703

GEOTECHNICAL INVESTIGATION
BORING 8, NEKTORALIK H-28
BEAUFORT SEA

Report to

CANADIAN MARINE DRILLING LTD.

Calgary, Canada

by

McClelland engineers, inc.

and

EBA Engineering Consultants Ltd.

GEOTECHNICAL INVESTIGATION
BORING 8, NEKTORALIK H-28
BEAUFORT SEA

* * *

Report

to

CANADIAN MARINE DRILLING LTD.
Calgary, Alberta, Canada

* * *

by

McCLELLAND ENGINEERS, INC.
Houston, Texas

and

EBA ENGINEERING CONSULTANTS LTD.
Edmonton, Alberta, Canada

January 1981

McClelland engineers, inc. / geotechnical consultants
6100 HILLCROFT / HOUSTON, TEXAS 77081
TEL. 713 / 772-3701 / TELEX 762-447

Report No. 0179-0128-4
January 14, 1981

Canadian Marine Drilling Ltd.
P. O. Box 200
Calgary, Alberta, Canada T2P 2H8

Attention: Mr. Muharrem Gajtani

Geotechnical Investigation
Boring 8, Nektoralik H-28
Beaufort Sea

Gentlemen:

This report presents the results of our geotechnical investigation of soil and foundation conditions at the above offshore location. McClelland Engineers, Inc. and EBA Engineering Consultants Ltd. jointly performed this investigation under your Beaufort Sea Coring Services Contract dated June 19, 1979.

Various preliminary data and information have been provided to you from time to time upon request, including the results of the laboratory tests performed by EBA Engineering Consultants. All information developed in the field and laboratory is included here in detail along with our recommendations for design of conductor pipes and pile foundations.

We appreciate the opportunity to be of service to you in this interesting project. Please call on us when we can be of further assistance.

Very truly yours,

McCLELLAND ENGINEERS, INC.

Bernardo Susi
Geotechnical Engineer

Clarence J. Ehlers, P.E.
Senior Engineer Manager

BS/CJE/mmt
Copies Submitted:

Canadian Marine Drilling Ltd. (10)
EBA Engineering Consultants Ltd. (3)

C O N T E N T S

ILLUSTRATIONS

SUMMARY

A geotechnical investigation of soil and foundation conditions was performed for Canadian Marine Drilling Ltd. at the Nektoralik H-28 exploratory drilling site in the Beaufort Sea. The study included a foundation boring drilled to 318-ft penetration in 193 ft of water. Field and laboratory tests were performed on soil samples retrieved from the boring, and engineering analyses were made of the field and laboratory data to compute the ultimate axial capacity of conductors and open-end pipe piles.

The boring disclosed fine-grained soils throughout the 318-ft penetration explored. The soils consist primarily of clays, clayey silts, and silts. The consistency of the clays and silts is very soft at the seafloor, increasing with penetration and becoming very stiff at about 50-ft penetration. The soils from the seafloor to about 50-ft penetration are of Recent geologic origin, underlain by soils of older geologic origin. Temperatures of recovered soil samples were generally above or slightly below the freezing point (0° C) from the seafloor to about 70-ft penetration and from about 110-ft to 125-ft penetration. From about 70-ft to 110-ft penetration and below 125-ft penetration, the temperature decreased below freezing, and the soils were classifed as frozen. The ice content of the frozen soils is low. Visible ice is present from about 125-ft to 175-ft penetration. Below 175-ft penetration, the frozen soils are described as Nbn (no excessive ice, well-bonded).

The axial capacity of conductor pipes and open-end pipe piles was analyzed for three design cases. The three design cases are (1) a driven conductor pipe with thawing of permafrost permitted, (2) a drilled-and-grouted insulated conductor pipe whose exterior surface is refrozen after installation, and (3) a driven open-end pipe pile assuming good contact between the pile surface and permafrost with no thawing of permafrost. Ultimate frictional capacity and unit end bearing curves are presented herein.

The driving of piles or conductors by conventional percussion techniques below about 125-ft penetration is expected to be very difficult, and driving refusal will probably be experienced because of the presence of permafrost. Methods to aid the driving of piles and conductors include prethawing or predrilling a hole in the permafrost and using a vibratory pile driver. An alternate method for placement of a conductor is by grouting the conductor in an oversized drilled hole.

INTRODUCTION

Project Description

Canadian Marine Drilling, Ltd. (Canmar) is developing their oil and gas leases in the southern Beaufort Sea. The development of these leases is currently in the exploration phase. Drilling operations for the exploration phase of development have been conducted from a fleet of drill ships which have been modified to be ice-classed.

The type of fixed structure that might be constructed at the Nektoralik H-28 location for support of drilling and production operations has not been decided. We understand that artificial islands constructed of dredged fill are being given consideration at this time. At the request of Canmar, this report does not present design analyses and recommendations for artificial islands.

Due to the presence of shallow permafrost soils, design of conductor pipe and foundation piles presents unique problems. Since the conductor pipe is supported in permafrost soils, special design precautions are taken. The design of conductors, therefore, includes the possibility of progressive thawing around the conductor during fluid extraction. The properties of thawed soils thus present the controlling factors for design. This report presents axial design analyses for conductor pipes and open-end pipe piles.

Purposes and Scope of Study

The purposes of this study were (1) to obtain information on soil stratigraphy and properties at the Nektoralik H-28 exploratory drilling site, (2) to determine the extent of permafrost within the 318-ft penetration explored, (3) to establish general geological control and extent of subsea permafrost from other borings in the southern Beaufort Sea, (4) to predict the ultimate axial capacity for conductor pipes and foundation piles installed to various penetrations, and (5) to develop installation recommendations for conductors and foundation piles. To accomplish these objectives, the study was conducted in the following phases:

- drilling of a soil boring to explore soil stratigraphy and to obtain soil samples

- laboratory testing of soil samples to determine pertinent engineering properties
- engineering analyses of the information obtained from the field and laboratory phases of the study to develop recommendations to guide axial design and installation of conductor pipes and foundation piles

Description of Job Responsibility

McClelland Engineers, Inc., Houston, Texas and EBA Engineering Consultants Ltd., Edmonton, Canada jointly performed this geotechnical investigation. McClelland Engineers provided two drillers, two helpers, one technician, and one geotechnical engineer, and EBA provided one technician or geotechnical engineer to perform the field investigation. EBA performed most of the laboratory soil tests with laboratory test assignments under the general direction of Professor N. R. Morgenstern at the University of Alberta. This report was prepared by McClelland Engineers. The boring log and many of the illustrations in Appendix A that present laboratory soil test results were prepared by EBA.

FIELD INVESTIGATION

An undisturbed-sample boring was drilled at the Nektoralik H-28 location at Latitude 70°27'27.33" N and Longitude 136°06'12.32" W. The water depth at the site, measured by wire-line techniques, was 193 ft at 0800 hrs on August 22, 1979. The drilling and sampling depths were not corrected for tidal variations. The boring was drilled to a total penetration of 318 ft below the seafloor or El -511 ft.

The boring was drilled with 4-in.-IF drill pipe by a skid-mounted Failing 1500 rotary drilling rig operating through the centerwell in the deck of the Canmar supply boat, "Supplier V." Marine and drilling equipment were provided by Canmar. Drilling operations were conducted with a Reed core barrel equipped with a drag bit. The core barrel and collar have internal locking devices capable of accepting a wire line-retrievable rotary core barrel. Soil samples were obtained by percussion technique at 3-ft intervals to 50-ft penetration, at 5-ft intervals from 50-ft to 150-ft penetration and at 10-ft intervals below 150-ft penetration. A 2-1/2-in.-OD, 2-1/8-in.-ID liner sampler was used to obtain samples to 8-ft penetration, and a 2-1/4-in.-OD, 2-1/8-in.-ID thin-wall tube sampler was used to obtain all other samples. These samplers were operated on a wire line through the bore of the drill pipe and driven with a 175-lb sliding weight. The weight was dropped approximately 5 ft a sufficient number of times to achieve the desired 24-in. penetration of the sampler.

The temperature of most soil samples was measured prior to extruding them from the sampling tube or core barrel. A thermocouple with a 2-in.-long probe was inserted into the end of the sample while still in the sampling device. Temperature was then read to the nearest tenth of a degree centigrade on a digital indicator. Since this is not an in situ technique of obtaining temperature, measurements are affected by ambient temperature, drilling fluid temperature (the drilling fluid was not chilled), and the time interval between obtaining a sample and making the temperature reading. Although temperature measurements are affected by the factors mentioned above, we feel that these temperature records may be valuable in the assessment of the presence of permafrost.

After the temperature was measured, each sample was removed from the sampling tube, photographed with a 35 mm SLR camera, and then examined and classified by our field engineer or soil technician. Frozen samples were quickly classified, appropriately packaged and stored in a freezer. The soil samples were then transported to EBA Engineering Consultants in Edmonton for subsequent laboratory testing. Photographs of the samples were presented in a bound report submitted previously.

Descriptions of the soils encountered in the boring are presented on the boring log shown on Plates 1 and 2. The boring log includes soil classifications according to the Unified Soil Classification (USC) System and ground ice descriptions. A key to the Unified Soil Classification and Ground Ice Descriptions given on the log is presented on Plate 3. Sample temperatures measured in the field are plotted on Plate 4.

The amount of sampler penetration for driven samples and the number of blows of the sliding weight required to achieve that penetration is shown on the boring log. Blow counts with the wire-line sampler do not coincide with those obtained by the Standard Penetration Test (SPT). As an approximation, limited onshore tests indicate that driving resistance with the wire-line sampler is about 50 percent of driving resistance (N) from the Standard

Penetration Test. As an example, we believe that 30 blows of the 175-lb wire-line sampler to achieve a penetration of 24 in. is roughly equivalent to 30 blows for 12-in. penetration for the SPT. We wish to stress that this is only a rough approximation based upon limited data obtained onshore at relatively shallow penetrations.

A brief chronological summary of the field operations at this location is given on Plate 5.

FIELD AND LABORATORY SOIL TESTS

The field and laboratory testing programs were designed to evaluate the pertinent engineering and physical properties of the foundation soils. We performed three types of strength tests in the field concurrently with drilling operations. Undisturbed shear strengths of most unfrozen cohesive samples were determined with a motorized miniature vane device while the samples were still in the sampling tube. Unconfined compression tests were performed on selected specimens of cohesive soils after the samples were extruded from the sampling tube. Estimates of the shear strength of cohesive soils were also made using a Torvane.

All other tests were conducted by EBA Engineering Consultants. The types and number of strength, thaw strain, and consolidation tests performed are as follows:

	Number of Tests	
Type of Test	Laboratory	Field
Miniature Vane		
Undisturbed	3	30
Remolded	2	0
Torvane	0	31
Unconfined Compression	0	11
Unconsolidated-Undrained Triaxial Compression	18	0
Direct Shear	2	0
Thaw Strain	6	0
Consolidation	8	0

All strength tests were performed on thawed samples.

Water content and unit weight determinations were made as routine parts of the test procedures for all specimens subjected to unconfined compression, triaxial compression, direct shear, thaw strain, and consolidation tests. Water content was also measured on the samples used in the miniature vane tests. Additional laboratory classification tests included the following:

Type of Test	Number of Tests
Water Content	37
Liquid and Plastic Limits	34
Grain-Size Analysis	
Sieve Analysis through No. 200 Sieve	7
Hydrometer	19
Pore Water Salinity	23
Specific Gravity	2
Bulk Density	21

Most test results are tabulated on Plate A-1 in Appendix A, and most results are presented in graphical form on the boring log on Plates 1 and 2. Field strength test results are plotted in red and laboratory strength tests in black to aid in the evaluation of the effect of thermal disturbance on measured shear strengths. The results of all tests including grain-size curves, liquidity index profile, pore water salinity profile, and specific gravity are presented on Plates A-2 through A-15. Results of all strength tests including unconsolidated-undrained triaxial compression, direct shear, miniature vane, unconfined compression, and Torvane are presented on Plates A-16 through A-26. The results of the thaw strain and consolidation tests are presented on Plates A-27 through A-37.

In addition to the above physical tests, selected samples were analyzed for geochemical constituents by Carbon Systems, Inc. of Baton Rouge, Louisiana. The samples were analyzed for light hydrocarbon gases, sulfate, salinity, dissolved inorganic carbon, and total organic carbon. The results of the geochemical analyses are presented in a report submitted by Carbon Systems, Inc. on December 13, 1979.

SOIL STRATIGRAPHY

The soils at the Nektoralik H-28 location are highly stratified and consist primarily of fine-grained soils that vary texturally from silt to clay. The soils are frozen from about 70-ft to 110-ft penetration and below about 125-ft penetration. A generalized summary of the major soil strata at Nektoralik H-28 based on the log of the boring presented on Plates 1 and 2 is given in the following tabulation:

Stratum	Penetration, ft From	To	Description
1	0	6.5	Clayey silt; frozen from 1.5' to 5.0'
2	6.5	10.0	Very soft clay; frozen below 8'
3	10.0	12.0	Clayey silt
4	12.0	30.5	Very soft clay
5	30.5	85.0	Clayey silt; frozen from 58' to 60', 70' to 76' and below 84'
6	85.0	114.5	Frozen clay and silt
7	114.5	119.0	Very stiff silty clay
8	119.0	175.5	Frozen clayey silt with clay layers
9	175.5	185.0	Frozen clay and silt
10	185.0	203.5	Frozen very stiff silty clay
11	203.5	272.0	Frozen silt
12	272.0	318.0+	Frozen very stiff clay

Detailed descriptions that include color and textural variations, inclusions, and ground ice for each stratum are noted on the boring log. In addition, descriptions of sedimentary structure noted in the field are presented in Appendix B on Plate B-1.

Subsequent recommendations for foundation pile and conductor pipe design and installation contained in this report were developed assuming the soil conditions revealed by the boring. Considerations of possible stratigraphic changes, faulting, or other differences in soil conditions that could occur within the general area of the boring and that could influence foundation pile and conductor pipe design were beyond the scope of this investigation.

SOIL PROPERTIES

Definition of Permafrost

The classical definition of permafrost is any earth material that has been at or below the freezing temperature of water (0° C) for a prolonged period of time without regard to the state of any moisture present in the soil fabric. Generally, the smaller the grain size of a material, the lower the freezing point (the temperature at which there is no unfrozen moisture content). Therefore, a granular material such as sand can appear and feel frozen at the same temperature that a clay sample will appear and feel unfrozen. In this report, we have adopted the convention that materials would be classified as "frozen" if there was visible ice and the measured temperature of samples was below 0° C.

According to the temperature measurements made on recovered samples in the field, the temperatures of the sediments to about 70-ft penetration were variable, ranging from about -1° C to $+1.5^{\circ}$C. The sediments from about 70-ft to 110-ft penetration and below about 125-ft penetration were below the freezing point with temperatures ranging from about -1.5 to -2.0° C and decreasing with depth. From about 110 to 125-ft penetration, measured temperatures were about 0° C. A plot of temperatures of recovered soil samples measured during drilling operations is presented on Plate 4.

Unfrozen Soils

Based on temperature measurements discussed in the previous section, the soils are generally unfrozen from 0 to about 70-ft and from about 110-ft to 125-ft penetrations at the Nektoralik H-28 location. The unfrozen soils are clays and clayey silts of medium to high plasticity. Based on measured shear strengths and liquidity indices, the clays and silts to about 50-ft penetration are of Recent geologic origin and are normally consolidated to slightly underconsolidated with respect to the present over-burden pressure. Based on three consolidation tests, the computed overconsolidation ratios (OCR) range from 0.5 to 1.0, which also indicates the soils are normally consolidated to slightly underconsolidated. (A plot of overconsolidation ratio (OCR) versus penetration is presented on Plate A-38 in Appendix A.)

Below about 50-ft penetration, the soils appear to be overconsolidated and are probably of older geologic origin.

The clays of Strata 2 and 4 are very soft in consistency. The clayey silt of Strata 1 and 3 is loose based upon the driving resistance of the wire-line operated percussion soil sampler, or is very soft in consistency based upon measured undrained shear strengths. The clayey silt of Stratum 5 becomes denser and stronger at about 50-ft penetration, changing in consistency from very soft to véry stiff and reflecting a probable difference in geologic origin as discussed above.

Frozen Soils

Frozen soils or permafrost were encountered from about 70 to 110-ft penetration and below about 125-ft penetration. The frozen soils consist primarily of clays and silts of moderate plasticity. The liquid limits of the soils range from 22 to 67 with plasticity indices ranging from 8 to 44. Measured shear strengths of thawed samples generally range from about 2 ksf (100 kPa) to 4 ksf (200 kPa).

The frozen soils contain visible ice from about 125 to 175-ft penetration. Below 175-ft penetration, there is no visible ice, and the frozen soils are described as Nbn (no excessive ice, well-bonded). The permafrost is not ice rich and is considered to be relatively thaw-stable due to its low ice content.

Based on measured shear strengths on thawed samples, the frozen soils appear to be normally consolidated to slightly overconsolidated. Incremental consolidation tests indicate that the soils are normally consolidated to underconsolidated with overconsolidation ratios ranging from about 0.25 to 1.05.

AXIAL CONDUCTOR AND PILE DESIGN ANALYSIS

A significant factor that affects the axial capacity of conductor pipes and foundaton piles in arctic regions is the thawing of frozen ground, or permafrost. Because the conductor pipe is used as a conduit to transfer superheated liquids or gases to the surface, a significant amount of thawing will occur where such a conductor comes in contact with permafrost. When permafrost thaws, strength and volume changes may result. This thawing is not expected to occur with the foundation piles.

Canmar has requested that three design cases be considered in the analysis of the axial capacity of conductor pipes and foundation piles in permafrost. The three design cases are:

Case 1: Driven conductor pipe with thawing of permafrost permitted.

Case 2: Drilled-and-grouted insulated conductor pipe whose exterior surface is refrozen after installation.

Case 3: Driven foundation pipe pile assuming good contact between pile surface and permafrost with no thawing of permafrost.

Method of Predicting Axial Capacity

Although the method of installation is different for a driven than for a drilled-and-grouted pile or conductor, we have assumed that the difference is negligible with respect to the method of predicting axial capacity for the two installation procedures (Cases 1, 2, and 3). There are other analytical methods available for computation of axial capacity of drilled-and-grouted piles and conductors; however, we feel that the method used for this study gives a reasonable prediction of axial capacity for drilled-and-grouted conductors (Case 2) as well as for driven piles and conductors (Cases 1 and 3).

The presence of permafrost will affect the axial capacity for the three design cases. The effect of permafrost is incorporated into the axial capacity analysis by changing the design parameters within the frozen soils for the three design cases. The method of predicting axial capacity is not affected and is identical for the three cases. Therefore, considering the methods of installation and the influence of permafrost, the parameters used in the axial capacity calculations are identical except in the frozen soils.

In addition to axial capacity considerations, pile and conductor settlement is an important design consideration. In frozen soils of high ice content, the creep rate under stress may cause excessive settlements over the design life of a pile-supported structure, which may govern design. For the low-ice-content permafrost at the Nektoralik H-28 site, settlement of piles and conductors is expected to be within tolerable limits if piles and conductors are designed in accordance with the method of predicting axial capacity described herein.

Foundation Pile. The ultimate axial capacity of foundation piles was predicted using the static method of analysis as described in API RP 2A (January 1980)[1]. In this method, the ultimate compressive capacity, Q, for a given penetration is taken as the sum of the friction on the wall of the pile, Q_s, and the end bearing, Q_p, so that:

$$Q = Q_s + Q_p$$

Conductor Pipe. The ultimate axial capacity of conductor pipes also was predicted using the static method of axial pile capacity analysis. In this method, the ultimate compressive and tensile capacity, Q, for a given penetration is taken as the friction on the wall of the conductor, Q_s, so that:

$$Q = Q_s$$

The end bearing component, Q_p, of axial pile capacity will not be developed by a conductor pipe and, therefore, is neglected.

Skin Friction

The skin friction, Q_s, is expressed as:

$$Q_s = f\ A_s$$

where f is the unit skin friction between soil and pile, and A_s is the embedded surface area of the pile (or the surface area of the drilled hole for the drilled-and-grouted conductor for Case 2). Computations based on the selected strength parameters shown in the left graph of Plate 6 and the criteria discussed in the following paragraphs produced the curves of unit skin friction shown in the left graph of Plate 7.

Cohesive Soils. Computation of unit skin friction, f, by the API RP 2A (January 1980) Method is in accordance with Sec. 2.6.4, Para. b.1. With this method, the unit skin friction may be equal to or less than the undrained shear strength of the clay, but may not exceed 1.0 kip per sq ft for shallow penetrations or the undrained shear strength equivalent to a normally

---

(1) American Petroleum Institute (1980), *Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms*, API RP 2A, 11th Edition.

consolidated clay for deeper penetrations, whichever is greater. The values of undrained shear strength used in our computations are based on the interpreted shear strength presented on the left graph of Plate 6. The unit skin friction values are plotted on the left graph of Plate 7.

Granular Soils. Computation of unit skin friction for pipe piles and conductors embedded in granular soils was in general accordance with Sec. 2.27, Para. c of API RP 2A (January 1980) and was obtained from the equation:

$$f = K \bar{\sigma}_v \tan \delta$$

where

K = coefficient of lateral earth pressure

$\bar{\sigma}_v$ = effective vertical stress

δ = angle of friction between foundation material and steel pile

The value of K was taken as 0.7 for compressive loads and 0.5 for tensile loads. Effective vertical stress was computed from the submerged unit weight profile shown on the right graph of Plate 6. The angle of friction, δ, as well as the maximum limiting value of unit skin friction, f_{max}, considered appropriate for the granular materials are presented on the left graph of Plate 6. The values of δ and f_{max} are in accordance with those cited by McClelland[(2)].

Frozen Soils. The frozen soils encountered at the Nektoralik site range in grain size from clay to silt. The method of computation of adfreeze bond or unit skin friction, f, for frozen granular soils was assumed to be the same as described above for unfrozen granular soils. The maximum limiting values of unit skin friction, f_{max}, were assumed to be different for unfrozen and frozen granular soils. The limiting values of adfreeze bond (f_{max}) used for design Cases 1, 2, and 3 for different gradations of frozen granular soils are tabulated below:

[(2)] McClelland, Bramlette (1974), "Design of Deep Penetration Piles for Ocean Structures," *Journal, Geotechnical Engineering Division,* ASCE, Vol. 100, No. GT7, pp. 705-747.

	Fine Sand $\phi = 35^o$	Silty Sand $\phi = 30^o$	Sandy Silt $\phi = 25^o$	Silt and Clayey Silt $\phi = 20^o$
Case 1	0.80 ksf	0.70 ksf	0.55 ksf	0.40 ksf
Case 2	1.25 ksf	1.1 ksf	0.90 ksf	0.65 ksf
Case 3	1.80 ksf	1.60 ksf	1.25 ksf	0.90 ksf

The limiting adfreeze bond values for sand were used in our 1978 geotechnical investigations at Ukalerk, Tarsiut, Kopanoar, and Natsek where the frozen soils consisted primarily of fine sands. These limiting adfreeze bond values were based upon research conducted at the University of Alberta and were conferred to us by Professor N. R. Morgenstern. At the Nektoralik location, the frozen granular soils consist primarily of clays and silts. The adfreeze bond between the pile surface and soil is dependent on soil grain size and decreases with decreasing grain size. The limiting adfreeze bond values presented above for silty sand, sandy silt, and silt were proportioned to the values for sand in accordance with the proportions cited by McClelland(2) for limiting skin friction values for unfrozen granular soils.

The adfreeze bond and corresponding axial load capacity of piles in frozen soils is temperature dependent. The warmer the temperature, the lower the adfreeze bond. The adfreeze bond values presented herein assume that the frozen soils are warm, i.e. slightly below freezing. In the future, if in situ measurements of temperature indicate that the frozen soils are colder than assumed, an increase in the adfreeze bond values may be possible.

The ice content of the frozen cohesive soils was low, and based on field descriptions, a portion of the moisture present in the soil fabric was unfrozen. Therefore, when computing adfreeze bond in frozen cohesive soils, we assumed that the soils would behave similar to unfrozen cohesive soils. Therefore, unit skin friction was computed using the same procedure used for unfrozen cohesive soils.

End Bearing

The end bearing, Q_p, is expressed as:

$$Q_p = q A_p$$

where A_p is the gross end area of the pile and q is the unit end bearing. Computations based on the selected strength parameters shown in the left graph of Plate 6 and the criteria discussed in the following paragraphs produced the curve of unit end bearing in the right graph of Plate 7.

For the conductor (Cases 1 and 2), there will be no end bearing. For driven open-end pipe piles, the end bearing must be limited to the frictional resistance of the soil plug inside the pile. This limiting value was taken as the cumulative frictional resistance along the embedded length of the pile.

Cohesive Soils. The unit end bearing of piles in clay was computed using the following equation:

$$q = s_u N_c$$

where s_u = undrained shear strength
N_c = a dimensionless bearing capacity factor

A value of 9 was used for N_c as recommended by API RP 2A. The values of s_u correspond to the shear strength profile plotted on the left graph of Plate 6.

Granular Soils. The unit end bearing for piles in granular material was computed from the equation:

$$q = \bar{\sigma}_v N'_q$$

where $\bar{\sigma}_v$ = effective vertical stress
N'_q = dimensionless bearing capacity factor which is a function of ϕ, the angle of internal friction of the material

The effective vertical stress, $\bar{\sigma}_v$, was calculated using the submerged unit weight profile given in the right graph of Plate 6. Values of N'_q selected for the granular materials are taken from API RP 2A (January 1980) and are presented on the left graph of Plate 6 along with the maximum limiting values of unit end bearing, q_{max}, considered appropriate for these materials (see McClelland[2]). Full end bearing as computed for granular strata cannot be relied upon unless the pile has penetrated a distance of at least three pile diameters into the strata, and the strata continues at least three pile diameters below the pile tip.

Frozen Soils. The bearing capacity of frozen soil is a function of many variables including temperature of permafrost, ice content, salinity of pore water, rate of loading, and grain size. Generally, the bearing capacity of soil in a frozen state will be higher than in an unfrozen state; however, the axial pile movement or deformation required to develop the higher bearing capacity in frozen soils is expected to be greater than in unfrozen soils. As a simplifying assumption to reduce pile movements, the end bearing for soil in the frozen state was assumed to be the same as in the unfrozen state.

An important consideration pertaining to end bearing in frozen soil is resistance to pile driving. We anticipate that refusal to conventional percussion pile driving will be encountered in the frozen soils below about 125-ft penetration. Installation techniques to aid pile driving in permafrost are discussed in a subsequent section of this report.

Ultimate Frictional Pile Capacity Curves

Using the design criteria discussed above, the ultimate frictional capacity was computed for a unit circumference pipe pile or conductor (12-in. circumference) assuming the three design cases previously discussed. Cases 1, 2, and 3 differ only below 203.5-ft penetration where the frozen soils were assumed to behave as granular soils. There is no difference between the computed compressive and tensile capacities for Cases 1, 2, and 3. Curves of ultimate frictional pile capacity are presented on Plate 8.

The ultimate frictional pile capacity curves may be used in determining the frictional capacities for any other size pile or conductor by multiplying the curve coordinates by the ratio of the new pile circumference to a 12-in. pile circumference. The resulting curve will depict total axial pile capacity for Cases 1 and 2, while for Case 3, end bearing must be added. End bearing may be computed by multiplying the gross end area of the pile tip by the value of unit end bearing shown on the right graph of Plate 7. The end bearing component of capacity must not exceed the frictional resistance of a soil plug inside the pile at any penetration.

PILE AND CONDUCTOR INSTALLATION CONSIDERATIONS

As defined by the three design cases, there are two proposed methods of installation for the conductor pipes and foundation piles, namely: (1) driving and (2) a drilled-and-grouted technique. Comments and recommendations concerning the two installation techniques are discussed in the following paragraphs.

Driven Piles and Conductors

Installation of driven piles and conductors at the Nektoralik H-28 location is complicated by the presence of frozen soils. Below about 125-ft penetration, the advancement of piles or conductors by conventional percussion driving is expected to be very difficult, and driving refusal will probably be experienced because of the presence of permafrost.

Alternate methods used onshore to aid the advancement of driven piles in permafrost are many. Some of these methods are:

- prethawing a hole in permafrost with a steam jet, either larger or smaller than the pile, and driving the pile in place
- rotary drilling a hole and driving a pile in an undersized hole, or "slurring" back in an oversized hole
- driving piles using a vibratory pile driver

Some of these techniques could be adaptable for use offshore. The most feasible alternatives would probably be pile driving assistance by vibratory techniques or predrilling of a pilot hole. The availability of high energy vibratory hammers capable of driving large diameter piles offshore is doubtful, but the possible use of a vibratory hammer should be given further consideration.

Predrilling a pilot hole, having a diameter less than that of the pile or conductor, may aid the advancement of a pile because of the reduction of end bearing. Caution must be exercised to insure that the pilot hole is not drilled larger than the pile or conductor, resulting in reduced skin friction. The optimum diameter of the pilot hole is primarily a function of the pile or conductor diameter, the strength and temperature of the permafrost, and the energy and type of driving hammer. If pilot holes are used as an aid to driving, we recommend that pilot holes have a diameter approximately one-half the diameter of the pile and be drilled in increments no deeper than 10 pile diameters below the pile tip. If pile driving is not aided, additional increases (about 10 to 15 percent of pile diameter) in the size of the pilot hole may be made up to a maximum of 90 percent of the pile diameter.

For a foundation pile where an appreciable amount of end bearing is counted upon for capacity, we recommend that drilling of pilot holes be kept to a level of at least 10 ft above design tip elevation and that driving alone be used to advance piles for the final several feet of penetration. The soil plug that results from this final driving should be left in place and a cement grout plug should be placed in the bottom of the piles to restore end bearing. The length of the grout plug will depend on the end bearing capacity of the soils beneath the pile tip. We recommend that an engineer familiar with pile driving and the effects of predrilling on pile design parameters be on site at the time of pile installation.

Drilled-and-Grouted Conductors

An alternate method for placement of the conductor pipe is by grouting the conductor pipe in an oversized drilled hole. During the installation of a drilled-and-grouted conductor, a number of construction-related phenomena can influence its axial capacity. Some of these phenomena are:

- stress release due to drilling
- mechanical disturbance to the soil fabric
- formation of a mudcake on the borehole wall
- interference of drilling fluid with the development of grout-pile bond
- migration of soil, water, and cement due to chemical potential gradients

When conductors are drilled and grouted in frozen soils, additional problems related to thawing of frozen materials may occur.

To minimize construction problems and develop the maximum axial capacity for drilled-and-grouted conductors, the following recommendations for construction surveillance are made:

(1) Minimize the amount of time between the completion of the drilled excavation and the completion of the grouting activities.

(2) Monitor the viscosity and weight of drilling fluid during construction, weighing the benefit of the drilling mud's reduction of stress relief versus its detrimental effect on grout-pile bonding.

(3) Utilize grout placement techniques that minimize drilling fluid contamination of bonding surfaces.

(4) Control drilling procedures that could influence borehole stability and create mechanical disturbance of soil fabric.

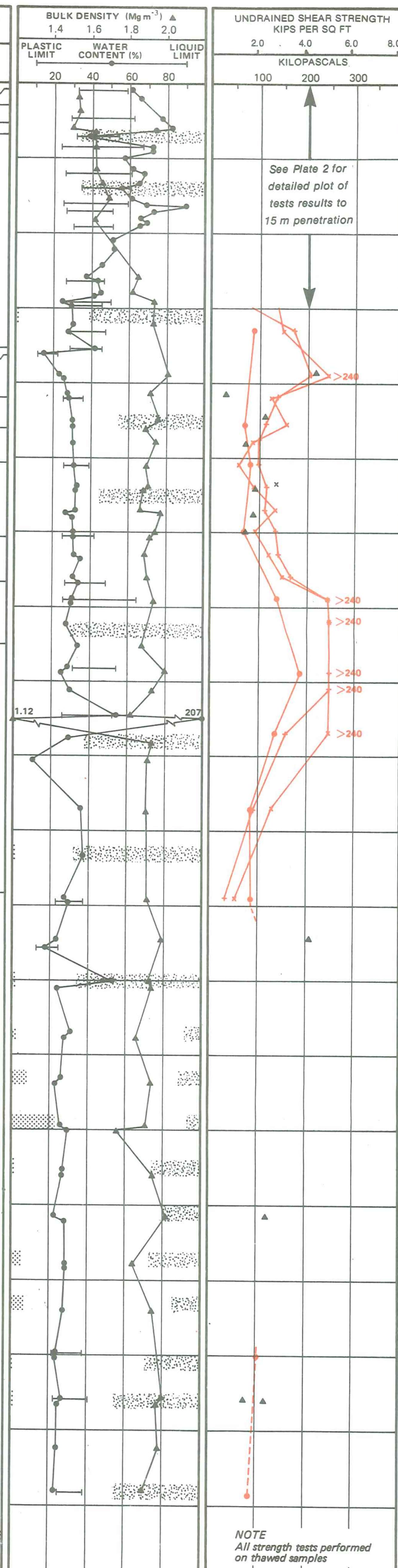
(5) Insure that the entire length of the annulus has been grouted and grout returns to seafloor.

(6) Design grout mixes to promote water migration from soil to grout.

ILLUSTRATIONS

LOCATION: **BORING 8, NEKTORALIK H-28**
LAT. 70° 27′ 27.33″ N LONG. 136° 06′ 12.32″ W WATER DEPTH: 58.8 m**

USC	SOIL DESCRIPTION	"BLOW COUNT	GROUND ICE
MH	**SILT** - clayey, some organic streaks and pockets, very soft, high plasticity, olive grey (6.5′)	See Plate 2 for Blow Count	NOT FROZEN / FROZEN
CH / MH / CH	**CLAY** - some silt, organic odour, high plasticity, olive grey 5Y 4/2, olive grey 5Y 5/2 (MH), clayey silt, dark olive grey 5Y 3/2		NOT FROZEN / FROZEN / NOT FROZEN
	- dark grey 5Y 4/1, grey 5Y 5/1		
	- 12.2% organic content		
CL	- clay and silt, high plasticity, shell fragments		
CH	- 9.6% organic content (30.5′)		
	- dark olive grey 5Y 3/2, olive grey 5Y 5/2		
MH	**SILT** - clayey, soft, high plasticity, very dark grey 5Y 3/1		
ML	- dark olive grey 5Y 3/2, light grey 5Y 7/1		
CH	- clay and silt, platy, very stiff		
ML	- 10.8% organic content, dark olive grey, 5Y 3/2	10/12″ 30/24″	
	- fine sand layer, silty, very dark grey 2.5Y N3/, 17.8 - 18.0 m	30/8″	FROZEN
	- shell fragments	30/16″	NOT FROZEN?
	- silt seams and pockets to 29 m	30/18″	
	- dark olive grey, 5Y 3/2, light grey 5Y 7/1		FROZEN
	- silt and clay, stiff, olive grey 5Y 4/2, grey 5Y 6/1	30/18″ 30/20″	NOT FROZEN
	- dark olive grey 5Y 3/2, light grey 5Y 7/1 (85.0′)	30/24″	
CL	**CLAY AND SILT** - very stiff, dark olive grey, 5Y 3/2, light grey 5Y 7/1, 12.9% organic content	30/18″	FROZEN?
CL-ML	- blocky structure,	30/18″	
	- dark olive grey 5Y 3/2, grey 5Y 6/1	30/16″	
CL	- dark grey 5Y 4/1, grey 5Y 5/1	30/16″	Vx-trace
CL-ML	- horizontal ice veins - thinly laminated, few dark grey streaks - vertical ice vein 32.9-33.1 m	30/16″	
CH-MH	- hard, medium to high plasticity - shell fragments (114.5′)	30/16″	NOT FROZEN
CL	**CLAY** - silty, fissured (119.0′)	30/16″	
MH	**SILT** - clayey, dark grey, 5Y 4/1, grey 5Y 5/1, 25 mm ice vein 30° from vertical at 37.5-37.8 m	40/18″	Vr-20%
	- very dark grey 5Y 3/1, grey 5Y 6/1	50/15″ 40/16″	Vr<5%
CH	- olive grey 5Y 4/2, olive grey 5Y 5/2 - (CH), ice + clay, few inclusions of clay in ice	50/18″	Vr-40-50%
MH	- fissured, stiff, 9.1% organic content	50/18″	Vr-5%
ML	- clay and silt, high plasticity - 25 mm vertical ice vein 45.1-46.0 m - nonplastic, shell fragments, foliated with thin ice lenses (0.1-0.3 mm), occasional particles of coarse sand	40/18″	Vr-40%
	- stiff	40/24″	Vr-20%
	- silty clay, nonplastic (175.5′)		Vr-20-25%
CL-ML	**CLAY AND SILT** - blocky structure, medium plasticity (185.0′)	40/18″	Nbn
CL	**CLAY** - silty, trace very fine sand, dark olive grey, 5Y 3/2, grey 5Y 6/1 low plasticity (203.5′)	50/18″ 50/14″	Nbn
ML	**SILT** - trace to some clay, trace sand, laminations at 30° to horizontal, nonplastic, few thin beds of fine sand (1-3 mm), dark grey 5Y 4/1, grey 5Y 5/1, 12.9% organic content	50/24″	Nbn
		50/18″	
	- dark olive grey 5Y 3/2, grey 5Y 5/1	50/18″	Nf-Nbn
	- olive grey 5Y 4/2, olive grey 5Y 5/2	50/18″	Nbn
	- dark grey 5Y 4/1, grey 5Y 5/1 - nonplastic	50/18″	
	- interbedded greyish brown silty clay with light brown silt, trace very fine sand, some dark grey organic streaks and shell fragment, (interbeds 1 mm thick) black 5Y 3/1	50/18″	Nbn
	72.0′)	50/18″	Nbn
CL / ML	**CLAY** - silty, few streaks of very fine light brown sand, stiff, medium plasticity, grey	50/18″	
CL	- dark grey 5Y 4/1, grey 5Y 5/1 - very dark grey 5Y 3/1, olive grey 5Y 5/2	50/15″	Nbn
	- olive grey 5Y 4/2, olive grey 5Y 5/2	50/14″	Nbn
	- occasional organic seam (318.0′)	50/14″ 50/12″	Nbn
	END OF BOREHOLE		



SPECIALIZED TESTS (by depth, ft): S,GAS; T,S; T,S,GAS; C,S; T T T; C; S,GAS; T; C,S; T; T,S,GAS; T; T,S,GAS; T; C,T; T,S,GAS S T; TS; S,GAS S; TS,C; S; S,GAS; DS; TS; T; C,S; TS,S,GAS; DS,S,GAS; TS,C; T,S; S; S,GAS; T,S; TS,C

PENETRATION BELOW SEAFLOOR, METRES (0–100) — PENETRATION BELOW SEAFLOOR, FEET (0–320)

McCLELLAND ENGINEERS JOB NO. 0179-0128
EBA JOB NO. 101-2581
DRILLING COMPLETED: JULY 27, 1979
BOREHOLE PENETRATION: 96.9 m
FIELD ENGINEER: J.A. WOOLEY

LEGEND

GRAIN SIZE: % Sand, % Silt, % Clay

SHEAR STRENGTH: + Torvane; × Min. Vane; ● Unconfined Compr.; ▲ UU Triaxial; ■ CU Triaxial; Field Laboratory Test Results

TEST IDENTIFICATION: C - Consolidation; TS - Thaw Strain; DS - Direct Shear; T - Triaxial Shear; S - P.W. Salinity; X - X-Ray Diffr.

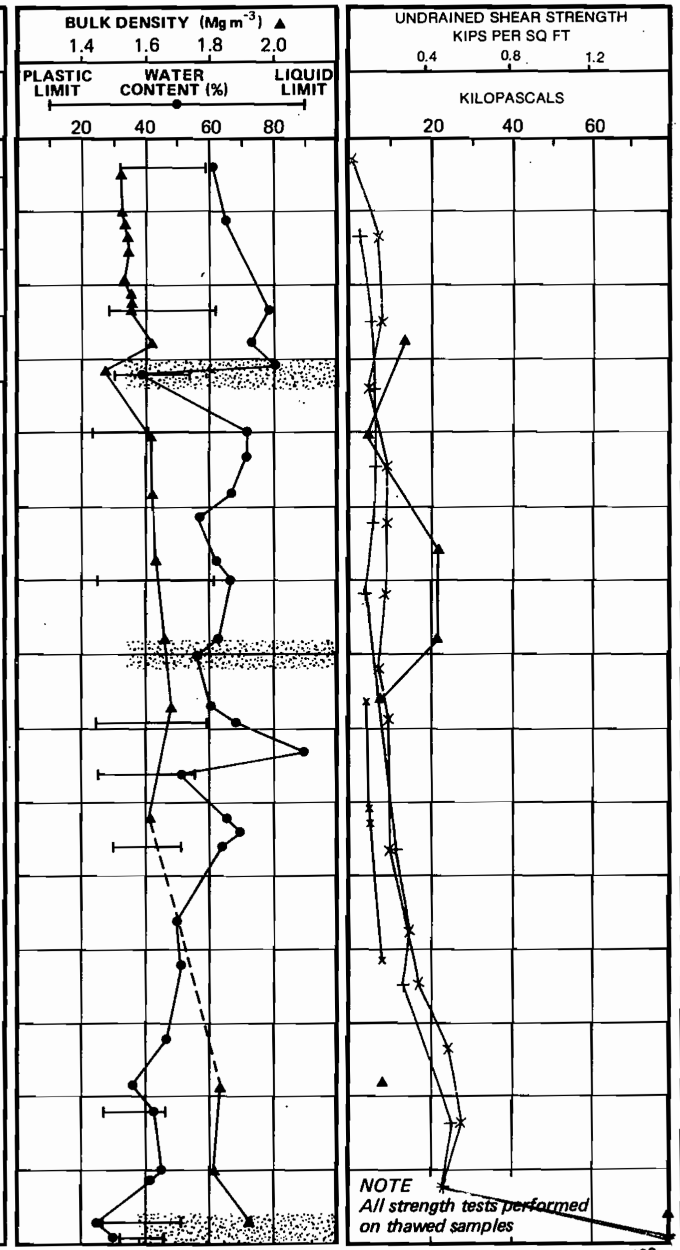
BOREHOLE LOG AND LABORATORY TEST RESULTS

LOCATION: BORING 8, NEKTORALIK H-28
LAT. 70° 27′ 27.33″ N LONG. 136° 06′ 12.32″ W WATER DEPTH: 58.8 m**

Depth (m)	USC	SMPL.	SOIL DESCRIPTION	*BLOW COUNT	GROUND ICE
0–2	MH	J, L, L, J, PF, L, L	SILT - clayey, some organic streaks and pockets, very soft, high plasticity, olive grey (6.5′)	0/24″, 0/24″	NOT FROZEN; FROZEN; NOT FROZEN
2–3	CH	L, J, PF	CLAY - some silt, organic odour, high plasticity, olive grey 5Y 4/2, olive grey 5Y 5/2 (10.0′)	0/24″, 0/24″	FROZEN
3–3.6	MH	J	SILT - clayey, dark olive grey 5Y 3/2 (12.0′)		NOT FROZEN
3.6–6.7	CH	Q, J, Q, J, Q, J	CLAY - silty, high plasticity, dark grey 5Y 4/1, grey 5Y 5/1 - 12.2% organic content	0/24″, 0/24″, 4/24″	
6.7–6.9	MH	Q		4/24″	
6.9–7.5	CL	J	- clay and silt, high plasticity, shell fragments		
7.5–9.3	CH	Q, J, J, J, Q	- 9.6% organic content - dark olive grey 5Y 3/2, olive grey 5Y 5/2 (30.5′)	4/24″, 4/24″	
9.3–11.8	MH	Q, J, G, J, Q	SILT - clayey, soft, high plasticity, very dark grey, 5Y 3/1	3/24″, 3/24″, 5/24″	
11.8–15	ML	J, Q, J, Q, J, Q, J	- dark olive grey 5Y 3/2, light grey, 5Y 7/1 - (CH) clay and silt, platy, very stiff	6/24″, 6/24″, 6/24″, 4/24″	

*Number of blows of a 175-lb weight dropped approximately 5-ft as required to produce a 24-in. penetration, except as noted, of a 2.25-in.-OD, 2.125-in.-ID thin-wall tube sampler. A 2.5-in.-OD, 2.125-in.-ID liner sampler was used to 8-ft penetration.

**Water depth was measured at 0800 hours on August 22, 1979.



Depth (ft)	SPECIALIZED TESTS
~0.5	S, GAS
~9	T
~12	T, S, GAS
~15	C
~18	T
~22	T
~25	T
~30	C
~33	S, GAS
~42	T
~45	S, C
~47.5	T, 34

PENETRATION BELOW SEAFLOOR, METRES: 0–15
PENETRATION BELOW SEAFLOOR, FEET: 0–45

McCLELLAND ENGINEERS JOB NO. 0179-0128
EBA JOB NO. 101-2581
DRILLING COMPLETED: JULY 27, 1979
BOREHOLE PENETRATION: 96.9 m
FIELD ENGINEER: J.A. WOOLEY

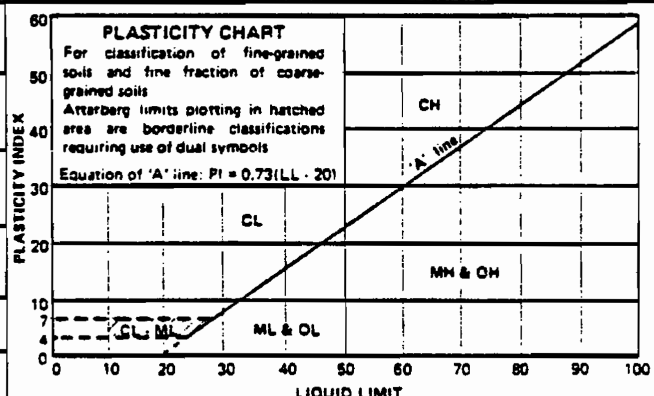
LEGEND

GRAIN SIZE	SHEAR STRENGTH	TEST IDENTIFICATION
% Sand, % Silt, % Clay	+ Torvane; × Min. Vane; ● Unconfined Compr.; ▲ UU Triaxial; ■ CU Triaxial — Field / Laboratory Test Results	C - Consolidation; TS - Thaw Strain; DS - Direct Shear; T - Triaxial Shear; S - P.W. Salinity; X - X-Ray Diffr.

BOREHOLE LOG AND LABORATORY TEST RESULTS

UNIFIED SOIL CLASSIFICATION†

MAJOR DIVISIONS			GROUP SYMBOLS	TYPICAL NAMES	CLASSIFICATION CRITERIA		
COARSE-GRAINED SOILS More than 50% retained on No. 200 sieve*	GRAVELS 50% or more of coarse fraction retained on No. 4 sieve	CLEAN GRAVELS	GW	Well-graded gravels and gravel-sand mixtures, little or no fines	Classification on basis of percentage of fines: Less than 5% pass No. 200 sieve GW, GP, SW, SP; More than 12% pass No. 200 sieve GM, GC, SM, SC; 5% to 12% pass No. 200 sieve Borderline classification requiring use of dual symbols	$C_u = D_{60}/D_{10}$ Greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3	
			GP	Poorly-graded gravels and gravel-sand mixtures, little or no fines		Not meeting both criteria for GW	
		GRAVELS WITH FINES	GM	Silty gravels, gravel-sand-silt mixtures		Atterberg limits plot below 'A' line or plasticity index less than 4	Atterberg limits plotting in hatched area are borderline classifications requiring use of dual symbols
			GC	Clayey gravels, gravel-sand clay mixtures		Atterberg limits plot above 'A' line and plasticity index greater than 7	
	SANDS More than 50% of coarse fraction passes No. 4 sieve	CLEAN SANDS	SW	Well-graded sands and gravelly sands, little or no fines		$C_u = D_{60}/D_{10}$ Greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3	
			SP	Poorly-graded sands and gravelly sands, little or no fines		Not meeting both criteria for SW	
		SANDS WITH FINES	SM	Silty sands, sand-silt mixtures		Atterberg limits plot below 'A' line or plasticity index less than 4	Atterberg limits plotting in hatched area are borderline classifications requiring use of dual symbols
			SC	Clayey sands, sand-clay mixtures		Atterberg limits plot above 'A' line and plasticity index greater than 7	
FINE-GRAINED SOILS 50% or more passes No. 200 sieve*	SILTS AND CLAYS	Liquid limit 50% or less	ML	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands			
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays			
			OL	Organic silts and organic silty clays of low plasticity			
	SILTS AND CLAYS	Liquid limit greater than 50%	MH	Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts			
			CH	Inorganic silts of high plasticity, fat clays			
			OH	Organic clays of medium to high plasticity			
HIGHLY ORGANIC SOILS			PT	Peat, muck and other highly organic soils			



*Based on the material passing the 3 in. (75 mm) sieve
†ASTM Designation D 2487, for identification procedure see D 2488

GROUND ICE DESCRIPTION

ICE NOT VISIBLE

GROUP SYMBOLS	SYMBOLS	SUBGROUP DESCRIPTION
N	Nf	Poorly-bonded or friable
	Nbn	No excess ice, well-bonded
	Nbe	Excess ice, well-bonded

VISIBLE ICE LESS THAN 50% BY VOLUME

GROUP SYMBOLS	SYMBOLS	SUBGROUP DESCRIPTION
V	Vx	Individual ice crystals or inclusions
	Vc	Ice coatings on particles
	Vr	Random or irregularly oriented ice formations
	Vs	Stratified or distinctly oriented ice formations

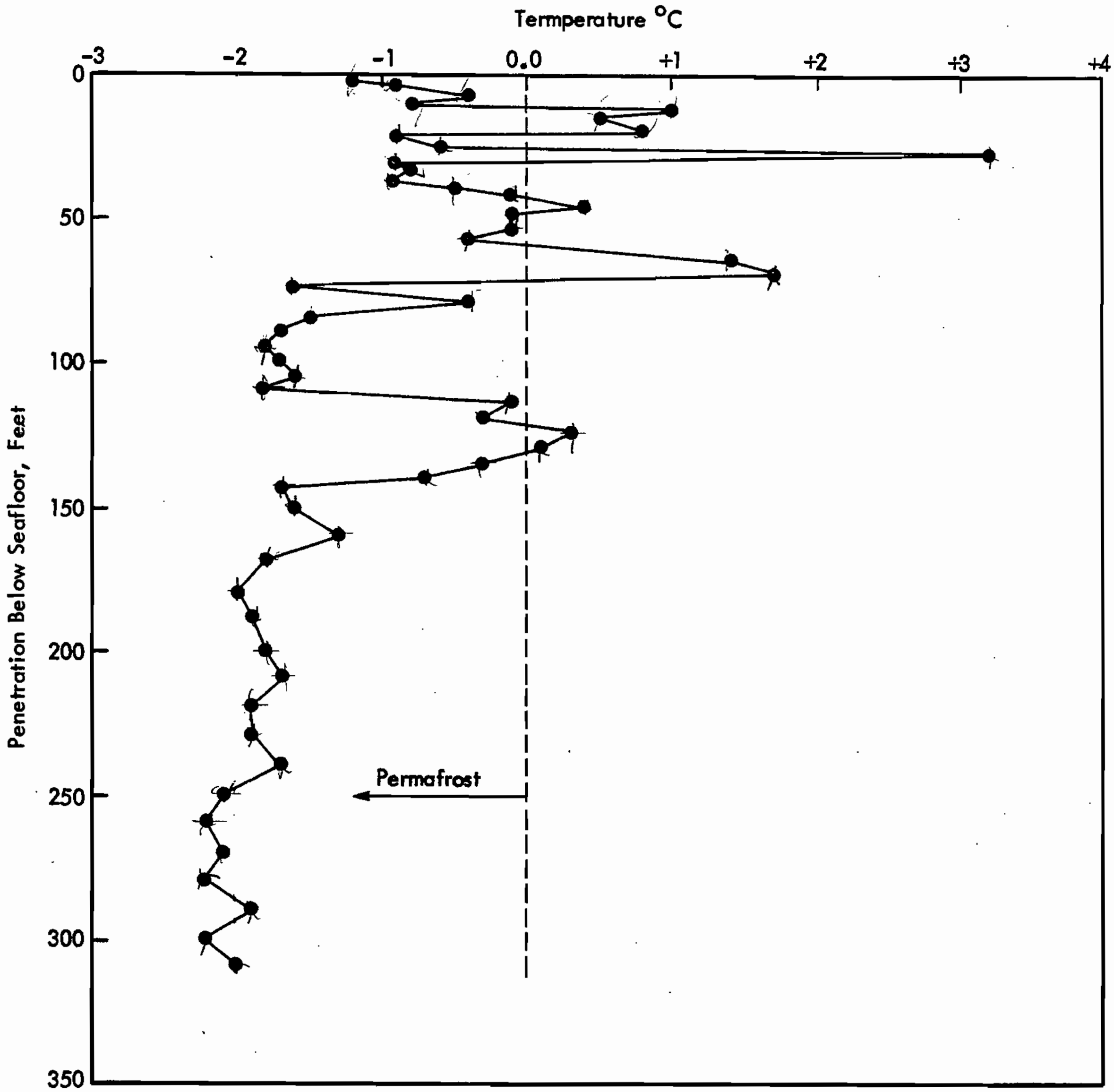
VISIBLE ICE GREATER THAN 50% BY VOLUME

GROUP SYMBOLS	SYMBOLS	SUBGROUP DESCRIPTION
ICE	ICE + Soil Type	Ice with soil inclusions
	ICE	Ice without soil inclusions (greater than 25 mm (1 in.) thick)

NOTE:
1. *Dual symbols are used to indicate borderline or mixed ice classifications*
2. *Visual estimates of ice contents indicated on borehole logs ± 5%*
3. *This system of ground ice description has been modified from NRC Technical Memo 79, Guide to the Field Description of Permafrost for Engineering Purposes*

LEGEND
Soil ——— Ice ▬

McCLELLAND ENGINEERS



TEMPERATURE vs DEPTH
Boring 8, Nektoralik H-28
Beaufort Sea

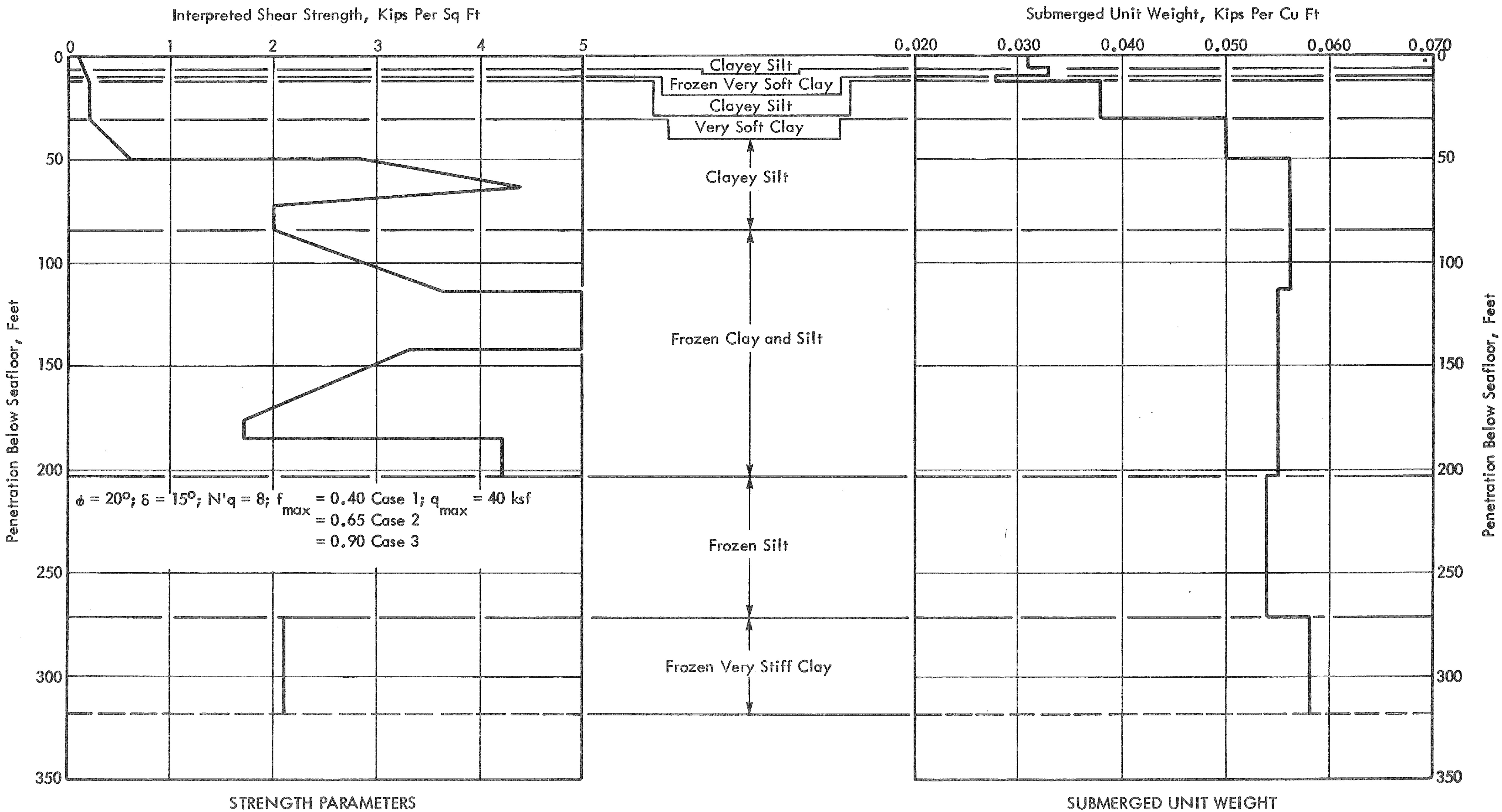
Date	Time From	To	Description
August 20, 1979	0500	0830	Traveling from Admiral's Finger Pingo to Explorer I
	0830	1130	Standing by at Explorer I to offload passengers
	1130	1915	Traveling from Explorer I to Nektoralik H-28
	1915	2400	Waiting on weather
August 21, 1979	0000	2215	Waiting on weather
	2215	2400	Anchoring
August 22, 1979	0000	0300	Anchoring
	0300	0330	Rigging up equipment and measuring water depth
	0330	0800	Resetting anchors
	0800	0915	Attempting to pick up core barrel; boat motion prevents safe handling
	0915	2400	Waiting on weather
August 23, 1979	0000	0745	Waiting on weather
	0745	0845	Pulling anchors to change heading
	0845	1945	Anchoring
	1945	2000	Rigging up equipment and measuring water depth
	2000	2115	Running pipe to mudline
	2115	2400	Drilling Boring Nektoralik H-28 to 24-ft penetration
August 24, 1979	0000	0345	Drilling Boring Nektoralik H-28 to 44-ft penetration
	0345	0445	Replacing fuel filter and dewatering fuel lines
	0445	0830	Attempting to restart rig; hydraulic starter inoperable
	0830	1200	Locating replacement engine starter
	1200	2400	Standing by for replacement starter and installing fuel/water separator

(continued on Plate 5a)

Date	Time From	Time To	Description
	(Continued from Plate 5)		
August 25, 1979	0000	0300	Replacing engine starter; arrived at 0005 hrs via helicopter
	0300	0400	Pulling pipe partially
	0400	1300	Replacing fuel injectors
	1300	2400	Waiting on weather
August 26, 1979	0000	0015	Repositioning Supplier V due to surveying equipment malfunction
	0015	0200	Running pipe to mudline
	0200	2345	Redrilling Boring Nektoralik to 47 ft; drilling boring to completion depth of 318 ft
	2345	2400	Fishing sampler; unsuccessful
August 27, 1979	0000	0130	Attempting to drill past sampler; unsuccessful; bent three joints of pipe
	0130	0600	Pulling pipe
	0600	0900	Waiting on weather; too rough to set down drill collar; requested to abandon hole
	0900	1130	Pulling anchors
	1130	1830	Traveling to Explorer I
	1830	1915	Standing by at Explorer I
	1915	2400	Traveling to Kaglulik A-75 to locate marine riser package
August 28, 1979	0000	0230	Traveling to Kaglulik A-75
	0230	2245	Locating marine riser package; standing by for orders
	2245	2400	Traveling to Tuk Base
August 29, 1979	0000	0900	Traveling to Tuk Base
	0900	1500	Standing by at Tuk Base

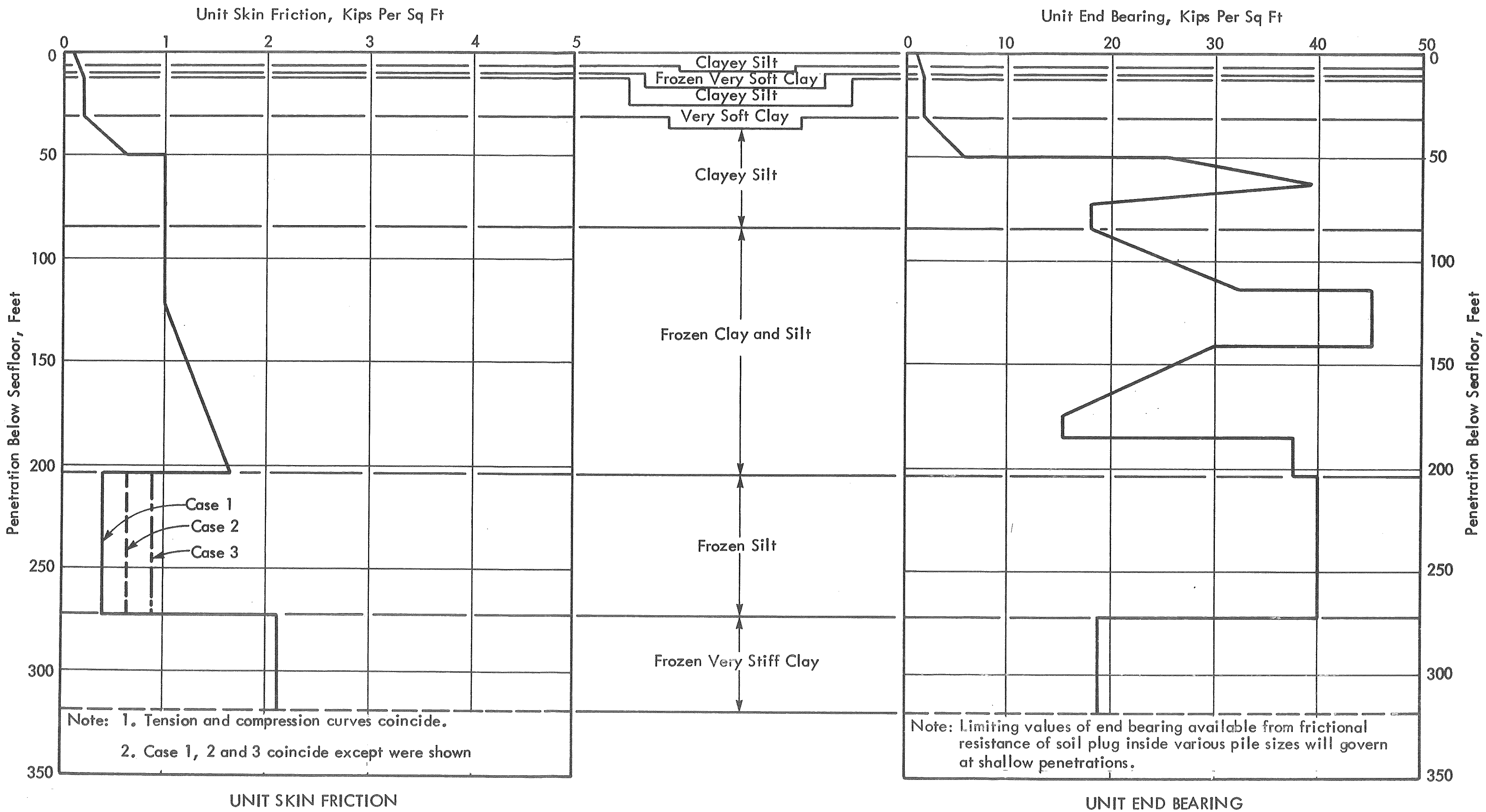
(Continued on Plate 5b)

Date	Time From	Time To	Description
	(Continued from Plate 5a)		
August 29, 1979	1500	1700	Demobilizing personnel and storing equipment
	1700	2100	Standing by for transportation to Edmonton
	2100	2400	Traveling to Edmonton
August 30, 1979	0000	0200	Traveling to Edmonton
	0200	0700	Standing by in Edmonton
	0700	1700	Traveling from Edmonton to Houston

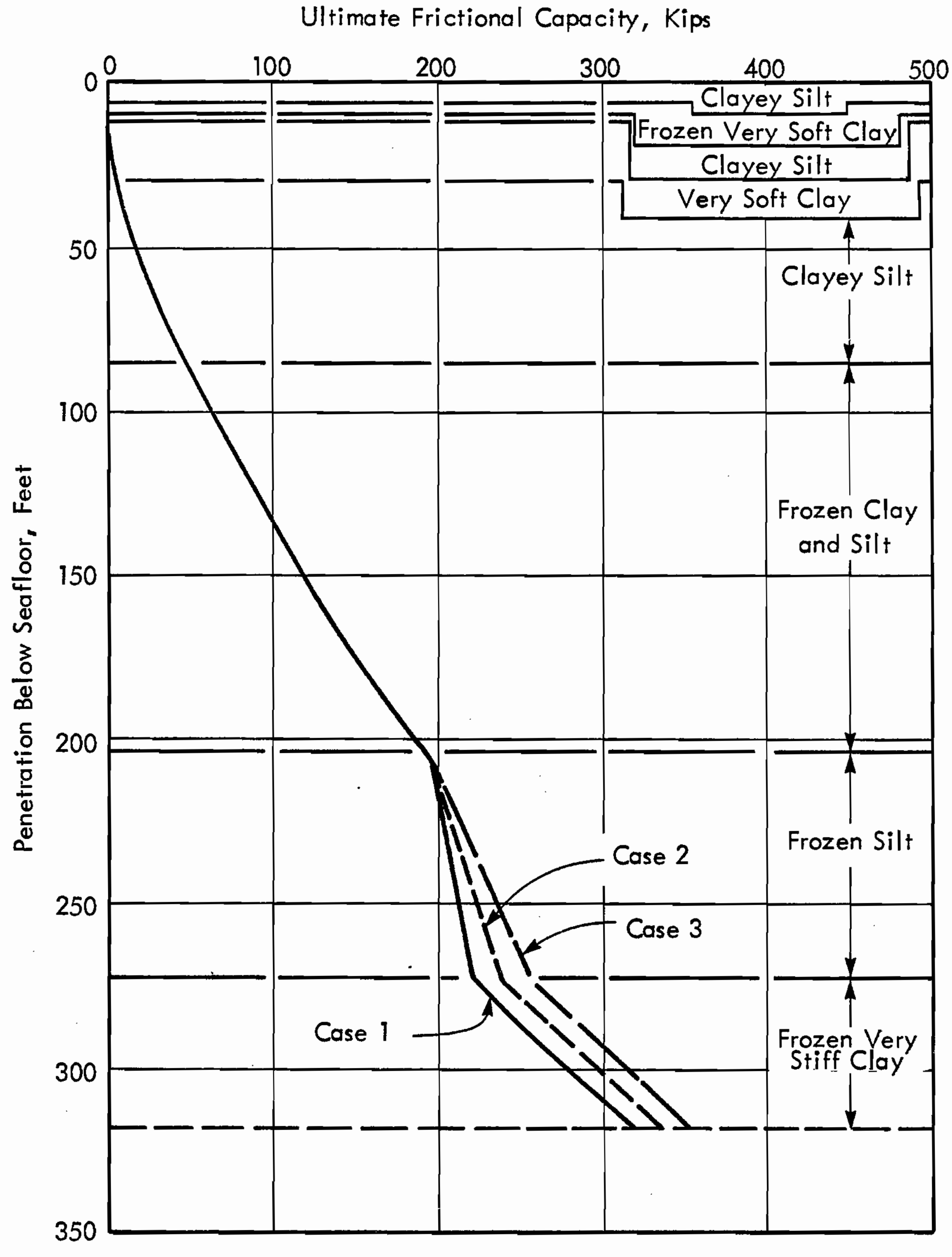


	Sand	Silty Sand	Sandy Silt	Silt and Clayey Silt
Case 1: f_{max} (ksf) =	0.80	0.70	0.55	0.40
Case 2: f_{max} (ksf) =	1.25	1.10	0.90	0.65
Case 3: f_{max} (ksf) =	1.80	1.60	1.25	0.90

INTERPRETATION OF DATA
Boring 8, Nektoralik H-28
Beaufort Sea



UNIT PILE DESIGN DATA
Boring 8, Nektoralik H-28
Beaufort Sea



ULTIMATE FRICTIONAL CAPACITY CURVES

12-in.-Circumference Pile

API RP 2A (January 1980) Method

Boring 8, Nektoralik H-28

Beaufort Sea

A P P E N D I X A

FIELD AND LABORATORY SOIL TEST RESULTS

APPENDIX A

ILLUSTRATIONS

SUMMARY OF LABORATORY TESTING RESULTS – PERMAFROST

SAMPLE NO.	SAMPLE TYPE	DEPTH INTERVAL (metres)	MOIST. CONT. (%)	BULK DENS. (Mg/m³)	GROUND ICE DESCRIPTION (%)	ATTERBERG LIMITS LL (%)	PL (%)	PI (%)	GRAIN SIZE DISTRIBUTION CLAY (%)	SILT (%)	SAND (%)	GRAV. (%)	ORGANIC CONTENT (%)	SOIL DESCRIPTION
1	J	0.0-0.6			Not Frozen									
2	J	0.0-0.1			Not Frozen									
3	G	0.1-0.3	61		Not Frozen									
4	Jv	0.3-0.5	61		Not Frozen	59	33	26						(MH) SILT
5	L	0.5-0.6		1.52	Frozen?									
6	L	0.9-1.1		1.52	Frozen?									
7	Jv	1.1-1.2	65	1.53	Frozen									(MH) SILT
8	PF	1.2-1.4		1.54	Frozen									
9	L	1.4-1.5		1.54	Frozen									
10	L	1.8-2.0		1.53	Not Frozen									
11	L	2.0-2.1		1.56	Not Frozen									
12	L	2.1-2.3		1.57	Not Frozen									
13	J	2.3-2.4	79	1.55	Not Frozen	62	29	33						(CH) CLAY
14	PF	2.7-3.2	73/81	1.63/1.47	Frozen									(CH) CLAY
15	Jv	3.2-3.3	39		Frozen	55	31	24	66	34	0	0		(MH) SILT
19	G	3.6-3.8	39		Not Frozen									
16	Q	3.8-4.0			Not Frozen									
17	Q	4.0-4.1	72	1.61	Not Frozen	67	23	44						(CH) CLAY
18	J	4.3-4.4	72		Not Frozen									
20	Q	4.7-4.9	68	1.62	Not Frozen									
21	Q	4.9-5.0			Not Frozen									
22	J	5.0-5.2	58		Not Frozen								12.2	
23	Q	5.6-5.8	62	1.63	Not Frozen									
24	Q	5.8-5.9			Not Frozen									
25	J	5.9-6.1	67		Not Frozen	62	26	36						(CH) CLAY

PROJECT NUMBER 101-2581 SITE NUMBER NEKTORALIK BOREHOLE 8

EBA Engineering Consultants Ltd.

McCLELLAND ENGINEERS

FORM DFT-1.1 (1978) Job No. 0179-0128

SUMMARY OF LABORATORY TESTING RESULTS — PERMAFROST

SAMPLE		DEPTH INTERVAL	MOIST. CONT.	BULK DENS.	GROUND ICE DESCRIPTION	ATTERBERG LIMITS			GRAIN SIZE DISTRIBUTION				ORGANIC CONTENT	SOIL DESCRIPTION
NO.	TYPE					LL	PL	PI	CLAY	SILT	SAND	GRAV.		
		(metres)	(%)	(Mg/m3)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	
26	Q	6.5 - 6.7			Not Frozen									
27	Q	6.7 - 6.9	64	1.67	Not Frozen									
28	J	6.9 - 7.0	57		Not Frozen	60	35	25	65	35	0	0		(CL) CLAY
29	Q	7.5 - 7.6			Not Frozen									
30	Q	7.6 - 7.8	61	1.69	Not Frozen									
31	J	7.8 - 7.9	69		Not Frozen	60	25	35						(CH) CLAY
32	J	8.2 - 8.4	91		Not Frozen								9.6	
51	J	8.5 - 8.7	72		Not Frozen	54	26	28						(CH) CLAY
33	Q	9.1 - 9.3	66	1.61	Not Frozen									
34	Q	9.3 - 9.4	70		Not Frozen									
35	J	9.4 - 9.6	65		Not Frozen	52	31	21						(MH) SILT
36	G	10.1 - 10.2	58		Not Frozen									
37	Q	10.2 - 10.4			Not Frozen									
38	Q	10.4 - 10.5			Not Frozen									
39	J	10.5 - 10.7	51		Not Frozen									
40	Q	11.1 - 11.3	52		Not Frozen									
41	J	11.3 - 11.4			Not Frozen									
42	Q	11.9 - 12.0			Not Frozen									
43	Q	12.0 - 12.2			Not Frozen									
44	J	12.2 - 12.3	48		Not Frozen									
45	Qs	12.8 - 12.9	37	1.84	Not Frozen									
46	Q	12.9 - 13.1			Not Frozen									
47	J	13.1 - 13.3	44		Not Frozen	47	28	19						(ML) SILT
48	G	13.7 - 13.9	44		Not Frozen									
49	Q	13.9 - 14.0	46	1.81	Not Frozen									

PROJECT NUMBER 101-2581 SITE NUMBER NEKTORALIK BOREHOLE 8

EBA Engineering Consultants Ltd.

McCLELLAND ENGINEERS

PLATE A-1b

SUMMARY OF LABORATORY TESTING RESULTS – PERMAFROST

SAMPLE NO.	SAMPLE TYPE	DEPTH INTERVAL (metres)	MOIST. CONT. (%)	BULK DENS. (Mg/m³)	GROUND ICE DESCRIPTION (%)	ATTERBERG LIMITS LL (%)	ATTERBERG LIMITS PL (%)	ATTERBERG LIMITS PI (%)	GRAIN SIZE DISTRIBUTION CLAY (%)	GRAIN SIZE DISTRIBUTION SILT (%)	GRAIN SIZE DISTRIBUTION SAND (%)	GRAIN SIZE DISTRIBUTION GRAV. (%)	ORGANIC CONTENT (%)	SOIL DESCRIPTION
50	Jv	14.0 - 14.2	43		Not Frozen									
52	Q	14.6 - 14.8	26	1.93	Not Frozen	52	27	25						(CH) CLAY
53	Jv	14.8 - 14.9	31		Not Frozen	47	31	16	61	38	1	0		(ML) SILT
54	J_T	16.1 - 16.3	31	1.92	Not Frozen								10.8	
55	Jv	16.3 - 16.5	29		Not Frozen	48	28	20						(ML) SILT
56	J	17.6 - 17.8	42		Frozen	45	29	16						(ML) SILT
57	J	17.8 - 18.0	17		Frozen	22	14	8						(ML) SILT
58	G	19.2 - 19.3	26		Not Frozen									
59	Q	19.3 - 19.5	23	2.01	Not Frozen									
60	Jv	19.5 - 19.7	26		Not Frozen									
61	Q	20.7 - 20.9	28	1.92	Not Frozen									
62	Jv	20.9 - 21.0	29		Not Frozen	37	27	10						(ML) SILT
63	J	21.0 - 21.2			Frozen									
64	G	22.2 - 22.4	33		Frozen									
65	Q	22.4 - 22.6	31	1.96	Frozen									
66	J_T	22.6 - 22.7	33		Frozen				44	56	0	0		(ML) SILT
67	Jv	22.7 - 22.9	30	1.89	Frozen									
68	Q	23.8 - 23.9			Not Frozen									
69	Q	23.9 - 24.1	31	1.95	Not Frozen									
70	Jv	24.1 - 24.2			Not Frozen									
71	J_T	25.3 - 25.4	32	1.89	Frozen?									
72	Jv	25.4 - 25.6	32		Frozen?	40	26	14						(ML) SILT
73	Q	26.8 - 27.0	34	1.91	Frozen?									
74	Q	27.0 - 27.1	32	1.89	Frozen?									
75	Jv	27.1 - 27.3	33		Frozen?				55	45	0	0		(CL-ML) CLAY AND SILT

PROJECT NUMBER 101-2581 SITE NUMBER NEKTORALIK BOREHOLE 8

EBA Engineering Consultants Ltd.

McCLELLAND ENGINEERS

SUMMARY OF LABORATORY TESTING RESULTS – PERMAFROST

SAMPLE NO.	SAMPLE TYPE	DEPTH INTERVAL (metres)	MOIST. CONT. (%)	BULK DENS. (Mg/m³)	GROUND ICE DESCRIPTION (%)	ATTERBERG LIMITS LL (%)	ATTERBERG LIMITS PL (%)	ATTERBERG LIMITS PI (%)	GRAIN SIZE DISTRIBUTION CLAY (%)	SILT (%)	SAND (%)	GRAV. (%)	ORGANIC CONTENT (%)	SOIL DESCRIPTION
76	G	28.3 - 28.5	30		Frozen?									
77	PF	28.5 - 28.6	33	1.87	Frozen?									
78	Q	28.6 - 28.8	28	1.99	Frozen?									
79	Jv	28.8 - 29.0	30		Frozen?								12.9	
80	Q	29.9 - 30.0	31	1.95	Frozen?									
81	J_T	30.0 - 30.2	32		Frozen?	42	26	16						(CL-ML) CLAY AND SILT
82	Jv	30.2 - 30.3	32	1.91	Frozen?									
83	PF	31.4 - 31.7	32	1.88	Vx-trace									
84	Jv	31.7 - 31.8	36		Vx-trace									
85	G	32.9 - 33.1	33		Vx-trace									
86	PF	33.1 - 33.2	31	1.90	Vx < 5									
87	Jv	33.2 - 33.4	33		Frozen	48	27	21						(CL-ML) CLAY AND SILT
88	J_T	34.4 - 34.6	30		Not Frozen	63	26	37						(CH-MH) CLAY AND SILT
89	Jv	34.6 - 34.7	30	1.95	Not Frozen									
90	Q	36.0 - 36.1			Not Frozen									
91	Jv	36.1 - 36.3	28		Not Frozen				70	30	0	0		(CL) CLAY
92	PF	37.5 - 37.8	34	1.88	Vr-20									
93	G	39.0 - 39.2	30		Frozen									
94	J_T	39.2 - 39.3	28	2.00	Frozen	55	31	24						(MH) SILT
95	J	39.3 - 39.5	25		Frozen									
96	PF	40.5 - 40.8	29	1.94	Vr < 5									
97	PF	42.1 - 42.5	207/54	1.12/1.61	Vr-40-50	52	25	27						(CH) CLAY
98	PF	43.6 - 43.7			Vr-5									
99	Jv	43.7 - 43.9	30	1.94	Vr-5								9.1	
100	J_T	43.9 - 44.0	30		Vr-5				62	38	0	0		(CH) CLAY

PROJECT NUMBER 101-2581 SITE NUMBER NEKTORALIK BOREHOLE 8

EBA Engineering Consultants Ltd.

McCLELLAND ENGINEERS

SUMMARY OF LABORATORY TESTING RESULTS – PERMAFROST

SAMPLE NO.	SAMPLE TYPE	DEPTH INTERVAL (metres)	MOIST. CONT. (%)	BULK DENS. (Mg/m³)	GROUND ICE DESCRIPTION (%)	ATTERBERG LIMITS LL (%)	PL (%)	PI (%)	GRAIN SIZE DISTRIBUTION CLAY (%)	SILT (%)	SAND (%)	GRAV. (%)	ORGANIC CONTENT (%)	SOIL DESCRIPTION
101	PF	45.1 - 45.6	11	1.91	Vr-40	Nonplastic								(ML) SILT
102	PF	48.2 - 48.5			Vr-20									
103	J_T	48.5 - 48.6	37	1.90	Vr-20									
104	PF	51.2 - 51.5			Vr-20-25									
105	J	51.5 - 51.7	38		Vr-20-25	Nonplastic			68	31	1	0		(ML) SILT
106	G	54.2 - 54.4	28		Frozen?									
107	J_T	54.4 - 54.6	27	1.90	Frozen?									(CL-ML) CLAY AND SILT
108	Jv	54.6 - 54.7	30		Frozen?	38	24	14						(CL-ML) CLAY AND SILT
109	Q	57.3 - 57.4	23	1.99	Frozen?									
110	Q	57.4 - 57.6			Frozen?									
111	J	57.6 - 57.8	18		Frozen?	24	14	10						(CL) CLAY
112	PF	60.3 - 60.7	55/23	1.91/1.93	Nbn				66	33	1	0		(CL) CLAY
113	J	63.4 - 63.5	31		Nbn	Nonplastic			9	88	3	0		(ML) SILT
114	PF	63.5 - 63.9	28	1.84	Nbn									
115	G	63.9 - 64.0	31		Nbn									
116	J	66.4 - 66.6	26		Nbn	Nonplastic							12.9	(ML) SILT
117	PF	66.6 - 66.9	23	1.94	Nbn				12	80	8	0		(ML) SILT
118	G	69.5 - 69.6	28		Nbn									
119	Q	69.6 - 69.8	26	1.90	Nbn									
120	PF	69.8 - 70.0	30	1.77	Nf-Nbn				6	71	23	0		(ML) SILT
121	J	72.5 - 72.7	28		Nbn	Nonplastic			24	74	2	0		(ML) SILT
122	PF	72.7 - 73.0	28	1.94	Nbn									
123	Q	75.6 - 75.7			Frozen									
124	Q	75.7 - 75.9	22	2.01	Frozen									
125	J	75.9 - 76.0	29		Frozen				19	80	1	0		(ML) SILT

PROJECT NUMBER 101-2581 SITE NUMBER NEKTORALIK BOREHOLE 8

EBA Engineering Consultants Ltd.

McCLELLAND ENGINEERS

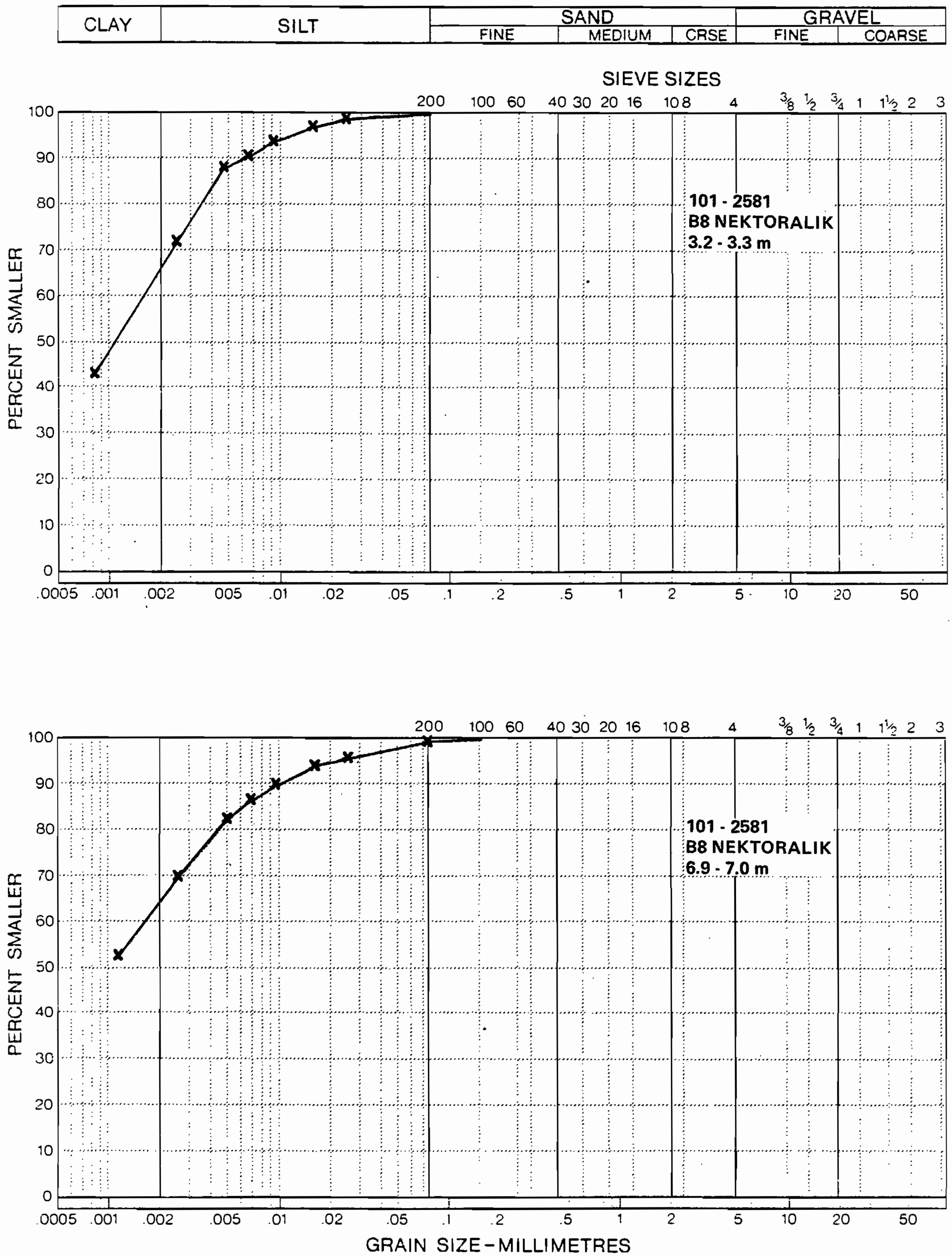
SUMMARY OF LABORATORY TESTING RESULTS – PERMAFROST

SAMPLE NO.	SAMPLE TYPE	DEPTH INTERVAL (metres)	MOIST. CONT. (%)	BULK DENS. (Mg/m³)	GROUND ICE DESCRIPTION (%)	ATTERBERG LIMITS LL (%)	ATTERBERG LIMITS PL (%)	ATTERBERG LIMITS PI (%)	GRAIN SIZE DISTRIBUTION CLAY (%)	GRAIN SIZE DISTRIBUTION SILT (%)	GRAIN SIZE DISTRIBUTION SAND (%)	GRAIN SIZE DISTRIBUTION GRAV. (%)	ORGANIC CONTENT (%)	SOIL DESCRIPTION
126	PF	78.6 - 78.9	28	1.84	Nbn				26	70	4	0		(ML) SILT
127	J	78.9 - 79.1	28		Nbn	Nonplastic								(ML) SILT
128	G	81.7 - 81.8			Nbn									
129	PF	81.8 - 82.1	28	1.96	Nbn	Nonplastic			12	81	7	0		(ML) SILT
130	G	84.7 - 84.9	28		Frozen									
131	J_T	84.9 - 85.0	23		Frozen	38	23	15						(CL) CLAY
132	J	85.0 - 85.2	24		Frozen				29	70	1	0		(ML) SILT
133	Q	87.8 - 87.9	27	2.00	Frozen	41	23	18	43	56	1	0		(CL) CLAY
134	PF	87.9 - 88.2	26	1.98	Nbn									
135	G	90.8 - 91.0			Frozen									
136	PF	91.0 - 91.3	26	1.99	Nbn									
137	J_T	94.0 - 94.2	23		Nbn	39	24	15	45	55	0	0		(CL) CLAY
138	Q	94.2 - 94.3		1.90	Nbn									

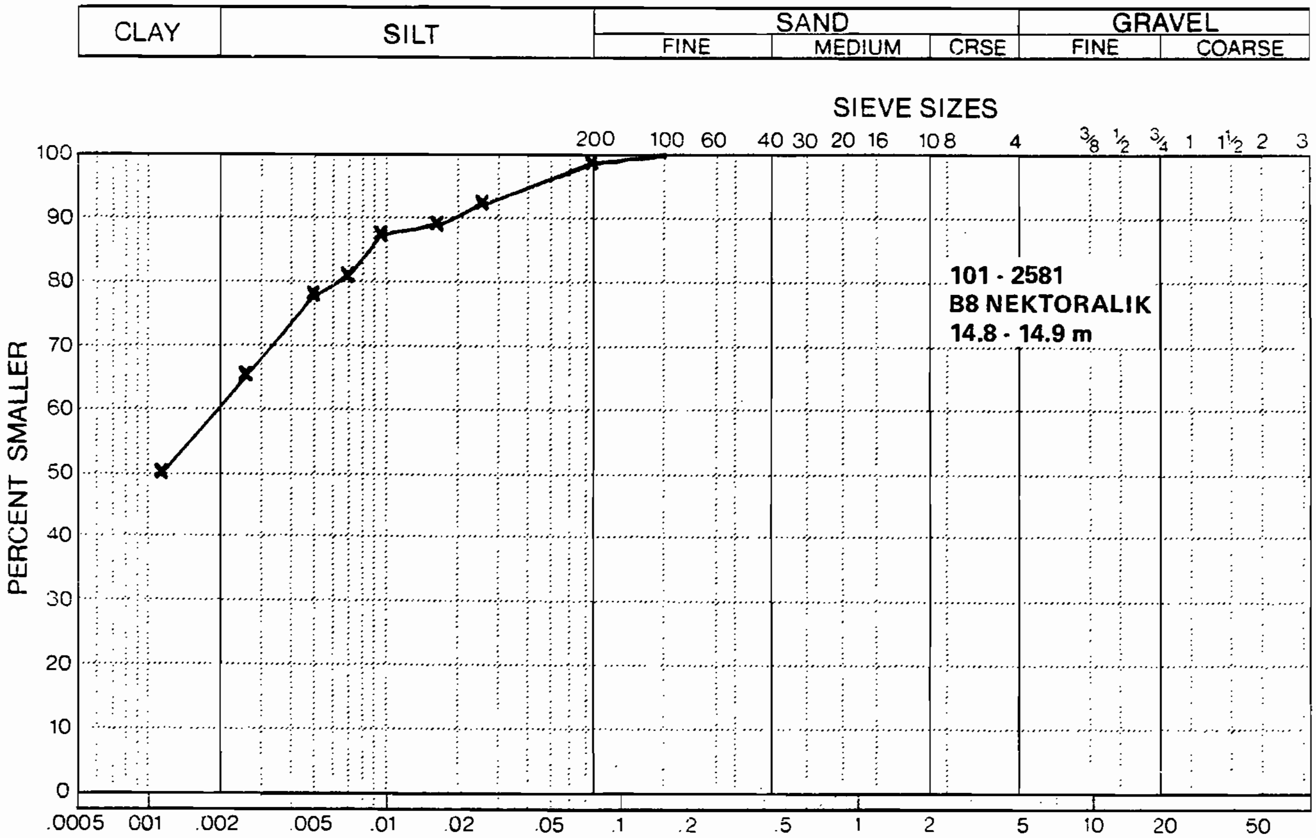
PROJECT NUMBER 101-2581 SITE NUMBER NEKTORALIK BOREHOLE 8

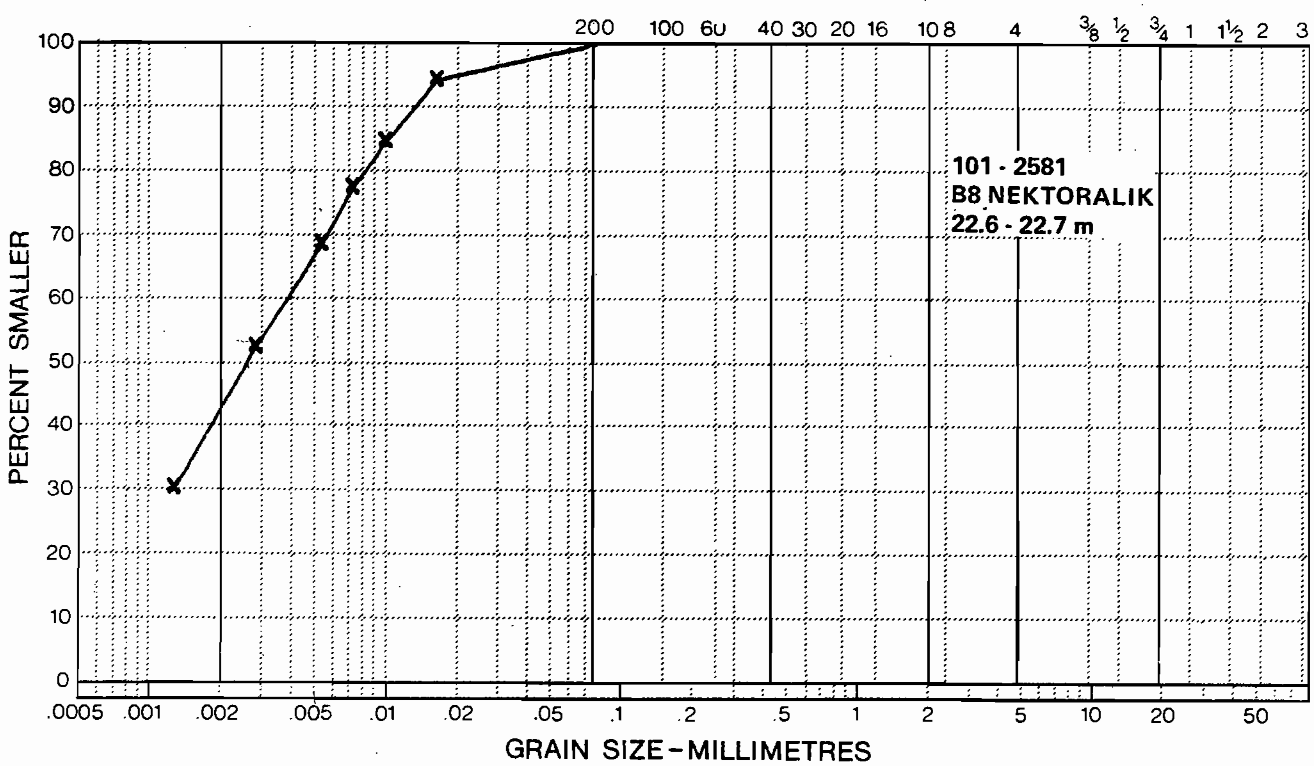
EBA Engineering Consultants Ltd.

McCLELLAND ENGINEERS

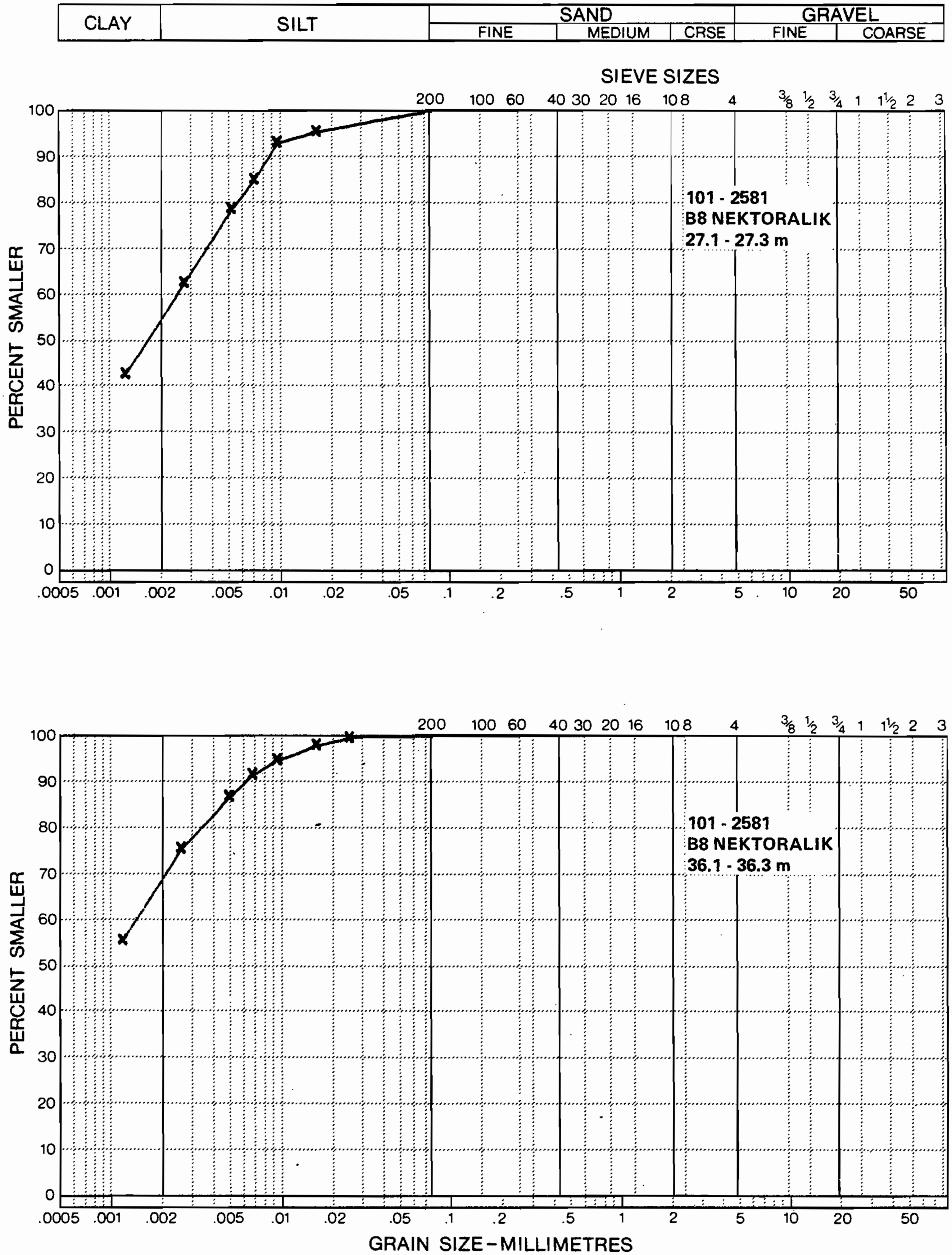


EBA Engineering Consultants Ltd.

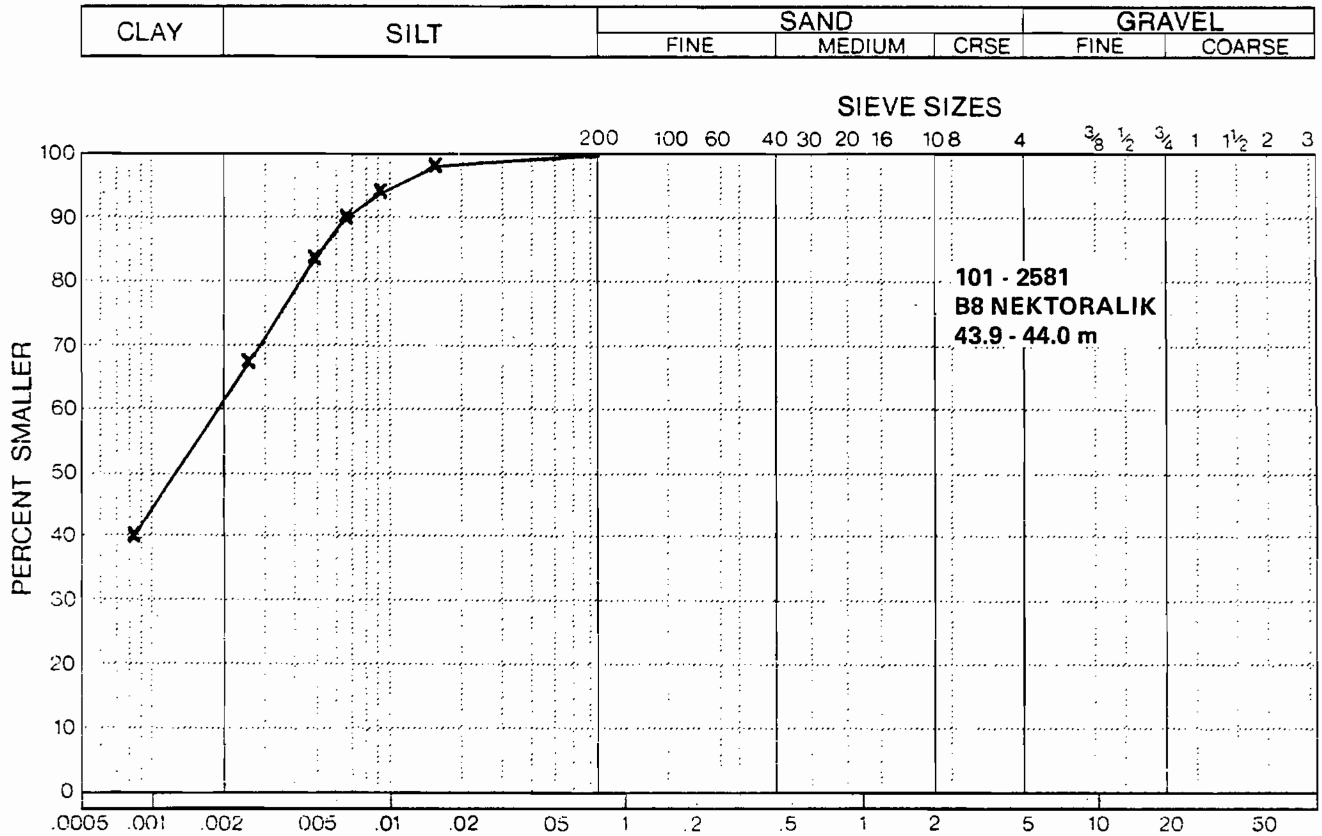


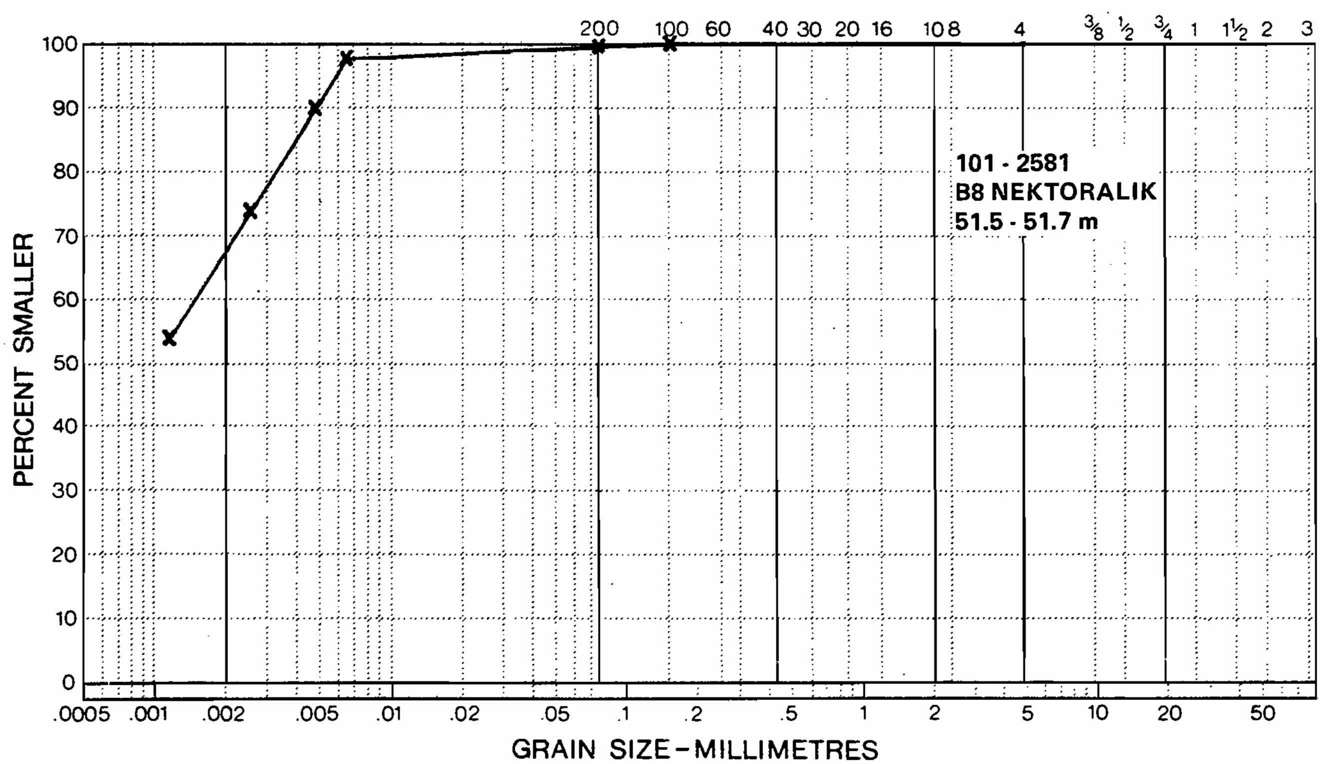


EBA Engineering Consultants Ltd.

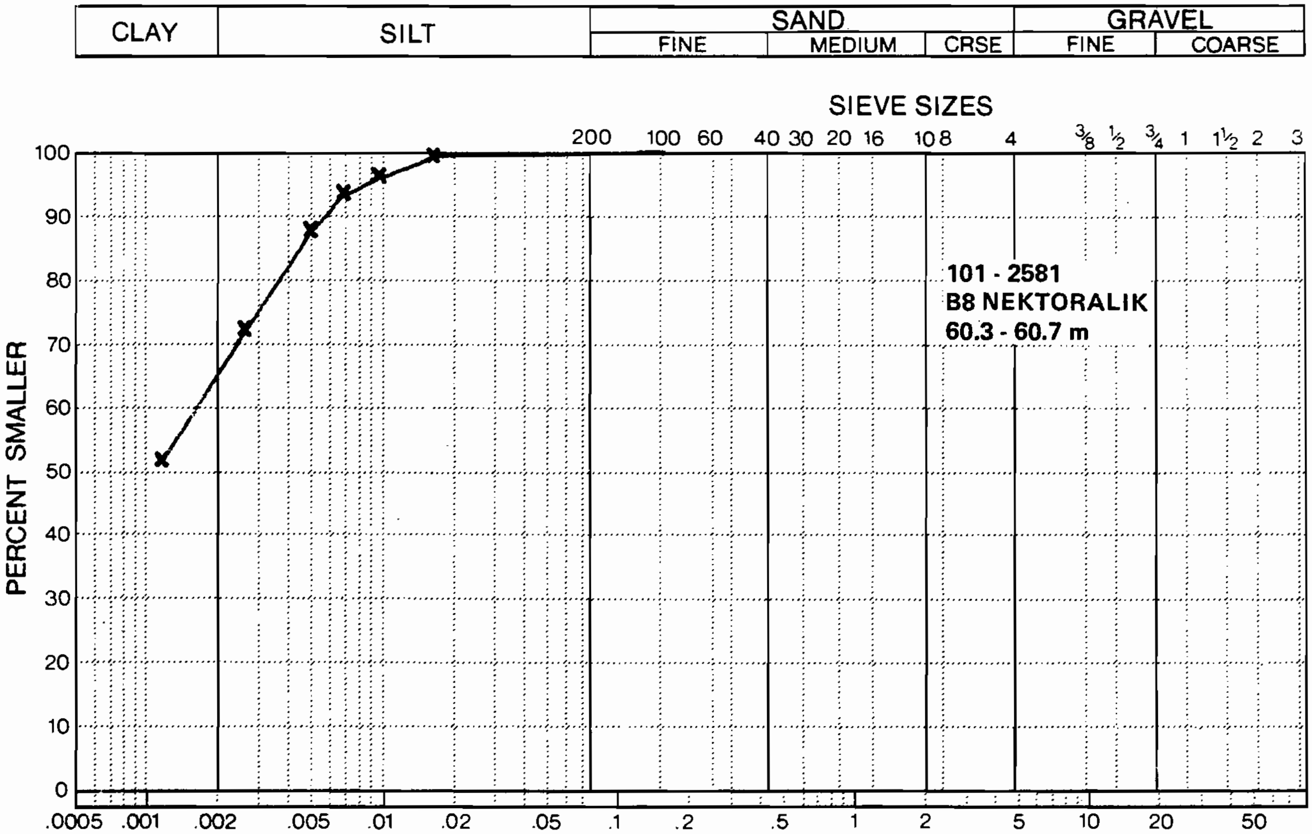


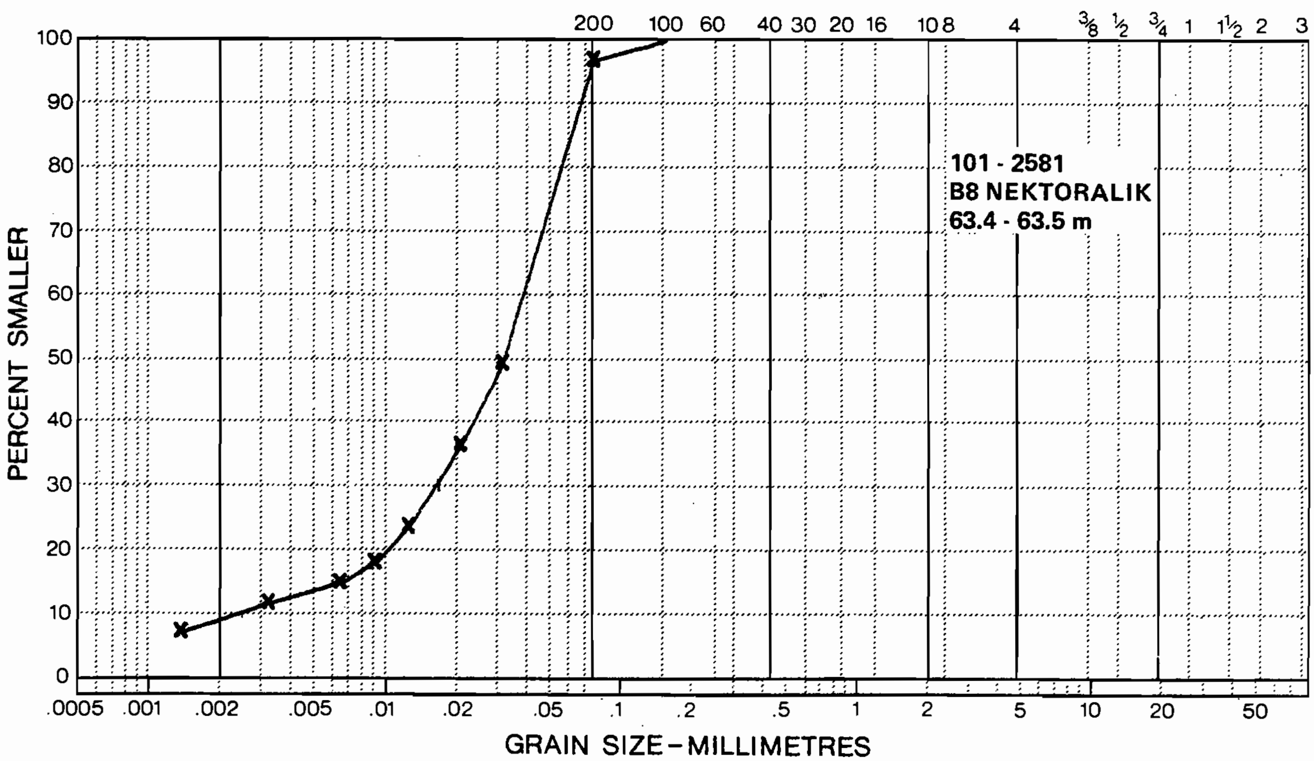
EBA Engineering Consultants Ltd.



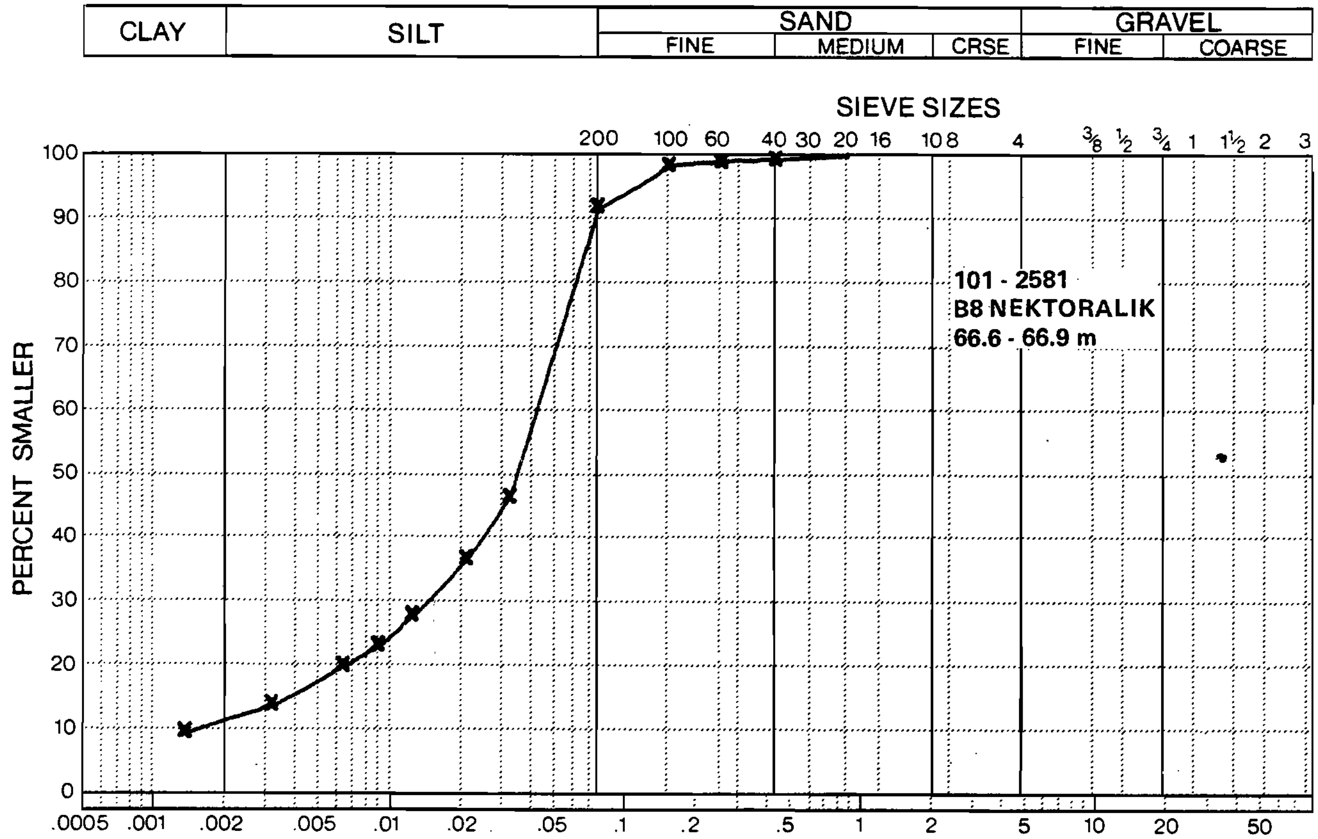


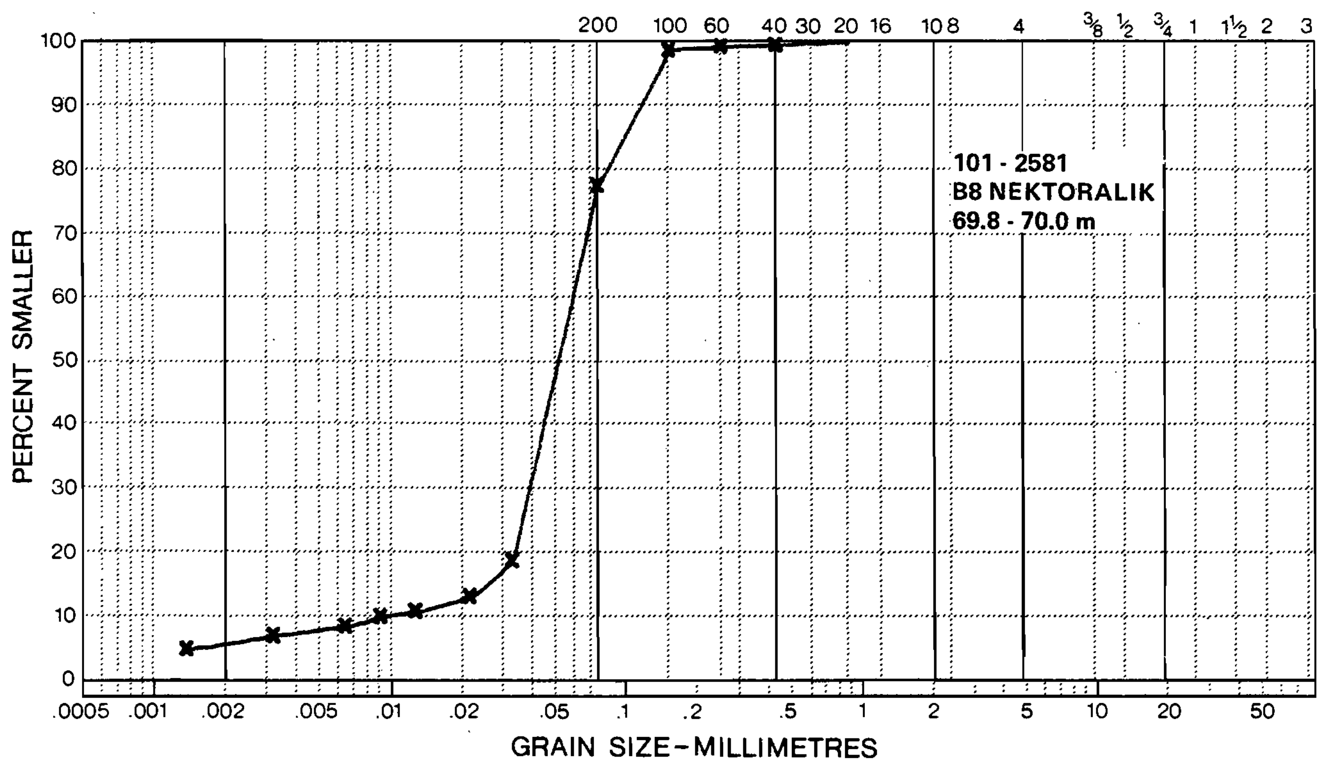
EBA Engineering Consultants Ltd.



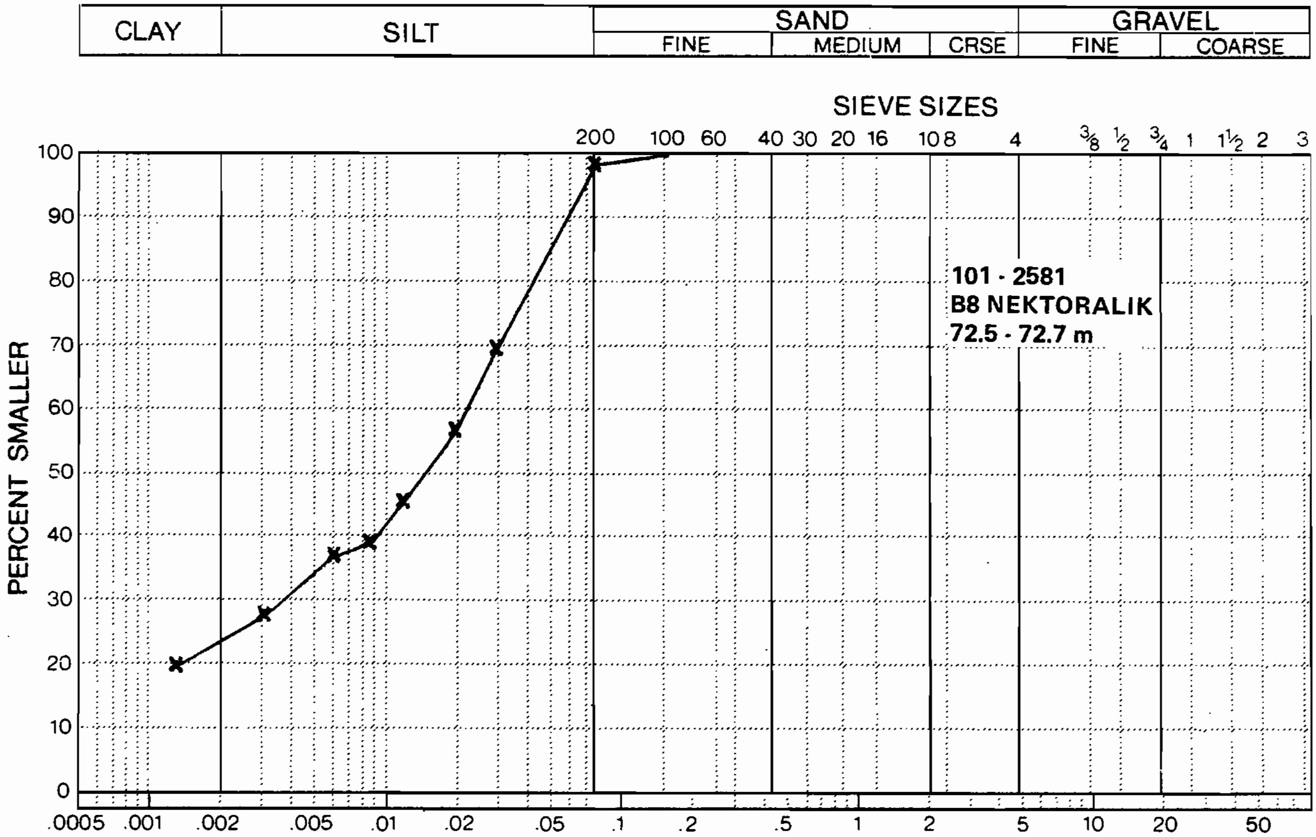


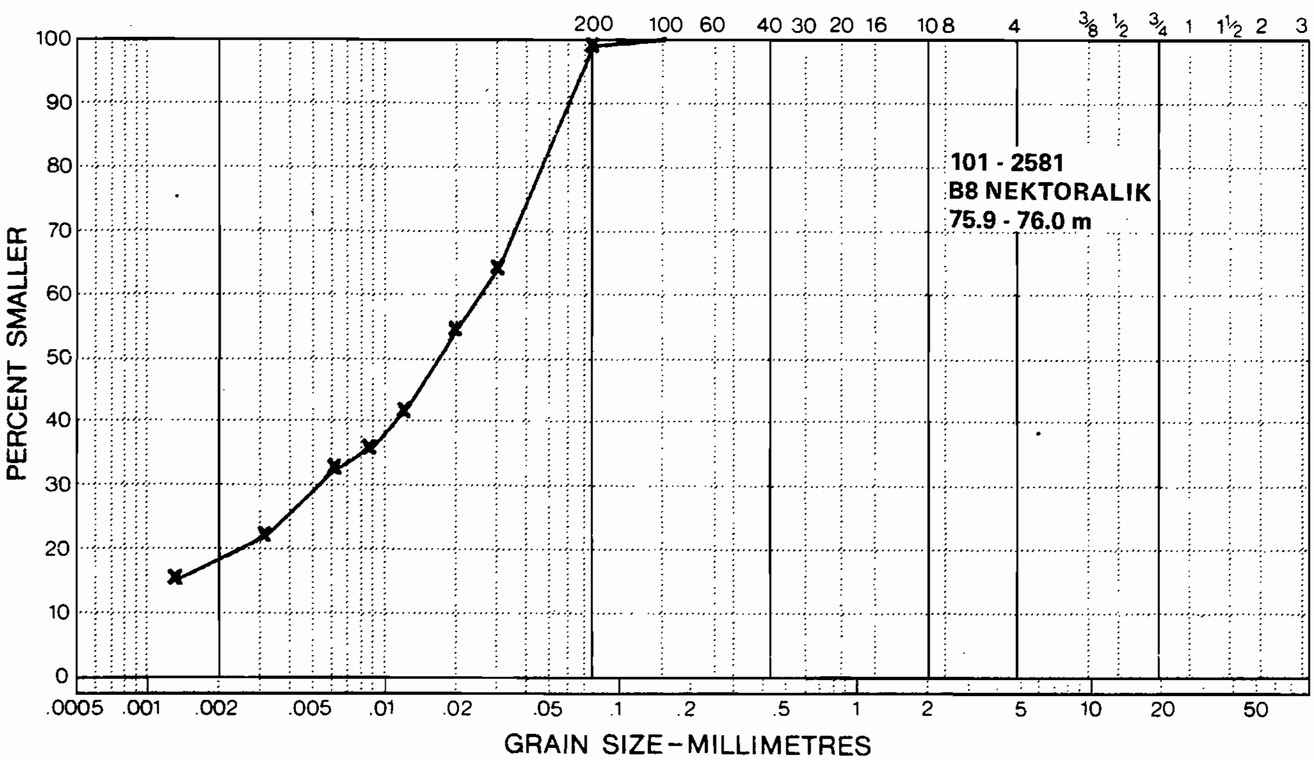
EBA Engineering Consultants Ltd.



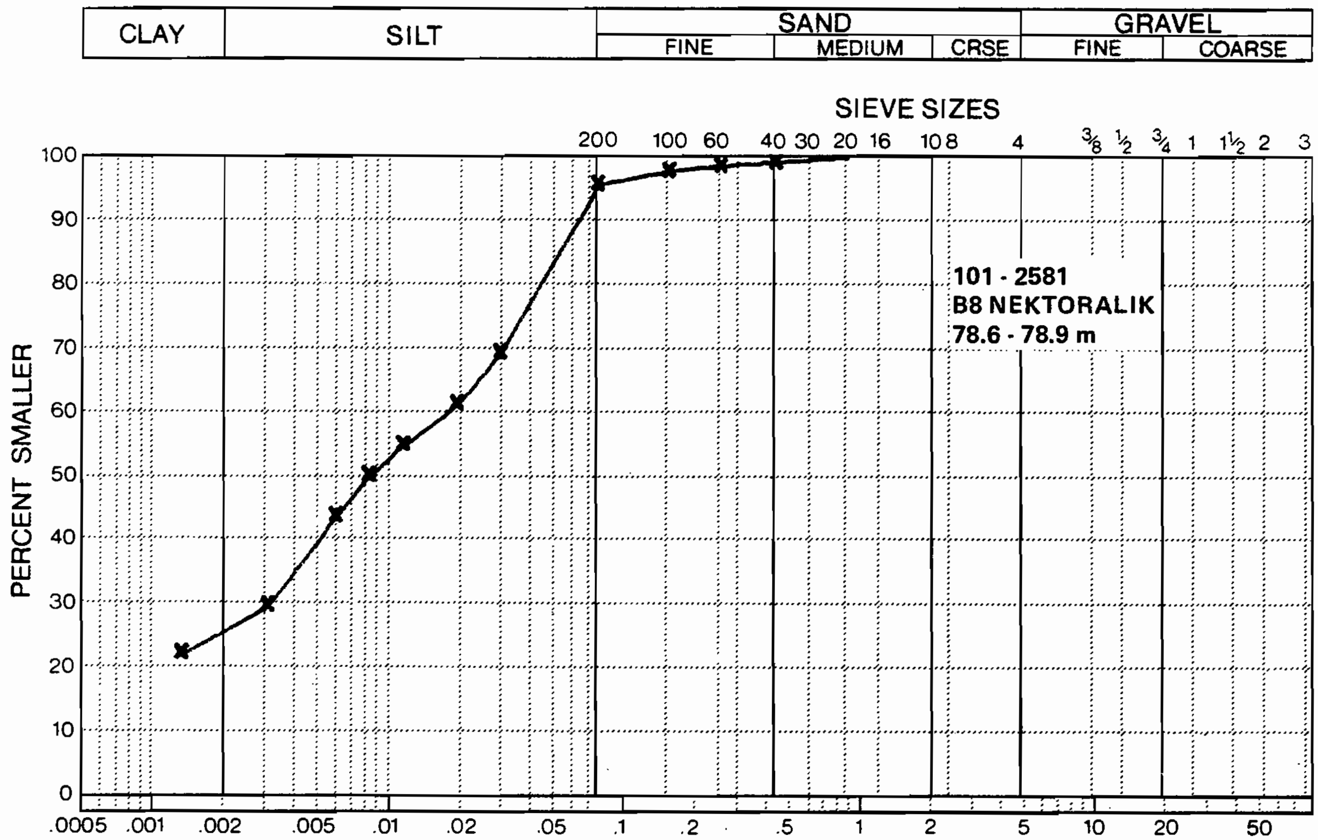


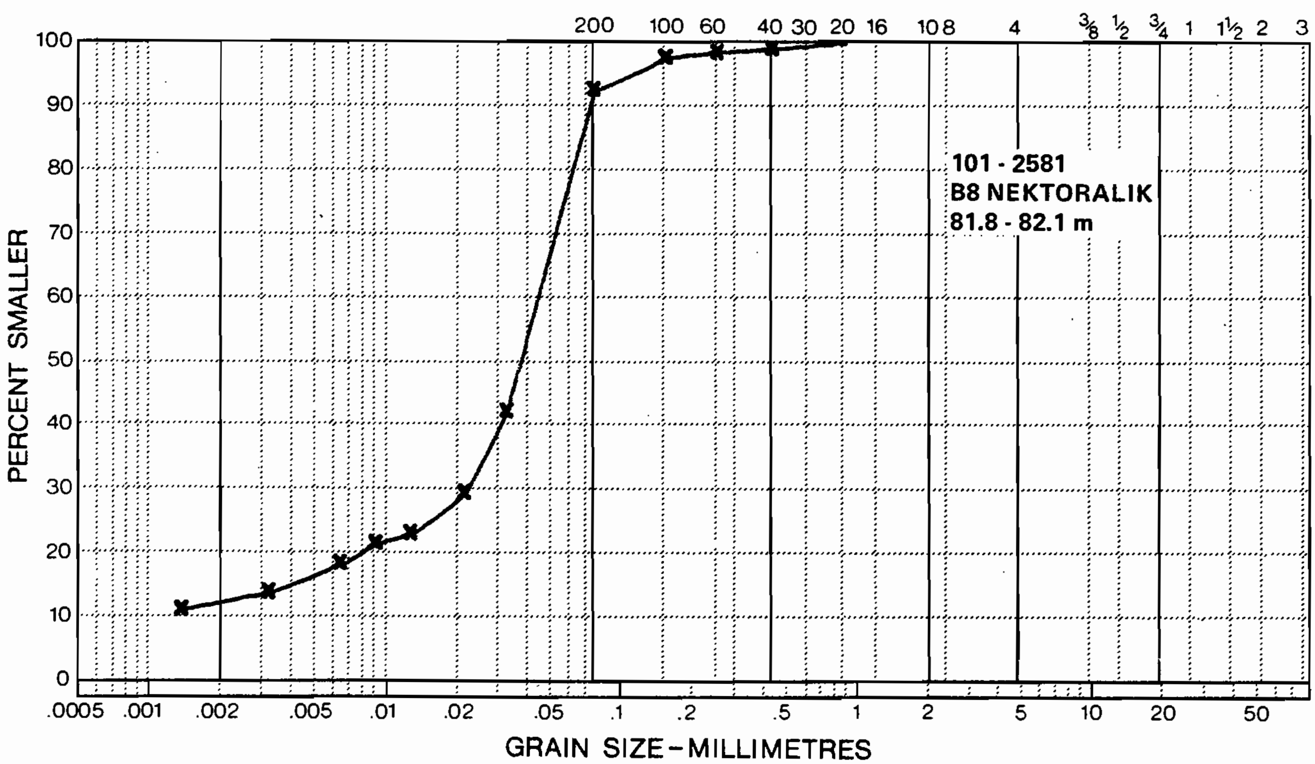
EBA Engineering Consultants Ltd.



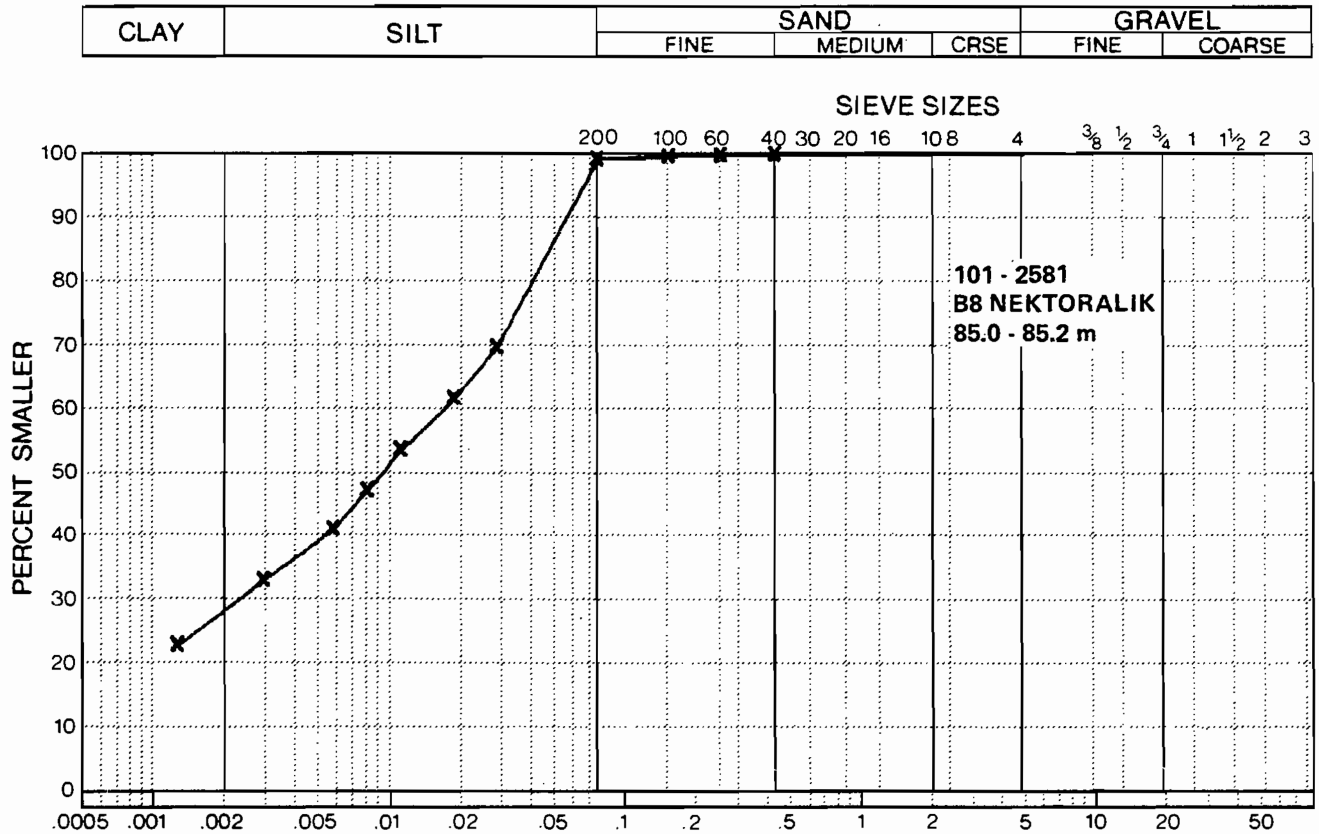


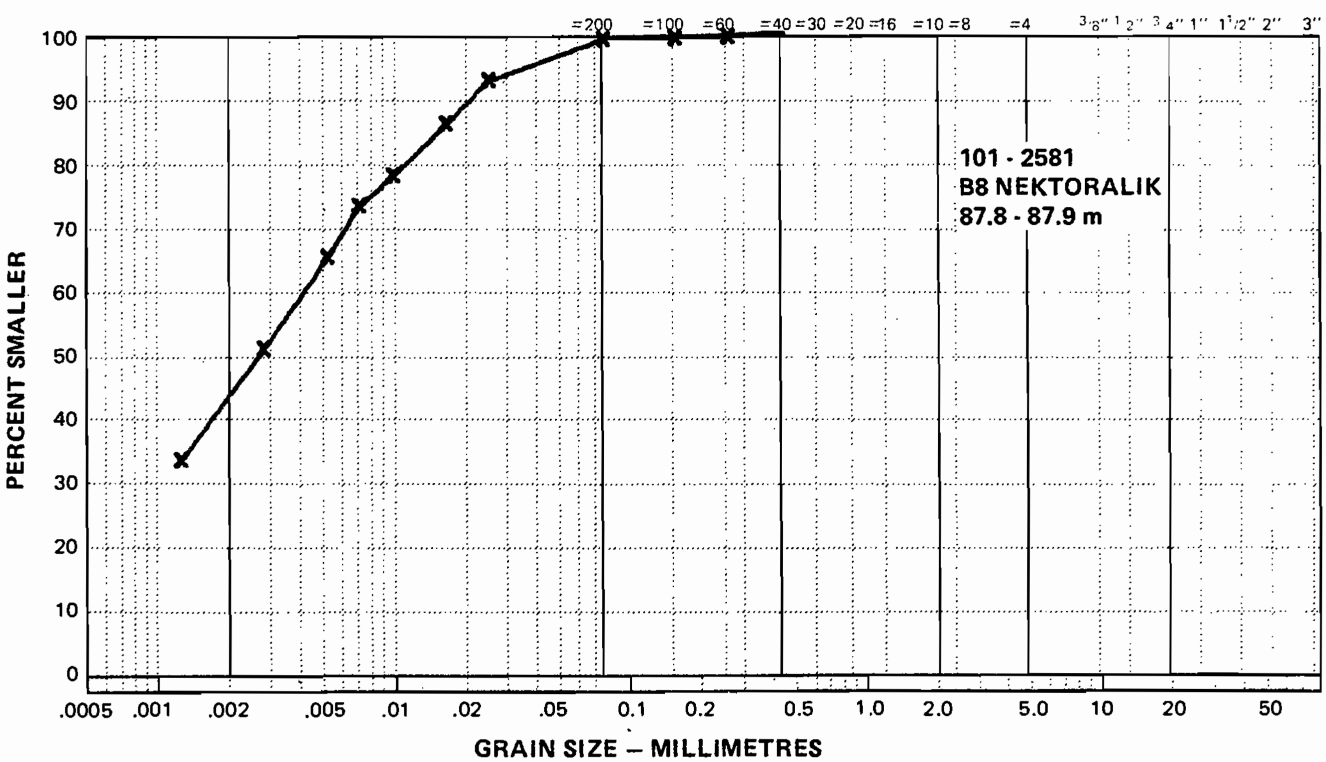
EBA Engineering Consultants ltd.

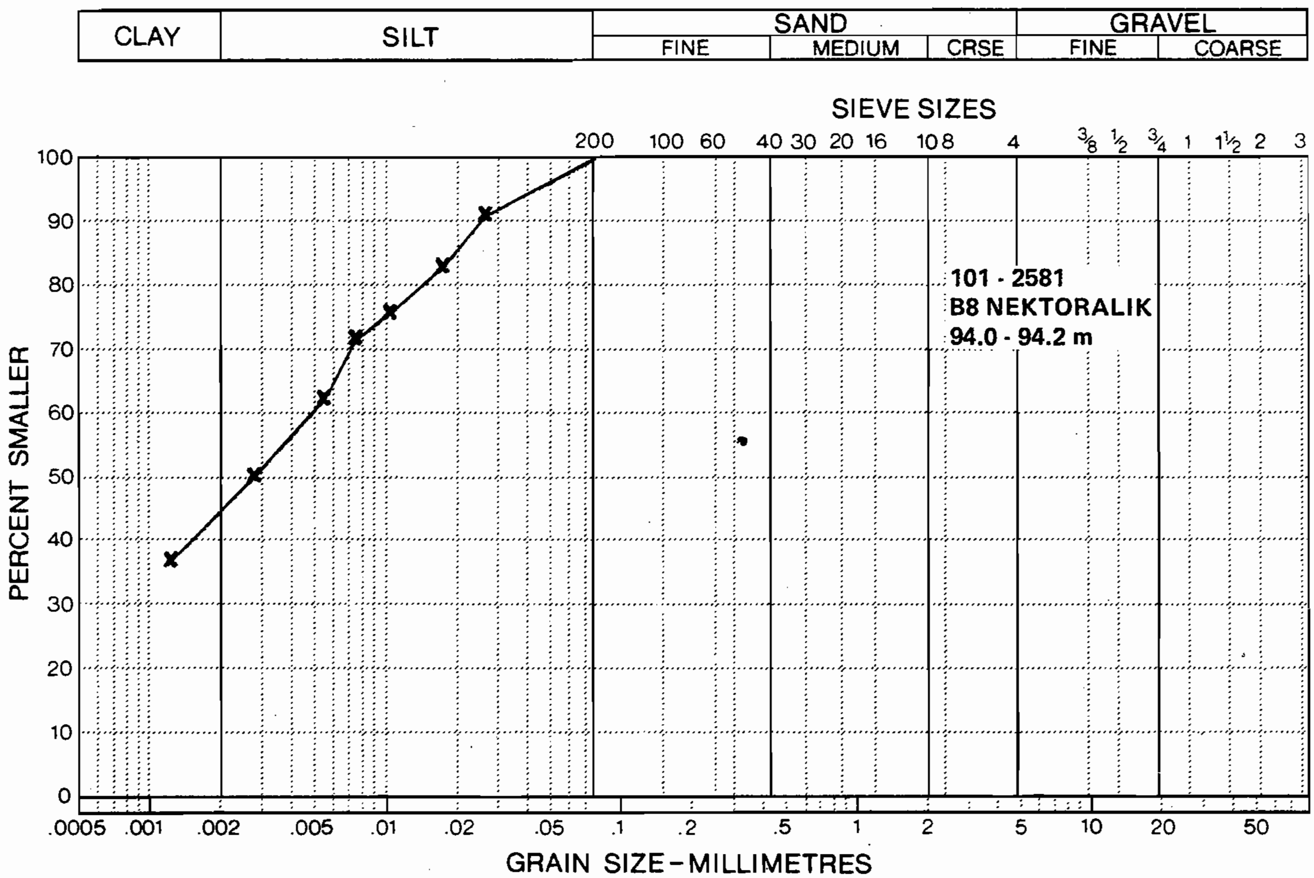




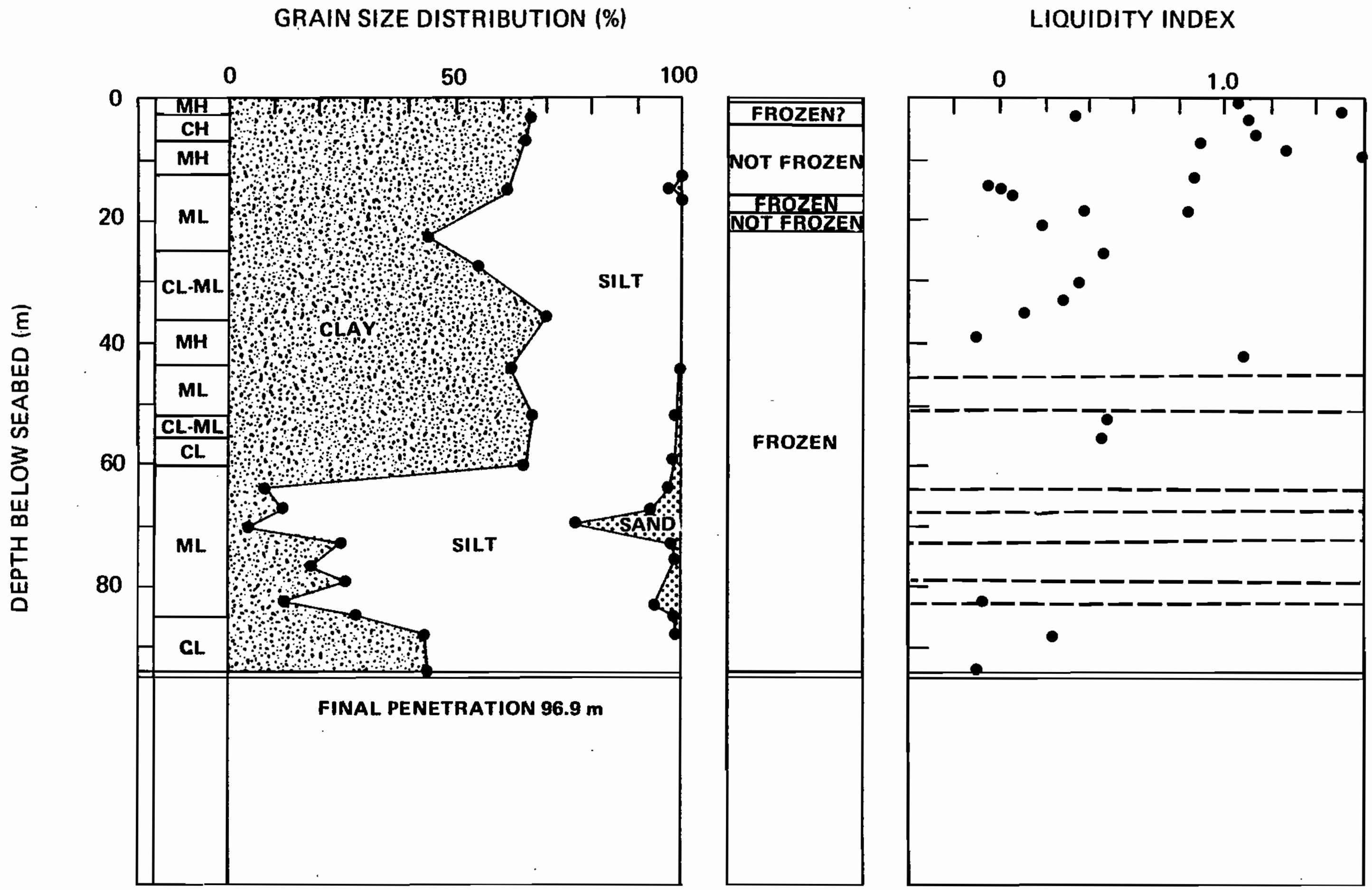
EBA Engineering Consultants Ltd.


CLAY
SILT
SAND
FINE
MEDIUM
CRSE
GRAVEL
FINE
COARSE
SIEVE SIZES
200 100 60 40 30 20 16 10 8 4 3/8 1/2 3/4 1 1½ 2 3
PERCENT SMALLER
0 10 20 30 40 50 60 70 80 90 100
.0005 .001 .002 .005 .01 .02 .05 .1 .2 .5 1 2 5 10 20 50
101 - 2581
B8 NEKTORALIK
85.0 - 85.2 m


=200 =100 =60 =40 =30 =20 =16 =10 =8 =4 3/8" 1/2" 3/4" 1" 1½" 2" 3"
PERCENT SMALLER
0 10 20 30 40 50 60 70 80 90 100
.0005 .001 .002 .005 .01 .02 .05 0.1 0.2 0.5 1.0 2.0 5.0 10 20 50
GRAIN SIZE – MILLIMETRES
101 - 2581
B8 NEKTORALIK
87.8 - 87.9 m



EBA Engineering Consultants Ltd.

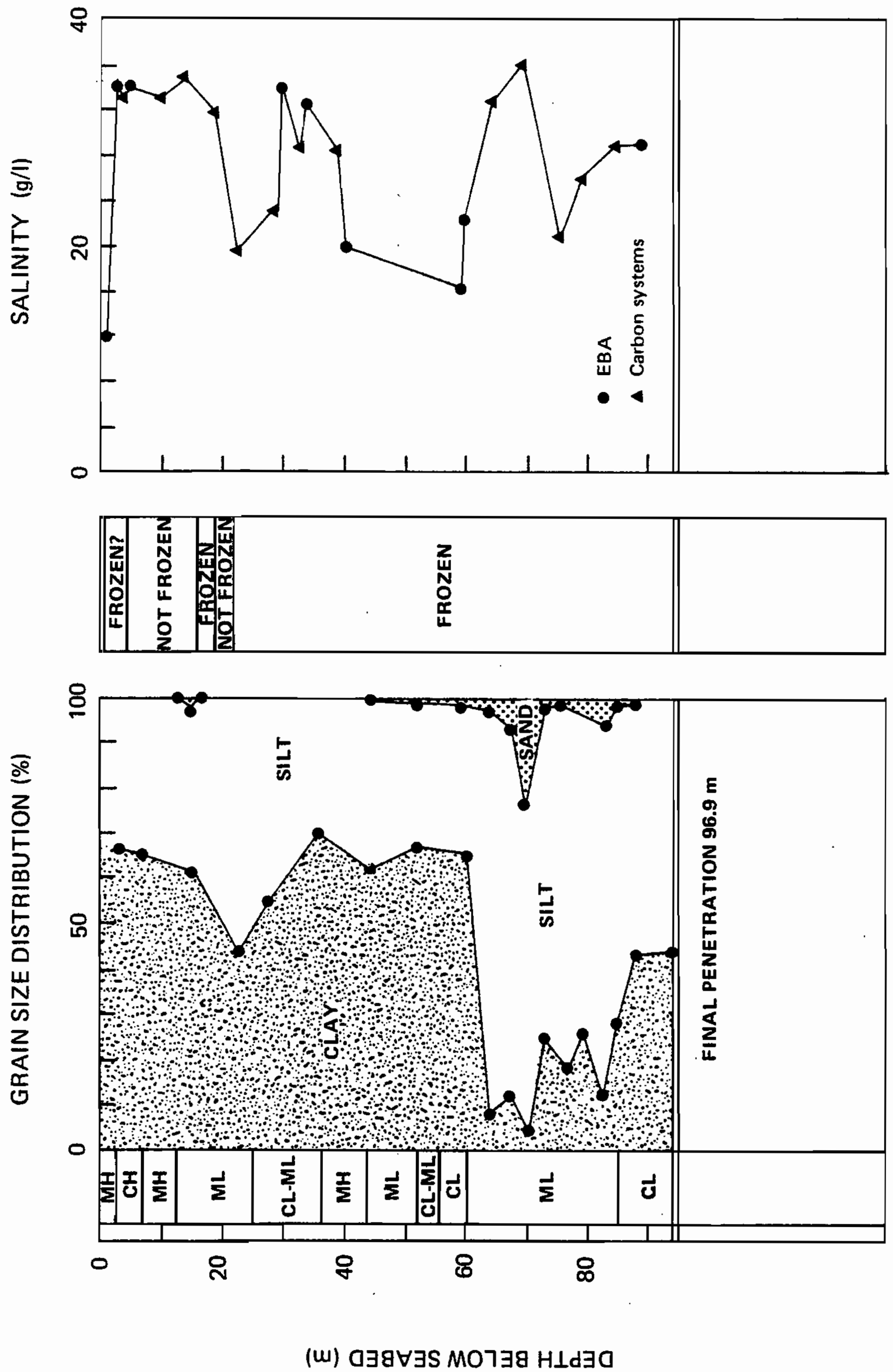


Note: **FROZEN** *indicates that ice bonding was distinguished.*

– – – – – – Denotes nonplastic

LIQUIDITY INDEX PROFILE

EBA Engineering Consultants Ltd.



Note: FROZEN *indicates that ice bonding was distinguished.*

PORE WATER SALINITY PROFILE

EBA Engineering Consultants Ltd.

SALINITY TEST RESULTS

DEPTH (metres)	DEPTH (feet)	SALINITY (ppt)	CLAY FRACTION (%)
0.3	1.0	12 *	60 **
2.7	9.0	34	65
3.7	12.0	33 *	65
4.9	16.0	34	65
10.1	33.0	33 *	63
13.7	45.0	35 *	61
19.2	63.0	31 *	53
22.3	73.0	19 *	39
28.3	93.0	23 *	57
28.5	93.5	23	57
28.5	93.5	34	57
32.9	108.0	29 *	65
33.1	108.5	33	65
39.0	128.0	28 *	68
39.3	129.0	20	68
60.4	198.0	16	66
60.4	198.0	22	66
64.0	210.0	33 *	33
69.5	228.0	36 *	7
75.9	249.0	21	19
78.6	258.0	26	26
84.7	278.0	29 *	27
87.9	288.5	29	35

NOTE: *Test performed by Carbon Systems, Inc.
**Clay fraction interpolated.

EBA Engineering Consultants Ltd.

SPECIFIC GRAVITY TEST RESULTS

SAMPLE NUMBER	DEPTH (m)	SPECIFIC GRAVITY OF SOIL PARTICLES
97	42.1	2.80
136	91.0	2.77

EBA Engineering Consultants Ltd.

NEKTORALIK

UNCONSOLIDATED - UNDRAINED

TRIAXIAL TESTS

(including laboratory vane shear tests)

SAMPLE NUMBER	DEPTH (metres)	USC	MOISTURE CONTENT (%)	INITIAL BULK DENSITY (Mg/m^3)	CONFINING PRESSURE (kPa)	AXIAL STRAIN AT FAILURE (%)	UNDRAINED SHEAR STRENGTH JACKETED TRIAXIAL (kPa)	UNDRAINED SHEAR STRENGTH LABORATORY VANE SHEAR (kPa)	REMARKS
S-14	2.7	CH	75.6	1.47	290	30*	14	-	
S-17	4.0	CH	71.9	1.61	300	9	5	-	bulged
S-23	5.6	CH	61.7	1.63	310	11	22	-	bulged
S-27	6.7	CH	51.6	1.67	320	9	22	-	bulged
S-30	7.6	CH	57.1	1.69	325	12	8	-	bulged
S-30	7.6	CH	59.9	-	-	-	-	5.3	
S-33	9.1	CH	61.4	-	-	-	-	6.4	
S-34	9.3	MH	69.8	-	-	-	-	5.7	
S-40	11.1	MH	52.3	-	-	-	-	8.7	
S-45	12.8	ML	36.7	1.84	360	9	9	-	bulged
S-52	14.6	ML	25.9	1.93	380	8	73	-	
S-59	19.4	ML	22.7	2.01	420	13	216	-	
S-61	20.7	ML	27.8	1.92	430	16	35	-	
S-65	22.4	ML	30.7	1.96	440	12	108	-	
S-69	23.9	ML	30.6	1.95	450	16	62	-	bulged
S-73	26.8	CL	34.0	-	-	-	-	130	
S-74	27.0	CL	31.9	1.89	480	16	94	-	
S-78	28.7	CL	27.8	1.99	490	20	82	-	
S-80	29.9	CL	28.1	1.95	500	16	63	-	
S-109	57.3	CL	21.5	1.99	740	23	203	-	
S-124	75.7	ML	22.4	2.01	890	28*	119	-	laminated

EBA Engineering Consultants Ltd.

FORM DFT-1.1 (1978) Job No. 0179-0128

EBA Engineering Consultants Ltd.

14535 – 118th AVENUE
EDMONTON, ALBERTA
Phone (403) 451-2121

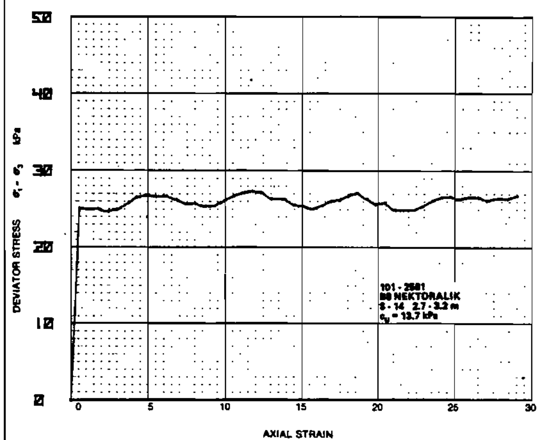
eba

5664 BURLEIGH CRES. S.E.
CALGARY, ALBERTA
Phone (403) 253-7121

UNCONSOLIDATED — UNDRAINED TRIAXIAL TEST

Project:
Address:
Job No.: 101-2581
Date Tested: 800306 By: H.R.H.
Client:
Attention:

Test No.: 1
Test Hole No.: S-14
Depth of Sample m.: 2.7-3.2
Confining Pressure kPa: 290.0
Water Content %: 75.6
Wet Density Mg/m³: 1.466
Peak Stress kPa: 27.33



Reviewed by ______________ P.Eng.

EBA Engineering Consultants Ltd.

14535 – 118th AVENUE
EDMONTON, ALBERTA
Phone (403) 451-2121

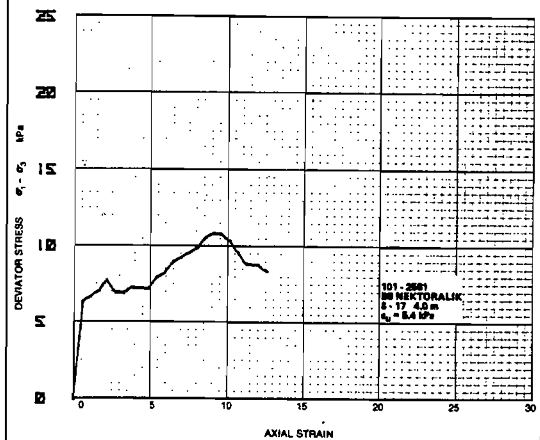
eba

5664 BURLEIGH CRES. S.E.
CALGARY, ALBERTA
Phone (403) 253-7121

UNCONSOLIDATED — UNDRAINED TRIAXIAL TEST

Project:
Address:
Job No.: 101-2581
Date Tested: 800320 By: H.R.H.
Client:
Attention:

Test No.: 11
Test Hole No.: S-17
Depth of Sample m.: 4.0
Confining Pressure kPa: 300.0
Water Content %: 71.9
Wet Density Mg/m³: 1.607
Peak Stress kPa: 10.87



Reviewed by ______________ P.Eng.

EBA Engineering Consultants Ltd.

14535 – 118th AVENUE
EDMONTON, ALBERTA
Phone (403) 451-2121

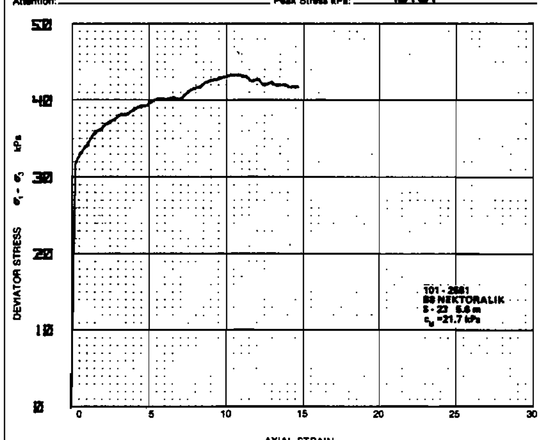
eba

5664 BURLEIGH CRES. S.E.
CALGARY, ALBERTA
Phone (403) 253-7121

UNCONSOLIDATED — UNDRAINED TRIAXIAL TEST

Project:
Address:
Job No.: 101-2581
Date Tested: 800320 By: H.R.H.
Client:
Attention:

Test No.: 12
Test Hole No.: S-23
Depth of Sample m.: 5.6
Confining Pressure kPa: 310.0
Water Content %: 61.7
Wet Density Mg/m³: 1.629
Peak Stress kPa: 43.37



Reviewed by ______________ P.Eng.

EBA Engineering Consultants Ltd.

14535 – 118th AVENUE
EDMONTON, ALBERTA
Phone (403) 451-2121

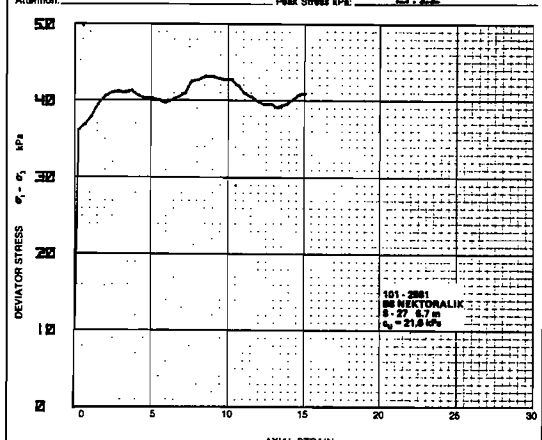
eba

5664 BURLEIGH CRES. S.E.
CALGARY, ALBERTA
Phone (403) 253-7121

UNCONSOLIDATED — UNDRAINED TRIAXIAL TEST

Project:
Address:
Job No.: 101-2581
Date Tested: 800320 By: H.R.H.
Client:
Attention:

Test No.: 13
Test Hole No.: S-27
Depth of Sample m.: 6.7
Confining Pressure kPa: 320.0
Water Content %: 51.6
Wet Density Mg/m³: 1.669
Peak Stress kPa: 43.22



Reviewed by ______________ P.Eng.

EBA Engineering Consultants Ltd.

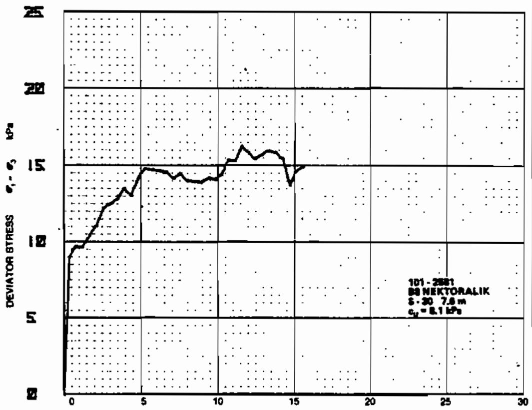
14535 - 118th AVENUE
EDMONTON, ALBERTA
Phone (403) 451-2121

5664 BURLEIGH CRES. S.E.
CALGARY, ALBERTA
Phone (403) 253-7121

UNCONSOLIDATED — UNDRAINED TRIAXIAL TEST

Project:
Address:
Job No.: 101-2581
Date Tested: 800320 By: H.R.H.
Client:
Attention:

Test No.: 14
Test Hole No.: S-30
Depth of Sample m.: 7.6
Confining Pressure kPa: 325.0
Water Content %: 57.1
Wet Density Mg/m³: 1.654
Peak Stress kPa: 16.22



Reviewed by ______________________ P.Eng.

EBA Engineering Consultants Ltd.

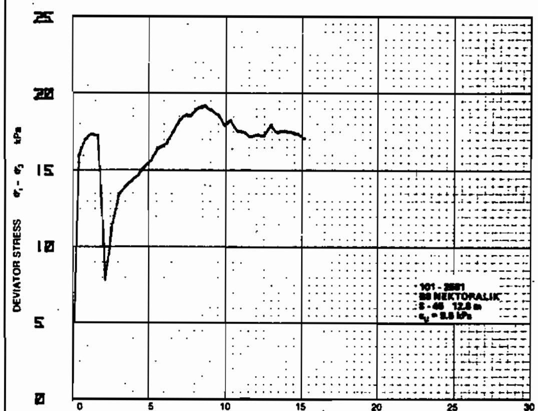
14535 - 118th AVENUE
EDMONTON, ALBERTA
Phone (403) 451-2121

5664 BURLEIGH CRES. S.E.
CALGARY, ALBERTA
Phone (403) 253-7121

UNCONSOLIDATED — UNDRAINED TRIAXIAL TEST

Project:
Address:
Job No.: 101-2581
Date Tested: 800321 By: S.K.
Client:
Attention:

Test No.: 15
Test Hole No.: S-46
Depth of Sample m.: 12.8
Confining Pressure kPa: 360.0
Water Content %: 35.7
Wet Density Mg/m³: 1.841
Peak Stress kPa: 19.24



Reviewed by ______________________ P.Eng.

EBA Engineering Consultants Ltd.

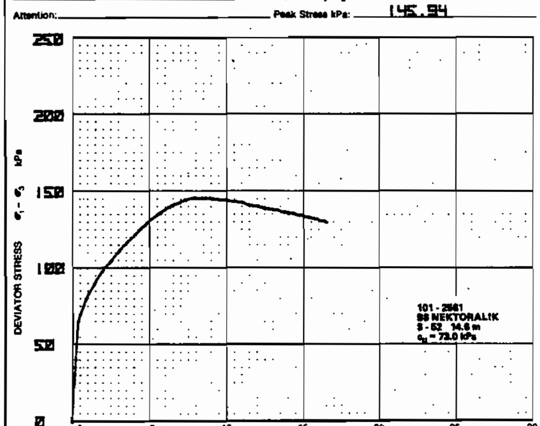
14535 - 118th AVENUE
EDMONTON, ALBERTA
Phone (403) 451-2121

5664 BURLEIGH CRES. S.E.
CALGARY, ALBERTA
Phone (403) 253-7121

UNCONSOLIDATED — UNDRAINED TRIAXIAL TEST

Project:
Address:
Job No.: 101-2581
Date Tested: 800321 By: S.K.
Client:
Attention:

Test No.: 16
Test Hole No.: S-52
Depth of Sample m.: 14.6
Confining Pressure kPa: 380.0
Water Content %: 25.9
Wet Density Mg/m³: 1.934
Peak Stress kPa: 145.94



Reviewed by ______________________ P.Eng.

EBA Engineering Consultants Ltd.

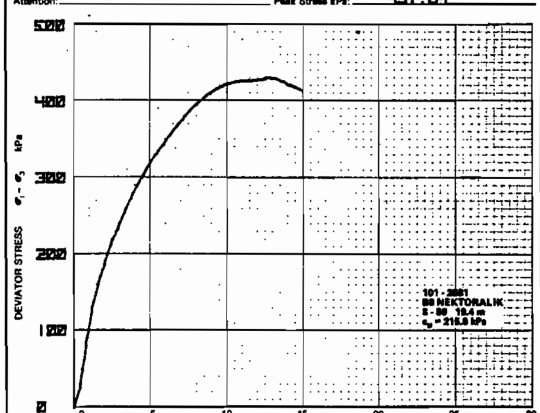
14535 - 118th AVENUE
EDMONTON, ALBERTA
Phone (403) 451-2121

5664 BURLEIGH CRES. S.E.
CALGARY, ALBERTA
Phone (403) 253-7121

UNCONSOLIDATED — UNDRAINED TRIAXIAL TEST

Project:
Address:
Job No.: 101-2581
Date Tested: 800321 By: H.R.H.
Client:
Attention:

Test No.: 17
Test Hole No.: S-59
Depth of Sample m.: 19.4
Confining Pressure kPa: 420.0
Water Content %: 22.7
Wet Density Mg/m³: 2.009
Peak Stress kPa: 431.64



Reviewed by ______________________ P.Eng.

FORM DET-1.1 (1978) Job No 0179-0128

EBA Engineering Consultants Ltd.

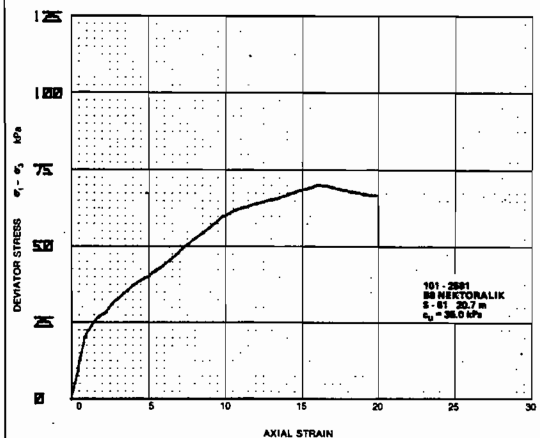
14535 - 118th AVENUE
EDMONTON, ALBERTA
Phone (403) 451-2121

5664 BURLEIGH CRES. S.E.
CALGARY, ALBERTA
Phone (403) 253-7121

UNCONSOLIDATED — UNDRAINED TRIAXIAL TEST

Project:
Address:
Job No.: 101-2581
Date Tested: 800321 By: S.K.
Client:
Attention:

Test No.: 18
Test Hole No.: S-61
Depth of Sample m.: 20.7
Confining Pressure kPa: 430.0
Water Content %: 27.8
Wet Density Mg/m³: 1.915
Peak Stress kPa: 69.92



Reviewed by ____________ P.Eng.

EBA Engineering Consultants Ltd.

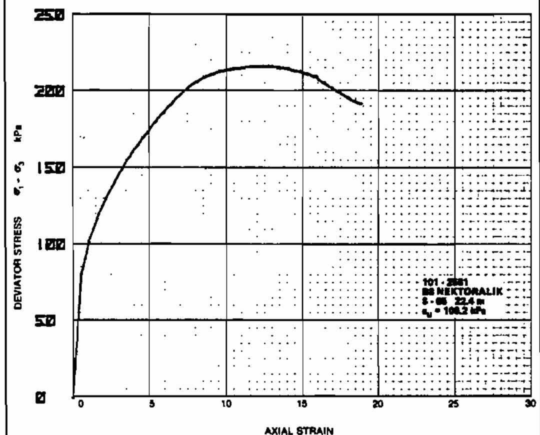
14535 - 118th AVENUE
EDMONTON, ALBERTA
Phone (403) 451-2121

5664 BURLEIGH CRES. S.E.
CALGARY, ALBERTA
Phone (403) 253-7121

UNCONSOLIDATED — UNDRAINED TRIAXIAL TEST

Project:
Address:
Job No.: 101-2581
Date Tested: 800324 By: S.K.
Client:
Attention:

Test No.: 19
Test Hole No.: S-65
Depth of Sample m.: 22.4
Confining Pressure kPa: 440.0
Water Content %: 30.7
Wet Density Mg/m³: 1.956
Peak Stress kPa: 216.46



Reviewed by ____________ P.Eng.

EBA Engineering Consultants Ltd.

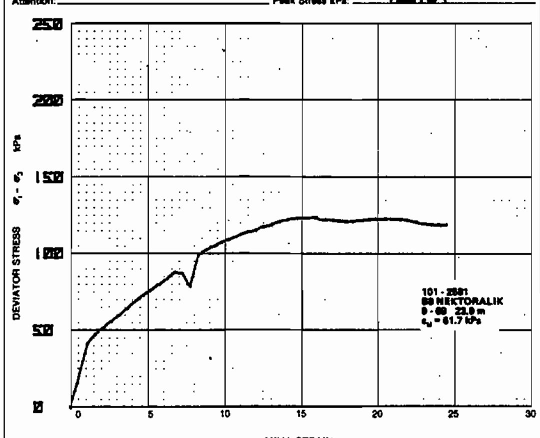
14535 - 118th AVENUE
EDMONTON, ALBERTA
Phone (403) 451-2121

5664 BURLEIGH CRES. S.E.
CALGARY, ALBERTA
Phone (403) 253-7121

UNCONSOLIDATED — UNDRAINED TRIAXIAL TEST

Project:
Address:
Job No.: 101-2581
Date Tested: 800324 By: S.K.
Client:
Attention:

Test No.: 20
Test Hole No.: S-69
Depth of Sample m.: 23.9
Confining Pressure kPa: 450.0
Water Content %: 30.6
Wet Density Mg/m³: 1.948
Peak Stress kPa: 123.34



Reviewed by ____________ P.Eng.

EBA Engineering Consultants Ltd.

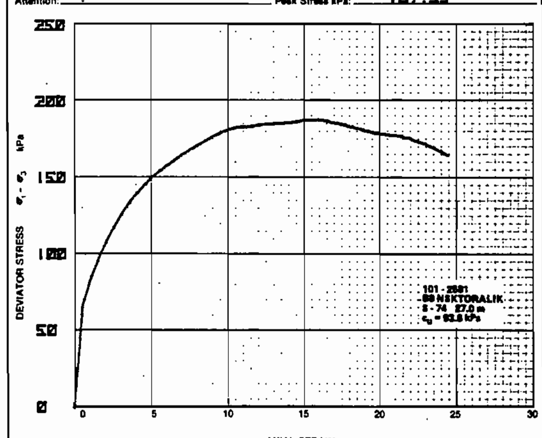
14535 - 118th AVENUE
EDMONTON, ALBERTA
Phone (403) 451-2121

5664 BURLEIGH CRES. S.E.
CALGARY, ALBERTA
Phone (403) 253-7121

UNCONSOLIDATED — UNDRAINED TRIAXIAL TEST

Project:
Address:
Job No.: 101-2581
Date Tested: 800324 By: S.K.
Client:
Attention:

Test No.: 21
Test Hole No.: S-74
Depth of Sample m.: 27.0
Confining Pressure kPa: 480.0
Water Content %: 31.9
Wet Density Mg/m³: 1.893
Peak Stress kPa: 187.59



Reviewed by ____________ P.Eng.

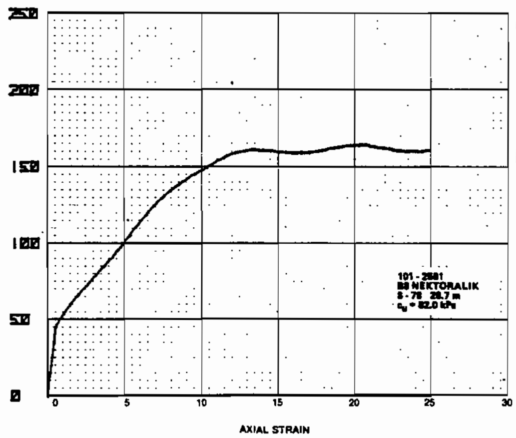
EBA Engineering Consultants Ltd.

14535 - 118th AVENUE
EDMONTON, ALBERTA
Phone (403) 451-2121

5664 BURLEIGH CRES. S.E.
CALGARY, ALBERTA
Phone (403) 253-7121

UNCONSOLIDATED — UNDRAINED TRIAXIAL TEST

Project:
Address:
Test No.: 22
Test Hole No.: S-78
Job No.: 101-2581
Depth of Sample m.: 28.7
Date Tested: 800325 By: S.K.
Confining Pressure kPa: 490.0
Client:
Water Content %: 27.8
Wet Density Mg/m³: 1.987
Attention:
Peak Stress kPa: 164.00



Reviewed by ______________ P.Eng.

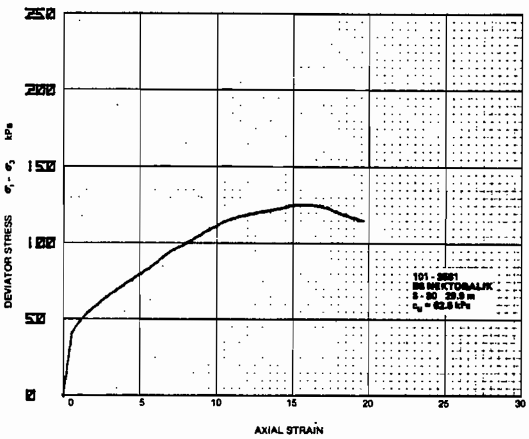
EBA Engineering Consultants Ltd.

14535 - 118th AVENUE
EDMONTON, ALBERTA
Phone (403) 451-2121

5664 BURLEIGH CRES. S.E.
CALGARY, ALBERTA
Phone (403) 253-7121

UNCONSOLIDATED — UNDRAINED TRIAXIAL TEST

Project:
Address:
Test No.: 23
Test Hole No.: S-80
Job No.: 101-2581
Depth of Sample m.: 29.9
Date Tested: 800325 By: S.K.
Confining Pressure kPa: 500.0
Client:
Water Content %: 28.1
Wet Density Mg/m³: 1.947
Attention:
Peak Stress kPa: 125.11



Reviewed by ______________ P.Eng.

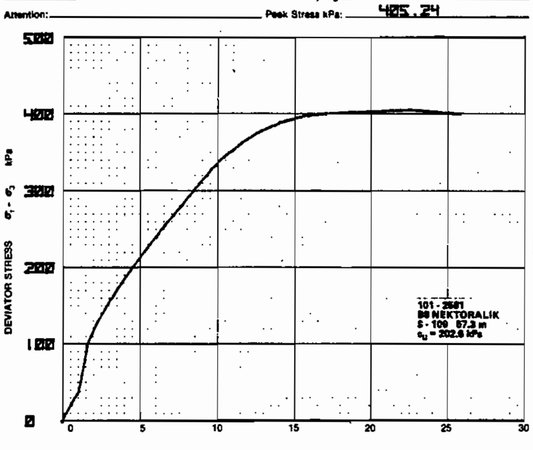
EBA Engineering Consultants Ltd.

14535 - 118th AVENUE
EDMONTON, ALBERTA
Phone (403) 451-2121

5664 BURLEIGH CRES. S.E.
CALGARY, ALBERTA
Phone (403) 253-7121

UNCONSOLIDATED — UNDRAINED TRIAXIAL TEST

Project:
Address:
Test No.: 24
Test Hole No.: S-109
Job No.: 101-2581
Depth of Sample m.: 57.3
Date Tested: 800325 By: S.K.
Confining Pressure kPa: 740.0
Client:
Water Content %: 21.5
Wet Density Mg/m³: 1.987
Attention:
Peak Stress kPa: 405.24



Reviewed by ______________ P.Eng.

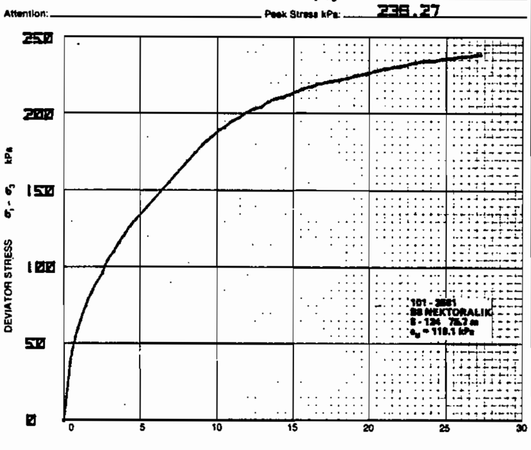
EBA Engineering Consultants Ltd.

14535 - 118th AVENUE
EDMONTON, ALBERTA
Phone (403) 451-2121

5664 BURLEIGH CRES. S.E.
CALGARY, ALBERTA
Phone (403) 253-7121

UNCONSOLIDATED — UNDRAINED TRIAXIAL TEST

Project:
Address:
Test No.: 37
Test Hole No.: S-124 NEK.
Job No.: 101-2581
Depth of Sample m.: 75.7
Date Tested: 800516 By: H.R.H.
Confining Pressure kPa: 880.0
Client:
Water Content %: 22.4
Wet Density Mg/m³: 2.010
Attention:
Peak Stress kPa: 238.27



Reviewed by ______________ P.Eng.

EBA Engineering Consultants Ltd.

14535 – 118th AVENUE
EDMONTON, ALBERTA
Phone (403) 451-2121

5664 BURLEIGH CRES. S.E.
CALGARY, ALBERTA
Phone (403) 253-7121

UNCONSOLIDATED — UNDRAINED TRIAXIAL TEST

Project:

Address:

Test No.: 38

Test Hole No.: S-133 NEK.

Job No.: 101-2581

Depth of Sample m.: 87.8

Date Tested: 800516

By: H.R.H.

Confining Pressure kPa: 1000.0

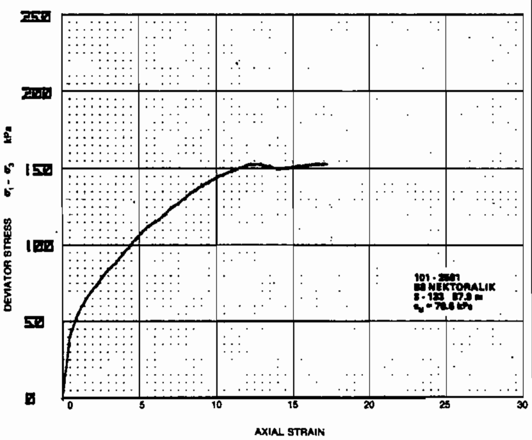
Client:

Water Content %: 27.2

Wet Density Mg/m³: 2.000

Attention:

Peak Stress kPa: 153.24



Reviewed by ______________ P.Eng.

EBA Engineering Consultants Ltd.

14535 – 118th AVENUE
EDMONTON, ALBERTA
Phone (403) 451-2121

5664 BURLEIGH CRES. S.E.
CALGARY, ALBERTA
Phone (403) 253-7121

UNCONSOLIDATED — UNDRAINED TRIAXIAL TEST

Project:

Address:

Test No.: 29

Test Hole No.: S-134 NEk

Job No.: 101-2581

Depth of Sample m.: 87.9

Date Tested: 800427

By: H.R.H.

Confining Pressure kPa: 990.0

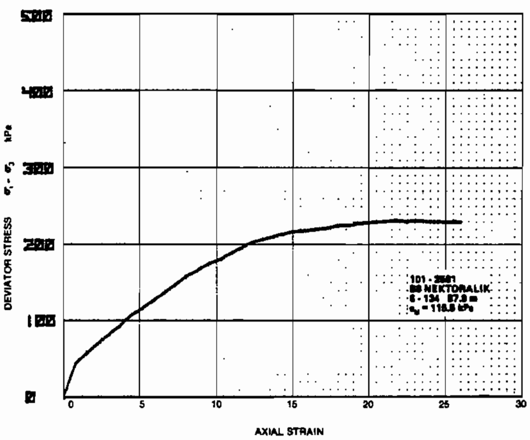
Client:

Water Content %: 24.5

Wet Density Mg/m³: 1.977

Attention:

Peak Stress kPa: 230.91



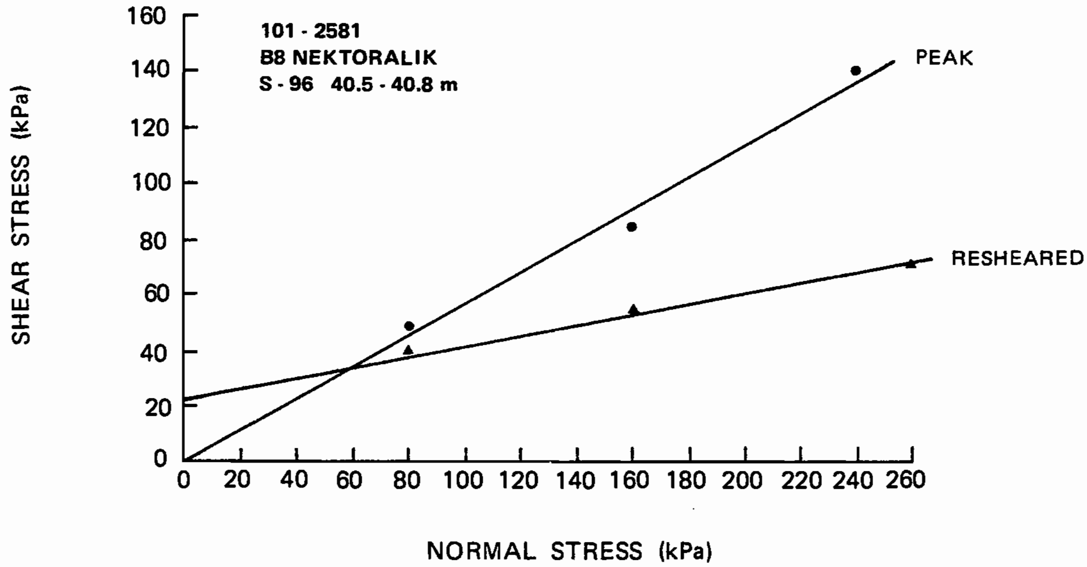
Reviewed by ______________ P.Eng.

NEKTORALIK

DIRECT SHEAR TESTS

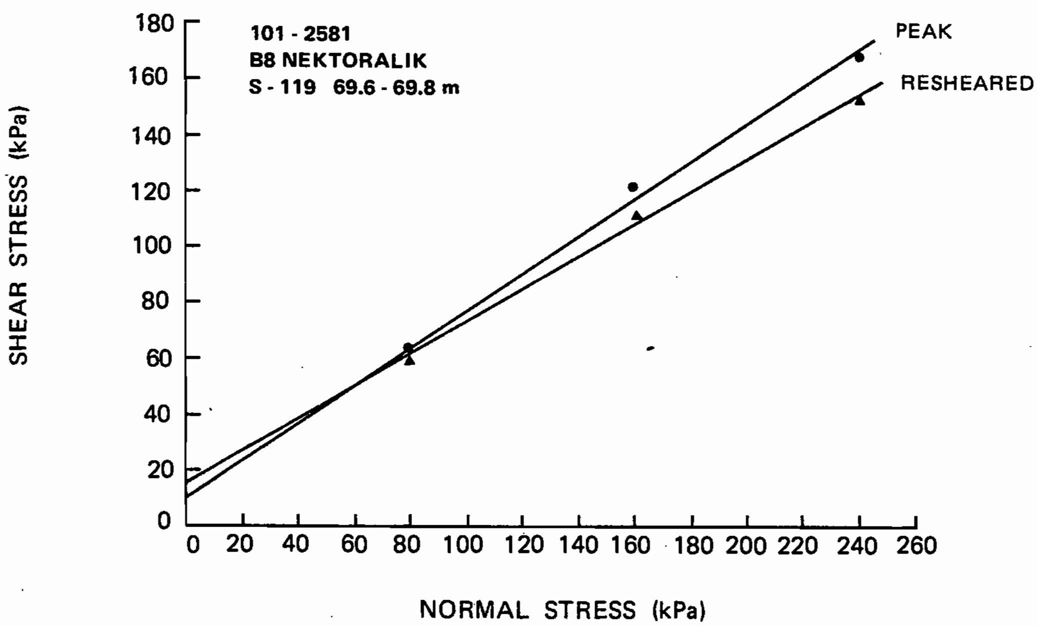
SAMPLE NUMBER	DEPTH (metres)	USC	MOISTURE CONTENT INITIAL (%)	MOISTURE CONTENT FINAL (%)	INITIAL BULK DENSITY (Mg/m^3)	NORMAL STRESS (σ'_v) (kPa)	PEAK SHEAR STRESS (τ_p) (kPa)	RESIDUAL SHEAR STRESS (kPa)	VOLUMETRIC STRAIN ($\frac{\Delta v}{v}$) AT τ_p (%)	c'_p (kPa)	ϕ'_p (degrees)	ϕ'_r (degrees)
S-96	40.5	MH	31.3	31.8	1.90	80	48	39	0.9			
			29.5	27.6	1.93	160	84	54	0.9	0	29	11
			27.7	28.1	1.99	240	140	72	0.9			
S-119	69.6	ML	24.7	21.9	1.90	80	62	60	0.8			
			26.9	22.0	1.90	160	121	111	0.6	10	34	30
			27.0	22.3	1.92	240	169	153	1.1			

EBA Engineering Consultants Ltd.



$\phi_p' = 29°$ $c_p' = 0$ kPa

$\phi_r' = 11°$ $c_r' = 22$ kPa



$\phi_p' = 34°$ $c_p' = 10$ kPa

$\phi_r' = 30°$ $c_r' = 16$ kPa

SUMMARY OF DIRECT SHEAR TEST RESULTS

EBA Engineering Consultants Ltd.

Sample Number	Penetration (meters)	Penetration (feet)	Water Content, %	Miniature Vane Peak (kpa)	Miniature Vane Peak (ksf)	Miniature Vane Remolded (kpa)	Miniature Vane Remolded (ksf)	Sensitivity
4	0.3 -0.5	1.0-1.5	61	5.3	0.11			
7	1.1 -1.2	3.5-4.0	65	6.9	0.14			
13	2.3 -2.4	7.5-8.0	79	7.7	0.16			
15	3.2 -3.4	10.5-11.0	39	5.7	0.12			
18	4.2 -4.4	14.0-14.5	72	9.6*	0.20*			
22	5.0 -5.2	16.5-17.0	58	9.6	0.20			
25	5.9 -6.1	19.5-20.0	67	9.1	0.19			
25	5.9 -6.1	19.5-20.0	67	7.0*	0.15*	2*	0.04*	3.5*
28	7.0 -7.2	23.0-23.5	57	7.0	0.15			
31	7.8 -7.9	25.5-26.0	69	8.9	0.19			
31	7.8 -7.9	25.5-26.0	69	2.0*	0.04	1*	0.02	2.0
35	9.4 -9.6	31.0-31.5	65	9.6	0.20			
41	11.2 -11.4	37.0-37.5		16.3	0.34			
44	12.2 -12.3	40.0-40.5	48	23.4	0.49			
47	13.1 -13.3	43.0-43.5	44	26.8	0.56			
50	14.0 -14.2	46.0-46.5	43	22.0	0.46			
53	14.8 -14.9	48.5-49.0	31	135.0	2.80			
55	16.3 -16.5	53.5-54.0	29	145.6	3.00+			
60	19.5 -19.7	64.0-64.5	26	239.5	5.00+			
62	20.9 -21.0	68.5-69.0	29	124.5	2.60			
67	22.7 -22.9	74.5-75.0	30	149.9	3.10			
70	24.0 -24.2	79.0-79.5	-	84.8	1.80			
72	25.4 -25.6	83.5-84.0	32	57.5	1.20			
75	27.1 -27.3	89.0-89.5	33	84.8	1.80			
79	28.8 -29.0	94.5-95.0	30	127.4	2.70			
82	30.2 -30.3	99.0-99.5	32	89.1	1.90			
84	31.7 -31.8	104.0-104.5	36	122.1	2.55			
87	33.2 -33.4	109.0-109.5	33	143.7	3.00			
89	34.6 -34.7	113.5-114.0	30	239.5+	5.00+			
91	36.1 -36.3	118.5-119.0	28	239.5+	5.00+			
99	43.6 -43.9	143.0-144.0	30	239.5+	5.00+			
103	48.5 -48.6	159.0-159.5	37	120.7	2.52			
108	54.6 -54.7	179.0-179.5	30	50.8	1.06			

Notes:

1. Tests performed on samples that were either thawed subsequent to recovery or not frozen in situ.
2. Asterix demotes tests performed in EBA laboratory. All other tests were performed in the field.

FIELD AND LABORATORY VANE SHEAR TEST RESULTS

Boring 8, Nektoralik H-28

Beaufort Sea

Sample Numbers	Penetration (meters)	Penetration (feet)	Water Content, %	Shear Strength (kPa)	Shear Strength (ksf)
54	16.2 - 16.3	53.0 - 53.5	31	85.7	1.79
66	22.6 - 22.7	74.0 - 74.5	33	62.75	1.31
71	25.3 - 25.5	83.0 - 83.5	32	82.40	1.72
81	30.0 - 30.2	98.5 - 99.0	32	61.31	1.29
88	34.5 - 34.6	113.0 - 113.5	30	136.99	2.86
94	39.2 - 39.3	128.5 - 129.0	28	184.40	3.85
100	43.9 - 44.1	144.0 - 144.5	30	135.10	2.82
103	48.5 - 48.6	159.0 - 159.5	27	83.83	1.75
107	54.0 - 54.6	178.5 - 179.0	27	80.95	1.69
131	84.9 - 85.1	287.5 - 279.0	23	104.90	2.19
137	94.0 - 94.3	308.5 - 309.5	23	84.30	1.76

FIELD UNCONFINED COMPRESSION TEST RESULTS
Boring 8, Nektoralik H-28
Beaufort Sea

Sample Number	Penetration (meters)	Penetration (feet)	Shear Strength (kpa)	Shear Strength (ksf)
7	1.2	4.0	1.9	0.04
13	2.4	8.0	5.7	0.12
15	3.3	11.0	6.7	0.14
18	4.4	14.5	6.7	0.14
22	5.2	17.0	5.7	0.12
25	6.1	20.0	3.8	0.08
35	9.6	31.5	11.0	0.23
39	10.7	35.0	13.9	0.29
41	11.4	37.5	11.9	0.25
47	13.3	43.5	24.9	0.52
50	14.2	46.5	22.0	0.46
53	14.9	49.0	83.8	1.75
55	16.5	54.0	165.7+	3.46+
60	19.7	64.5	203.6	4.25
62	21.0	69.0	136.5	2.85
67	22.9	75.0	110.2	2.30
70	24.2	79.5	95.8	2.00
72	25.6	84.0	93.4	1.95
75	27.3	89.5	112.6	2.35
79	28.8	95.0	110.2	2.30
82	30.3	99.5	131.7	2.75
84	31.9	104.5	131.7	2.75
87	33.4	109.5	160.5	3.35
89	34.7	114.0	239.5+	5.00+
91	36.2	119.0	239.5+	5.00+
92	37.8	124.0	239.5+	5.00+
95	39.5	129.5	239.5+	5.00+
96	40.8	134.0	239.5+	5.00+
99	43.9	144.0	155.7	3.25
102	49.5	159.0	88.6	1.85
108	54.7	179.5	35.9	0.75

FIELD TORVANE RESULTS
Boring 8, Nektoralik H-28
Beaufort Sea

NEKTORALIK

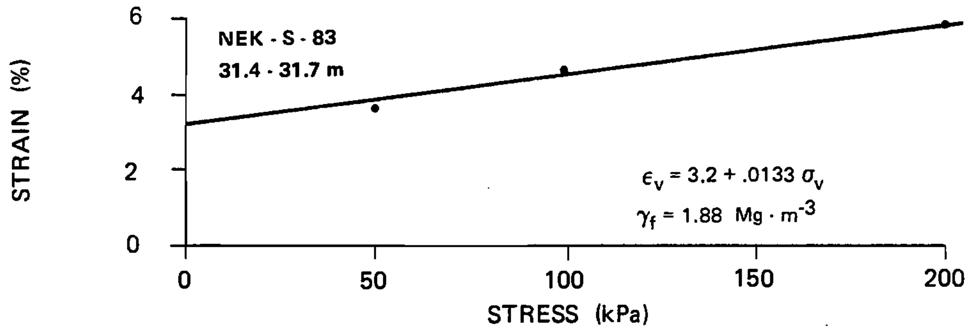
THAW STRAIN TESTS

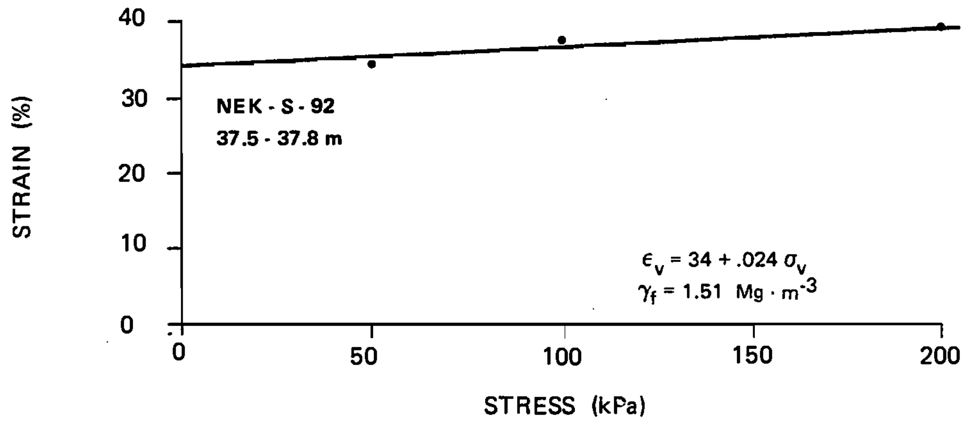
$$(\epsilon_v = A + \sigma_v a_o)$$

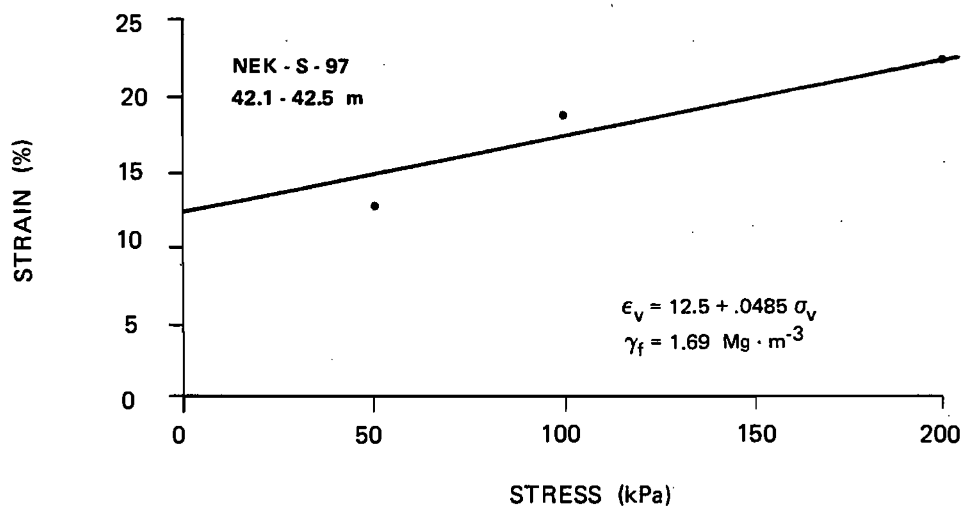
SAMPLE NUMBER	DEPTH (metres)	USC	MOISTURE CONTENT INITIAL (%)	MOISTURE CONTENT FINAL (%)	DENSITY FROZEN BULK (Mg/m^3)	DENSITY DRY (Mg/m^3)	A	a_o	EFFECTIVE NORMAL STRESS (σ_v) (kPa)	C_v (m^2/yr)	k[1] (m/s)
S-83C	31.4	CL	31.5	33.8	1.88	1.46	3.2	0.01	50		
										1.4	9.0E-11
									100		
										1.1	8.1E-11
									150		
S-92C	37.5	MH	67.5	37.1	1.51	1.41	34	0.02	50		
										0.57	1.6E-10
									100		
										0.40	5.3E-11
									150		
S-97	42.1	MH	46.5	35.4	1.69	1.43	12	0.05	50		
										0.80	2.5E-08
									100		
										0.58	8.4E-09
									200		
S-114	63.6	ML	27.2	27.7	1.84	1.53	4.6	0.01	50		
										500	2.5E-08
									100		
										330	8.4E-09
									200		
S-122	72.7	ML	27.1	25.4	1.86	1.61	5.4	0.03	50		(1.2E-09)
										3.3	4.3E-10
									100		(9.6E-10)
										9.4	8.4E-10
									200		(5.3E-10)
S-136	91.0	CL	24.3	24.3	2.01	1.72	2.9	0.02	50		(7.0E-10)
										0.46	2.2E-11
									100		
										3.8	2.1E-10
									200		

[1] Permeabilities shown in parentheses represent direct permeability readings; the remainder have been calculated.

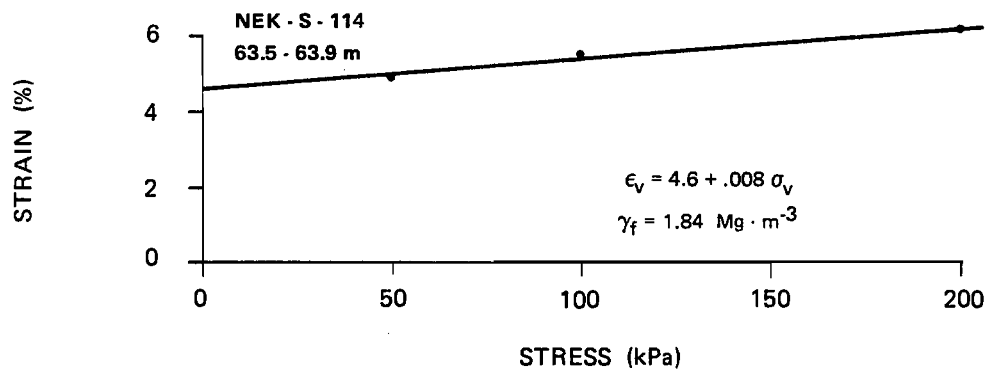
EBA Engineering Consultants Ltd.

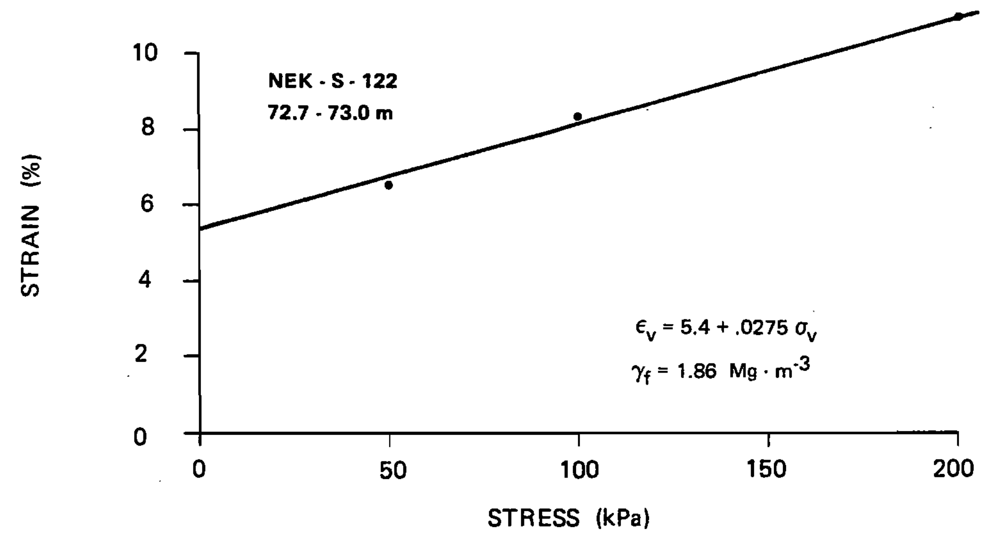


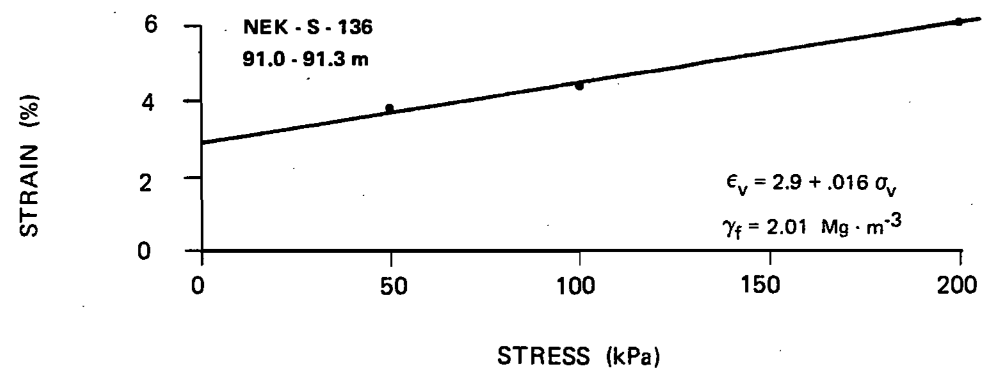




THAW STRAIN TEST RESULTS







THAW STRAIN TEST RESULTS

FORM DFT-1.1 (1978) Job No. 0179-0128

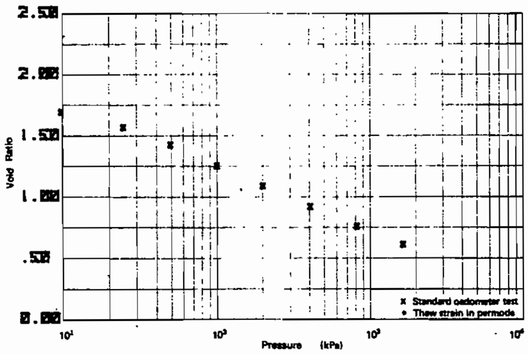
EBA Engineering Consultants Ltd.

14535 – 118th AVENUE
EDMONTON, ALBERTA
Phone (403) 451-2121

5664 BURLEIGH CRES. S.E.
CALGARY, ALBERTA
Phone (403) 253-7121

CONSOLIDATION TEST RESULTS

Project: ______ Test No.: 20
Address: ______ Borehole No.: 5-20 NEK.
Depth (m): 4.72
Project No: 101-2581 Diameter (mm): 49.9
Date Tested: 800509 By: H.R.H. Specific Gravity: 2.8



	INITIAL	FINAL
Height (mm):	26.6	19.4
Water Content (%):	66.1	37.1
Wet Density (Mg/m³):	1.62	1.83
Dry Density (Mg/m³):	.97	1.34
Void Ratio	1.8046	1.0308
Saturation (%):	102.0	100.0

Sample Description: SILTY CLAY/SOFT

Overburden Pressure P_o ______ kPa
Swelling Pressure P_s 0 kPa
Pre-Consolidation Pressure P_c ______ kPa
Compression Index C_c ______

Note: 1 kPa = 1.044 x 10^{-2} Tf/ft.²

Tested in accordance with ASTM standard D2435 unless otherwise noted.

2072

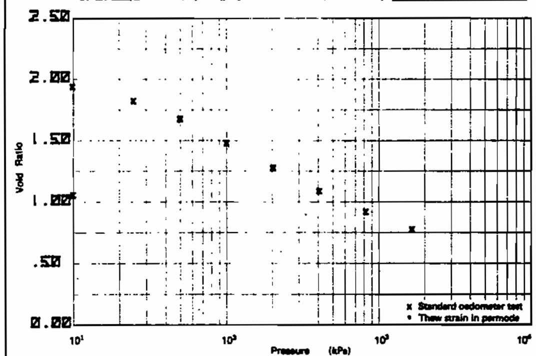
EBA Engineering Consultants Ltd.

14535 – 118th AVENUE
EDMONTON, ALBERTA
Phone (403) 451-2121

5664 BURLEIGH CRES. S.E.
CALGARY, ALBERTA
Phone (403) 253-7121

CONSOLIDATION TEST RESULTS

Project: ______ Test No.: 21
Address: ______ Borehole No.: 5-33 NEK.
Depth (m): 9.14
Project No: 101-2581 Diameter (mm): 49.9
Date Tested: 800501 By: H.R.H. Assumed Specific Gravity: 2.8



	INITIAL	FINAL
Height (mm):	26.6	18.3
Water Content (%):	70.7	37.8
Wet Density (Mg/m³):	1.61	1.90
Dry Density (Mg/m³):	.95	1.38
Void Ratio	1.9801	1.0548
Saturation (%):	99.8	100.0

Sample Description: SILTY CLAY

Overburden Pressure P_o ______ kPa
Swelling Pressure P_s 1.0 kPa
Pre-Consolidation Pressure P_c ______ kPa
Compression Index C_c ______

Note: 1 kPa = 1.044 x 10^{-2} Tf/ft.²

Tested in accordance with ASTM standard D2435 unless otherwise noted.

2072

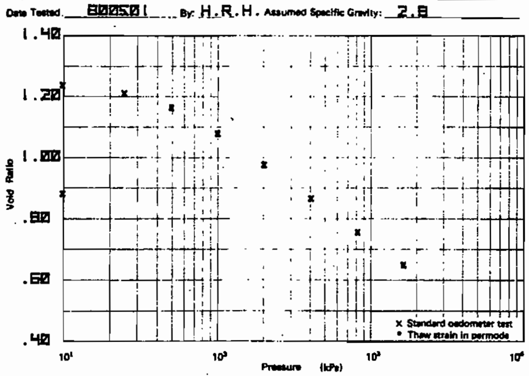
EBA Engineering Consultants Ltd.

14535 – 118th AVENUE
EDMONTON, ALBERTA
Phone (403) 451-2121

5664 BURLEIGH CRES. S.E.
CALGARY, ALBERTA
Phone (403) 253-7121

CONSOLIDATION TEST RESULTS

Project: ______ Test No.: 22
Address: ______ Borehole No.: 5-49 NEK.
Depth (m): 13.87
Project No: 101-2581 Diameter (mm): 49.9
Date Tested: 800501 By: H.R.H. Assumed Specific Gravity: 2.8



	INITIAL	FINAL
Height (mm):	26.6	22.3
Water Content (%):	44.6	31.5
Wet Density (Mg/m³):	1.81	1.96
Dry Density (Mg/m³):	1.25	1.49
Void Ratio	1.2426	.8831
Saturation (%):	100.7	100.0

Sample Description: CLAY-SILT

Overburden Pressure P_o ______ kPa
Swelling Pressure P_s 3.5 kPa
Pre-Consolidation Pressure P_c ______ kPa
Compression Index C_c ______

Note: 1 kPa = 1.044 x 10^{-2} Tf/ft.²

Tested in accordance with ASTM standard D2435 unless otherwise noted.

2072

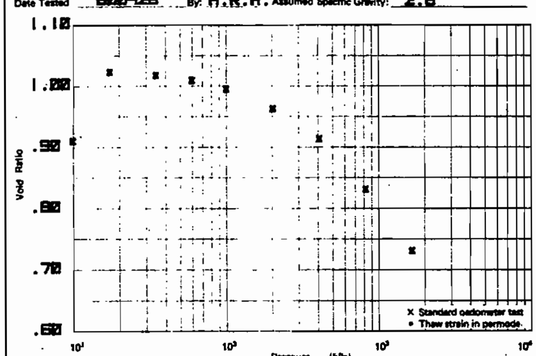
EBA Engineering Consultants Ltd.

14535 – 118th AVENUE
EDMONTON, ALBERTA
Phone (403) 451-2121

5664 BURLEIGH CRES. S.E.
CALGARY, ALBERTA
Phone (403) 253-7121

CONSOLIDATION TEST RESULTS

Project: ______ Test No.: 23
Address: ______ Borehole No.: 5-73 NEK
Depth (m): 26.82-26.97
Project No: 101-2581 Diameter (mm): 49.5
Date Tested: 800428 By: H.R.H. Assumed Specific Gravity: 2.8



	INITIAL	FINAL
Height (mm):	26.6	25.1
Water Content (%):	34.2	32.5
Wet Density (Mg/m³):	1.91	2.00
Dry Density (Mg/m³):	1.42	1.51
Void Ratio	1.0230	.9103
Saturation (%):	93.7	100.0

Sample Description: SILTY CLAY

Overburden Pressure P_o ______ kPa
Swelling Pressure P_s 17.5 kPa
Pre-Consolidation Pressure P_c ______ kPa
Compression Index C_c ______

Note: 1 kPa = 1.044 x 10^{-2} Tf/ft.²

Tested in accordance with ASTM standard D2435 unless otherwise noted.

2072

FORM DFT-1.1 (1976) Job No. 0179-8710

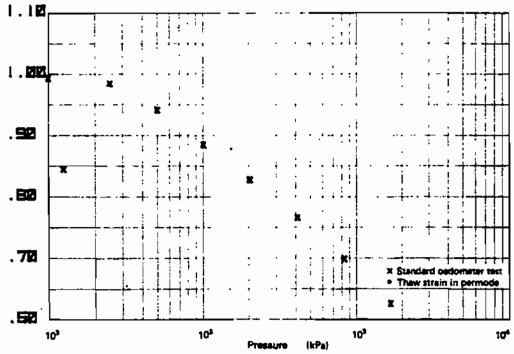
EBA Engineering Consultants Ltd.

14535 – 118th AVENUE
EDMONTON, ALBERTA
Phone (403) 451-2121

5684 BURLEIGH CRES. S.E.
CALGARY, ALBERTA
Phone (403) 253-7121

CONSOLIDATION TEST RESULTS

Project:
Address:
Project No: 101-2581
Date Tested: 800415 By: S.K.
Test No.: 13
Borehole No.: S-92 NEK
Depth (m): 37.45
Diameter (mm): 49.9
Assumed Specific Gravity: 2.8



	INITIAL	FINAL
Height (mm):	26.6	24.3
Water Content (%):	34.4	30.2
Wet Density (Mg/m³):	1.88	2.00
Dry Density (Mg/m³):	1.40	1.54
Void Ratio	1.0211	.8450
Saturation (%):	94.6	100.0

Sample Description: CLAY SILT
Overburden Pressure P_o ______ kPa
Swelling Pressure P_s 12.5 kPa
Pre-Consolidation Pressure P_c ______ kPa
Compression Index C_c ______

Note: 1 kPa = 1.044 x 10⁻³ Tf/ft.²

Tested in accordance with ASTM standard D2435 unless otherwise noted.

2072

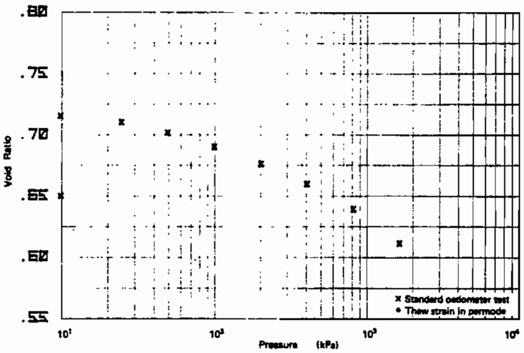
EBA Engineering Consultants Ltd.

14535 – 118th AVENUE
EDMONTON, ALBERTA
Phone (403) 451-2121

5684 BURLEIGH CRES. S.E.
CALGARY, ALBERTA
Phone (403) 253-7121

CONSOLIDATION TEST RESULTS

Project:
Address:
Project No: 101-2581
Date Tested: 800501 By: H.R.H.
Test No.: 24
Borehole No.: S-112 NEK
Depth (m): 50.35
Diameter (mm): 49.9
Assumed Specific Gravity: 2.8



	INITIAL	FINAL
Height (mm):	26.6	25.6
Water Content (%):	22.6	23.5
Wet Density (Mg/m³):	1.93	2.01
Dry Density (Mg/m³):	1.57	1.63
Void Ratio	.7165	.6510
Saturation (%):	87.7	100.0

Sample Description: SILT-SAND, TRACE CLAY
Overburden Pressure P_o ______ kPa
Swelling Pressure P_s 10.0 kPa
Pre-Consolidation Pressure P_c ______ kPa
Compression Index C_c ______

Note: 1 kPa = 1.044 x 10⁻³ Tf/ft.²

Tested in accordance with ASTM standard D2435 unless otherwise noted.

2072

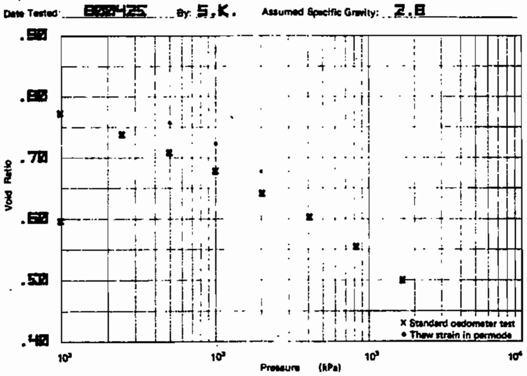
EBA Engineering Consultants Ltd.

14535 – 118th AVENUE
EDMONTON, ALBERTA
Phone (403) 451-2121

5684 BURLEIGH CRES. S.E.
CALGARY, ALBERTA
Phone (403) 253-7121

CONSOLIDATION TEST RESULTS

Project:
Address:
Project No: 101-2581
Date Tested: 800425 By: S.K.
Test No.: 19
Borehole No.: S-122 NEK
Depth (m): 72.60
Diameter (mm): 49.9
Assumed Specific Gravity: 2.8



	INITIAL	FINAL
Height (mm):	26.6	23.1
Water Content (%):	27.6	21.5
Wet Density (Mg/m³):	1.94	2.12
Dry Density (Mg/m³):	1.52	1.74
Void Ratio	.8345	.5968
Saturation (%):	91.9	100.0

Sample Description: CLAYEY SILT
Overburden Pressure P_o ______ kPa
Swelling Pressure P_s 0.0 kPa
Pre-Consolidation Pressure P_c ______ kPa
Compression Index C_c ______

Note: 1 kPa = 1.044 x 10⁻³ Tf/ft.²

Tested in accordance with ASTM standard D2435 unless otherwise noted.

2072

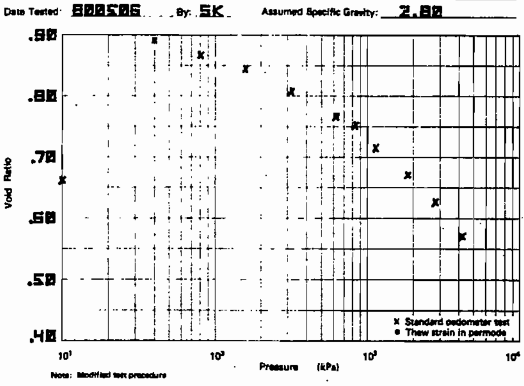
EBA Engineering Consultants Ltd.

14535 – 118th AVENUE
EDMONTON, ALBERTA
Phone (403) 451-2121

5684 BURLEIGH CRES. S.E.
CALGARY, ALBERTA
Phone (403) 253-7121

CONSOLIDATION TEST RESULTS

Project:
Address:
Project No: 101-2581
Date Tested: 800506 By: SK
Test No.: C-31
Borehole No.: S-122 NEK
Depth (m): 72.7
Diameter (mm): 49.9
Assumed Specific Gravity: 2.80



Note: Modified test procedure

	INITIAL	FINAL
Height (mm):	26.6	
Water Content (%):	28.4	23.6
Wet Density (Mg/m³):	1.84	2.06
Dry Density (Mg/m³):	1.43	1.67
Void Ratio	0.8309	0.6605
Saturation (%):	85.5	100.0

Sample Description: CLAYEY SILT
Overburden Pressure P_o ______ kPa
Swelling Pressure P_s ______ kPa
Pre-Consolidation Pressure P_c ______ kPa
Compression Index C_c ______

Note: 1 kPa = 1.044 x 10⁻³ Tf/ft.²

Tested in accordance with ASTM standard D2435 unless otherwise noted.

2072

McCLELLAND ENGINEERS

FORM DFT-1.1 (1978) Job No. 0179-0128

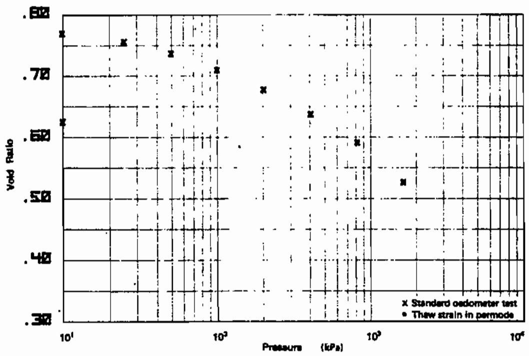
EBA Engineering Consultants Ltd.

14535 - 118th AVENUE
EDMONTON, ALBERTA
Phone (403) 451-2121

5684 BURLEIGH CRES. S.E.
CALGARY, ALBERTA
Phone (403) 253-7121

CONSOLIDATION TEST RESULTS

Project:
Address:
Project No: 101-2581
Date Tested: 800419 By: H.R.H.
Test No.: 15
Borehole No.: 5-136
Depth (m): 90.98
Diameter (mm): 49.9
Specific Gravity: 2.8



	INITIAL	FINAL
Height (mm):	26.6	24.3
Water Content (%):	26.6	22.3
Wet Density (Mg/m³):	1.99	2.10
Dry Density (Mg/m³):	1.57	1.72
Void Ratio	.7794	.6245
Saturation (%):	95.7	100.0

Sample Description: CLAYEY SILT

Overburden Pressure P_o ______ kPa
Swelling Pressure P_s 11.2 kPa
Pre-Consolidation Pressure P_c ______ kPa
Compression Index C_c ______

Note: 1 kPa = 1.044 x 10^{-2} Tf/ft.²

Tested in accordance with ASTM standard D2435 unless otherwise noted.

2072

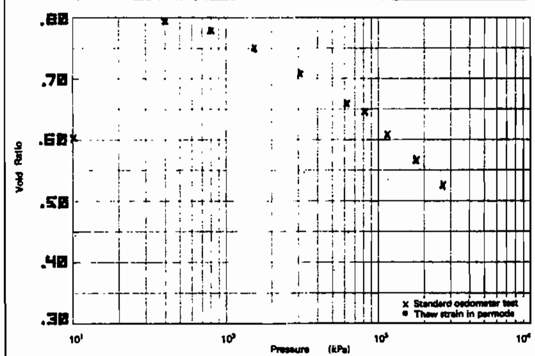
EBA Engineering Consultants Ltd.

14535 - 118th AVENUE
EDMONTON, ALBERTA
Phone (403) 451-2121

5684 BURLEIGH CRES. S.E.
CALGARY, ALBERTA
Phone (403) 253-7121

CONSOLIOATION TEST RESULTS

Project:
Address:
Project No: 101-2581
Date Tested: 800506 By: SK
Test No.: C-32
Borehole No.: 5-136 NEK
Depth (m): 90.98
Diameter (mm): 45.5
Assumed Specific Gravity: 2.80



Note: Modified test procedure

	INITIAL	FINAL
Height (mm):	20.0	
Water Content (%):	26.0	21.5
Wet Density (Mg/m³):	1.98	2.20
Dry Density (Mg/m³):	1.57	1.81
Void Ratio	0.8398	0.6028
Saturation (%):	86.8	100.0

Sample Description: CLAYEY SILT

Overburden Pressure P_o ______ kPa
Swelling Pressure P_s ______ kPa
Pre-Consolidation Pressure P_c ______ kPa
Compression Index C_c ______

Note: 1 kPa = 1.044 x 10^{-2} Tf/ft.²

Tested in accordance with ASTM standard D2435 unless otherwise noted.

2072

NEKTORALIK

CONSOLIDATION TESTS

SAMPLE NUMBER	DEPTH (metres)	USC	MOISTURE CONTENT INITIAL (%)	MOISTURE CONTENT FINAL (%)	DENSITY INITIAL BULK (Mg/m^3)	DENSITY DRY (Mg/m^3)	EFFECTIVE OVERBURDEN PRESSURE (P'_o) (kPa)	PRECONSOLIDATION PRESSURE (P'_c) (kPa)	C_c	EFFECTIVE NORMAL STRESS (σ'_v) (kPa)	c_v (m^2/yr)	m_v (1/MPa)	k (m/s)
S-20	4.7	CH	66.1	37.1	1.62	0.97	36	24	0.50	10			
											1.1	4.1	1.4E-09
										25			
											1.3	3.2	1.2E-09
										50			
											1.6	2.2	1.1E-09
										100			
											1.2	1.4	5.2E-10
										200			
											1.5	0.72	3.4E-10
										400			
											1.5	0.40	1.9E-10
										800			
											1.8	0.21	1.2E-10
										1600			
S-33	9.1	CH	70.7	37.8	1.61	0.95	60	27	0.60	10			
											3.0	1.7	1.5E-09
										25			
											2.4	2.6	2.0E-09
										50			
											1.8	2.0	1.1E-09
										100			
											1.4	1.5	6.3E-10
										200			
											1.5	0.80	3.7E-10
										400			
											1.5	0.41	1.9E-10
										800			
											1.7	0.20	1.0E-10
										1600			

EBA Engineering Consultants Ltd.

NEKTORALIK

CONSOLIDATION TESTS

SAMPLE NUMBER	DEPTH (metres)	USC	MOISTURE CONTENT INITIAL (%)	MOISTURE CONTENT FINAL (%)	DENSITY INITIAL BULK (Mg/m^3)	DENSITY DRY (Mg/m^3)	EFFECTIVE OVERBURDEN PRESSURE (P'_o) (kPa)	PRECONSOLIDATION PRESSURE (P'_c) (kPa)	c_c	EFFECTIVE NORMAL STRESS (σ'_v) (kPa)	c_v (m^2/yr)	m_v (1/MPa)	k (m/s)
S-49	13.9	ML	44.6	31.5	1.81	1.25	96	60	0.36	10			
											6.5	0.31	6.3E-10
										25			
											3.0	0.78	7.3E-10
										50			
											1.7	0.82	4.3E-10
										100			
											1.2	0.78	2.9E-10
										200			
											1.6	0.50	2.4E-10
										400			
											1.5	0.28	1.3E-10
										800			
											1.8	0.15	8.3E-11
										1600			
S-73	26.9	CL	34.2	32.5	1.91	1.42	203	430	0.31	35			
											46	0.13	1.8E-09
										60			
											27	0.17	1.4E-09
										100			
											22	0.18	1.2E-09
										200			
											23	0.16	1.1E-09
										400			
											21	0.13	8.2E-10
										800			
											16	0.11	5.2E-10
										1600			

EBA Engineering Consultants Ltd.

NEKTORALIK

CONSOLIDATION TESTS

SAMPLE NUMBER	DEPTH (metres)	USC	MOISTURE CONTENT INITIAL (%)	MOISTURE CONTENT FINAL (%)	DENSITY INITIAL BULK (Mg/m^3)	DENSITY DRY (Mg/m^3)	EFFECTIVE OVERBURDEN PRESSURE (P'_o) (kPa)	PRECONSOLIDATION PRESSURE (P'_c) (kPa)	C_c	EFFECTIVE NORMAL STRESS (σ'_v) (kPa)	c_v (m^2/yr)	m_v (1/MPa)	k (m/s)
S-92	37.5	MH	34.4	30.2	1.88	1.40	287	40 - 58	0.21-0.23	10			
											0.82	0.29	7.3E-11
										25			
											0.64	0.85	1.7E-10
										50			
											0.63	0.59	1.2E-10
										100			
											0.79	0.30	7.4E-11
										200			
											1.0	0.17	5.2E-11
										400			
											1.3	0.10	3.8E-11
										800			
											1.5	0.05	2.4E-11
										1600			
S-112	60.4	CL	22.6	23.5	1.93	1.57	502	467	0.09	25			
											65	0.20	4.1E-09
										50			
											35	0.19	2.1E-09
										100			
											46	0.14	2.0E-09
										200			
											76	0.08	1.9E-09
										400			
											75	0.05	1.1E-09
										800			
											73	0.03	7.1E-10
										1600			

EBA Engineering Consultants Ltd.

NEKTORALIK

CONSOLIDATION TESTS

SAMPLE NUMBER	DEPTH (metres)	USC	MOISTURE CONTENT INITIAL (%)	MOISTURE CONTENT FINAL (%)	DENSITY INITIAL BULK (Mg/m^3)	DENSITY DRY (Mg/m^3)	EFFECTIVE OVERBURDEN PRESSURE (P'_o) (kPa)	PRECONSOLIDATION PRESSURE (P'_c) (kPa)	C_c	EFFECTIVE NORMAL STRESS (σ'_v) (kPa)	c_v (m^2/yr)	m_v (1/MPa)	k (m/s)
S-122 (Conventional Procedure)	72.7	ML	27.6	21.5	1.94	1.52	600	400	0.17	10			
											9.8	3.3	1.0E-08
										25			
											9.3	1.3	3.8E-09
										50			
											15	0.68	3.1E-09
										100			
											18	0.35	2.0E-09
										200			
											21	0.22	1.4E-09
										400			
											22	0.12	8.3E-10
										800			
											23	0.07	5.4E-10
										1600			
S-122 (Revised Procedure)	72.7	ML	28.4	23.6	1.84	1.43	600	537	0.28	40			
											118	0.58	2.1E-08
										80			
											116	0.17	6.1E-09
										160			
											72	0.16	3.5E-09
										320			
											143	0.10	4.6E-09
										640			
											136	0.07	3.2E-09
										810			
											70	0.04	7.8E-10
										1225			
											52	0.05	8.2E-10
										1830			
											74	0.40	9.6E-10

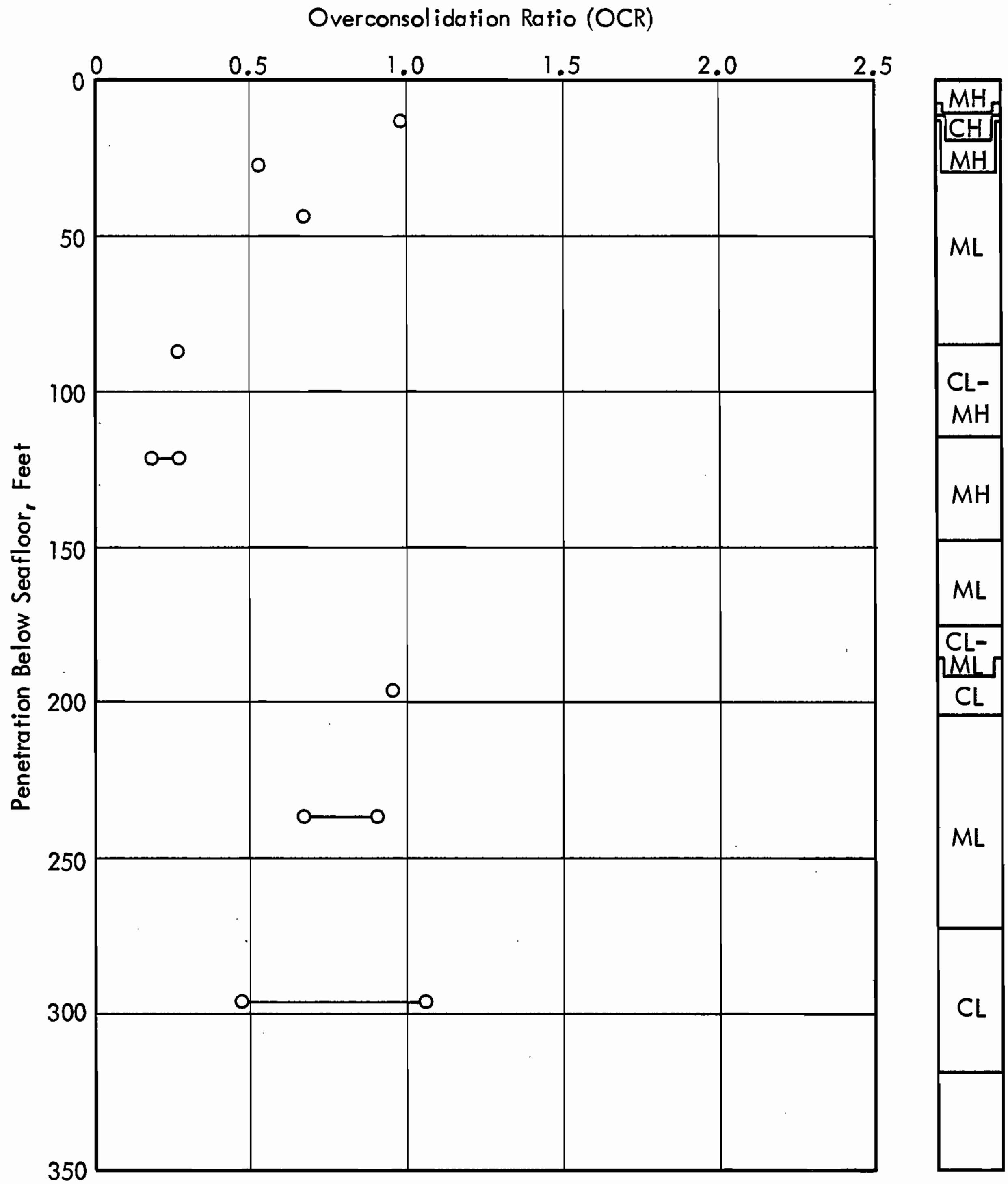
EBA Engineering Consultants Ltd.

NEKTORALIK

CONSOLIDATION TESTS

SAMPLE NUMBER	DEPTH (metres)	USC	MOISTURE CONTENT INITIAL (%)	MOISTURE CONTENT FINAL (%)	DENSITY INITIAL BULK (Mg/m^3)	DENSITY DRY (Mg/m^3)	EFFECTIVE OVERBURDEN PRESSURE (P'_o) (kPa)	PRECONSOLIDATION PRESSURE (P'_c) (kPa)	C_c	EFFECTIVE NORMAL STRESS (σ_v) (kPa)	c_v (m^2/yr)	m_v (1/MPa)	k (m/s)
S-136 (Conventional Procedure)	91.0	CL	26.6	22.3	1.99	1.57	766	800	0.21	10			
											13	0.50	2.1E-09
										25			
											14	0.43	1.9E-09
										50			
											14	0.31	1.4E-09
										100			
											23	0.19	1.3E-09
										200			
											23	0.12	8.6E-10
										400			
											29	0.07	6.2E-10
										800			
											26	0.05	4.0E-10
										1600			
S-136 (Revised Procedure)	91.0	CL	26.0	21.5	1.99	1.57	766	355	0.23	40			
											42	0.69	9.1E-09
										80			
											42	0.16	2.0E-09
										160			
											82	0.19	4.7E-09
										320			
											56	0.13	2.3E-09
										640			
											41	0.09	1.2E-09
										810			
											29	0.03	3.0E-10
										1225			
											34	0.05	5.6E-10
										1830			
											50	0.04	6.0E-10
										2750			

EBA Engineering Consultants Ltd.



OVERCONSOLIDATION RATIO vs PENETRATION
Boring 8, Nektoralik H-28
Beaufort Sea

A P P E N D I X B

LOG OF SEDIMENTARY STRUCTURE

LOG OF SEDIMENTARY STRUCTURE
BORING 8, NEKTORALIK
BEAUFORT SEA

DEPTH, FT	SYMBOL	SAMPLES	DESCRIPTION OF BEDDING
			Homegeneous
			Homogeneous
			Homogeneous
10			Homogeneous
			Homogeneous
			Even, parallel
20			Homogeneous
			Homogeneous
			Homogeneous
30			Homogeneous
			Homogeneous
			Curved, nonparallel
40			Wavy, nonparallel, discontinuous
			Even, parallel, discontinuous
50			Homogeneous
			Homogeneous
60			
			Wavy, parallel, discontinuous
70			Even, parallel
			Even, parallel
80			Even, parallel
			Even, parallel
90			Even, parallel
			Even, parallel
100			Even, parallel

(Continued on Plate B-1b)

LOG OF SEDIMENTARY STRUCTURE
BORING 8, NEKTORALIK
BEAUFORT SEA

DEPTH, FT	SYMBOL	SAMPLES	DESCRIPTION OF BEDDING
110			Homogeneous
			Homogeneous
120			
			Homogeneous
130			Homogeneous
			Homogeneous
140			Homogeneous
			Homogeneous and even, parallel
150			
160			Homogeneous
170			Homogeneous
180			Wavy, parallel
190			Even, parallel
200			Even, parallel

(Continued on Plate B-1c)

LOG OF SEDIMENTARY STRUCTURE
BORING 8, NEKTORALIK
BEAUFORT SEA

DEPTH, FT	SYMBOL	SAMPLES	DESCRIPTION OF BEDDING
210		■	Even, parallel
220		■	Even, parallel
230		■	Even, parallel
240		■	Even, parallel
250		■	Even, parallel
260		■	Even, parallel
270		■	Even, parallel
280		■	Even, parallel
290		■	Even, parallel
300		■	Even, parallel

(Continued on Plate B-1d)

LOG OF SEDIMENTARY STRUCTURE
BORING 8, NEKTORALIK
BEAUFORT SEA

DEPTH, FT	SYMBOL	SAMPLES	DESCRIPTION OF BEDDING
310			
320			
330			
340			
350			
360			
370			
380			
390			
400			

McCLELLAND ENGINEERS

PLATE B-1d