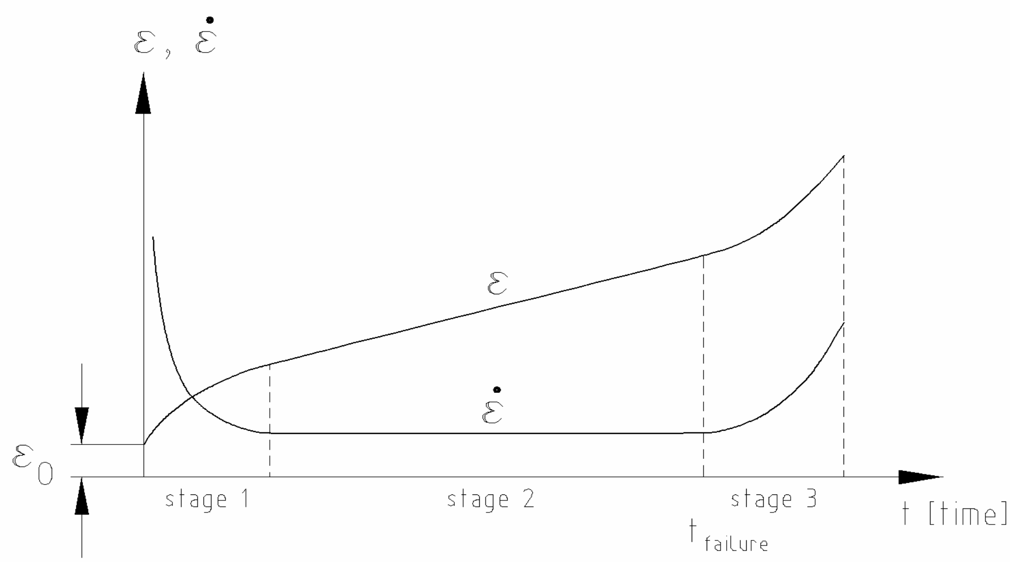


Figure 1: Typical Creep Curve of a Frozen Soil

As with unfrozen soils, the strength of frozen soils depends on inter-particle friction, particle interlocking, and cohesion. In frozen soils, however, the bonding of particles by ice is the major stabilizing factor. The recrystallization of the ice under pressure is especially important in this context. Pressure melting of ice can occur at the contact surfaces in the frozen soil, which increases the amount of unfrozen water, and the water flows to regions of lower stress where it refreezes. The visco-elastic behavior of ice is dependent on many factors, such as temperature, pressure, strain rate, crystal orientation, and density.

Fig. 1 shows a typical idealized creep curve and its corresponding strain rate in a strain/strain rate - time diagram, assuming constant stress and isothermal conditions. Three distinct phases or stages of creep are usually evident. After an instantaneous strain ε_0, the primary phase (or stage 1) is characterized by a strengthening factor with a continuously decreasing strain rate, $\dot{\varepsilon}$. The secondary or steady-state creep phase or stage 2 is characterized by a constant creep rate, which is the minimum rate reached during the test. Finally, the tertiary phase or stage 3 is characterized by an accelerated creep rate, which leads to ultimate failure of the specimen.

2.4.1 Uniaxial strength and Young's modulus

The parameters for the description of the strength properties and the deformation behavior of frozen soils are obtained from laboratory tests. The tests were performed carefully in such a way so that the stress and temperature conditions expected during execution in the field were simulated as closely as possible.

The uniaxial compressive strength was determined with a strain rate of $\dot{\varepsilon}_1$ = 1 %/min and is considered the short-term compressive strength of the frozen soil. The tests were performed in a cold room with temperatures of T = -10 °C (14°F) and T = -20 °C (-4°F), respectively. The test machine is a servo-hydraulic system with a maximum capacity of 700 kN (157 kip) and load cells from 5 to 700 kN (1.1 to 157 kip). During the test, the load and vertical deformation of the specimen is measured and recorded by a data acquisition system, which is used for the evaluation of the test results as well.

The result of the uniaxial compression tests is a stress-strain relationship. The uniaxial compressive strength (q_f) is defined as the peak point of the $\sigma_1 - \varepsilon_1$ - curve, i. e., the uniaxial compressive strength equals the axial stress at failure ($q_f = \sigma_c$ at failure).

The uniaxial compressive strength (q_f) of frozen soil is an important value for the structural design as well as for the evaluation of the material in connection with Young's modulus of elasticity (E). For deformation calculations, a representative Young's modulus must be chosen, which typically is defined as:

$$E_{50} = \frac{q_{f50}}{\varepsilon_{f50}}$$

Where

q_{f50} : 50 % of the uniaxial failure stress (peak compressive strength)

ε_{f50} : strain at 50 % of the uniaxial failure stress (peak compressive strength)

Young's modulus of elasticity is calculated based on the uniaxial compression test. The Young's modulus of elasticity E_v represents an initial tangent modulus E_T, which is evaluated by passing a tangent on the σ_1/ε - curve. The advantage of this method is that deformations at the beginning of the test caused by different condition at the bottom and top of each single specimen are not taken into consideration.

The σ_1/ε - curves and the chosen tangents are presented in the Attachments.

2.4.2 Creep behavior

The distinct non-linear stress-strain behavior of frozen soil can be explicitly expressed in a formula. The power law equation developed by *Vyalov* [U2] and its modifications by *Ladanyi* [U3] and *Klein* [U4] are suitable to describe the creep behavior of frozen soil obtained by laboratory testing.

Analogous to the concept of *Odquist* and *Hult* [U5], L*adanyi* [U3] presented a constitutive power law equation for the creep behavior of frozen soils using a straight- line approximation for the first two creep phases (stages 1 and 2 in Fig. 1):

$$\varepsilon = \frac{\sigma}{E} + \varepsilon_k \cdot \left(\frac{\sigma}{\sigma_k}\right)^k + \dot{\varepsilon}_c \cdot \left(\frac{\sigma}{\sigma_c}\right)^n \cdot t$$

The first term of the equation represents the instantaneous strain containing an elastic and sometimes a plastic strain portion. The second term expresses the time-dependent plastic deformation of the primary creep phase (stage 1 in Fig. 1). The third term describes the plastic deformation of the secondary creep phase (stage 2 in Fig. 1) characterized by a constant creep rate. All of the experimental parameters of this equation can be determined by plotting the creep test results in appropriate log-log plots.

Klein [U5] describes the creep behavior of frozen soils with the following power law equation:

$$\varepsilon = \frac{\sigma_1}{E_0} + A \cdot \sigma_1^{B} \cdot t^{C}$$

where

A, B, C	:	creep test parameters
E_0	:	initial Young's modulus
σ_1	:	constant axial stress
t	:	time

The time-dependent compressive strength q_f *(t)* can also be approximated using the creep parameters A, B, C. Hereby, it is assumed that the strain of frozen soil at failure is more or less independent of the amount of stress applied. In a constant-stress creep test, the strain at failure (ε_f) is defined as the strain which exists at time (t_f) when the creep curve turns from the secondary creep phase (stage 2), which has an almost constant creep rate, into the tertiary creep phase (stage 3), which has a progressively increasing creep rate.

Creep parameters A, B, C are determined using uniaxial creep tests. In uniaxial creep tests, the samples are loaded with specified percentages of the uniaxial short-term compressive strength (peak compressive strength). The International Symposium on Ground Freezing Working Group 2 (ISGF WG 2) recommends creep stresses between 10 % and 70 % of the short-term compressive strength. The creep tests performed for this project were completed at stresses between 25 and 70% of the short-term compressive strength.

The creep tests were performed at a temperature of -10 °C (14°F). The specimens were placed in a creep test device in a cold room which is kept at the temperature of -10 °C (14°F). Four creep tests with a constant axial load were performed for each test series. During the creep tests the axial load is adjusted taking to account for the enlargement of the cross section of the specimen caused by the creep process. The test period takes about 90 hours. Depending on the axial load and the properties of the soil material failure may occur earlier. By plotting the deformation over time the creep curve is given.

In the creep equation, A is a temperature dependent modulus of viscosity. B and C are dimensionless creep parameters of non-linearity and time hardening, respectively. If C = 1 stationary creep takes place, whereas with C < 1 instationary creep is existing, which is significant for time hardening material. For soils with internal friction, the creep parameter A is dependent on the hydrostatic stress field. The creep parameters A, B and C are determined by a curve fitting procedure based on the creep tests.

The creep curves of the test series and the theoretical creep curves, shown as dotted lines, are given as ε/t-diagrams in the Attachments.

2.4.3 Triaxial compressive strength

The shear strength parameters were determined using the results of triaxial compression tests. The samples were consolidated in a triaxial cell for 48 hours at a temperature of -10 °C (14°F). The samples were then compressed at an axial strain rate of 0.1 %/min, which is 10 % of the rate for the uniaxial compression tests. Each test series includes 4 single tests with cell pressures between σ_3 = 0 and 2.0 MN/m² (0 and 41.8 ksf).

In a triaxial compression test of frozen material, no porewater pressure is measured during the test. Therefore the mean stress p and the deviatoric stress q are given as p = (σ_1 + σ_3) /2 and q = (σ_1 - σ_3) /2, i.e., a total stress path.

The shear strength parameters φ and c are calculated from the parameters α (slope) and b (q-axis intercept), assuming a linear failure condition in the p/q - diagram.

φ = arc sin (tan α)
c = b / cos φ

The p/q - diagram is plotted for each test series and shown in the Attachments.

3 TEST RESULTS OF THE SOIL IN UNFROZEN CONDITIONS

3.1 Grain size distribution

Grain size distribution tests were performed to classify the soil layers. The grain size curves for each layer are given in Attachments 1.2, 2.2 and 3.2 for the ML, SM, and CL soils, respectively.

Layer ML

According to the results of the 2 grain size distributions, the layer ML can be described as a slightly clayey to clayey SILT with trace sand. The amount of silt ranges from 74.8 to 86.8 %,clay from 9.6 to 25.1 %, and sand from 0.2 to 1.6 %.

Layer SM

According to the results of the 2 grain size distributions, the layer SM can be classified as a silty, gravelly SAND with trace clay. The amount of clay ranges from 3.8 to 5.0 %, silt from 25.7 to 27.2 %, sand from 40.9 to 43.3 %, and gravel from 26.9 to 27.2 %.

Layer CL

The 2 grain size curves of this soil layer show that the grain size distribution of the tested material is not consistent with the USCS classification. The amount of clay ranges from 7.9 to 14.1 %, silt from 51.5 to 53.7 %, sand from 17.6 to 29.8 %, and gravel from 4.5 to 20.8 %. However, the soil can be classified as a slightly gravelly to gravelly, sandy, silty CLAY based on its plasticity characteristics, as defined in DIN 18196.

3.2 Moisture content and density

A summary of the densities, moisture content, porosity and water saturation is presented for each single layer in the respective tables of the Attachments.

4 SALINITY OF GROUNDWATER

The salinity has an important influence on the frozen soil properties. Salinity in pore water initiates a reduction of the freeze point. Lowering the freezing point influences the strength properties of frozen soil, which depend on the freezing of the water in the soil pores. The geohydrochemical characteristics of water are defined by the salinity (e. g. Cl, SO_4, HCO_3) and the alkalinity (Na, K, Ca, Mg). The content of the salt as NaCl has the largest influence on the reduction of the freezing point and the strength properties of the frozen soil.

The chemical analysis of the groundwater sample, which were performed by North Creek Analytical Inc. [U1] is summarized in Attachment 4.

The content of the salt as NaCl was determined to be 0.01 g/l and the total salt content was determined to be 0.11 g/l. Based on the results and experiences of other projects, no impact on the freezing temperature can be expected due to salinity.

5 TEST RESULTS OF THE SOIL IN FROZEN CONDITIONS

5.1 Uniaxial compressive strength

The strength of the frozen material was determined from the results of uniaxial compression tests (UCT) at temperatures of T = -10 °C (14°F) and -20 °C (-4°F). In the following sections, the results for each soil layer are presented and discussed.

Layer ML
The uniaxial compression tests of this soil type were only performed on undisturbed specimens. The dry density of the undisturbed specimens lies between ρ_d = 1.34 and 1.48 t/m³ (83.6 and 92.4 pcf).

The σ_1/ε_1-plots of each single test are presented in Attachments 1.3.1 through 1.3.8. A summary of the results is listed in table 1.

Table 1: Results of the UCT at T = -10 °C (14°F) and T = -20 °C (-4°F) for Layer ML

Specimen-No.	Depth [ft BGS]	Type	Temperature [°C]	Dry density ρ_d [t/m³]	Water saturation S_r [-]	Uniaxial Compressive strength q [MN/m²]	Deformation at failure ε [%]	Tangent Modulus E_T [MN/m²]
16571-01	79.2 to 80.2	Undisturbed	-10	1.46	0.94	5.4	15.7	400
16571-02	93.7 to 94.7	Undisturbed	-10	1.43	0.98	6.2	18.7	1088
16571-03	134.0 to 135.0	Undisturbed	-10	1.39	0.89	5.8	11.9	652
16571-16	94.7 to 95.7	Undisturbed	-10	1.40	0.88	5.7	11.4	417
16571-11	79.2 to 80.2	Undisturbed	-20	1.48	0.94	7.8	15.3	716
16571-12	80.2 to 81.2	Undisturbed	-20	1.40	0.81	7.8	13.8	472
16571-14	135.0 to 136.0	Undisturbed	-20	1.41	0.89	8.2	18.0	558
16571-15	100.8 to 101.8	Undisturbed	-20	1.34	0.86	8.0	19.3	967

The uniaxial compressive strength at T = -10 °C (14°F) varies from 5.4 to 6.2 MN/m² (113 to 129 ksf) with an average value of 5.8 MN/m² (121 ksf). At T = -20 °C (-4°F), the uniaxial compressive strength varies from 7.8 to 8.2 MN/m² (163 to 171 ksf), with an average value of 8.0 MN/m² (167 ksf).

The tangent modulus E_T varies from 400 to 1088 MN/m² (8,400 to 23,000 ksf) at T = -10 °C (14°F) and from 472 to 967 MN/m² (9,900 to 20,000 ksf) at T = -20 °C (-4°F).

Layer SM

For this layer, undisturbed specimens as well as one remolded specimen were tested. The remolded specimen was compacted to approximately the dry density of the undisturbed specimens, which lies between 1.81 and 2.02 t/m³ (113.0 and 126.1 pcf).

The σ_1/ε_1-plots of each test are presented in Attachments 2.3.1 to 2.3.8. A summary of the results is listed in table 2.

Table 2: Results of the UCT at T = -10 °C (14°F) and T = -20 °C (-4°F) for Layer SM

Specimen-No.	Depth [ft BGS]	Type	Temperature [°C]	Dry density ρ_d [t/m³]	Water saturation S_r [-]	Uniaxial Compressive strength Q [MN/m²]	Deformation at failure ε [%]	Tangent Modulus E_T [MN/m²]
16572-01	154.0 to 155.0	Undisturbed	-10	2.02	0.92	6.0	6.0	341
16572-02	155.0 to 156.0	Undisturbed	-10	1.96	0.76	6.2	4.1	379
16572-03	174.0 to 175.0	Undisturbed	-10	1.97	0.82	5.5	4.8	307
16572-09	178.0 to 179.0	Undisturbed	-10	2.00	0.85	5.2	3.9	527
16572-08	145.0 to 146.0	Undisturbed	-20	1.91	1.04	9.3	6.4	706
16572-10	175.0 to 176.0	Undisturbed	-20	1.81	0.98	11.1	8.9	1230
16572-11	144.0 to 145.0	Undisturbed	-20	1.91	1.05	7.1	6.9	813
16572-12	166.0 to 168.5	Remolded	-20	1.96	0.83	9.3	7.2	619

The uniaxial compressive strength at T = -10 °C (14°F) varies from 5.2 to 6.2 MN/m² (109 to 129 ksf), with an average value of 5.9 MN/m² (123 ksf). At T = -20 °C (-4°F), the uniaxial compressive strength varies from 7.1 to 11.1 MN/m² (148 to 232 ksf), with an average value of 9.3 MN/m² (194 ksf).

The tangent modulus E_T varies from 307 to 527 MN/m² (6,400 to 11,000 ksf) at T = -10 °C (14°F) and from 619 to 1,230 MN/m² (13,000 to 26,000 ksf) at T = -20 °C (-4°F).

Layer CL

The uniaxial compression tests of this soil type were only performed on undisturbed specimens. The σ_1/ε_1-plots of each single test are presented in Attachments 3.3.1 through 3.3.8. A summary of the results is listed in table 3.

Table 3: Results of the UCT at T = -10 °C (14°F) and T = -20 °C (-4°F) for Layer CL

Specimen-No.	Depth [ft BGS]	Type	Temperature [°C]	Dry density ρ_d [t/m³]	Water saturation S_r [-]	Uniaxial Compressive strength q [MN/m²]	Deformation at failure ε [%]	Tangent Modulus E_T [MN/m²]
16573-01	194.1 to 195.1	Undisturbed	-10	1.59	0.95	7.4	8.5	601
16573-02	200.7 to 201.7	Undisturbed	-10	1.54	0.98	4.2	7.5	347
16573-07	204.1 to 205.1	Undisturbed	-10	1.52	0.93	4.1	12.5	311
16573-09	222.5 to 223.5	Undisturbed	-10	1.58	1.04	3.9	4.5	328
16573-14	183.0 to 184.0	Undisturbed	-20	1.68	10.96	4.9	1.6	580
16573-15	183.0 to 184.0	Undisturbed	-20	1.69	0.96	3.7	1.1	725
16573-16	195.1 to 196.1	Undisturbed	-20	1.62	1.05	6.6	4.7	682
16573-17	205.7 to 206.7	Undisturbed	-20	1.46	0.91	6.9	5.3	850

The uniaxial compressive strength at T = -10 °C (14°F) varies from 3.9 to 7.2 MN/m² (81 to 150 ksf). Specimen 16573-01 contains a higher content of coarse gravel than the other specimens (more than 50 %) and has been ignored. Thus, the average value of the uniaxial compressive strength at T = -10 °C (14°F) is determined to be 4.1 MN/m² (86 ksf). At T = -20 °C (-4°F), the uniaxial compressive strength varies from 3.7 to 6.9 MN/m² (77 to 144 ksf). Slickensides were noted in the two samples exhibiting low deformation values at failure, and have been ignored. Thus, the average value of the uniaxial compressive strength at T = -20 °C (-4°F) is determined to be 6.8 MN/m² (142 ksf).

The tangent modulus E_T ranges from 311 to 347 MN/m² (6500 to 7200 ksf) at T = -10 °C (14°F) and from 682 to 850 MN/m² (14000 and 18000 ksf) at T = -20 °C (-4°F).

5.2 Uniaxial creep parameters

The uniaxial creep tests were performed at a temperature of T = -10 °C (14°F) under a constant axial load equivalent to values between 25 and 70 % of the short-term uniaxial compressive strength.

Uniaxial creep tests were conducted on undisturbed specimens for the layers ML and CL and remolded specimens for the layer SM.

The vertical deformation is plotted versus time. The creep curves of the specimens are presented in the Attachments.

The creep parameters A, B and C have been determined by fitting the measured curves to the following equation:

$\varepsilon = \varepsilon_0 + A \cdot \sigma^B \cdot t^c$.

After determination of these parameters, theoretical creep curves were plotted as dotted lines together with the measured creep curves.

Assuming that only the creep parameter A is affected by temperature changes, the creep behavior at a temperature of T = -20 °C can be estimated using a constant creep parameter B and C and a modified creep parameter A. The creep parameter A at -20 °C was estimated based on the measured creep parameter at -10 °C (14°F) and the uniaxial compressive strength at both -10 °C (14°F) and -20 °C (-4°F) by using the following equation:

$A (T = -20\ °C) = A (T = -10\ °C) \cdot (q_{f10} / q_{f20})^B$

q_{f10}: uniaxial compressive strength at -10 °C (14°F)
q_{f20}: uniaxial compressive strength at -20 °C (-4°F)

5.3 Triaxial compressive strength

Triaxial compression tests in frozen conditions at a temperature of - 10 °C were performed for the layers ML and CL.

The triaxial compression tests in the layer ML were performed on undisturbed samples. The shear strength parameters of this soil type are listed in table 4. The (σ_1-σ_3/ε) - plots and p/q - diagram are presented in Attachment 1.4.Cohesion (c') and effective friction angle (φ') were determined based on the entire test series. The dry density of the tested specimens lies between ρ_d = 1.35 and 1.47 t/m³ (84.3 and 91.8 pcf).

<u>Table 4</u>: Results of the triaxial compression tests at T = -10 °C (14°F) for Layer ML

Specimen-No.	Depth	Temperature	Dry density	cell pressure	Stress at failure	effective stresses	
			ρ_d	σ_3	σ_1-σ_3	c'	φ'
[-]	[ft BGS]	[°C]	[t/m³]	[MN/m²]	[MN/m²]	[MN/m²]	[°]
16571-04	123.7 to 124.7	-10	1.45	1.0	6.0	1.3	27.8
16571-05	118.0 to 119.0	-10	1.35	0.0	4.3	1.3	27.8
16571-06	124.7 to 125.7	-10	1.47	2.0	7.3	1.3	27.8
16571-07	134.0 to 135.0	-10	1.46	0.5	5.2	1.3	27.8

Triaxial compression tests in the layer CL were performed on undisturbed and remolded specimens. The shear strength parameters of this soil type are listed in table 5. The (σ_1-σ_3/ε) - plots and p/q - diagram are presented in Attachment 3.4. Cohesion (c') and effective friction angle (φ') were determined based on the entire test series.

<u>Table 5</u>: Results of the triaxial compression tests at T = -10 °C (14°F) for Layer CL

Specimen-No.	Depth	Temperature	Dry density	cell pressure	Stress at failure	effective stresses	
			ρ_d	σ_3	σ_1-σ_3	c'	φ'
[-]	[ft BGS]	[°C]	[t/m³]	[MN/m²]	[MN/m²]	[MN/m²]	[°]
16573-08	213.7 to 214.7	-10	1.53	0.5	4.8	1.33	25.1
16573-10	183.0 to 223.5	-10	1.61	0.0	4.2	1.33	25.1
16573-11	183.0 to 223.5	-10	1.57	1.0	5.1	1.33	25.1
16573-13	183.0 to 223.5	-10	1.60	2.0	7.1	1.33	25.1

According to the values of the literature the internal friction angle in unfrozen conditions for ML soils lies between φ' = 25 to 30° and for CL soils between φ' = 20 to 25°. A high content of gravel leads to higher internal friction angle.

Assuming that these soils are typical of their USCS classifications, the test results show that the internal friction angle of the material does not significantly change in frozen conditions.

6 FROZEN DESIGN PARAMETERS

6.1 Thermal frozen soil design parameters

Freezing will change the thermal as well as the strength properties of the soil. The thermal characteristics are important in thermal analyses to predict the required freeze time and the freeze plant capacity.

Frozen soil is not a homogeneous material, but a multi-phase system. Its thermal properties vary with its particulates and its composition. The water-ice phase composition of the soil will vary with particle mineral composition, specific surface area of particles, presence of solutes, and temperature. Soil pores contain free and bound water that freezes at different temperatures.

Each mathematical model for conductive heat transfer in soil requires various input data, geometry of the system, thermal boundary conditions, and soil characteristics. Apart from physical soil properties such as dry density, moisture content, and degree of saturation, the thermal soil properties such as heat capacity and thermal conductivity are equally important.

The heat capacity of a multi-phase soil system can determined as the weighted arithmetic mean of each individual soil component.

Volumetric heat capacity of unfrozen soil:

$$c_{vu} = \rho_d \cdot (c_{ms} + c_{mw} \cdot \frac{w}{100})$$

Volumetric heat capacity of frozen soil:

$$c_{vf} = \rho_d \cdot (c_{ms} + c_{mi} \cdot \frac{w}{100})$$

If the unfrozen water content (w_u) is considered, the volumetric heat capacity of the frozen soil can be determined as follows:

$$c_{vf} = \rho_d \cdot (c_{ms} + c_{mw} \cdot \frac{w_u}{100} + c_{mi} \cdot \frac{(w - w_u)}{100})$$

where

c_v : volumetric heat capacity [kJ/m³·K or BTU/ft³°F]
ρ_d : dry density [kg/m³]
c_{ms} : specific heat capacity of solids 0.7 – 0.84 J/kg (3.0×10^{-4} – 3.6×10^{-4} BTU/lb)
c_{mw} : specific heat capacity of water 4.2 J/kg (1.8×10^{-3} BTU/lb)
c_{mi} : specific heat capacity of ice 2.1 J/kg (9.0×10^{-4} BTU/lb)
w : moisture content (dry weight basis)
w_u : unfrozen water content

The thermal conductivity of the unfrozen and frozen soil can be determined by laboratory tests. Comparison of test results with thermal conductivity values determined by Johansen's method showed good agreement. Because of this, the thermal soil parameters were calculated using the method of Johansen [U6].

Johansen's equations are based on geomechanical soil parameters. The required input data were taken from the soil parameters which have been determined by the CDM testing program (dry density, moisture content, grain size distribution), assuming that the soil is fully saturated (Sr = 1.0) with water below the groundwater table.

The input data and the range of calculated thermal parameters are summarized in Attachment 5.

6.2 Structural frozen soil design parameters

The design parameters were determined based on the laboratory test results and experience with similar projects in similar soil types.

The uniaxial compressive strength q_f represents the short-term behavior (the tests are performed under a constant axial strain rate of $\dot{\varepsilon}$ = 1%/min – See Seite 13/26, Section 2.4.1) and therefore have to be regarded as index values. Creep of the frozen soil causes the strength and stiffness of the frozen soil to decrease with time depending on the magnitude of the load.

The long-term strength $q_{f(t)}$ and the time-dependent Young's modulus of elasticity $E_{(t)}$ can be determined using the creep equation

$$\varepsilon = \varepsilon_0 + A \cdot \sigma^{B} \cdot t^{C}$$

taking into account the elastic part of the strain ε_0. To estimate the long-term compressive strength $q_f(t)$, the strain at failure ε is taken from the results of the uniaxial compressive strength and creep tests and/or the experience and judgement based on test results of comparable frozen soils of other projects.

The time-dependent Young's modulus of elasticity is dependent on the compressive stress $\sigma_P(t)$ for the evaluated time period.

The creep parameters for the temperature T = -20 °C were estimated from the creep parameter at T = -10 °C (14°F) and the temperature dependence of the uniaxial compressive strength as shown in Section 5.2.

The design values of allowable stresses, Young's modulus of elasticity and shear parameters are presented for a free standing time varying from 1 week up to 15 months. The allowable stresses $\sigma_P(t)$ listed in Attachment 6.1 include a safety factor of 2. The allowable tensile stresses $\sigma_T(t)$ can be estimated from the allowable compressive strength $\sigma_P(t)$ through the following relationship:

$$\sigma_T(t) = 0.2 \cdot \sigma_P(t)$$

The friction angle φ_f is taken from the test results at the temperature of T = -10 °C (14°F) and the cohesion $c_f(t)$ is calculated by relating the Mohr-Coulomb parameter to the allowable compressive strength $\sigma_D(t)$. For the layer SM the friction angle φ_f was estimated based on experiences with similiar soils.

In general, CDM Jessberger prefers to apply the safety factor directly to the uniaxial compressive strength and therefore on cohesion, as this design is conservative in most cases compared to the safety design of partial safety factors, which can be used instead. For cases where partial safety factors will be used, the time-dependent structural soil parameters at failure are also listed in Attachment 6.2 without a safety factor applied.

Laboratory test results: Layer ML

project: Brightwater Conveyance System

																T= -10						T= -20
		specimen no.		classification	grain size distribution					density			water saturation	moisture content	porosity							
boring no.	depth		Layer		clay	silt	sand	gravel	stones	specific gravity	wet soil	dry soil				UCS_{f10}	TCT_{f10}		UCT_{f10}			UCS_{f20}
					<0,002 mm	0,002 to 0,063 mm	0,063 to 2,0 mm	2,0 to 63 mm	> 63 mm	ρ_s	ρ	ρ_d	S_r	w	n	q_{f10}	φ_{f10}	c_{f10}	A	B	C	q_{f20}
	FT BGS						%			t/m³	t/m³	t/m³		%		MN/m²	°	MN/m²	$(m^2/MN)^2xh^{-c}$			MN/m²
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
P5-04	94,7 -95,7	16571-01	ML							2,68	1,89	1,46	0,94	29,4	0,46	5,4						
P5-04	93,7-94,7	16571-02	ML	clayey SILT	25,1	74,8	0,2			2,68	1,89	1,43	0,98	32,0	0,47	6,2						
P5-04	134,0-135,0	16571-03	ML							2,68	1,82	1,39	0,89	30,7	0,48	5,8						
P5-04	94,7 -95,7	16571-16	ML							2,68	1,82	1,40	0,88	30,1	0,48	5,7						
P5-04	123,7-124,7	16571-04	ML							2,68	1,87	1,45	0,92	29,1	0,46		27,8	1,3				
P5-04	118,0-119,00	16571-05	ML							2,68	1,81	1,35	0,92	34,0	0,50		27,8	1,3				
P5-04	124,7-125,7	16571-06	ML							2,68	1,90	1,47	0,96	29,4	0,45		27,8	1,3				
P5-04	134,0-135,0	16571-07	ML	slightly sandy, slightly clayey SILT	9,6	86,8	3,5	0,1		2,68	1,89	1,46	0,93	29,1	0,46		27,8	1,3				

Laboratory test results: Layer ML

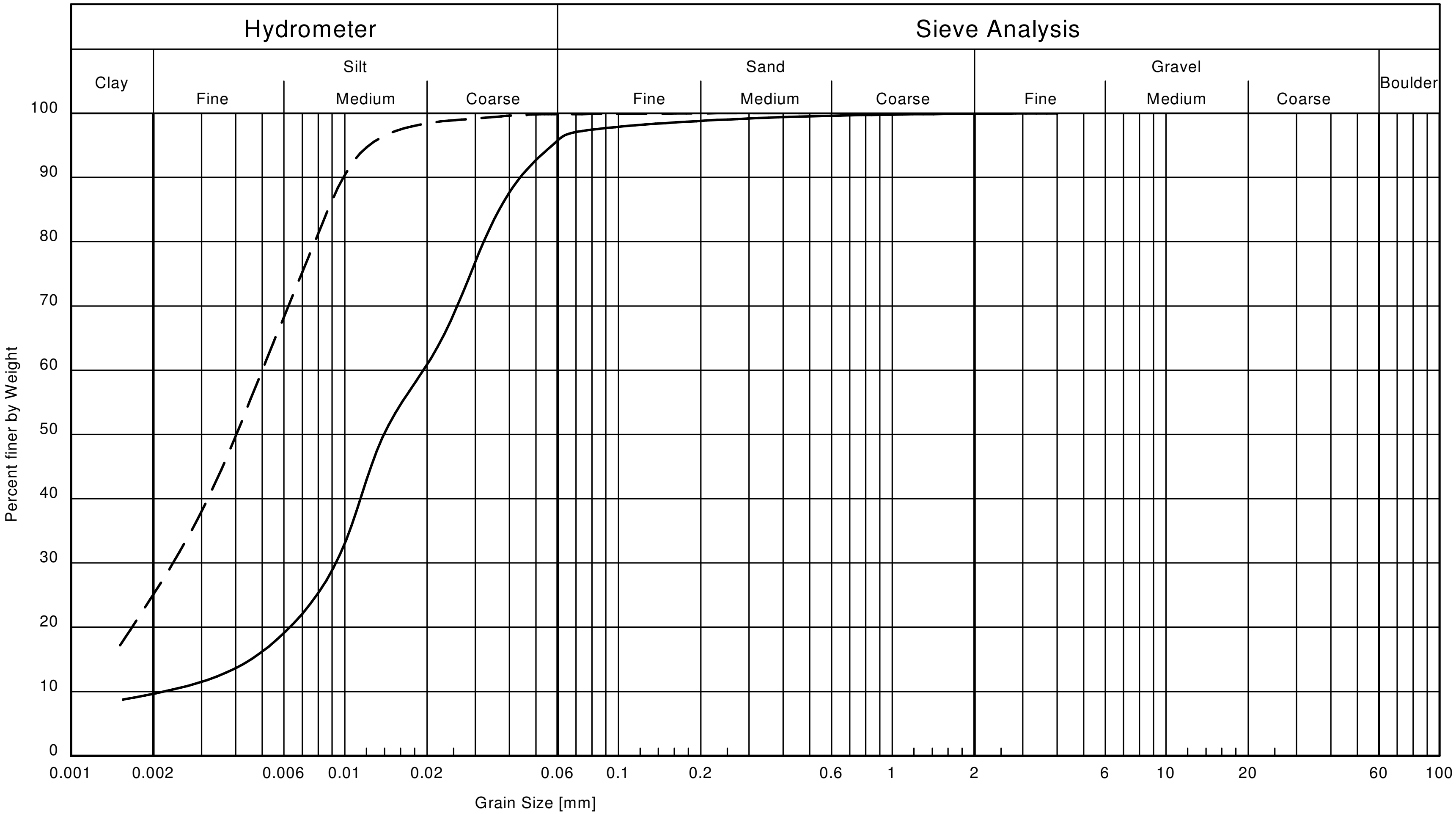
project: Brightwater Conveyance System

																T= -10						T= -20
		specimen no.		classification	grain size distribution					density			water saturation	moisture content	porosity							
boring no.	depth		Layer		clay	silt	sand	gravel	stones	specific gravity	wet soil	dry soil				UCS_{f10}	TCT_{f10}		UCT_{f10}			UCS_{f20}
					<0,002 mm	0,002 to 0,063 mm	0,063 to 2,0 mm	2,0 to 63 mm	> 63 mm	ρ_s	ρ	ρ_d	S_r	w	n	q_{f10}	φ_{f10}	c_{f10}	A	B	C	q_{f20}
	FT BGS				%					t/m³	t/m³	t/m³		%		MN/m^2	°	MN/m^2	$(m^2/MN)^x h^{-c}$			MN/m^2
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
P5-04A	115,7-116,7	16571-08	ML							2,68	1,86	1,46	0,88	27,5	0,46				0,00044	3,170	0,205	
P5-04	118,0-119,0	16571-09	ML							2,68	1,80	1,36	0,88	32,0	0,49				0,00044	3,170	0,205	
P5-04	123,7-124,7	16571-10	ML							2,68	1,84	1,42	0,91	30,0	0,47				0,00044	3,170	0,205	
P5-04	124,7-125,7	16571-13	ML							2,68	1,88	1,45	0,93	29,4	0,46				0,00044	3,170	0,205	
P5-04	79,2-80,2	16571-11	ML							2,68	1,90	1,48	0,94	28,5	0,45							7,8
P5-04	80,2-81,2	16571-12	ML							2,68	1,79	1,40	0,81	27,5	0,48							7,8
P5-04	135,0-136,0	16571-14	ML							2,68	1,83	1,41	0,89	30,0	0,47							8,2
P5-04	100,8-101,8	16571-15	ML							2,68	1,78	1,34	0,86	32,1	0,50							8,0

GRAIN SIZE CURVE

Client: King County WTD

Project: Brightwater Conveyance System



Signature	——— (solid line)	— — — (dashed line)
Specim. No	16571-02	16571-07
Depth [ft BGS]	134.0 - 135.0	93.7 - 94.7
Location	P 5 - 04	P 5 - 04
Layer	ML	ML
Amount of Clay/Silt/Sand/Gravel	9.6/86.8/3.5/0.1	25.1/74.8/0.2/ -

CDM

Technician: Rc

Engineer: Ha

Project-No.: 86804

Date: 03-05

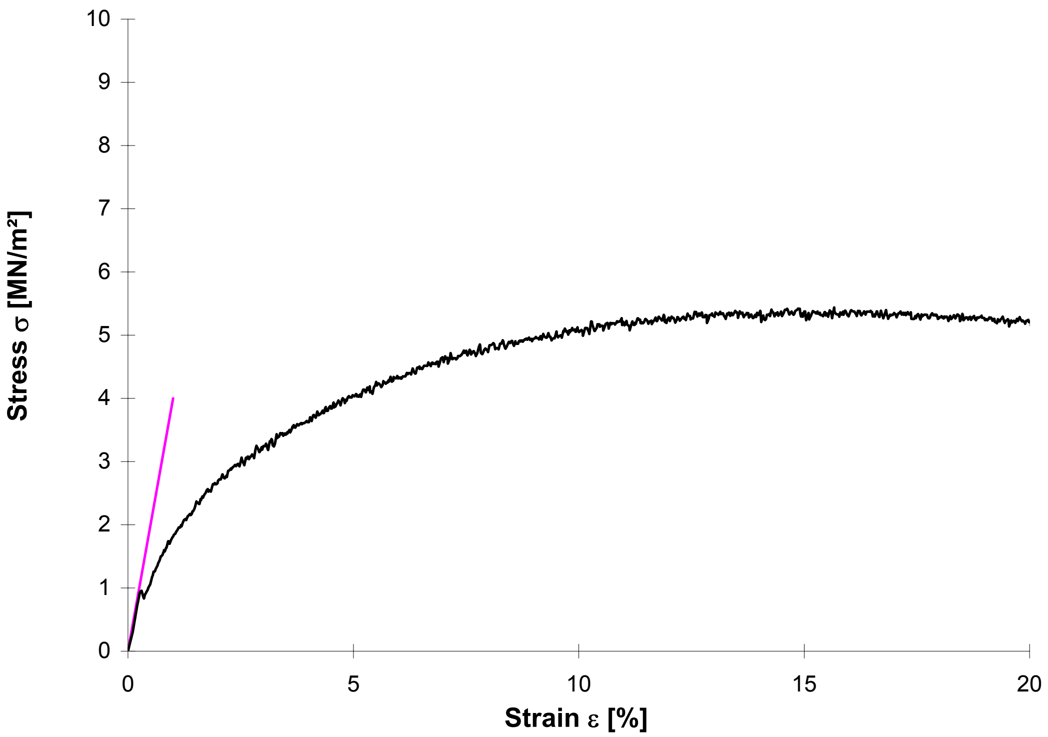
Attachment: 1.2

Specimen

Specimen no.		**16571-01**
Layer/ Material		ML
Type of specimen		undisturbed
Borehole no.		P5-04
Depth	[FT BGS]	94,7-95,7

Uniaxial Compressive Strength

Date		########
Weight	[g]	1385,00
Height	[cm]	14,95
Diameter	[cm]	7,9
Ratio		1,89
Area	[cm²]	49,02
Volume	[cm³]	732,80
Density	[g/cm³]	1,89
Moisture content	[%]	29,4
Dry density	[g/cm³]	1,46
Constant strain rate	[mm/min]	1,495
Temperature	[°C]	-10
UCS	**[MN/m²]**	**5,4**
Deformation at failure	**[%]**	**15,7**
Tangent Modulus	**[MN/m²]**	**400**



Note:

Client:
King County WTD

Project:
Brightwater Conveyance System

CDM

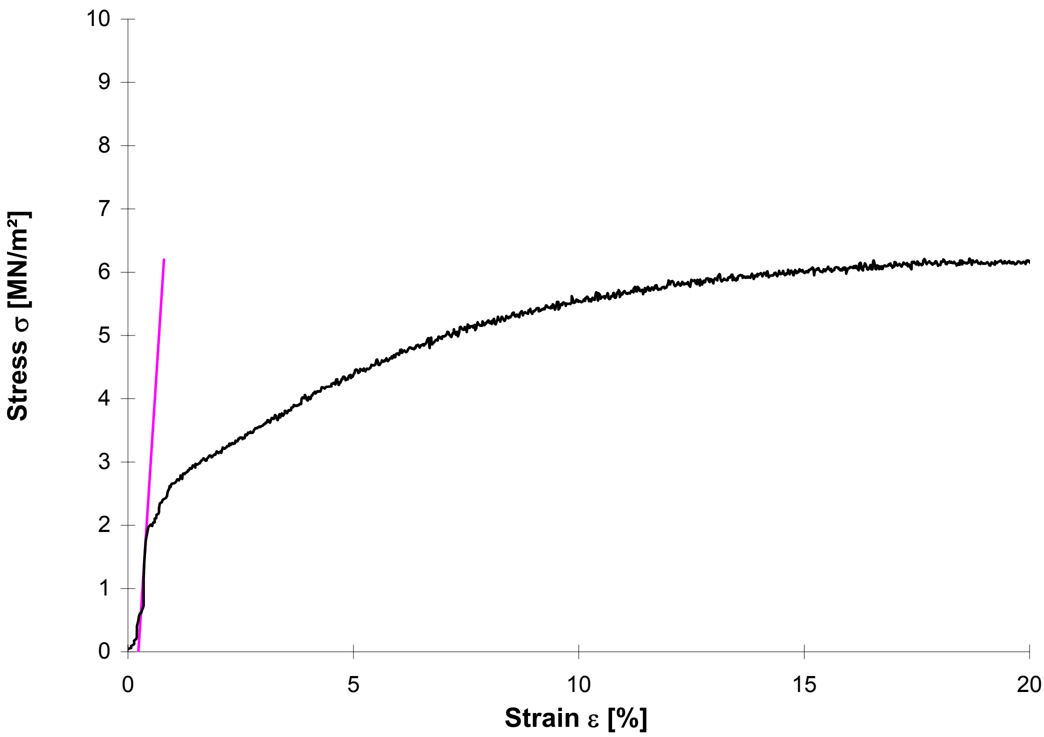
Determination of the Uniaxial Compressive Strength (UCS) T = -10 °C	Technician: Rc	Project-no.: 86804	Attachment: **1.3.1**
	Engineer: We	Date: 02/05	

Specimen

Specimen no.		**16571-02**
Layer/ Material		ML
Type of specimen		undisturbed
Borehole no.		P5-04
Depth	[FT BGS]	93,7-94,7

Uniaxial Compressive Strength

Date		########
Weight	[g]	1589,30
Height	[cm]	18,02
Diameter	[cm]	7,71
Ratio		2,34
Area	[cm²]	46,69
Volume	[cm³]	841,30
Density	[g/cm³]	1,89
Moisture content	[%]	32,0
Dry density	[g/cm³]	1,43
Constant strain rate	[mm/min]	1,802
Temperature	[°C]	-10
UCS	**[MN/m²]**	**6,2**
Deformation at failure	**[%]**	**18,7**
Tangent Modulus	**[MN/m²]**	**1088**



Note:

Client: King County WTD

Project: Brightwater Conveyance System

CDM

Determination of the Uniaxial Compressive Strength (UCS) T = -10 °C

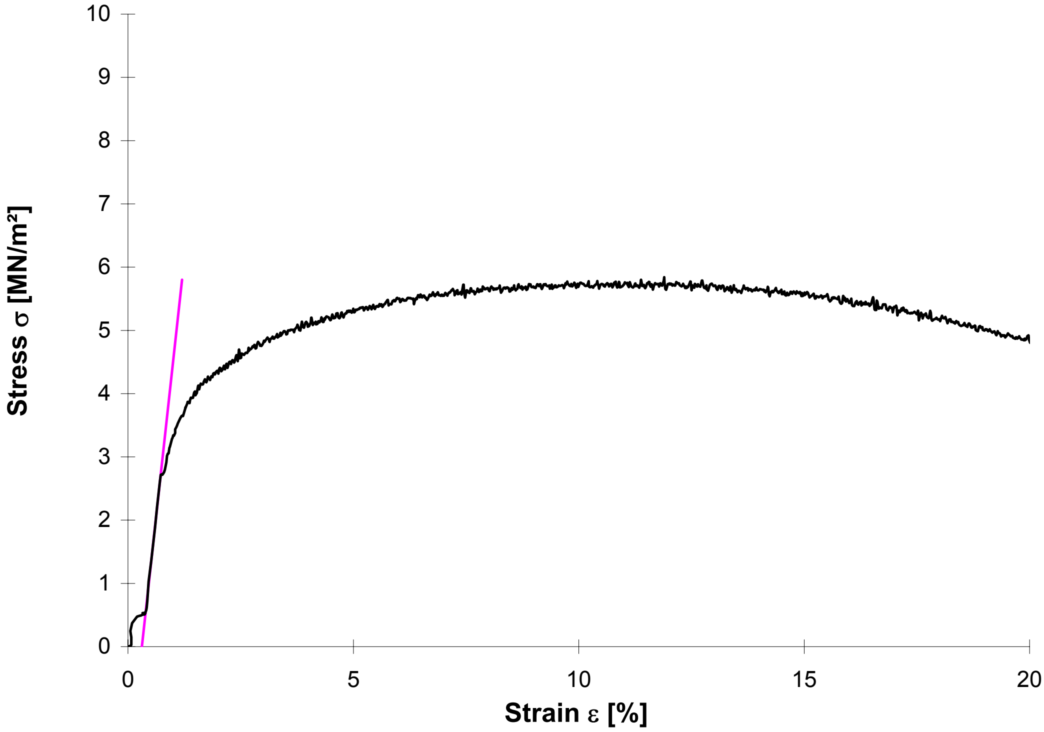
Technician:	Project-no.:	Attachment:
Rc	86804	**1.3.2**
Engineer: We	Date: 02/05	

Specimen

Specimen no.		**16571-03**
Layer/ Material		ML
Type of specimen		undisturbed
Borehole no.		P5-04
Depth	[FT BGS]	134,0-135,0

Uniaxial Compressive Strength

Date		########
Weight	[g]	1811,50
Height	[cm]	17,29
Diameter	[cm]	8,57
Ratio		2,02
Area	[cm²]	57,68
Volume	[cm³]	997,35
Density	[g/cm³]	1,82
Moisture content	[%]	30,7
Dry density	[g/cm³]	1,39
Constant strain rate	[mm/min]	1,729
Temperature	[°C]	-10
UCS	**[MN/m²]**	**5,8**
Deformation at failure	**[%]**	**11,9**
Tangent Modulus	**[MN/m²]**	**652**



Note:

Client: King County WTD

Project: Brightwater Conveyance System

CDM

Determination of the Uniaxial Compressive Strength (UCS) T = -10 °C

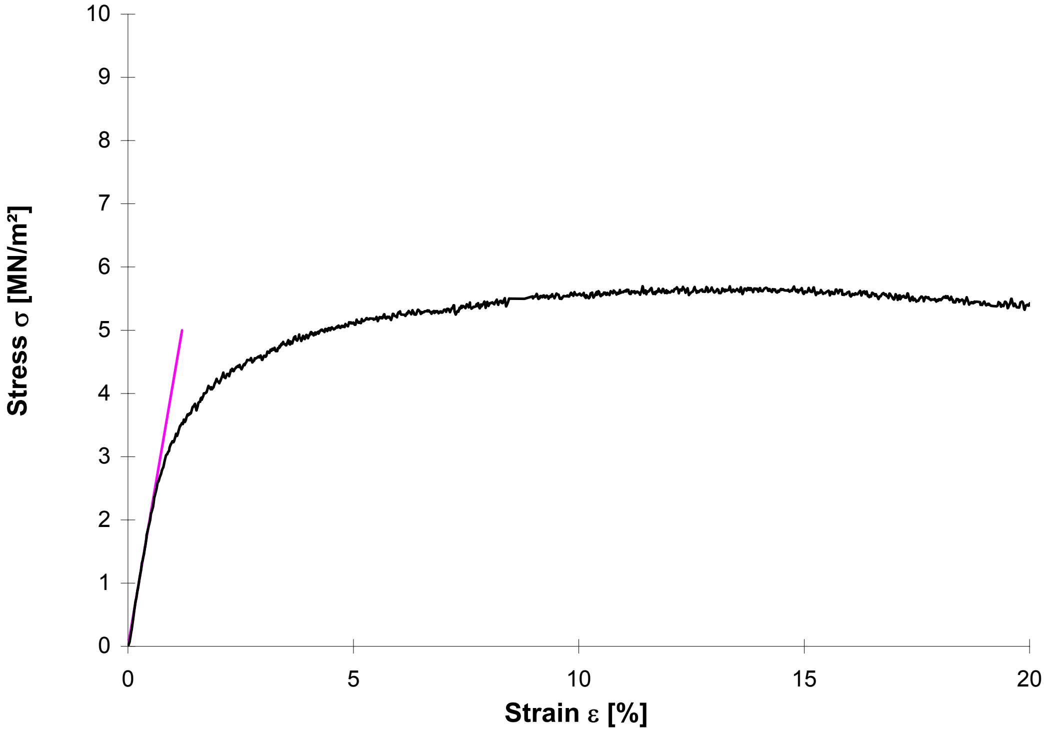
Technician:	Project-no.:	Attachment:
Rc	86804	**1.3.3**
Engineer:	Date:	
We	02/05	

Specimen

Specimen no.		**16571-16**
Layer/ Material		ML
Type of specimen		undisturbed
Borehole no.		P5-04
Depth	[FT BGS]	94,7 - 95,7

Uniaxial Compressive Strength

Date		########
Weight	[g]	1799,00
Height	[cm]	17,43
Diameter	[cm]	8,5
Ratio		2,05
Area	[cm²]	56,74
Volume	[cm³]	989,06
Density	[g/cm³]	1,82
Moisture content	[%]	30,1
Dry density	[g/cm³]	1,40
Constant strain rate	[mm/min]	1,743
Temperature	[°C]	-10
UCS	**[MN/m²]**	**5,7**
Deformation at failure	**[%]**	**11,4**
Tangent Modulus	**[MN/m²]**	**417**



Note:

Client: King County WTD

Project: Brightwater Conveyance System

CDM

Determination of the Uniaxial Compressive Strength (UCS) T = -10 °C

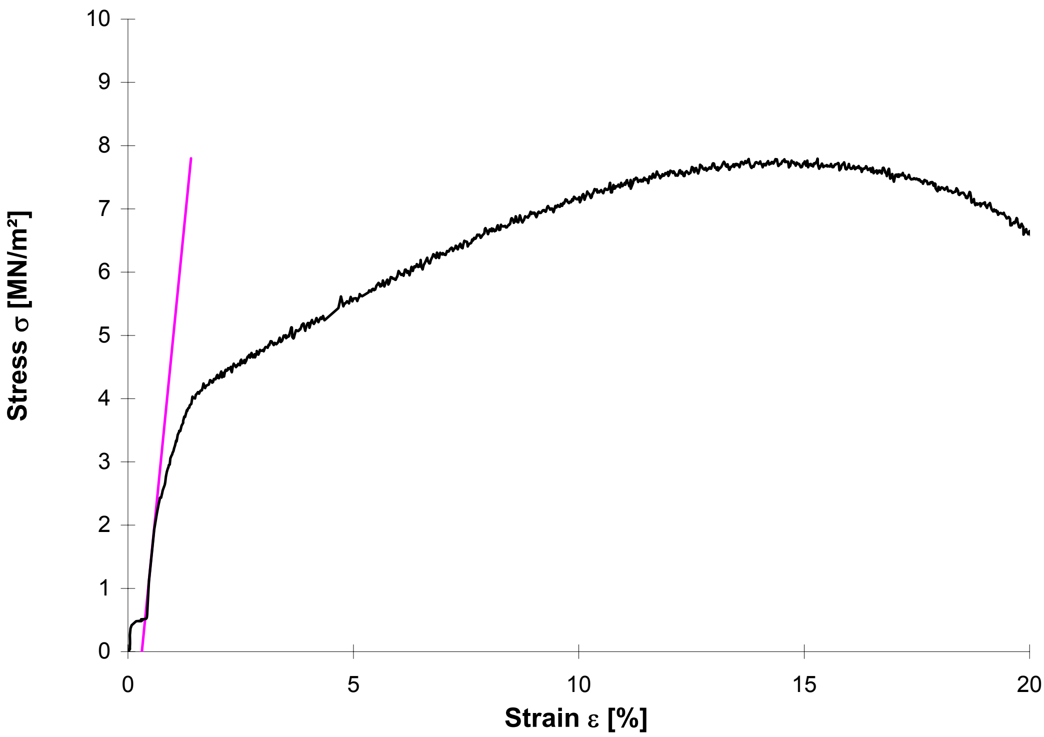
Technician:	Project-no.:	Attachment:
Rc	86804	**1.3.4**
Engineer:	Date:	
We	02/05	

Specimen

Specimen no.		**16571-11**
Layer/ Material		ML
Type of specimen		undisturbed
Borehole no.		P5-04
Depth	[FT BGS]	79,2-80,2

Uniaxial Compressive Strength

Date		########
Weight	[g]	1831,20
Height	[cm]	17,14
Diameter	[cm]	8,47
Ratio		2,02
Area	[cm²]	56,35
Volume	[cm³]	965,76
Density	[g/cm³]	1,90
Moisture content	[%]	28,5
Dry density	[g/cm³]	1,48
Constant strain rate	[mm/min]	1,714
Temperature	[°C]	-20
UCS	**[MN/m²]**	**7,8**
Deformation at failure	**[%]**	**15,3**
Tangent Modulus	**[MN/m²]**	**716**



Note:

Client: King County WTD

Project: Brightwater Conveyance System

CDM

Determination of the Uniaxial Compressive Strength (UCS) T = -20 °C

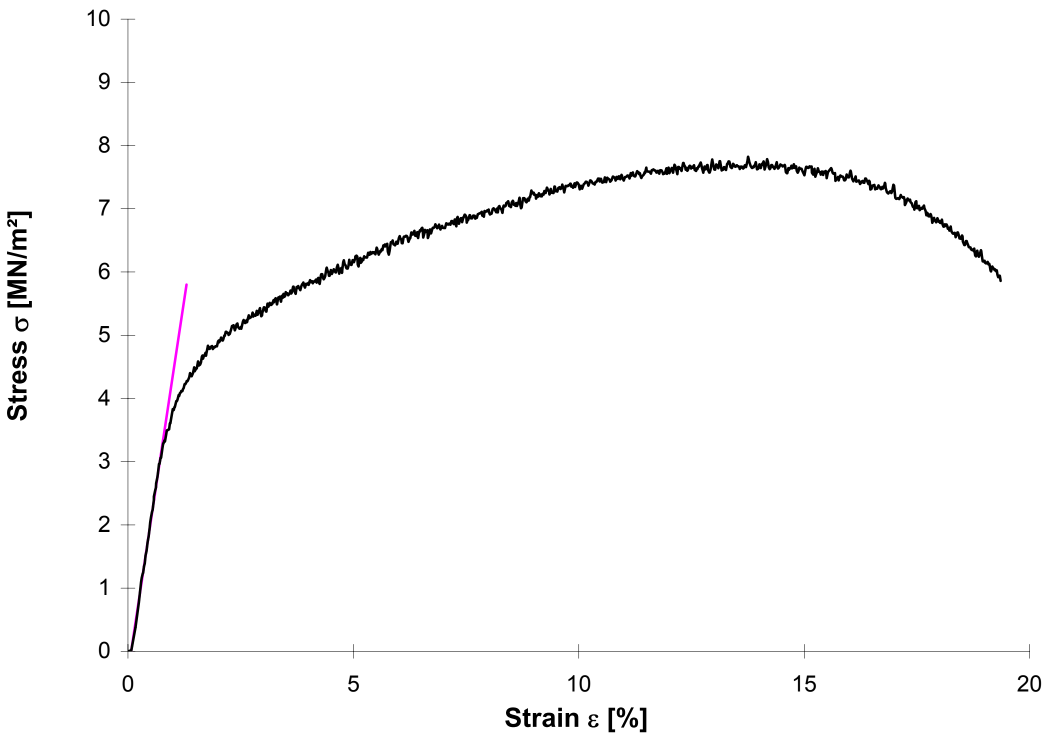
Technician:	Project-no.:	Attachment:
Rc	86804	1.3.5
Engineer:	Date:	
We	02/05	

Specimen

Specimen no.		**16571-12**
Layer/ Material		ML
Type of specimen		undisturbed
Borehole no.		P5-04
Depth	[FT BGS]	80,2-81,2

Uniaxial Compressive Strength

Date		#########
Weight	[g]	1897,00
Height	[cm]	17,42
Diameter	[cm]	8,81
Ratio		1,98
Area	[cm²]	60,96
Volume	[cm³]	1061,91
Density	[g/cm³]	1,79
Moisture content	[%]	27,5
Dry density	[g/cm³]	1,40
Constant strain rate	[mm/min]	1,742
Temperature	[°C]	-20
UCS	**[MN/m²]**	**7,8**
Deformation at failure	**[%]**	**13,8**
Tangent Modulus	**[MN/m²]**	**472**



Note:

Client:
King County WTD

Project:
Brightwater Conveyance System

CDM

Determination of the Uniaxial Compressive Strength (UCS) T = -20 °C

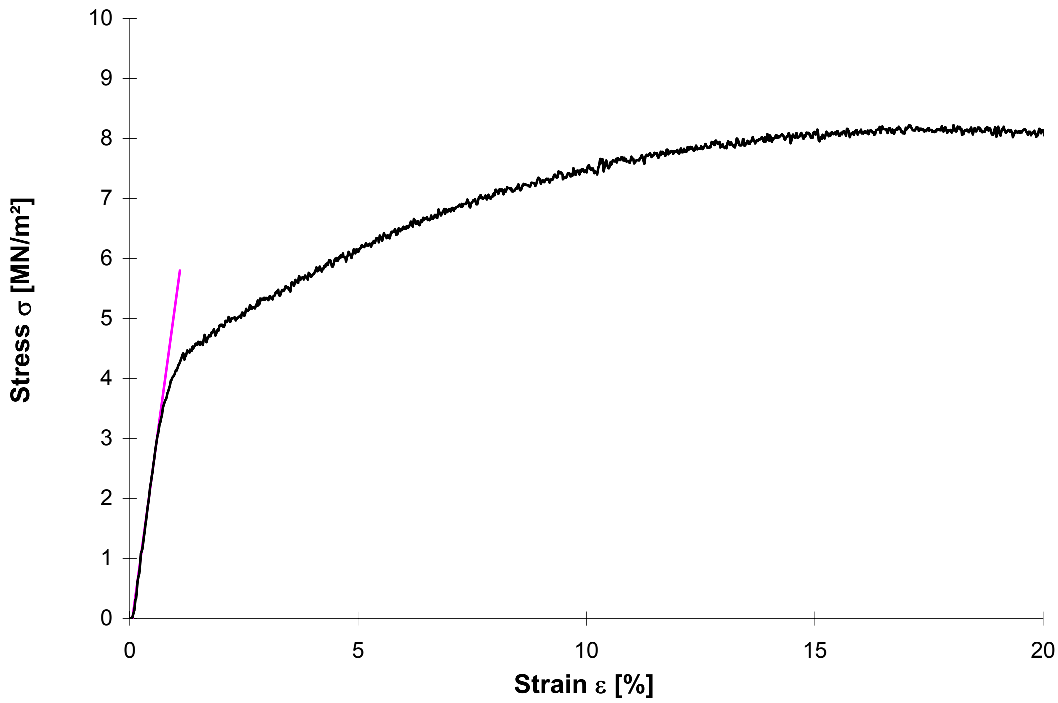
Technician:	Project-no.:	Attachment:
Rc	86804	**1.3.6**
Engineer:	Date:	
We	02/05	

Specimen

Specimen no.		**16571-14**
Layer/ Material		ML
Type of specimen		undisturbed
Borehole no.		P5-04
Depth	[FT BGS]	135,0-136,0

Uniaxial Compressive Strength

Date		20.04.2005
Weight	[g]	1883,00
Height	[cm]	18
Diameter	[cm]	8,52
Ratio		2,11
Area	[cm²]	57,01
Volume	[cm³]	1026,22
Density	[g/cm³]	1,83
Moisture content	[%]	30,0
Dry density	[g/cm³]	1,41
Constant strain rate	[mm/min]	1,800
Temperature	[°C]	-20
UCS	**[MN/m²]**	**8,2**
Deformation at failure	**[%]**	**18,0**
Tangent Modulus	**[MN/m²]**	**558**



Note:

Client: King County WTD

Project: Brightwater Conveyance System

CDM

Determination of the Uniaxial Compressive Strength (UCS) T = -20 °C

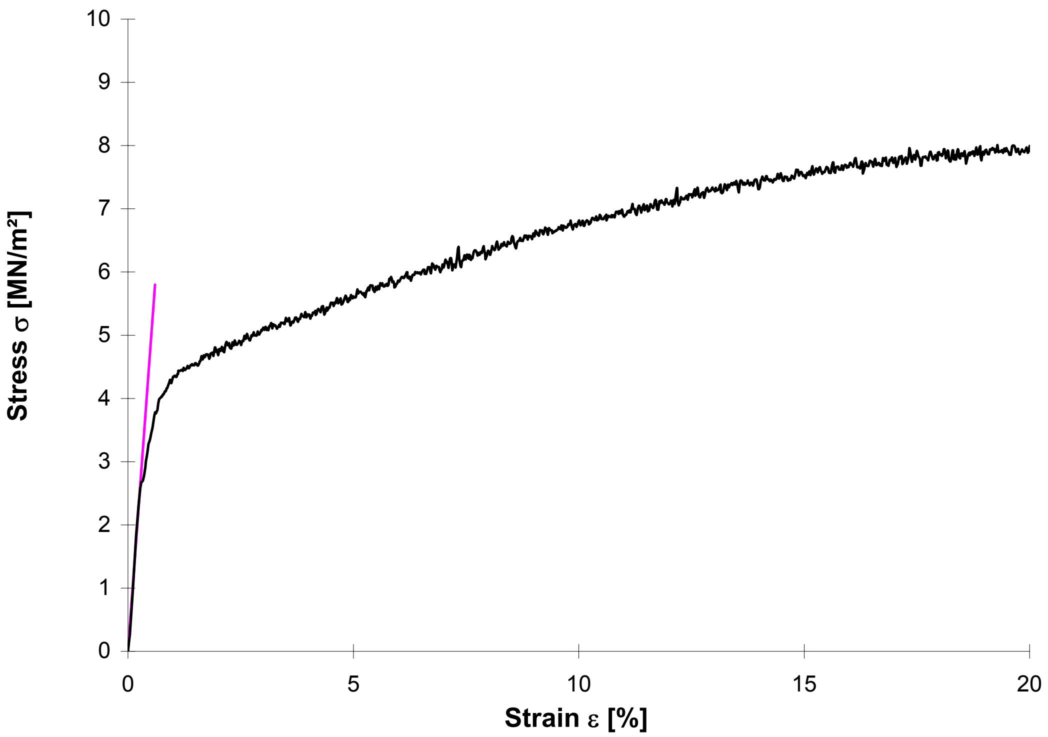
Technician:	Project-no.:	Attachment:
Rc	86804	**1.3.7**
Engineer: We	Date: 02/05	

Specimen

Specimen no.		**16571-15**
Layer/ Material		ML
Type of specimen		undisturbed
Borehole no.		P5-04
Depth	[FT BGS]	100,8 - 101,8

Uniaxial Compressive Strength

Date		########
Weight	[g]	1667,00
Height	[cm]	16,09
Diameter	[cm]	8,62
Ratio		1,87
Area	[cm²]	58,36
Volume	[cm³]	938,99
Density	[g/cm³]	1,78
Moisture content	[%]	32,1
Dry density	[g/cm³]	1,34
Constant strain rate	[mm/min]	1,609
Temperature	[°C]	-20
UCS	**[MN/m²]**	**8,0**
Deformation at failure	**[%]**	**19,3**
Tangent Modulus	**[MN/m²]**	**967**



Note:

Client: King County WTD

Project: Brightwater Conveyance System

CDM

Determination of the Uniaxial Compressive Strength (UCS) T = -20 °C

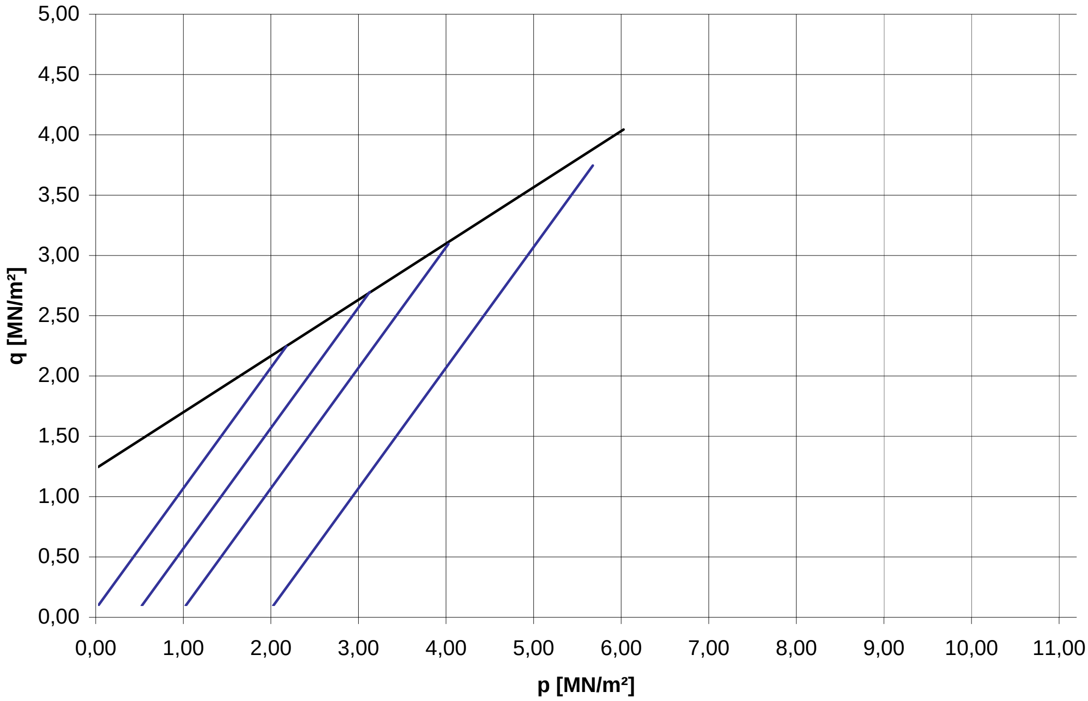
Technician:	Project-no.:	Attachment:
Rc	86804	**1.3.8**
Engineer: We	Date: 02/05	

Specimen

		16571-04	16571-05	16571-06	16571-07
Specimen no.		**16571-04**	**16571-05**	**16571-06**	**16571-07**
Layer/ Material		ML	ML	ML	ML
Type of specimen		undisturbed	undisturbed	undisturbed	undisturbed
Borehole no.		P5-04	P5-04	P5-04	P5-04
Depth	[m]	123,7-124,7	118,0-119,0	124,7-125,7	134,0-135,0
s3	**[MN/m²]**	**1,0**	**0,0**	**2,0**	**0,5**
Date		10.02.2005	14.02.2005	15.02.2005	17.02.2005
Weight	[g]	395,9	369,3	392,5	386,6
Height	[cm]	10,84	10,44	10,60	10,61
Diameter	[cm]	4,99	4,99	4,98	4,96
Ratio	[-]	2,17	2,09	2,13	2,14
Area	[cm²]	19,56	19,56	19,48	19,32
Volume	[cm³]	211,99	204,17	206,47	205,01
Density	[g/cm³]	1,87	1,81	1,90	1,89
Moisture content	[%]	29,1	34,0	29,4	29,1
Dry density	[g/cm³]	1,45	1,35	1,47	1,46
Constant strain rate	[mm/min]	0,108	0,104	0,106	0,106
Temperature	[°C]	**-10**	**-10**	**-10**	**-10**

j **[°] : 27,8**

c [MN/m²] : 1,30



Note:

Client:

King County WTD

Project:

Brightwater Conveyance System

CDM

Determination of the Triaxial Compressive Strength (TCS) T = -10 °C

Technician:	Project-no.:	Attachment:
Rc	86804	**1.4**
Engineer:	Date:	
We	02/05	

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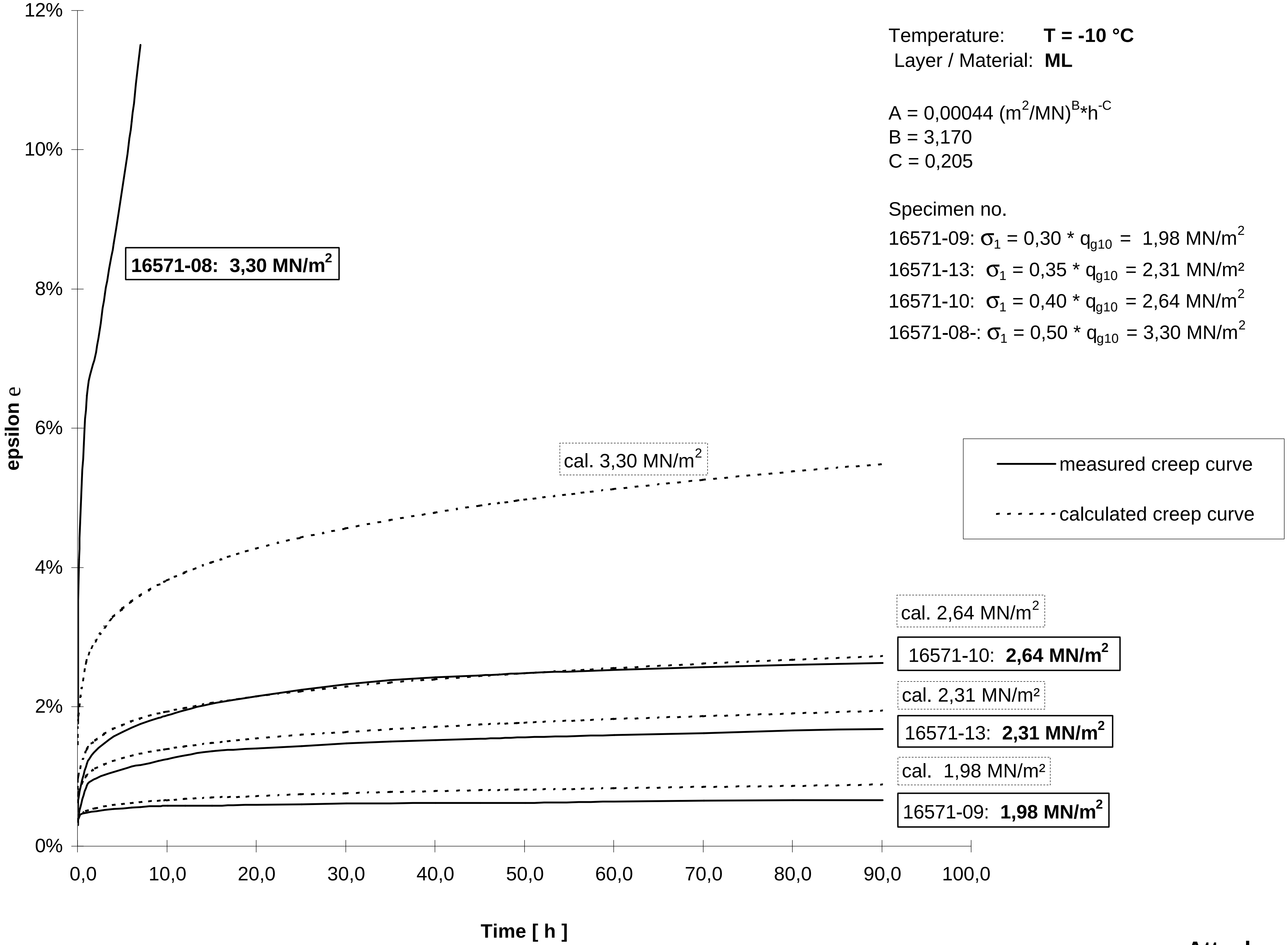
Uniaxial Creep Test



Attachment 1.5

Laboratory test results: Layer SM

project: Brightwater Conveyance System

		specimen no.		classification	grain size distribution					density			water saturation	moisture content	porosity	T= -10						T= -20
boring no.	depth		Layer		clay	silt	sand	gravel	stones	specific gravity	wet soil	dry soil				UCS_{f10}	TCT_{f10}		UCT_{f10}			UCS_{f20}
					<0,002 mm	0,002 to 0,063 mm	0,063 to 2,0 mm	2,0 to 63 mm	> 63 mm	ρ_s	ρ	ρ_d	S_r	w	n	q_{f10}	φ_{f10}	c_{f10}	A	B	C	q_{f20}
	FT BGS				%					t/m^3	t/m^3	t/m^3		%		MN/m^2	°	MN/m^2	$(m^2/MN)^2xh^{-c}$			MN/m^2
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
P5-04	154,0 - 155,0	16572-01	SM							2,65	2,23	2,02	0,92	10,8	0,24	6,0						
P5-04	155,0 - 156,0	16572-02	SM							2,65	2,16	1,96	0,76	10,1	0,26	6,2						
P5-04	174,0 - 175,0	16572-03	SM							2,65	2,18	1,97	0,82	10,7	0,26	5,5						
P5-04	178,0-179,0	16572-09	SM							2,65	2,21	2,00	0,85	10,4	0,25	5,2						
P5-04	166,0-168,5	16572-04*	SM							2,65	2,17	1,95	0,81	11,0	0,26				0,00209	2,069	0,095	
P5-04	166,0-168,5	16572-05*	SM							2,65	2,18	1,97	0,81	10,5	0,26				0,00209	2,069	0,095	
P5-04	166,0-168,5	16572-06*	SM							2,65	2,17	1,97	0,79	10,3	0,26				0,00209	2,069	0,095	
P5-04	166,0-168,5	16572-07*	SM							2,65	2,15	1,94	0,80	11,1	0,27				0,00209	2,069	0,095	

Laboratory test results: Layer SM

project: Brightwater Conveyance System

																T= -10						T= -20
		specimen no.		classification	grain size distribution					density			water saturation	moisture content	porosity							
boring no.	depth		Layer		clay	silt	sand	gravel	stones	specific gravity	wet soil	dry soil				UCS_{f10}	TCT_{f10}		UCT_{f10}			UCS_{f20}
					<0,002 mm	0,002 to 0,063 mm	0,063 to 2,0 mm	2,0 to 63 mm	> 63 mm	ρ_s	ρ	ρ_d	S_r	w	n	q_{f10}	φ_{f10}	c_{f10}	A	B	C	q_{f20}
	FT BGS				%					t/m³	t/m³	t/m³		%		MN/m^2	°	MN/m^2	$(m^2/MN)^2 x h^{-c}$			MN/m^2
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
P5-04	145,0-146,0	16572-08	SM							2,65	2,20	1,91	1,04	15,2	0,28							9,3
P5-04	175,0-176,0	16572-10	SM							2,65	2,11	1,81	0,98	17,1	0,32							11,1
P5-04	144,0-145,0	16572-11	SM							2,65	2,21	1,91	1,05	15,4	0,28							7,1
P5-04	166,0-168,5	16572-12*	SM							2,65	2,17	1,96	0,83	11,0	0,26							9,3
P5-04	144,0 - 179,0	16572-a	SM		5,0	27,2	40,9	26,9														
P5-04	144,0 - 179,0	16572-b	SM		3,8	25,7	43,3	27,2														

*: remolded

GRAIN SIZE CURVE

Client: King County WTD

Project: Brightwater Conveyance System

Technician: Fe

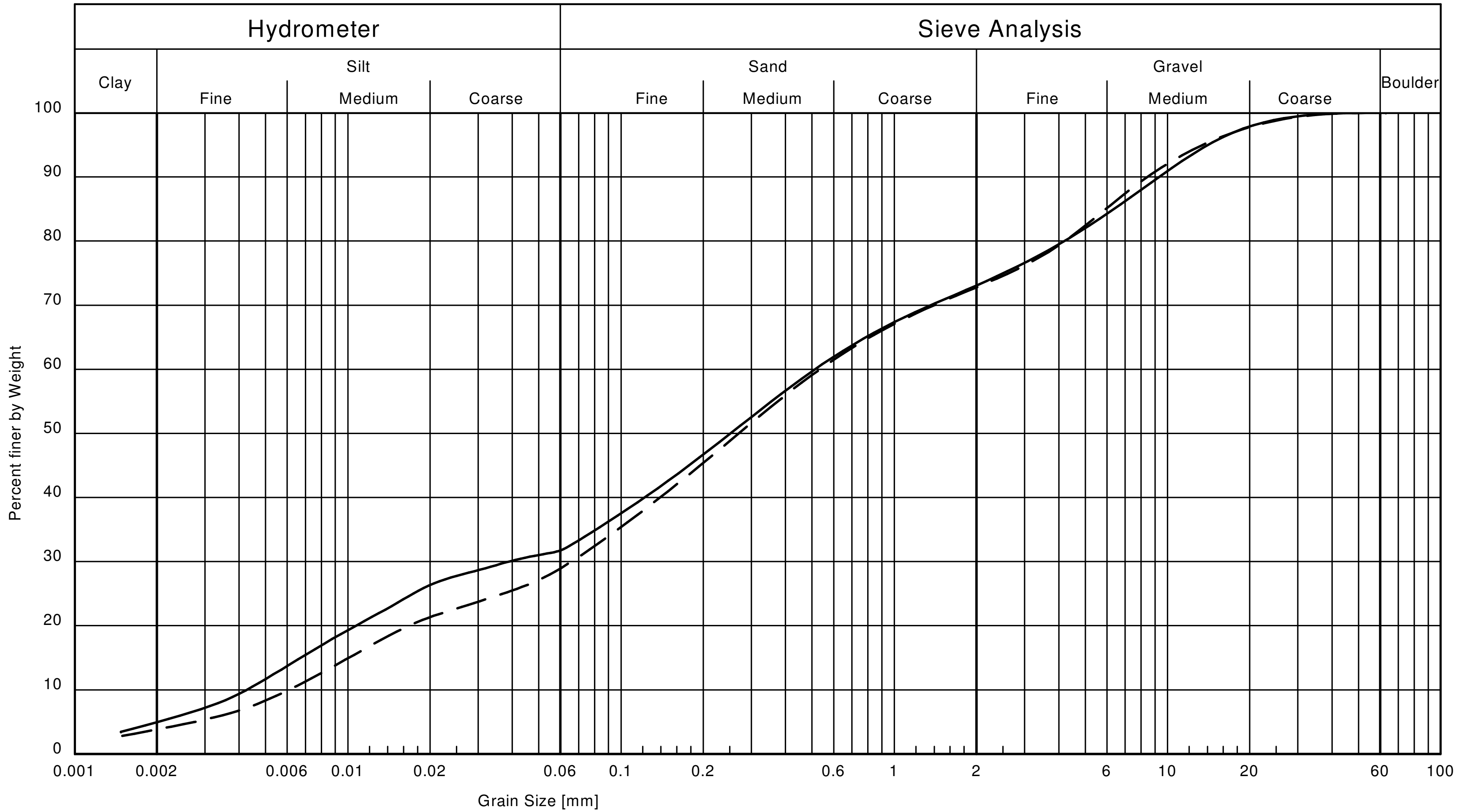
Engineer: Ha

Project-No.: 86804

Date: 05-05

Attachment: 2.2

CDM



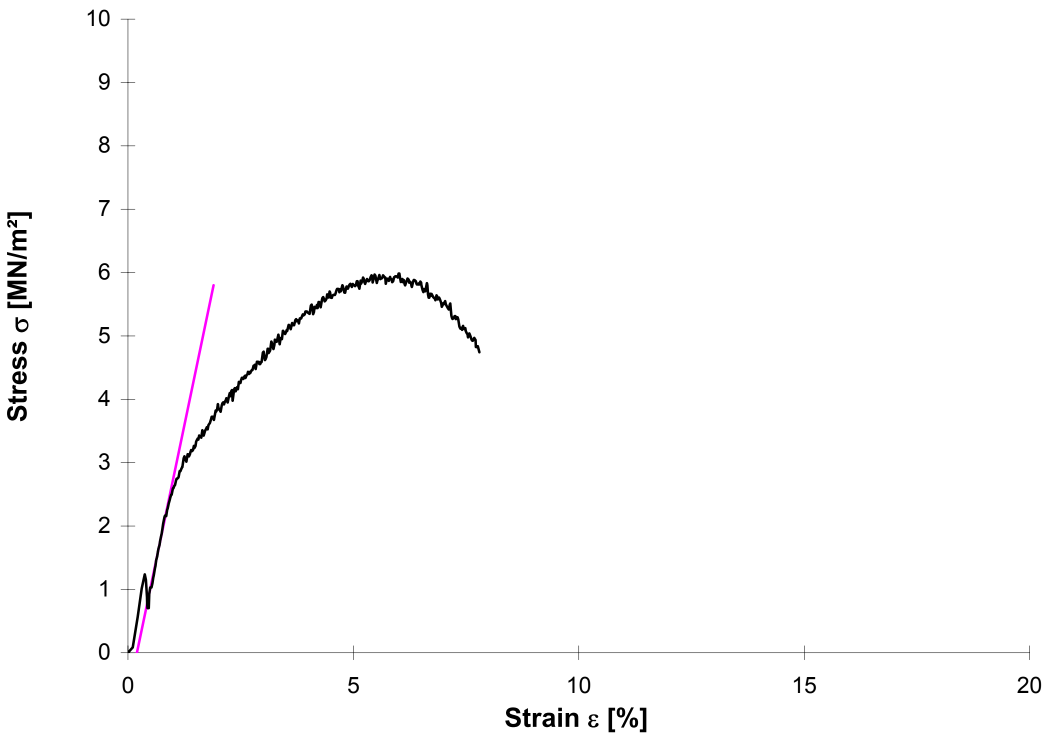
Signature	————	— — —
Specim. No	16572 - a	16572 - b
Depth [ft BGS]	144,0 - 179,0	144,0 - 179,0
Location	P 5 - 04	P 5 - 04
Layer	SM	SM
Amount of Clay/Silt/Sand/Gravel	5.0/27.2/40.9/26.9	3.8/25.7/43.3/27.2

Specimen

Specimen no.		**16572-01**
Layer/ Material		SM
Type of specimen		undisturbed
Borehole no.		P5-04
Depth	[FT BGS]	154,0 - 155,0

Uniaxial Compressive Strength

Date		########
Weight	[g]	2335,00
Height	[cm]	18,04
Diameter	[cm]	8,59
Ratio		2,10
Area	[cm²]	57,95
Volume	[cm³]	1045,47
Density	[g/cm³]	2,23
Moisture content	[%]	10,8
Dry density	[g/cm³]	2,02
Constant strain rate	[mm/min]	1,804
Temperature	[°C]	-10
UCS	**[MN/m²]**	**6,0**
Deformation at failure	**[%]**	**6,0**
Tangent Modulus	**[MN/m²]**	**341**



Note:

Client: King County WTD	CDM
Project: Brightwater Conveyance System	

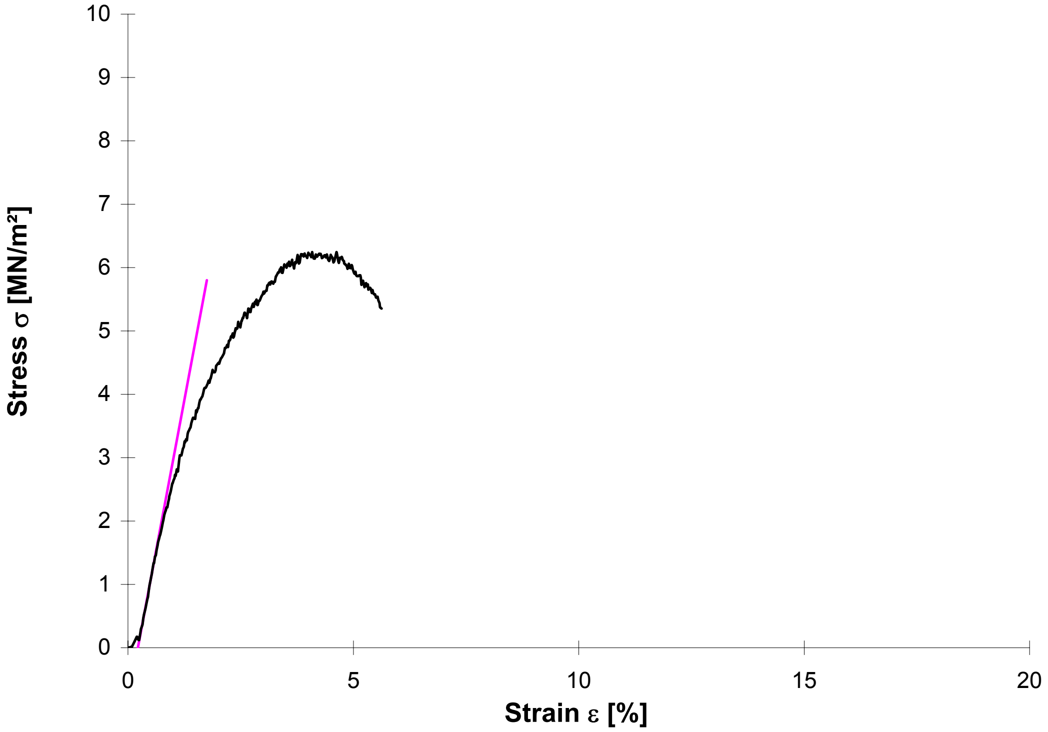
Determination of the Uniaxial Compressive Strength (UCS) T = -10 °C	Technician: Fe	Project-no.: 86804	Attachment: **2.3.1**
	Engineer: Ha	Date: 03-05	

Specimen

Specimen no.		**16572-02**
Layer/ Material		SM
Type of specimen		undisturbed
Borehole no.		P5-04
Depth	[FT BGS]	155,0 - 156,0

Uniaxial Compressive Strength

Date		########
Weight	[g]	2222,00
Height	[cm]	17,99
Diameter	[cm]	8,54
Ratio		2,11
Area	[cm²]	57,28
Volume	[cm³]	1030,47
Density	[g/cm³]	2,16
Moisture content	[%]	10,1
Dry density	[g/cm³]	1,96
Constant strain rate	[mm/min]	1,799
Temperature	[°C]	-10
UCS	**[MN/m²]**	**6,2**
Deformation at failure	**[%]**	**4,1**
Tangent Modulus	**[MN/m²]**	**379**



Note:

Client: King County WTD

Project: Brightwater Conveyance System

CDM

Determination of the Uniaxial Compressive Strength (UCS) T = -10 °C

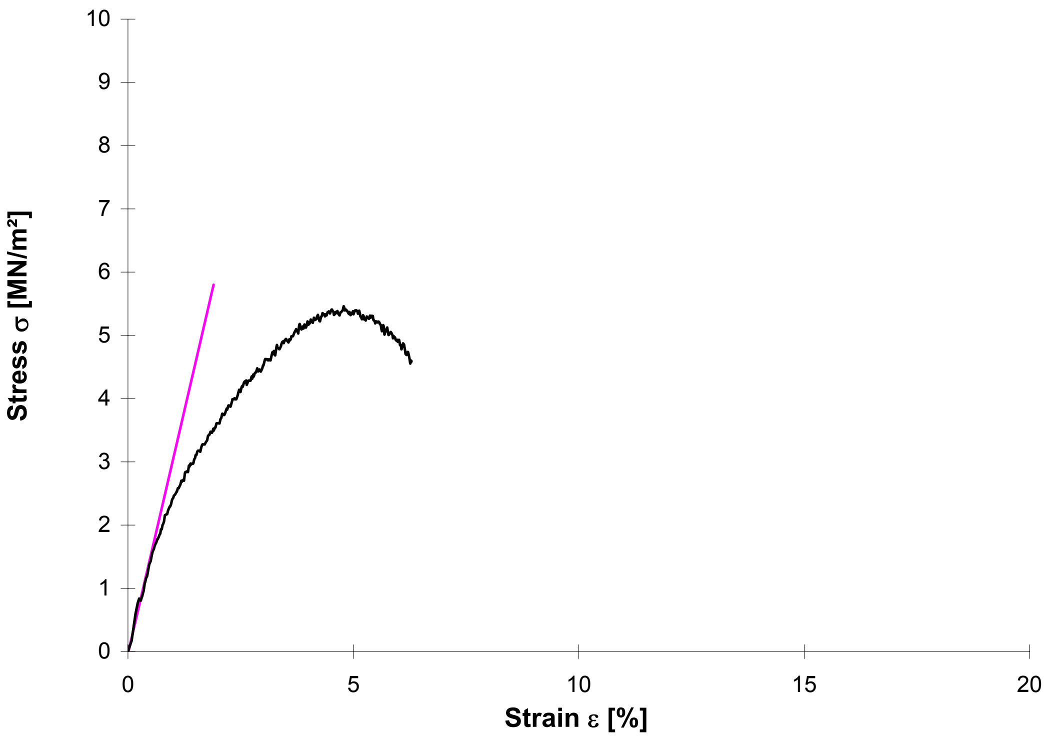
Technician:	Project-no.:	Attachment:
Fe	86804	**2.3.2**
Engineer: Ha	Date: 03-05	

Specimen

Specimen no.		**16572-03**
Layer/ Material		SM
Type of specimen		undisturbed
Borehole no.		P5-04
Depth	[FT BGS]	174,0 - 175,0

Uniaxial Compressive Strength

Date		########
Weight	[g]	2240,00
Height	[cm]	18,03
Diameter	[cm]	8,52
Ratio		2,12
Area	[cm²]	57,01
Volume	[cm³]	1027,93
Density	[g/cm³]	2,18
Moisture content	[%]	10,7
Dry density	[g/cm³]	1,97
Constant strain rate	[mm/min]	1,803
Temperature	[°C]	-10
UCS	**[MN/m²]**	**5,5**
Deformation at failure	**[%]**	**4,8**
Tangent Modulus	**[MN/m²]**	**307**



Note:

Client: King County WTD	CDM
Project: Brightwater Conveyance System	

Determination of the Uniaxial Compressive Strength (UCS) T = -10 °C	Technician: Fe	Project-no.: 86804	Attachment: **2.3.3**
	Engineer: Ha	Date: 03-05	

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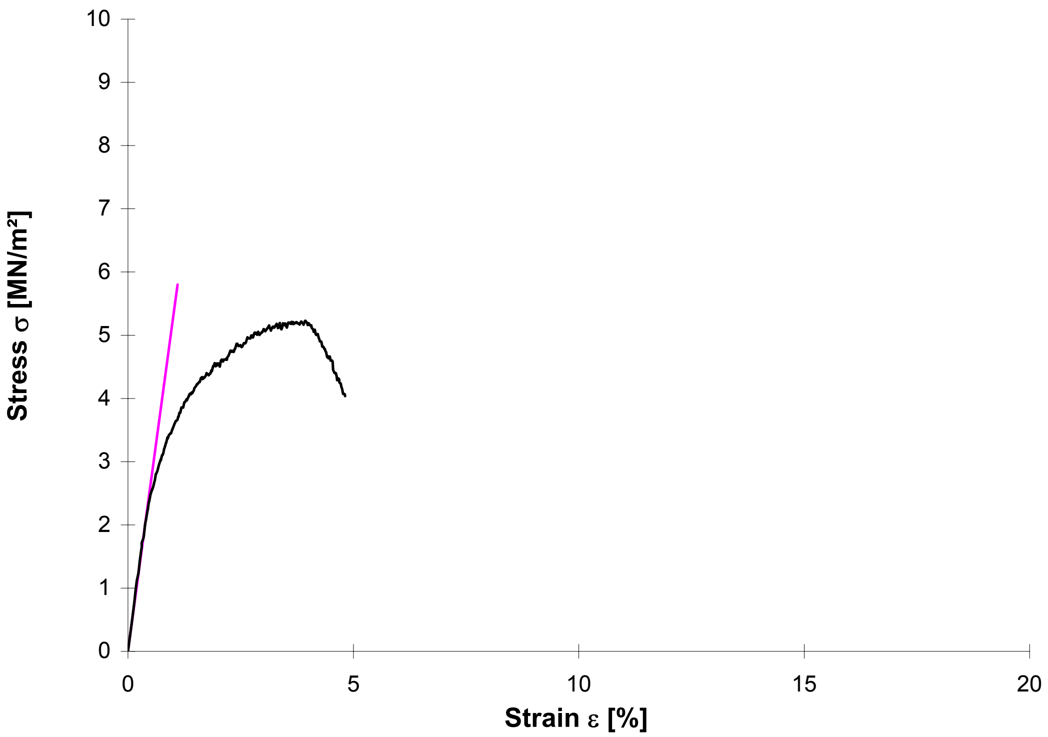
Specimen

Specimen no.		**16572-09**
Layer/ Material		SM
Type of specimen		undisturbed
Borehole no.		P5-04
Depth	[FT BGS]	178,0-179,0

Uniaxial Compressive Strength

Date		########
Weight	[g]	2263,00
Height	[cm]	17,31
Diameter	[cm]	8,68
Ratio		1,99
Area	[cm²]	59,17
Volume	[cm³]	1024,30
Density	[g/cm³]	2,21
Moisture content	[%]	10,4
Dry density	[g/cm³]	2,00
Constant strain rate	[mm/min]	1,731
Temperature	[°C]	-10
UCS	**[MN/m²]**	**5,2**
Deformation at failure	**[%]**	**3,9**
Tangent Modulus	**[MN/m²]**	**527**



Note:

Client: King County WTD

Project: Brightwater Conveyance System

CDM

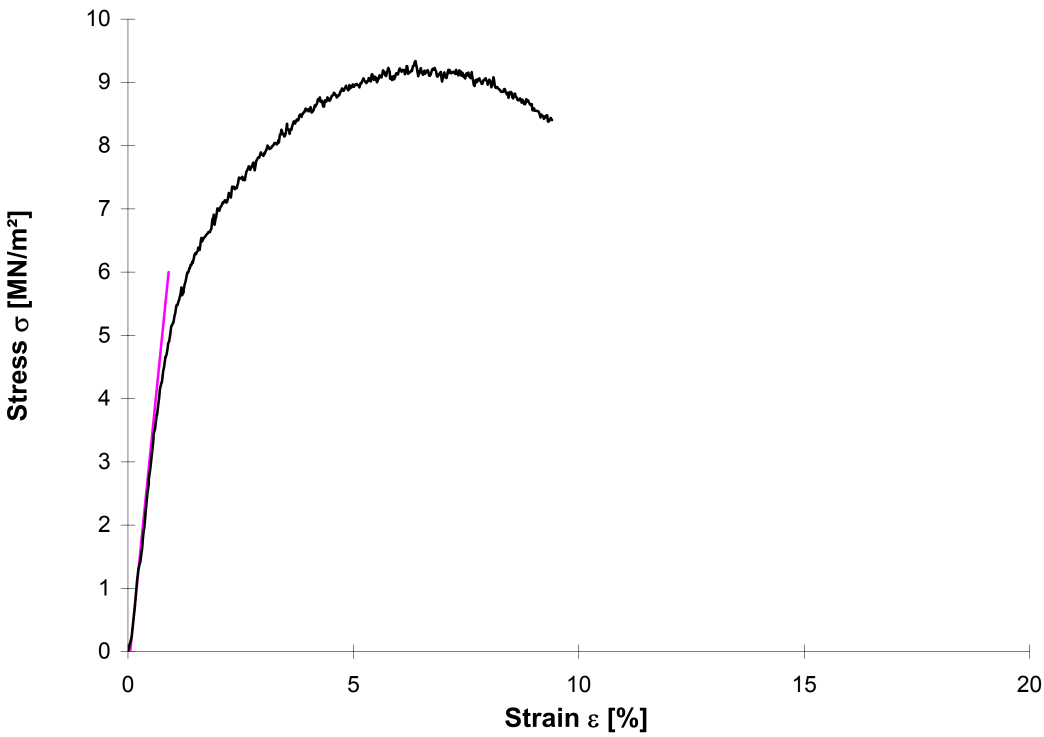
Determination of the Uniaxial Compressive Strength (UCS) T = -10 °C	Technician: Fe	Project-no.: 86804	Attachment: **2.3.4**
	Engineer: Ha	Date: 04-05	

Specimen

Specimen no.		**16572-08**
Layer/ Material		SM
Type of specimen		undisturbed
Borehole no.		P5-04
Depth	[FT BGS]	145,0-146,0

Uniaxial Compressive Strength

Date		########
Weight	[g]	2115,00
Height	[cm]	17,18
Diameter	[cm]	8,44
Ratio		2,04
Area	[cm²]	55,95
Volume	[cm³]	961,16
Density	[g/cm³]	2,20
Moisture content	[%]	15,2
Dry density	[g/cm³]	1,91
Constant strain rate	[mm/min]	1,718
Temperature	[°C]	-20
UCS	**[MN/m²]**	**9,3**
Deformation at failure	**[%]**	**6,4**
Tangent Modulus	**[MN/m²]**	**706**



Note:

Client:
King County WTD

Project:
Brightwater Conveyance System

CDM

Determination of the Uniaxial Compressive Strength (UCS) T = -20 °C

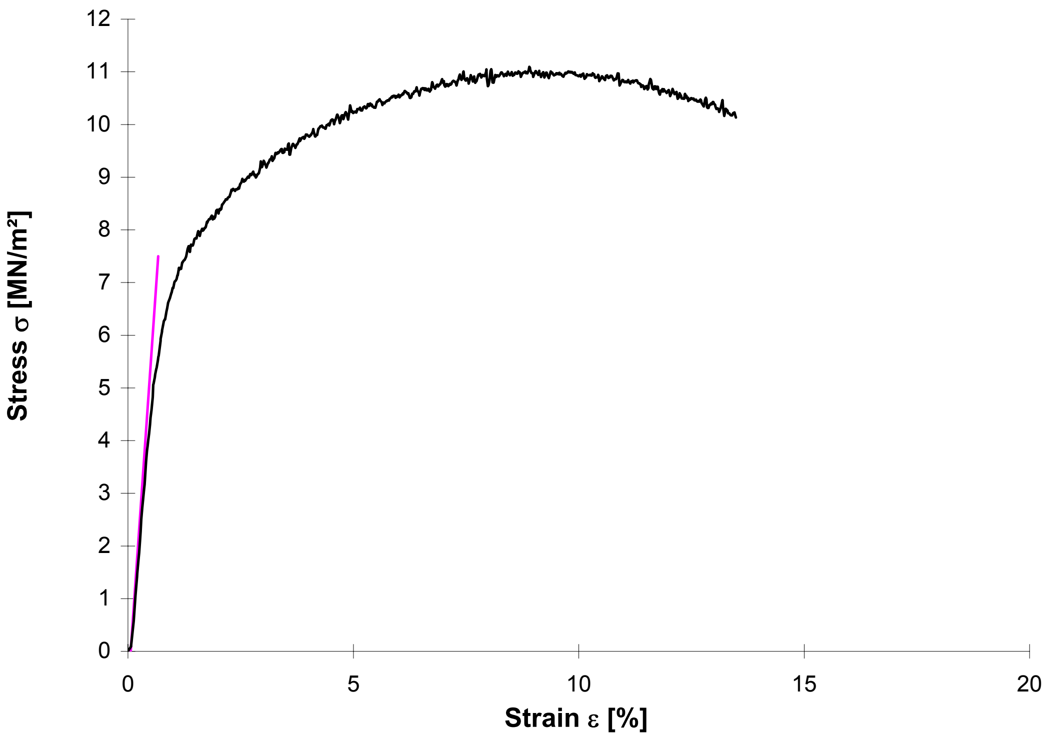
Technician:	Project-no.:	Attachment:
Fe	86804	**2.3.5**
Engineer:	Date:	
Ha	04-05	

Specimen

Specimen no.		**16572-10**
Layer/ Material		SM
Type of specimen		undisturbed
Borehole no.		P5-04
Depth	[FT BGS]	175,0-176,0

Uniaxial Compressive Strength

Date		########
Weight	[g]	1751,00
Height	[cm]	14,94
Diameter	[cm]	8,4
Ratio		1,78
Area	[cm²]	55,42
Volume	[cm³]	827,94
Density	[g/cm³]	2,11
Moisture content	[%]	17,1
Dry density	[g/cm³]	1,81
Constant strain rate	[mm/min]	1,494
Temperature	[°C]	-20
UCS	**[MN/m²]**	**11,1**
Deformation at failure	**[%]**	**8,9**
Tangent Modulus	**[MN/m²]**	**1230**



Note:

Client:
King County WTD

Project:
Brightwater Conveyance System

CDM

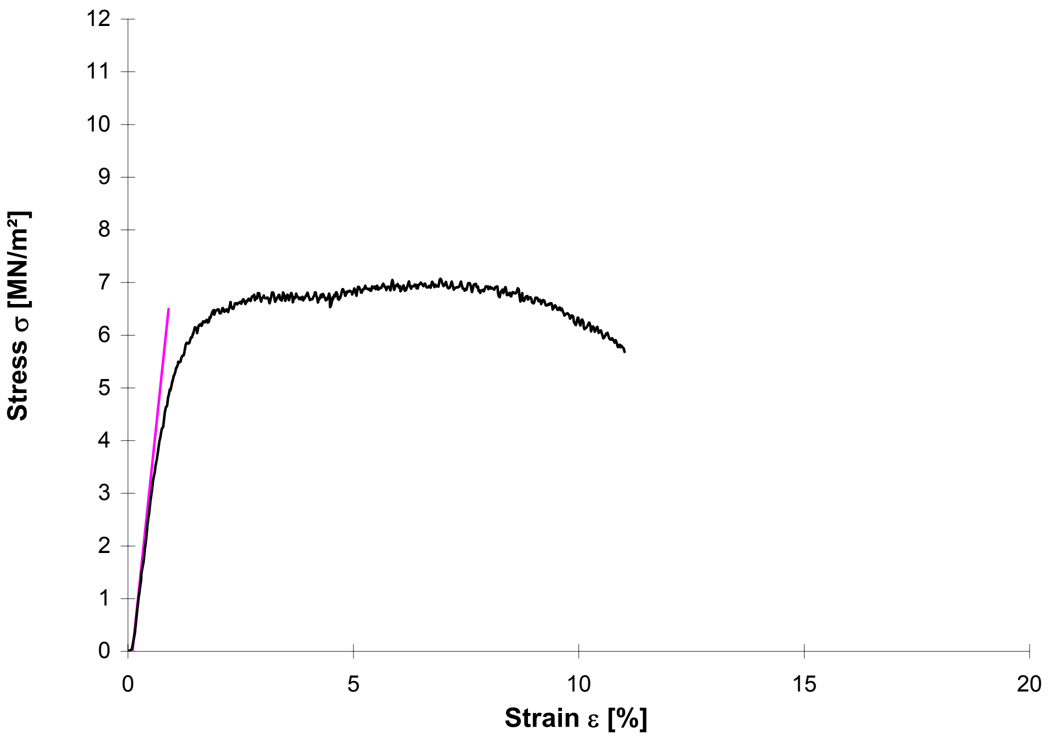
Determination of the Uniaxial Compressive Strength (UCS) T = -20 °C	Technician: Fe	Project-no.: 86804	Attachment: **2.3.6**
	Engineer: Ha	Date: 04-05	

Specimen

Specimen no.		**16572-11**
Layer/ Material		SM
Type of specimen		undisturbed
Borehole no.		P5-04
Depth	[FT BGS]	144,0-145,0

Uniaxial Compressive Strength

Date		########
Weight	[g]	1756,00
Height	[cm]	14,36
Diameter	[cm]	8,4
Ratio		1,71
Area	[cm²]	55,42
Volume	[cm³]	795,80
Density	[g/cm³]	2,21
Moisture content	[%]	15,4
Dry density	[g/cm³]	1,91
Constant strain rate	[mm/min]	1,436
Temperature	[°C]	-20
UCS	**[MN/m²]**	**7,1**
Deformation at failure	**[%]**	**6,9**
Tangent Modulus	**[MN/m²]**	**813**



Note:

Client:
King County WTD

Project:
Brightwater Conveyance System

CDM

Determination of the Uniaxial Compressive Strength (UCS) T = -20 °C	Technician: Fe	Project-no.: 86804	Attachment: **2.3.7**
	Engineer: Ha	Date: 04-05	

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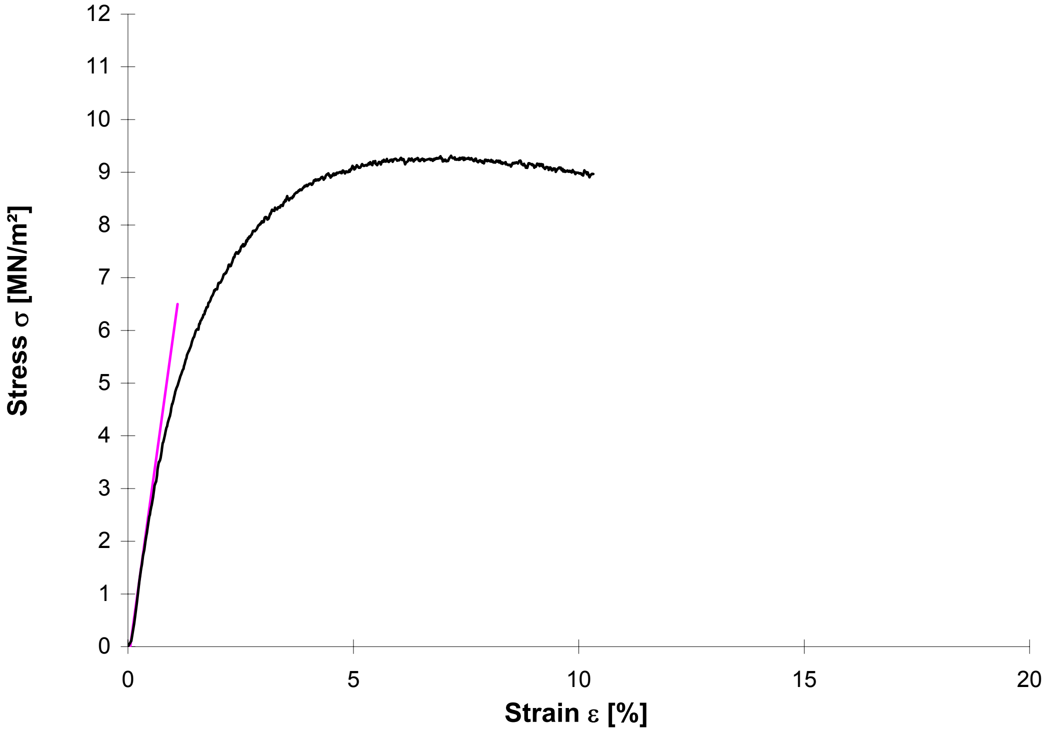
Specimen

Specimen no.		**16572-12**
Layer/ Material		SM
Type of specimen		remolded
Borehole no.		P5-04
Depth	[FT BGS]	166,0-168,5

Uniaxial Compressive Strength

Date		########
Weight	[g]	4008,00
Height	[cm]	21,00
Diameter	[cm]	10,58
Ratio		1,98
Area	[cm²]	87,91
Volume	[cm³]	1846,21
Density	[g/cm³]	2,17
Moisture content	[%]	11,0
Dry density	[g/cm³]	1,96
Constant strain rate	[mm/min]	2,100
Temperature	[°C]	-20
UCS	**[MN/m²]**	**9,3**
Deformation at failure	**[%]**	**7,2**
Tangent Modulus	**[MN/m²]**	**619**

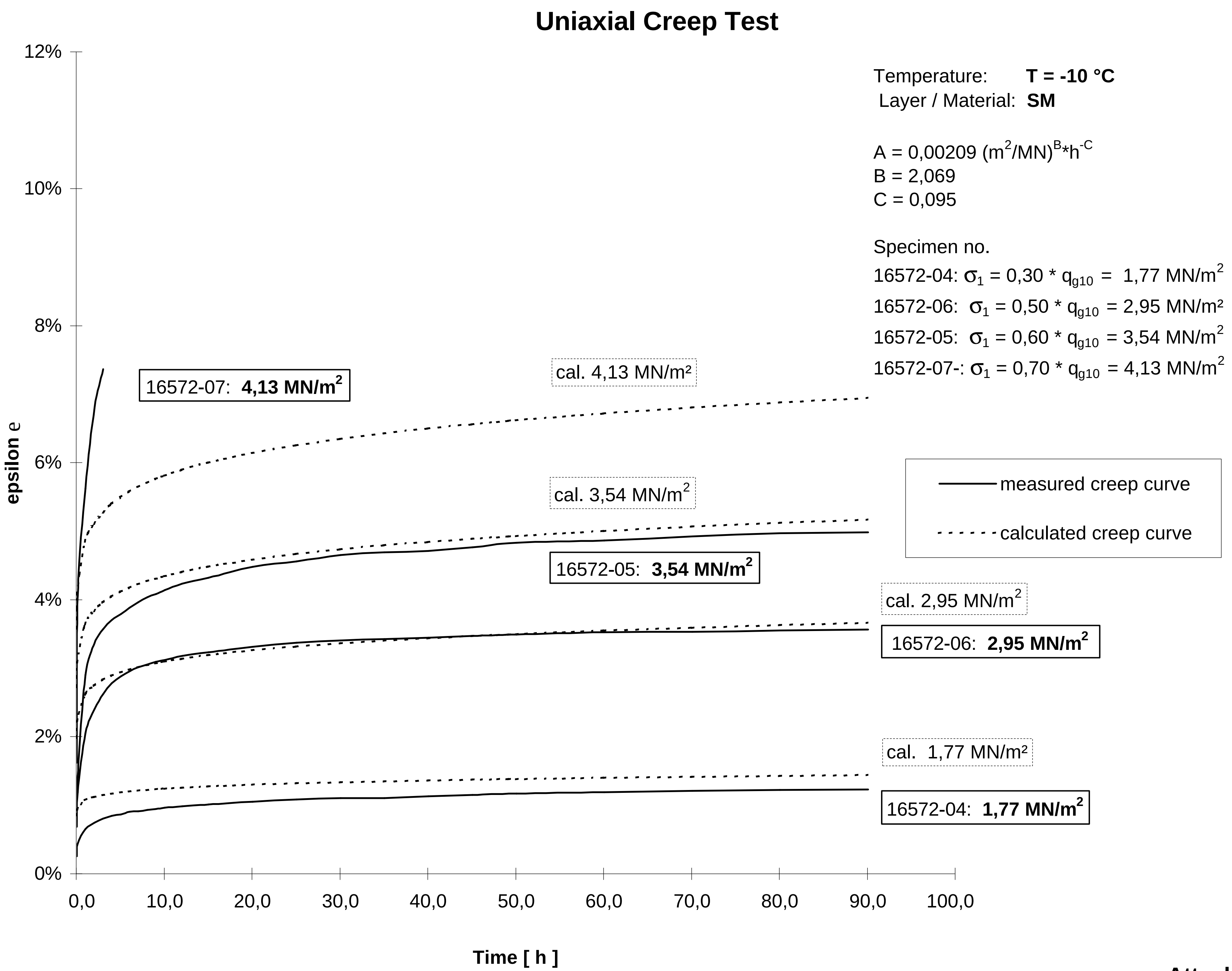


Note:

Client:
King County WTD

Project:
Brightwater Conveyance System

Determination of the Uniaxial Compressive Strength (UCS) T = -20 °C	Technician: Fe	Project-no.: 86804	Attachment: **2.3.8**
	Engineer: Ha	Date: 04-05	



Attachment 2.4

Laboratory test results: Layer CL

project: Brightwater Conveyance System

		specimen no.		classification	grain size distribution					density			water saturation	moisture content	porosity	T= -10						T= -20
boring no.	depth		Layer		clay	silt	sand	gravel	stones	specific gravity	wet soil	dry soil				UCS_{f10}	TCT_{f10}		UCT_{f10}			UCS_{f20}
					<0,002 mm	0,002 to 0,063 mm	0,063 to 2,0 mm	2,0 to 63 mm	> 63 mm	ρ_s	ρ	ρ_d	S_r	w	n	q_{f10}	φ_{f10}	c_{f10}	A	B	C	q_{f20}
	FT BGS				%					t/m³	t/m³	t/m³		%		MN/m^2	°	MN/m^2	$(m^2/MN)^2xh^{-c}$			MN/m^2
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
P5-04	194,1 - 195,1	16573-01	CL							2,70	1,98	1,59	0,95	24,6	0,41	7,4						
P5-04	200,7 - 201,7	16573-02	CL		14,1	51,5	29,8	4,5		2,70	1,96	1,54	0,98	27,3	0,43	4,2						
P5-04	204,1- 205,1	16573-07	CL							2,70	1,92	1,52	0,93	26,6	0,44	4,1						
P5-04	222,5- 223,5	16573-09	CL							2,70	2,01	1,58	1,04	27,4	0,41	3,9						
P5-04	218,0 - 219,0	16573-03	CL							2,70	1,95	1,54	0,96	26,8	0,43				0,0070	1,330	0,125	
P5-04	218,0 - 219,0	16573-04	CL							2,70	1,98	1,57	0,97	25,9	0,42				0,0070	1,330	0,125	
P5-04	214,7- 215,7	16573-05	CL							2,70	2,01	1,58	1,04	27,2	0,41				0,0070	1,330	0,125	
P5-04	215,7- 216,7	16573-06	CL							2,70	1,97	1,56	0,98	26,5	0,42				0,0070	1,330	0,125	
P5-04	213,7- 214,7	16573-08	CL							2,70	1,98	1,53	1,03	29,2	0,43		25,1	1,3				
P5-04	183,0- 223,5	16573-10*	CL							2,70	2,03	1,61	1,03	25,8	0,40		25,1	1,3				
P5-04	183,0- 223,5	16573-11*	CL							2,70	1,98	1,57	0,97	25,9	0,42		25,1	1,3				
P5-04	183,0- 223,5	16573-13*	CL							2,70	2,02	1,60	1,01	25,8	0,41		25,1	1,3				

Laboratory test results: Layer CL

project: Brightwater Conveyance System

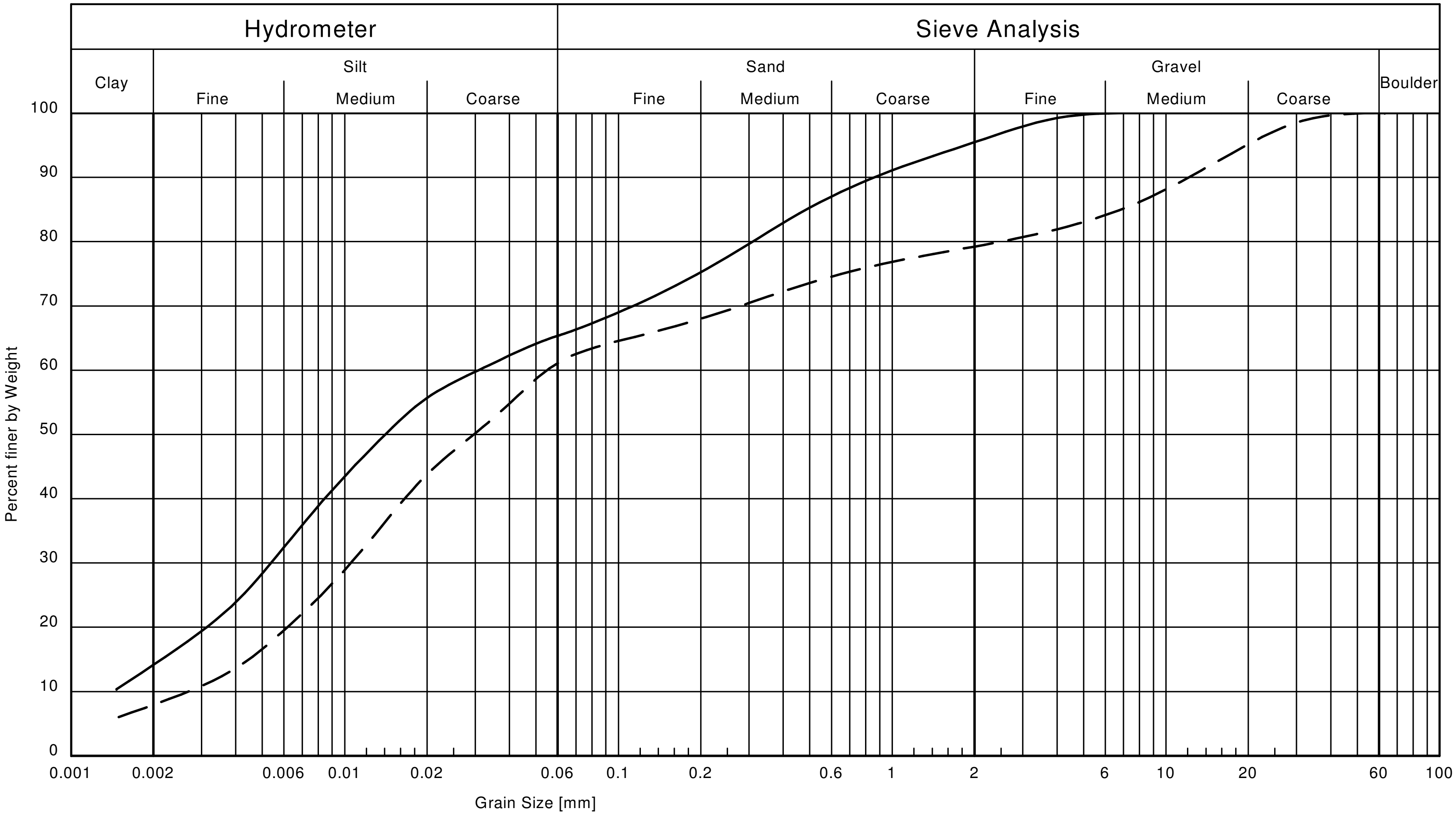
		specimen no.		classification	grain size distribution					density			water saturation	moisture content	porosity	T= -10						T= -20
boring no.	depth		Layer		clay	silt	sand	gravel	stones	specific gravity	wet soil	dry soil				UCS_{f10}	TCT_{f10}		UCT_{f10}			UCS_{f20}
					<0,002 mm	0,002 to 0,063 mm	0,063 to 2,0 mm	2,0 to 63 mm	> 63 mm	ρ_s	ρ	ρ_d	S_r	w	n	q_{f10}	φ_{f10}	c_{f10}	A	B	C	q_{f20}
	FT BGS				%					t/m³	t/m³	t/m³		%		MN/m^2	°	MN/m^2	$(m^2/MN)^2 xh^{-c}$			MN/m^2
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
P5-04	183,0-184,0	16573-14	CL							2,70	2,04	1,68	0,96	21,5	0,38							4,9
P5-04	183,0-184,0	16573-15	CL							2,70	2,05	1,69	0,96	21,2	0,37							3,7
P5-04	195,1-196,1	16573-16	CL							2,70	2,04	1,62	1,05	25,9	0,40							6,6
P5-04	205,7-206,7	16573-17	CL							2,70	1,88	1,46	0,91	28,5	0,46							6,9
P5-04	183,0 - 223,5	16573-b	CL		7,9	53,7	17,6	20,8														

*: remolded

GRAIN SIZE CURVE

Client: King County WTD

Project: Brightwater Conveyance System



Signature	————	— — —
Specim. No	16573 - 02	16573 - b
Depth [ft BGS]	200,70 - 201,70	183,0 - 223,5
Location	P 5 - 04	P 5 - 04
Layer	CL	CL
Amount of Clay/Silt/Sand/Gravel	14.1/51.5/29.8/4.5	7.9/53.7/17.6/20.8

Technician: Fe

Project-No.: 86804

Engineer: Ha

Date: 05-05

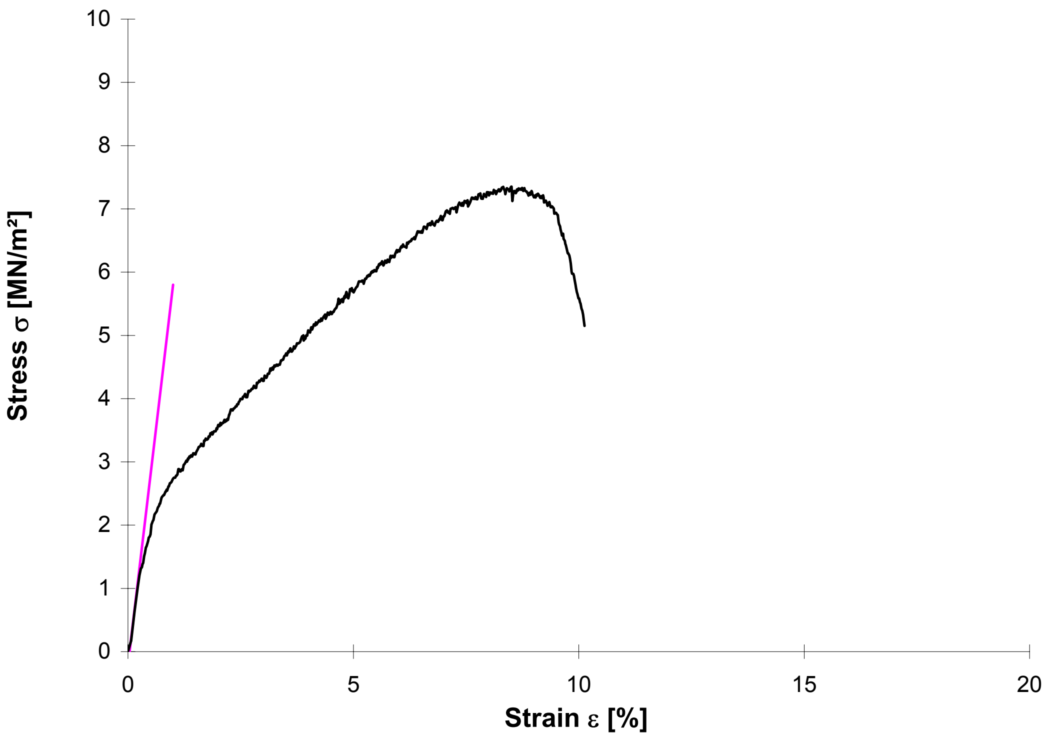
Attachment: 3.2

Specimen

Specimen no.		**16573-01**
Layer/ Material		CL
Type of specimen		undisturbed
Borehole no.		P5-04 A
Depth	[FT BGS]	194,1 - 195,1

Uniaxial Compressive Strength

Date		########
Weight	[g]	2029,00
Height	[cm]	18,04
Diameter	[cm]	8,51
Ratio		2,12
Area	[cm²]	56,88
Volume	[cm³]	1026,09
Density	[g/cm³]	1,98
Moisture content	[%]	24,6
Dry density	[g/cm³]	1,59
Constant strain rate	[mm/min]	1,804
Temperature	[°C]	-10
UCS	**[MN/m²]**	**7,4**
Deformation at failure	**[%]**	**8,5**
Tangent Modulus	**[MN/m²]**	**601**



Note:

drop stones

Client:

King County WTD

Project:

Brightwater Conveyance System

CDM

Determination of the Uniaxial Compressive Strength (UCS) T = -10 °C

Technician:	Project-no.:	Attachment:
Fe	86804	**3.3.1**
Engineer: Ha	Date: 03-05	

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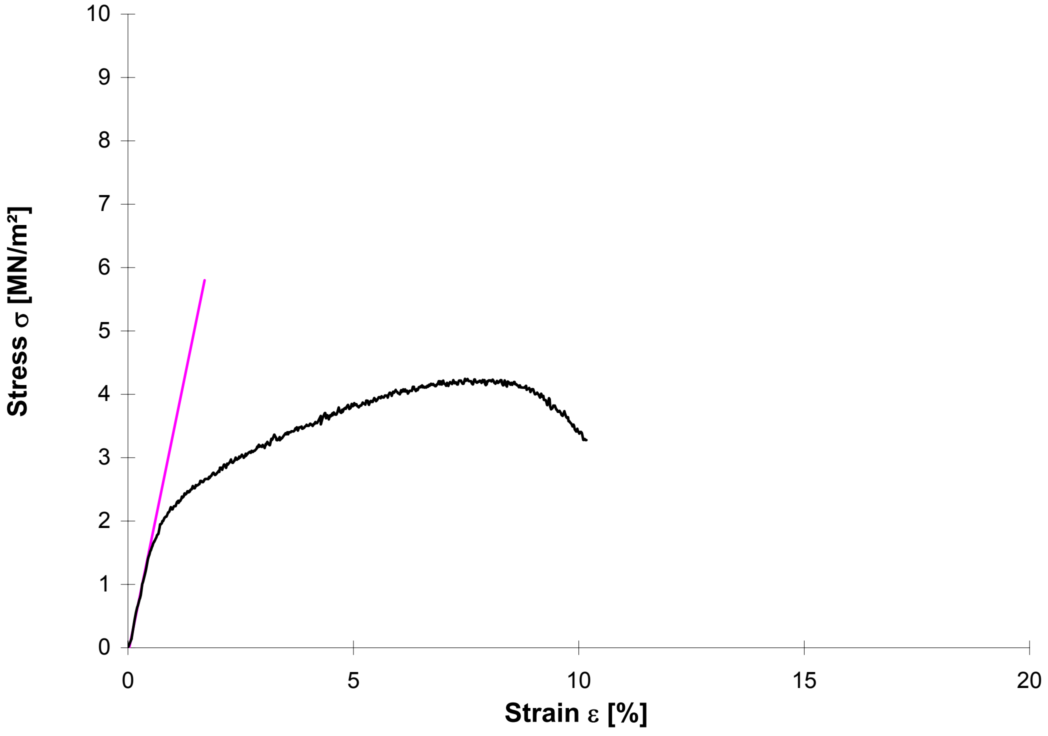
Specimen

Specimen no.		**16573-02**
Layer/ Material		CL
Type of specimen		undisturbed
Borehole no.		P5-04 A
Depth	[FT BGS]	200,7 - 201,7

Uniaxial Compressive Strength

Date		########
Weight	[g]	2039,00
Height	[cm]	18,07
Diameter	[cm]	8,56
Ratio		2,11
Area	[cm²]	57,55
Volume	[cm³]	1039,91
Density	[g/cm³]	1,96
Moisture content	[%]	27,3
Dry density	[g/cm³]	1,54
Constant strain rate	[mm/min]	1,807
Temperature	[°C]	-10
UCS	**[MN/m²]**	**4,2**
Deformation at failure	**[%]**	**7,5**
Tangent Modulus	**[MN/m²]**	**347**



Note:

Client:
King County WTD

Project:
Brightwater Conveyance System

CDM

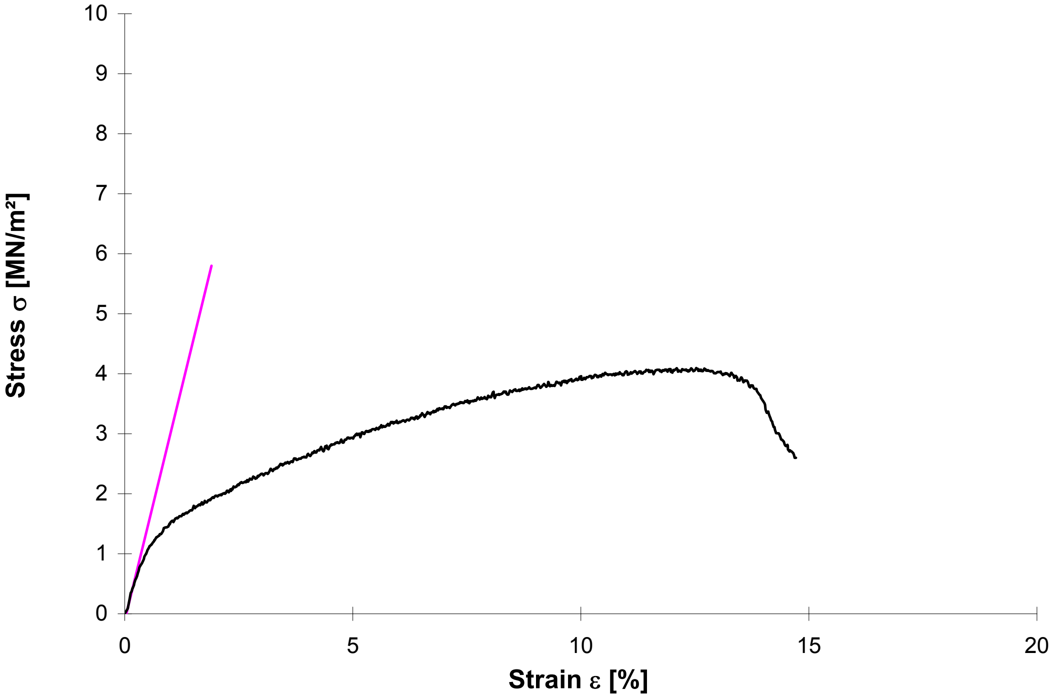
Determination of the Uniaxial Compressive Strength (UCS) T = -10 °C	Technician: Fe	Project-no.: 86804	Attachment: **3.3.2**
	Engineer: Ha	Date: 03-05	

Specimen

Specimen no.		**16573-07**
Layer/ Material		CL
Type of specimen		undisturbed
Borehole no.		P5-04 A
Depth	[FT BGS]	204,1-205,1

Uniaxial Compressive Strength

Date		16.03.2005
Weight	[g]	2011,10
Height	[cm]	18,45
Diameter	[cm]	8,5
Ratio		2,17
Area	[cm²]	56,74
Volume	[cm³]	1046,94
Density	[g/cm³]	1,92
Moisture content	[%]	26,6
Dry density	[g/cm³]	1,52
Constant strain rate	[mm/min]	1,845
Temperature	[°C]	-10
UCS	**[MN/m²]**	**4,1**
Deformation at failure	**[%]**	**12,5**
Tangent Modulus	**[MN/m²]**	**311**



Note:

Client: King County WTD

Project: Brightwater Conveyance System

CDM

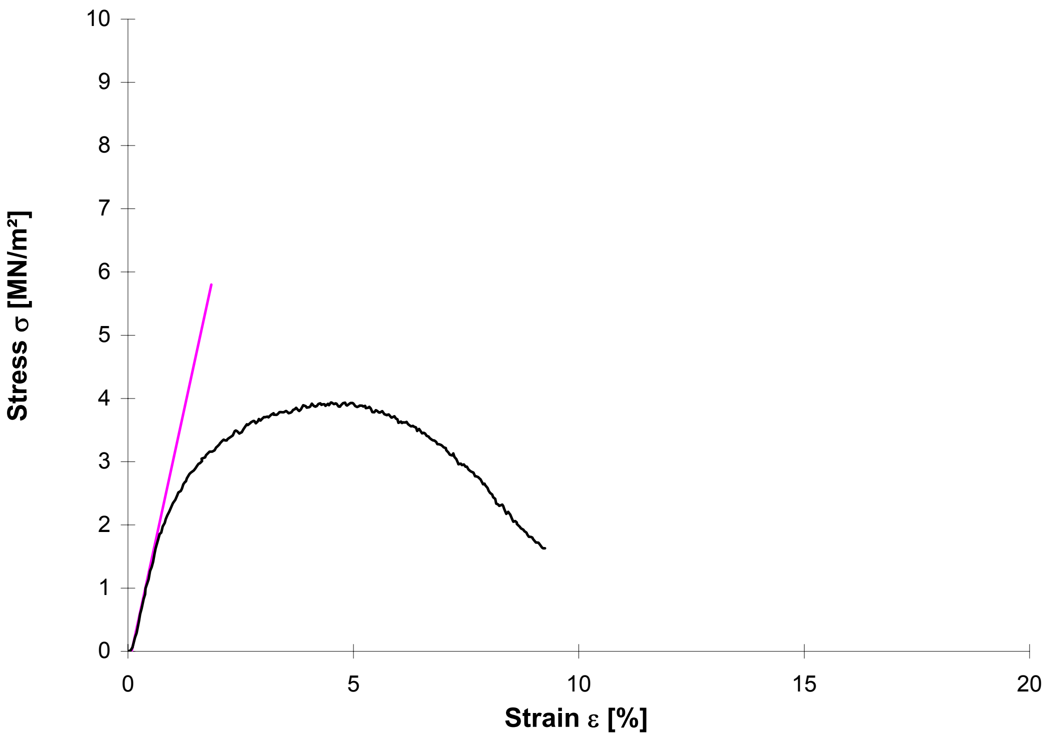
Determination of the Uniaxial Compressive Strength (UCS) T = -10 °C	Technician: Fe	Project-no.: 86804	Attachment: 3.3.3
	Engineer: Ha	Date: 03-05	

Specimen

Specimen no.		**16573-09**
Layer/ Material		CL
Type of specimen		undisturbed
Borehole no.		P5-04
Depth	[FT BGS]	222,5 - 223,5

Uniaxial Compressive Strength

Date		########
Weight	[g]	2094,00
Height	[cm]	17,9
Diameter	[cm]	8,6
Ratio		2,08
Area	[cm²]	58,09
Volume	[cm³]	1039,78
Density	[g/cm³]	2,01
Moisture content	[%]	27,4
Dry density	[g/cm³]	1,58
Constant strain rate	[mm/min]	1,790
Temperature	[°C]	-10
UCS	**[MN/m²]**	**3,9**
Deformation at failure	**[%]**	**4,5**
Tangent Modulus	**[MN/m²]**	**328**



Note:

Client: King County WTD

Project: Brightwater Conveyance System

CDM

Determination of the Uniaxial Compressive Strength (UCS) T = -10 °C

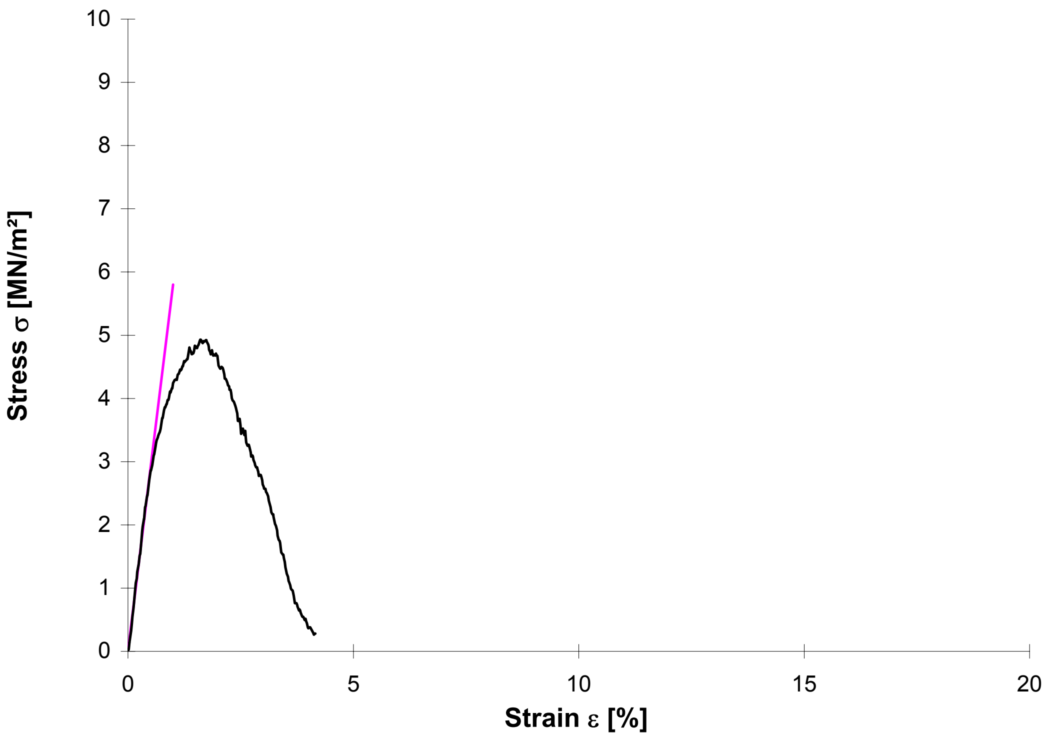
Technician:	Project-no.:	Attachment:
Fe	86804	**3.3.4**
Engineer:	Date:	
Ha	03-05	

Specimen

Specimen no.		**16573-14**
Layer/ Material		CL
Type of specimen		undisturbed
Borehole no.		P5-04
Depth	[FT BGS]	183,0-184,0

Uniaxial Compressive Strength

Date		########
Weight	[g]	2182,00
Height	[cm]	18,4
Diameter	[cm]	8,6
Ratio		2,14
Area	[cm²]	58,09
Volume	[cm³]	1068,82
Density	[g/cm³]	2,04
Moisture content	[%]	21,5
Dry density	[g/cm³]	1,68
Constant strain rate	[mm/min]	1,840
Temperature	[°C]	-20
UCS	**[MN/m²]**	**4,9**
Deformation at failure	**[%]**	**1,6**
Tangent Modulus	**[MN/m²]**	**580**



Note:

slickensides

Client: King County WTD

Project: Brightwater Conveyance System

CDM

Determination of the Uniaxial Compressive Strength (UCS) T = -20 °C

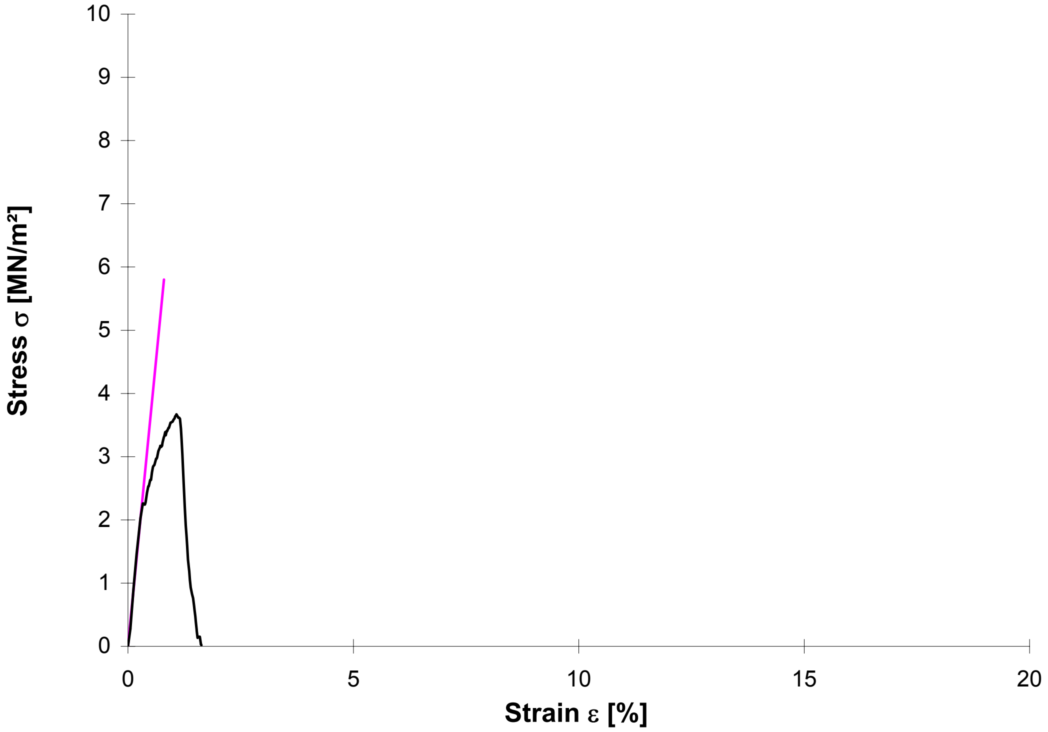
Technician:	Project-no.:	Attachment:
Fe	86804	**3.3.5**
Engineer: Ha	Date: 04-05	

Specimen

Specimen no.		**16573-15**
Layer/ Material		CL
Type of specimen		undisturbed
Borehole no.		P5-04
Depth	[FT BGS]	183,0-184,0

Uniaxial Compressive Strength

Date		########
Weight	[g]	2198,00
Height	[cm]	18,4
Diameter	[cm]	8,61
Ratio		2,14
Area	[cm²]	58,22
Volume	[cm³]	1071,31
Density	[g/cm³]	2,05
Moisture content	[%]	21,2
Dry density	[g/cm³]	1,69
Constant strain rate	[mm/min]	1,840
Temperature	[°C]	-20
UCS	**[MN/m²]**	**3,7**
Deformation at failure	**[%]**	**1,1**
Tangent Modulus	**[MN/m²]**	**725**



Note:

slickensides

Client: King County WTD

Project: Brightwater Conveyance System

CDM

Determination of the Uniaxial Compressive Strength (UCS) T = -20 °C

Technician:	Project-no.:	Attachment:
Fe	86804	**3.3.6**
Engineer: Ha	Date: 04-05	

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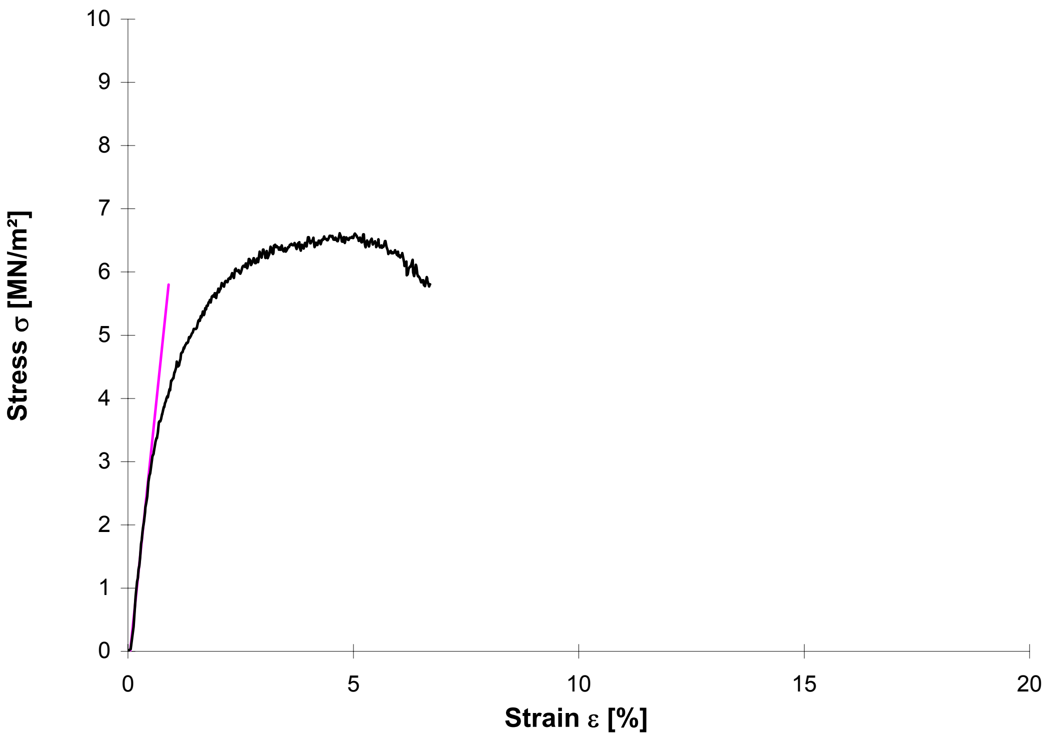
Specimen

Specimen no.		**16573-16**
Layer/ Material		CL
Type of specimen		undisturbed
Borehole no.		P5-04
Depth	[FT BGS]	195,1-196,1

Uniaxial Compressive Strength

Date		########
Weight	[g]	2158,00
Height	[cm]	18,65
Diameter	[cm]	8,5
Ratio		2,19
Area	[cm²]	56,74
Volume	[cm³]	1058,29
Density	[g/cm³]	2,04
Moisture content	[%]	25,9
Dry density	[g/cm³]	1,62
Constant strain rate	[mm/min]	1,865
Temperature	[°C]	-20
UCS	**[MN/m²]**	**6,6**
Deformation at failure	**[%]**	**4,7**
Tangent Modulus	**[MN/m²]**	**682**



Note:

Client:
King County WTD

Project:
Brightwater Conveyance System

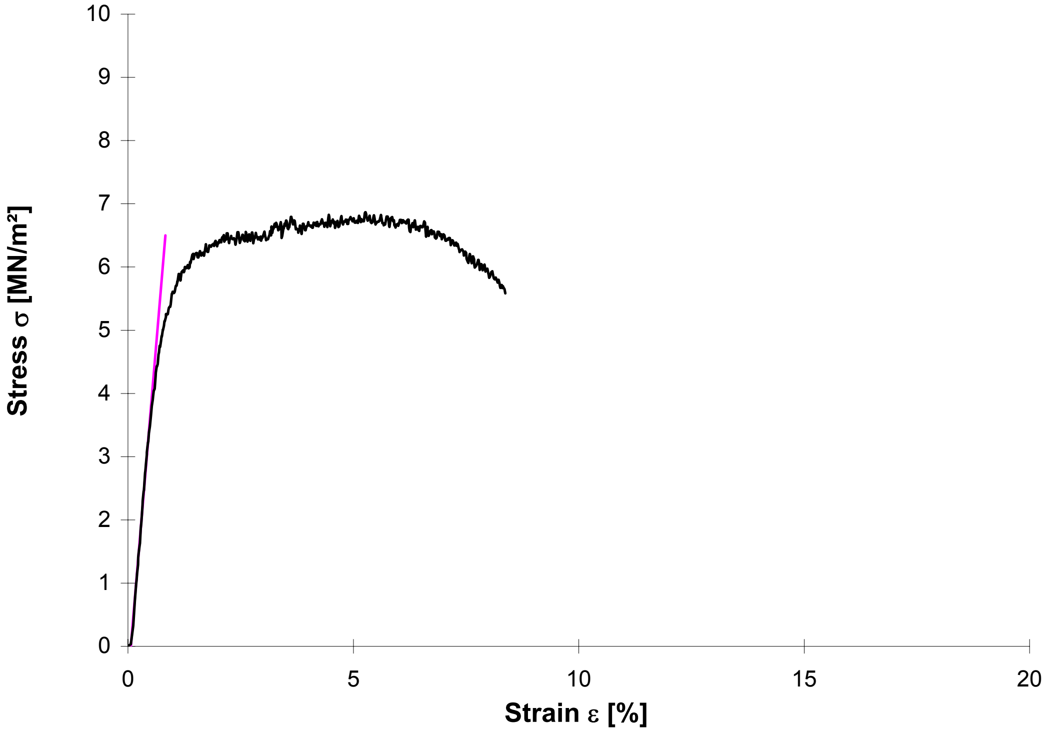
Determination of the Uniaxial Compressive Strength (UCS) T = -20 °C	Technician: Fe	Project-no.: 86804	Attachment: **3.3.7**
	Engineer: Ha	Date: 04-05	

Specimen

Specimen no.		**16573-17**
Layer/ Material		CL
Type of specimen		undisturbed
Borehole no.		P5-04
Depth	[FT BGS]	205,1-206,1

Uniaxial Compressive Strength

Date		########
Weight	[g]	2059,00
Height	[cm]	18,9
Diameter	[cm]	8,6
Ratio		2,20
Area	[cm²]	58,09
Volume	[cm³]	1097,86
Density	[g/cm³]	1,88
Moisture content	[%]	28,5
Dry density	[g/cm³]	1,46
Constant strain rate	[mm/min]	1,890
Temperature	[°C]	-20
UCS	**[MN/m²]**	**6,9**
Deformation at failure	**[%]**	**5,3**
Tangent Modulus	**[MN/m²]**	**850**



Note:

Client:
King County WTD

Project:
Brightwater Conveyance System

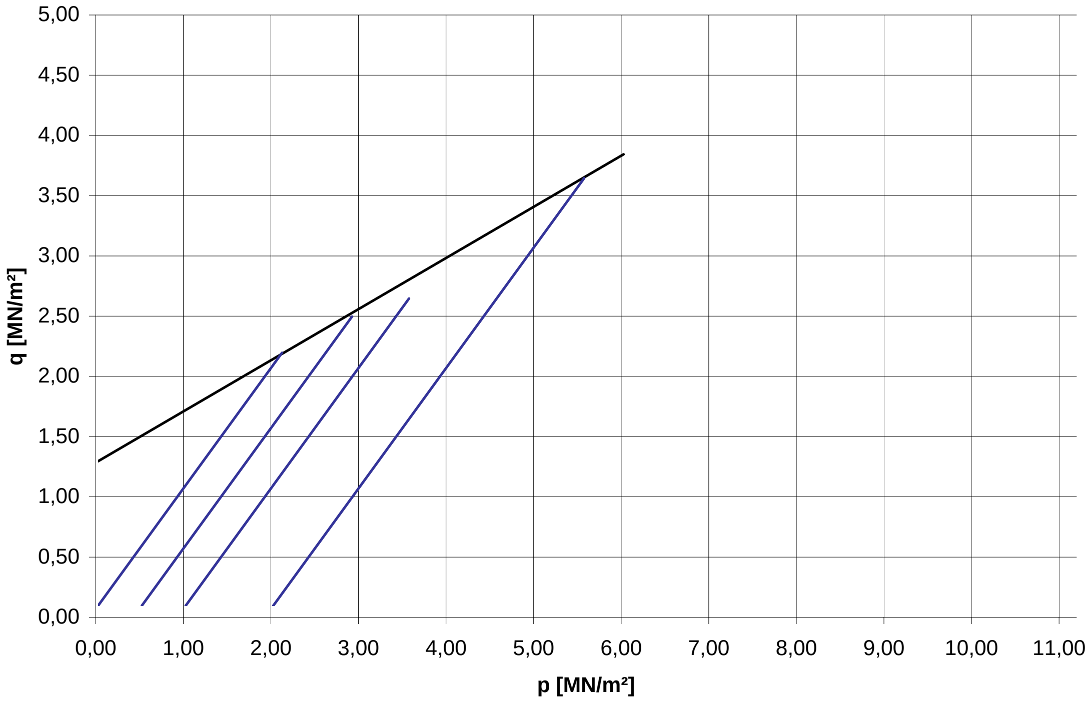
Determination of the Uniaxial Compressive Strength (UCS) T = -10 °C	Technician: Fe	Project-no.: 86804	Attachment: **3.3.8**
	Engineer: Ha	Date: 04-05	

Specimen

		16573-11	16573-10	16573-13	16573-08
Specimen no.		**16573-11**	**16573-10**	**16573-13**	**16573-08**
Layer/ Material		CL	CL	CL	CL
Type of specimen		remolded	remolded	remolded	undisturbed
Borehole no.		P5-04	P5-04	P5-04	P5-04
Depth	[m]	183,0-223,5	183,0-223,5	183,0-223,5	134,0-135,0
s3	**[MN/m²]**	**1,0**	**0,0**	**2,0**	**0,5**
Date		18.03.2005	21.03.2005	16.03.2005	14.03.2005
Weight	[g]	424,0	409,0	411,0	441,7
Height	[cm]	10,00	9,50	9,48	11,11
Diameter	[cm]	5,22	5,20	5,23	5,06
Ratio	[-]	1,92	1,83	1,81	2,20
Area	[cm²]	21,40	21,24	21,48	20,11
Volume	[cm³]	214,01	201,75	203,66	223,41
Density	[g/cm³]	1,98	2,03	2,02	1,98
Moisture content	[%]	25,9	25,8	25,8	29,2
Dry density	[g/cm³]	1,57	1,61	1,60	1,53
Constant strain rate	[mm/min]	0,100	0,095	0,095	0,111
Temperature	[°C]	**-10**	**-10**	**-10**	**-10**

j **[°] : 25,1**

c [MN/m²] : 1,33



Note:

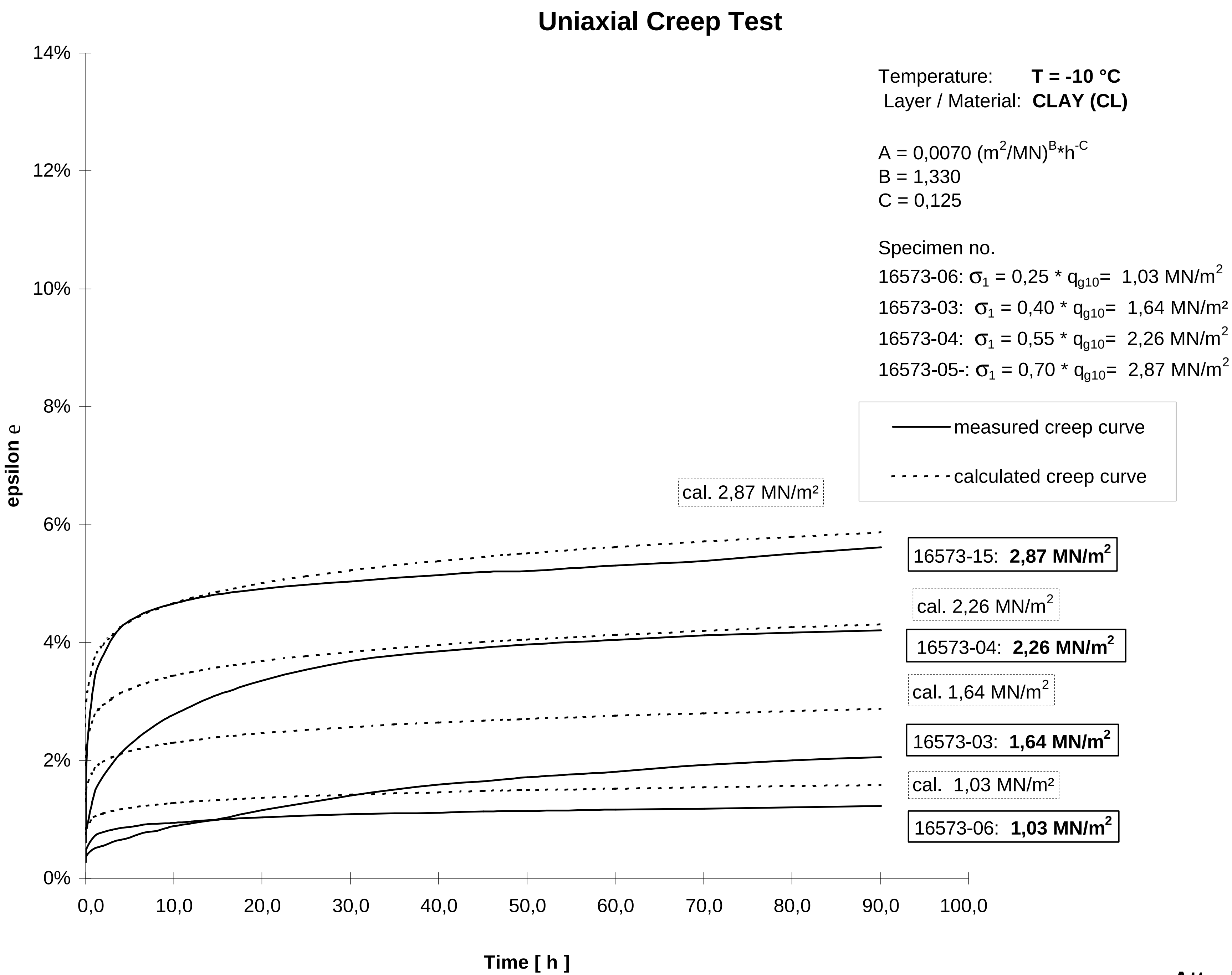
Client:
King County WTD

Project:
Brightwater Conveyance System

CDM

Determination of the Triaxial Compressive Strength (TCS) T = -10 °C

Technician:	Project-no.:	Attachment:
Rc	86804	**3.4**
Engineer: We	Date: 02/05	



Attachment 3.5

Evaluation of the salinity of groundwater

water sample

Lab-no.: B5A0319-01

location: P5-01

1	2	3	4	5	6	7	8	9	10	11	12	13
		cations [mval/l] (+)				anions [mval/l] (-)			salt concentration		molecular weight	salt content
		Na	K	Ca	Mg	Cl	SO_4	HCO_3	[mval/l]	[mmol/l]	[g/mmol]	[g/l]
amount	[mg/l]	24,1	3,88	13,5	3,61	2,52	3	86,9				
Val-weight	mg/mval	22,99	39,10	20,04	12,16	35,50	48,00	61,00				
equiva-lencecon-centra-tion [mval/l]	single value	1,05	0,10	0,67	0,30	0,07	0,06	1,42				
	sum		2,12				1,56					
	adjust. value	1,05	0,10	0,67	0,30	0,10	0,08	1,94				
	sum		2,12				2,12					
salt	[mval/l]											
NaCl	0,10	0,95				0,00			0,10	0,10	0,0585	0,01
KCl	0,00		0,10			0,00			0,00	0,00	0,0746	0,00
$CaCl_2$	0,00			0,67		0,00			0,00	0,00	0,1110	0,00
$MgCl_2$	0,00				0,30	0,00			0,00	0,00	0,0953	0,00
Na_2SO_4	0,08	0,87					0,00		0,08	0,04	0,1420	0,01
K_2SO_4	0,00		0,10				0,00		0,00	0,00	0,1742	0,00
Na_2CO_3	0,87	0,00						1,07	0,87	0,43	0,1060	0,05
K_2CO_3	0,10		0,00					0,97	0,10	0,05	0,1382	0,01
$MgS0_4$	0,00				0,30		0,00		0,00	0,00	0,1203	0,00
$CaSO_4$	0,00			0,67			0,00		0,00	0,00	0,1361	0,00
$MgCO_3$	0,30				0,00			0,67	0,30	0,15	0,0843	0,01
$CaCO_3$	0,67			0,00				0,00	0,67	0,34	0,1001	0,03
									total salt content			**0,11**

Attachment 4

Brightwater Groundfreezing, Portal 5

Determination of thermal conductivity and heat capacity according to Johansen					
Layer			**SM**	**ML**	**CL**
Soil Parameter Values for Groundfreezing					
Depth (ft)			144 to 179	79,2 to 136,0	183,0 to 223,5
remark			Sr assumed = 1,0	Sr assumed = 1,0	Sr assumed = 1,0
input data					
dry unit weight [1)]	Rho-d	[t/m³]	1,95	1,45	1,60
unit weight of soil particles [2)]	Rho-s	[t/m³]	2,65	2,68	2,70
nat. moisture content [3)]	w	[%]	13,5	31,8	25,5
amount of clay (< 0,002 mm) [1)]		[%]	5	10	14
amount of particles < 0,02 mm [1)]		[%]	25	60	55
calculated values					
wet unit weight	Rho-f	[t/m³]	2,21	1,91	2,01
porosity	n	[-]	0,26	0,46	0,41
water saturation [2)]	Sr	[-]	1,00	1,00	1,00
dry thermal conductivity	k°	[W/mK]	0,56	0,17	0,22
thermal conductivity of particles	ks	[W/mK]	3,00	3,00	3,00
saturated th. conductivity, unfrozen	k1u	[W/mK]	1,93	1,40	1,53
saturated th. conductivity, frozen	k1f	[W/mK]	2,80	2,66	2,69
Kersten value, unfrozen	Ke	[-]	1,00	1,00	1,00
Kersten value, frozen	Ke	[-]	1,00	1,00	1,00
calculated thermal parameters					
thermal conductivity, unfrozen	ku	[W/mK]	1,93	1,40	1,53
thermal conductivity, frozen	kf	[W/mK]	2,79	2,67	2,70
thermal conductivity, unfrozen	ku	[kJ/h mK]	6,96	5,05	5,49
thermal conductivity, frozen	kf	[kJ/h mK]	10,04	9,60	9,70
heat capacity, unfrozen	cu	[kJ/m³K]	2.744	3.155	3.058
heat capacity, frozen	cf	[kJ/m³K]	2.191	2.186	2.201
thermal conductivity, unfrozen	ku	[kcal/h mK]	1,66	1,21	1,31
thermal conductivity, frozen	kf	[kcal/h mK]	2,40	2,29	2,32
heat capacity, unfrozen	cu	[kcal/m³K]	656	754	731
heat capacity, frozen	cf	[kcal/m³K]	524	523	526
thermal conductivity, unfrozen	ku	[B/ft hr°F]	1,12	0,81	0,88
thermal conductivity, frozen	kf	[B/ft hr°F]	1,61	1,54	1,56
heat capacity, unfrozen	ku	[B/ft³hr°F]	40,98	47,12	45,67
heat capacity, frozen	kf	[B/ft³hr°F]	32,73	32,66	32,87

Notes

1) based on lab tests

2) assumption

3) calculated for a water saturation of 100 % (Sr = 1)

Time Dependent Frozen Soil Parameter

		short term values (lab conditions)		time dependent values											
layer	temperature	uniaxial compressive strength	shear parameter	Young's modulus of elasticity				compressive strength [2] (allowable)				cohesion (allowable)			
	T °C	q_f MN/m² UCS_f	j_f / c_f [1] ° / MN/m²	$E_f(t)$ MN/m²				$S_P(t)$ [4] MN/m²				$c_f(t)$ [3] MN/m²			
				1 week	3 weeks	6 weeks	3 months	1 week	3 weeks	6 weeks	3 months	1 week	3 weeks	6 weeks	3 months
SM	-10	5,9	30 / 1,7 (estimated)	135	130	125	120	1,90	1,80	1,75	1,70	0,55	0,52	0,51	0,49
ML	-10	5,8	28 / 1,7	245	230	225	220	1,80	1,70	1,65	1,55	0,54	0,51	0,50	0,47
CL	-10	4,1	25 / 1,3	105	100	90	85	1,10	1,00	0,95	0,90	0,35	0,32	0,30	0,29
SM	-20	9,5	30 / 2,7 (estimated)	225	215	210	205	3,05	2,90	2,80	2,70	0,88	0,84	0,81	0,78
ML	-20	8,0	28 / 2,4	325	310	300	290	2,50	2,35	2,25	2,15	0,75	0,71	0,68	0,65
CL	-20	6,8	25 / 2,2	190	170	160	150	1,90	1,75	1,65	1,50	0,61	0,56	0,53	0,48

[1] friction angle φ_f = time independent
[2] tensile strength $\sigma_T(t) = 0,2\ \sigma_P(t)$
[3] cohesion c_f is calculated based on Mohr-Coulomb using the respective $\sigma_P(t)$ and φ_f
[4] allowable $\sigma_P(t)$ MN/m² contains a safety factor of $s_f = 2$

Time Dependent Frozen Soil Parameter															
		short term values (lab conditions)		time dependent values											
layer	temperature	uniaxial compressive strength	shear parameter	Young's modulus of elasticity				compressive strength [2)] (at failure)				cohesion (at failure)			
	T °C	q_f MN/m² UCS_f	j_f / c_f [1)] ° / MN/m²	$E_f(t)$ MN/m²				$s_P(t)$ MN/m²				$c_f(t)$ [3)] MN/m²			
				1 week	3 weeks	6 weeks	3 months	1 week	3 weeks	6 weeks	3 months	1 week	3 weeks	6 weeks	3 months
SM	-10	5,9	30 / 1,7 (estimated)	135	130	125	120	3,8	3,6	3,5	3,4	1,10	1,04	1,01	0,98
ML	-10	5,8	28 / 1,7	245	230	225	220	3,6	3,4	3,3	3,1	1,08	1,02	0,99	0,93
CL	-10	4,1	25 / 1,3	105	100	90	85	2,2	2,0	1,9	1,8	0,70	0,64	0,61	0,57
SM	-20	9,5	30 / 2,7 (estimated)	225	215	210	205	6,1	5,8	5,6	5,4	1,76	1,67	1,62	1,56
ML	-20	8,0	28 / 2,4	325	310	300	290	5,0	4,7	4,5	4,3	1,50	1,41	1,35	1,29
CL	-20	6,8	25 / 2,2	190	170	160	150	3,8	3,5	3,3	3,0	1,21	1,11	1,05	0,96

1) friction angle φ_f = time independent
2) tensile strength $\sigma_T(t) = 0,2\ \sigma_P(t)$
3) cohesion c_f is calculated based on Mohr-Coulomb using the respective $\sigma_P(t)$ and φ_f

Attachment 6.2

APPENDIX 1

Overview of the received soil material

Borehole	Sample-no.	from (FT BGS)	to (FT BGS)	Specimen-no.	type of specimen	Layer
P5-04	1	79,2	80,2	16571-11	undisturbed	ML
P5-04	2	80,2	81,2	16571-12	undisturbed	ML
P5-04	3	93,7	94,7	16571-02	undisturbed	ML
P5-04	4	94,7	95,7	16571-01 / -16	undisturbed	ML
P5-04	5	100,8	101,8	16571-15	undisturbed	ML
P5-04	6	115,7	116,7	16571-08	undisturbed	ML
P5-04	7	118,0	119,0	16571-05 / -09	undisturbed	ML
P5-04	8	123,7	124,7	16571-120	undisturbed	ML
P5-04	9	124,7	125,7	16571-06 / -13	undisturbed	ML
P5-04	10	134,0	135,0	16571-03 / -07	undisturbed	ML
P5-04	11	135,0	136,0	16571-14	undisturbed	ML
P5-04	12	144,0	145,0	16572-11	undisturbed	SM
P5-04	13	145,0	146,0	16572-08	undisturbed	SM
P5-04	14	154,0	155,0	16572-01	undisturbed	SM
P5-04	15	155,0	156,0	16572-02	undisturbed	SM
P5-04	16	166,0	167,0	16572-04 / -05	remolded	SM
P5-04	17	167,5	168,5	-06 / -07 / -12	remolded	SM
P5-04	18	174,0	175,0	16572-03	undisturbed	SM
P5-04	19	175,0	176,0	16572-10	undisturbed	SM
P5-04	20	178,0	179,0	16572-09	undisturbed	SM
P5-04	21	183,0	184,0	16573-14 / -15	undisturbed	CL
P5-04A	22	194,1	195,1	16573-01	undisturbed	CL
P5-04A	23	195,1	196,1	16573-16	undisturbed	CL
P5-04A	24	200,7	201,7	16573-02	undisturbed	CL
P5-04A	25	204,1	205,1	16573-07	undisturbed	CL
P5-04A	26	205,1	206,1	16573-17	undisturbed	CL
P5-04A	27	213,7	214,7	16573-08	undisturbed	CL
P5-04A	28	214,7	215,7	16573-05	undisturbed	CL
P5-04	29	215,7	216,7	16573-06	undisturbed	CL
P5-04A	30	218,0	219,0	16573-03 / -04	undisturbed	CL
P5-04A	31	222,5	223,5	16573-09	undisturbed	CL
P5-04A		183,0	223,5	16573-10 / -11 / -13	remolded	CL