G.I.-30 SEPT. 1976

GEOCRES No.

DIST. 52 REGION

W.P. No. 454-93-00 (A)

CONT. No.

W. O. No.

STR. SITE No. 42-317

HWY. No. 11

LOCATION Muskoka Rd 3 Interchange

No OF PAGES -

OVERSIZE DRAWINGS TO BE INCLUDED WITH THIS REPORT.

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Golder Associates

FINAL REPORT

FOUNDATION INVESTIGATION AND DESIGN REPORT FOR MUSKOKA ROAD 3 INTERCHANGE W.P. 454-93-00, SITE 42-317 HIGHWAY 11, DISTRICT 52 HUNTSVILLE, ONTARIO

Submitted to:
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971-8033-1

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1.0 INTRODUCTION

Golder Associates Ltd. has been retained by Cole, Sherman & Associates (Cole, Sherman) on behalf of the Ministry of Transportation, Ontario (MTO) to carry out a geotechnical investigation at the site of the proposed bridge to carry Muskoka Road 3 (Old North Road) over the new widened Highway 11. The Highway 11 underpass at Muskoka Road 3 is part of the four laning of Highway 11 project, which extends from 2.2 km north of Highway 60 in Huntsville and northerly 4.5 km. This report addresses the proposed bridge and its approaches within 20 m of the structure. The project site is designated as MTO Site 42-317.

The purpose of this investigation is to determine the subsurface conditions at the site of the proposed bridge structure by means of a limited number of boreholes, in-situ tests and laboratory tests on selected samples. Based on our interpretation of the data obtained, recommendations are provided on the geotechnical aspects of foundation design. Comments are also provided on anticipated construction problems where they may affect the design of the proposed bridge and approach embankments.

The terms of reference for the scope of work are outlined in our proposal letter P71-8053, dated June 18, 1997. The work was carried out in accordance with our Quality Control Plan for Foundation Design Services, dated August 1, 1997. During the course of the field work, the number of boreholes and extent of testing were revised, as required, to accommodate the encountered subsoil and site conditions.

2.0 SITE DESCRIPTION

The proposed Highway 11 underpass structure, designated as Site 42-317, is located approximately 6 km north of Highway 60 at Huntsville within MTO District 52, Huntsville, Ontario. A swamp is present to the east of the existing highway; a property of Tembec Forest Products Ltd. is located to the west of the Highway 11. The topography of the site is relatively level with ground surface between approximately Elevation 289 m and Elevation 290 m. Vegetation cover on both sides of the Highway 11 consists of trees, shrubs and grass.

3.0 INVESTIGATION PROCEDURES

The field work for this investigation was carried out between September 5 and September 12, 1997. At this time, three boreholes were drilled; one borehole was put down at each of the proposed bridge abutments and one borehole was put down at the proposed pier. Dynamic cone penetration testing was carried out within and adjacent to the boreholes at the proposed abutment locations. The investigation was carried out using a bombardier mounted CME 55 drill rig supplied and operated by Marathon Drilling Inc. of Ottawa.

In the borings, samples were obtained at regular intervals of depth using 50 mm outside diameter split spoon samplers in accordance with Standard Penetration Test (SPT) procedures. Groundwater conditions in the open boreholes were observed throughout the drilling operations, and two piezometers were installed in one of the boreholes.

The field work was supervised on a full time basis by a member of our technical staff who located the boreholes in the field, directed the drilling, sampling and in-situ testing operations, and logged the boreholes. The soil samples were identified in the field, placed in containers and transported back to our laboratory in Sudbury for further examination. Index and classification tests were carried out on selected samples.

The as-drilled borehole and dynamic cone penetration test locations were initially determined by our field personnel based on the chainages as staked in the field. The borehole locations and elevations were surveyed by Cole, Sherman; we understand that the elevations are referenced to Geodetic datum. The location of the boreholes and cone tests are shown on Drawing M8033004; the northing and easting co-ordinates are indicated on the Record of Borehole and cone sheets.

4.0 GENERAL SITE GEOLOGY AND STRATIGRAPHY

4.1 Site Geology

From published geologic information, the site is located in the physiographic region known as the Canadian Precambrian Shield. The shield terrain comprises large expanses of intrusive rocks such as gneisses and gneissic or massive granitic rocks. The rocks are geologically complex with considerable folding, intrusive activity, regional metamorphism and faulting. Pleistocene lacustrine/fluvial deposits and recent swamp sediments have been laid down in depressions and are associated with the Glacial Lake Algonquin. The local physiography is characterized by the overburden consisting mainly of discontinuous glaciolacustrine deposits and irregular, variable bedrock surface with frequent rock outcrops and shallow bedrock. Since irregular bedrock surface is typical in the area, organic terrain is widespread.

4.2 Site Stratigraphy

The detailed subsurface soil and groundwater conditions encountered in the boreholes, together with the results of the laboratory tests carried out on selected soil samples, are given on the attached Record of Borehole sheets following the text of this report. The stratigraphic boundaries shown on the Record of Borehole sheets are inferred from non-continuous sampling and, therefore, represent transitions between soil types rather than exact planes of geological change. Subsoil conditions will vary between and beyond the borehole locations.

Information on subsurface conditions was obtained from Boreholes 97-14 and 97-15 put down in the area of the west and east abutments, respectively, and Borehole 97-16 which was located in the area of the proposed pier, on the median of the proposed highway. Borehole 97-14 and dynamic cone testing CT97-3 had to be located approximately 16 m to the north of the proposed centreline of the west abutment due to difficult access to the site (an area of mature trees). Boreholes 97-14 and 97-15 were advanced to about 35.0 m and 34.1 m depths (Elevation 254.5 m and 254.7 m), respectively; Borehole 97-16 was drilled to 59.4 m depth (Elevation 230.0 m). One dynamic cone test (CT 97-3) was carried out adjacent to Borehole 97-14 to 30.5 m depth (Elevation 258.9 m) and dynamic cone testing was also carried out below the sampled depth of Boreholes 97-14 and 97-15. The cone test in Borehole 97-14 was carried out to 43.9 m depth (Elevation 245.6 m) and in Borehole 97-15 to 48.5 m depth (Elevation 240.5 m).

In summary, the soils encountered in the boreholes consist of an extensive glaciofluvial and/or lacustrine origin deposit of sand and silty sand underlain by silt and clayey silt. Bedrock was not encountered in the boreholes.

The locations of the boreholes and a stratigraphic section showing the inferred subsurface conditions at the proposed bridge site are shown on Drawing M8033004. A detailed description of the subsurface conditions encountered in the boreholes is provided in the following sections.

4.2.1 Fill Material

Some 1.7 m of fill material consisting of wood chips was found in Borehole 97-14, put down on the west side of the existing Highway 11 within the Tembec Forest Products property. This fill material is probably related to production processes at the Tembec Forest Products plant.

4.2.2 Sand to Silty Sand

Extending from the ground surface and/or underlying the fill is an extensive deposit of grey to brown sand and silty sand. Silt layers were encountered within this deposit at various depths. In Boreholes 97-14 and 97-15, the upper 2 m or so of the deposit was greenish grey in colour with trace organic matter and contains some 100 mm to 300 mm thick interlayers of peat. The sand and silty sand extends to about 15 m depth (Elevation 274.5 m) in Borehole 97-16 and to about 19.9 m (Elevation 269.7 m) and 22.9 m depths (Elevation 266.0 m) in Boreholes 97-14 and 97-15, respectively.

The sand is in a very loose to loose state of packing; the measured Standard Penetration Test (SPT) 'N' values range from weight of hammer to 9 blows for 0.3 m of penetration. The measured natural water contents of selected samples of this deposit range from 10 per cent to 46 per cent. The grain size distribution test results on samples of this deposit are shown on Figure 1.

4.2.3 Silt

Underlying the sand in all of the boreholes is a deposit of silt which is greenish grey to grey in colour and contains trace clay and thin sand seams. Trace organics was noted within the silt deposit in Borehole 97-15. Where fully penetrated in Boreholes 97-15 and 97-16, the silt deposit extends to 32.9 m and 32.6 m depths (Elevations 255.9 m and 256.9 m), respectively. Borehole 97-14 was sampled to about 27.4 m depth (Elevation 262.1 m) and did not fully penetrate the silt deposit.

The silt is in a very loose to loose state of packing. The measured SPT 'N' values range from weight of hammer to 10 blows for 0.3 m of penetration. The measured natural water contents of selected samples of this deposit range from 26 per cent to 34 per cent.

A 3 m thick silt layer was found in Borehole 97-16 at about 35.2 m depth (Elevation 254.3 m) separating the silty clay and clayey silt deposits. This silt layer is in a dense state of packing.

4.2.4 Silty Clay

Underlying the silt in Boreholes 97-16 and Borehole 97-15 is a layer of silty clay. Where fully penetrated in Borehole 97-16, the silty clay layer is about 2.6 m thick and extends to about 35.2 m depth (Elevation 252.1 m). The sampled Borehole 97-15 was terminated within the silty clay at about 34.1 m depth (Elevation 254.7 m). Two measured SPT 'N' values in the silty clay were 4 blows and 7 blows per 0.3 m of penetration indicating a firm consistency.

Two Atterberg Limit tests indicated liquid limits of about 33 per cent and 37 per cent and plasticity indices of about 10 per cent and 17 per cent. The measured natural water contents of these two samples of the deposit were 38 per cent and 37 per cent.

4.2.5 Clayey Silt to Silty Clay

A deposit of clayey silt to silty clay was encountered in Borehole 97-16 extending to the depth investigated in the borehole of 59.4 m (Elevation 230.0 m). The measured SPT 'N' values generally range from 19 to 39 blows per 0.3 m of penetration indicating a very stiff to hard consistency.

Atterberg Limit tests were carried out on two samples of this deposit. A liquid limit of 30 per cent and plasticity index of 7 per cent were obtained on one of the samples. A liquid limit of 23 per cent and plasticity index of about zero per cent were obtained for the second test which represents a silt seam within the deposit. The measured natural water contents of the two samples of this deposit were 29 per cent and 30 per cent.

4.2.6 Groundwater Conditions

The water levels in both piezometers installed in Borehole 97-16 were measured to be at about 3.6 m depth (Elevation 285.9 m) below the ground surface.

The water levels noted in the open boreholes varied from 1.8 m to 2.4 m depth during drilling operations. It should be noted that the water levels are subject to seasonal fluctuations.

5.0 ENGINEERING RECOMMENDATIONS

5.1 General

This section of the report provides our recommendations on the geotechnical aspects of foundation design of the Muskoka Road 3 bridge, based on our interpretation of the factual information obtained during our investigation. It should be noted that the interpretation and recommendations are intended for use only by the design engineer. Where comments are made on construction they are provided only to highlight those aspects which could affect the design of the project. Those requiring information on aspects of construction should make their own interpretation of the factual information provided as it may affect equipment selection, proposed construction method and scheduling.

The work described in this report is associated with the proposed Highway 11 underpass to carry Muskoka Road 3 over the new Highway 11 and the approach embankments within 20 m of the structure. It is understood that Muskoka Road 3 will be carried over Highway 11 by a new two span structure with a total length of approximately 75 m. The alignment of the proposed road crosses the existing highway and the property of Tembec Forest Products. The immediate approach embankment on the east side of the proposed bridge encroaches into the swampy area extending to the east. The proposed horizontal and vertical alignment for Highway 11 and the location of the bridge was provided to us on 1: 2,000 plan drawings and section prepared by Cole, Sherman. Based on the drawing provided, the proposed grade of Muskoka Road 3 will be some 9 m above the existing ground surface, at about Elevation 299.9 m at the centre of the bridge.

5.2 Bridge Foundations

The loose to very loose sands and silts encountered in the boreholes, extending to approximately 33 m depth are not suitable for support of shallow spread footings. Consideration could be given to the use of timber piles size 30 or larger with minimum length of 15 m terminated within the sands or/and silty sands and acting as friction piles for the support of the bridge. Alternatively, steel H-piles or pipe piles driven to the very stiff to hard clayey silt/silty clay deposit encountered below about 38 m depth in Borehole 97-16 could be used.

For closed ended pipe piles, relatively hard driving through the silt deposit could be encountered during pile installation, given the nature of the 10 m to 17 m thick silt deposit at about 15 m depth and the dynamic cone test results. In addition, it is probable that closed ended pipe piles could not be driven more than a few metres into the hard clayey silt/silty clay deposit. Steel H-piles are, therefore, considered to be the most feasible for use where greater penetration into the clayey silt/silty clay founding stratum is required for higher load carrying capacity.

Based on the general arrangement drawing provided, the bases of the pile caps at the abutments and pier are at about Elevation 292 m and 290 m, respectively. All pile caps should be founded at least 1.8 m below final grade to provide soil cover for frost protection.

5.2.1 Factored Geotechnical Resistance

Based on the above, the following factored geotechnical axial resistance values at Ultimate Limit States (ULS) for 310x110 steel H-piles, 324 m dia. steel pipe piles and timber piles size 30 or larger can be assumed for design:

Pile Type	*Assumed Base of Pile Cap Elevation (m)*	*Factored Geotechnical Resistance at ULS (kN) for Pile with Driven Length of:*			
		15 m	*42 m*	*50 m*	*Assumptions*
310x110 H-pile	292.0/290.0	-	-	950	Piles extended about 12 m into hard clayey silt/silty clay founding stratum.
Closed-end pipe pile 324 mm OD		-	750 kN	-	Piles extended to at least 1 m into hard clayey silt/silty clay founding stratum.
Timber Pile size 30 or larger		225	-	-	Capacity based on shaft friction within sands/silts.

For the steel piles, a resistance factor of 0.5 was used to obtain the factored geotechnical resistance summarized in the above table. The design capacity assumes, therefore, that dynamic testing (consisting of strain gauge measurements of acceleration and strain induced in the pile) is carried out during pile installation at the site to confirm the load carrying capacity of the piles. For the timber piles, a resistance factor of 0.4 was assumed. A resistance factor of 0.6 can be used if static pile load testing is also carried out on at least one pile to confirm pile axial capacity.

The geotechnical resistance at Serviceability Limit States (SLS) is dependent on the settlement of the pile group and, therefore, is governed by the size of the pile group. Based on the plan provided on November 6, 1997, it is understood that H-piles will be adopted for the bridge support; one row of eight HP310x110 piles spaced at 1.6 m for the abutments and two rows of eight piles spaced at 1.8 m for the pier. For the above pile group configurations with the piles driven to Elevation 238.0 m (50 m long piles), a geotechnical resistance at SLS of 800 kN can be used for design. The above SLS value refers to 25 mm of settlement for the pile group.

5.2.2 Resistance to Lateral Loads

For resistance to lateral loads, the horizontal reaction to the pile can be calculated from the expression:

$$k_s = z \times n_h / d,$$

where is [illegible] ?

where

k_s = coefficient of horizontal subgrade reaction (MPa/m)
d = pile diameter (m)
n_h = constant of horizontal subgrade reaction (MPa/m)
z = depth (m)

The constant of horizontal subgrade reaction depends on the soil type and soil density/consistency around the pile shaft. For design of resistance to lateral loads, the values (or range of values) indicated in the following table may be assumed:

Elevation (m) (approx.)	*Soil Type*	*$z \times n_h$ (MPa)*
288.0 to 257.0	Sand and Silt, very loose to loose	z x 1.0
257.0 to 254.0	Silty Clay, firm	2.0 (constant with depth)
254.0 to 251.0	Silt, dense	z x 6.0
251.0 to 248.0	Clayey Silt to Silty Clay, very stiff	5.0 (constant with depth)
248.0 to 238.0	Clayey Silt to Silty Clay, hard	7.0 (constant with depth

Group action for lateral loading should be considered when the pile spacing in the direction of loading is less than six to eight pile diameters. Group action can be evaluated by reducing the coefficient of lateral subgrade reaction in the direction of loading by a reduction factor R as follows:

Pile Spacing in Direction of Loading d = Pile Diameter	*Subgrade Reaction Reduction Factor R*
8d	1.00
6d	0.70
4d	0.40
3d	0.25

5.3 Lateral Earth Pressures

The lateral pressures acting on the bridge abutments will depend on the type and method of placement of the backfill materials, on the nature of the soils behind the backfill and on the subsequent lateral movement of the structure. The following recommendations are made concerning the design of the abutments walls in accordance with OHBDC:

- Select free-draining non-frost susceptible granular fill meeting the specifications of OPSS Granular A or Granular B but with less than 5 per cent passing the 200 sieve should be used as backfill behind the walls. All granular fill should be compacted in lifts of loose thickness not greater than 200 mm to 95 per cent of the material's Standard Proctor maximum dry density.

- Longitudinal drains and weep holes should be installed to provide positive drainage of the granular backfill.

- The granular fill may be placed either in a zone with width equal to at least 1.8 m behind the back of the stem (Case I) or within the wedge-shaped zone defined by a 60 degree line extending up and back from the bottom of the rear face of the footing (Case II).

- If the wall support allows lateral yielding of the stem (unrestrained structure), active earth pressures may be used in the geotechnical design of the structure. If the abutment support does not allow lateral yielding (restrained structure), at-rest pressures should be assumed for geotechnical design.

- A compaction surcharge equal to 16 kPa should be included in the lateral earth pressures for the structural design of the abutment wall in accordance with OHBDC Figure 6-7.4.3.

- For Case I, the pressures are based on the in-situ soils/embankment fill materials and the following parameters (unfactored) may be assumed:

Soil unit weight (assuming the in-situ soils and/or clean earth fill)	20 kN/m^3
Coefficients of lateral earth pressure:	
'active'	0.33
'at rest'	0.50

- For Case II, the pressures are based on the granular fill as placed and the following parameters (unfactored) may be assumed:

	Granular A	**Granular B**
Soil Unit Weight	22 kN/m^3	21 kN/m^3
Coefficient of Lateral Earth Pressure		
'active'	0.27	0.31
'at rest'	0.43	0.47

It should be noted that the above design parameters assume level backfill and ground surface behind the wall. Other aspects of the abutment granular backfill requirements with respect to sub-drains and frost taper should be in accordance with OPSD-3501.00.

5.4 Excavations

Based on the general arrangement drawing provided, excavations for pile cap construction are not required; the base of pile caps are at about 2 m above the existing ground surface at the abutments and at the ground surface at the pier location.

5.5 Approach Embankments

The proposed road grade at the crossing (approximate Elevation 298 m) will involve approach embankments approximately 8 m to 9 m high. A swamp is present along the proposed Muskoka Road alignment to the east of the existing Highway 11 between approximately Stations 10+035 and 10+375. Silty sand with trace organic matter was encountered at ground surface to approximately 0.8 m depth in Borehole 97-15; and a hand auger probe put down at Station 10+060 encountered some 200 mm of organic deposit. The thickness of the organic deposit increases to the east based on the results of probeholes put down through the swamp. The organic deposit is underlain by an extensive deposit of very loose to loose sands and silts.

The organic deposits should be subexcavated from below the proposed embankment as defined by OPSD-203.05. With full removal of the organic deposit and given the nature of the underlying sands and silts, stability of the proposed embankments is not a concern with respect to deep seated failure through the founding soils within the swamp limits. No significant long term settlement of the road embankments is expected due to consolidation of the subsoils given the composition of the essentially granular founding materials. Some settlement of the embankments will occur during construction and within a relatively short time following construction due to consolidation of the very loose sands and silts underlying the site; however, the amount following construction is expected to be minimal.

The embankments should be constructed in general accordance with OPSS 206 to a final grading section as represented by OPSD 200.02.

5.6 Subgrade Preparation and Embankment Construction

In general, topsoil, organic deposits and fill materials should be stripped from below the fill embankment areas and all subgrade soils should be proof-rolled prior to fill placement. The subgrade consists of sand and silty sand.

Construction of the embankment above the prepared subgrade may be carried out using clean earth fill or granular fill. Clean earth fill (Select Subgrade Material, SSM or Select Borrow Material, SBM) is soil free of topsoil, organic matter, rubble, cobble sizes greater than 150 mm and other deleterious materials. The fill should have a water content at the time of placement within 2 per cent of the material's optimum water content. All embankment fills should be placed in regular lifts with loose thickness not exceeding 300 mm, and be compacted to at least 95 per cent of the material's Standard Proctor maximum dry density. The final lift prior to placement of the granular subbase or base course should be compacted to 100 per cent of the Standard Proctor maximum dry density. Inspection and field density testing should be carried out by qualified geotechnical personnel during all fill placement operations to ensure that appropriate materials are used and that adequate levels of compaction have been achieved.

The permanent slopes of the embankment should be maintained not steeper than 2 horizontal to 1 vertical. Vegetation cover should be established on all slopes to provide surficial erosion protection.

Alternatively, the approach embankments could be constructed using rockfill. The permanent side slopes of the rockfill embankments should be maintained not steeper than 1.25 horizontal to 1 vertical.

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AMP/ASP/DEB/amp/dh/clg
WORD S/FINALDAT/OTHPRJT/971-8033/78033LR1

LIST OF ABBREVIATIONS

The abbreviations commonly employed on Records of Boreholes, on figures and in the text of the report are as follows:

I. SAMPLE TYPE

AS	Auger sample
BS	Block sample
CS	Chunk sample
DO	Drive open
DS	Denison type sample
FS	Foil sample
RC	Rock core
SC	Soil core
ST	Slotted tube
TO	Thin-walled, open
TP	Thin-walled, piston
WS	Wash sample

II. PENETRATION RESISTANCE

Standard Penetration Resistance (SPT), N:
The number of blows by a 63.5 kg. (140 lb.) hammer dropped 760 mm (30 in.) required to drive a 50 mm (2 in.) drive open sampler for a distance of 300 mm (12 in.).

Dynamic Penetration Resistance; N_d:
The number of blows by a 63.5 kg (140 lb.) hammer dropped 760 mm (30 in.) to drive uncased a 50 mm (2 in.) diameter, 60° cone attached to "A" size drill rods for a distance of 300 mm (12 in.).

PH:	Sampler advanced by hydraulic pressure
PM:	Sampler advanced by manual pressure
WH:	Sampler advanced by static weight of hammer
WR:	Sampler advanced by weight of sampler and rod

Piezo-Cone Penetration Test (CPT):
An electronic cone penetrometer with a 60° conical tip and a projected end area of 10 cm^2 pushed through ground at a penetration rate of 2 cm/s. Measurements of tip resistance (Q_t), porewater pressure (PWP) and friction along a sleeve are recorded electronically at 25 mm penetration intervals.

III. SOIL DESCRIPTION

(a) Cohesionless Soils

Density Index (Relative Density)	**N** Blows/300 mm or Blows/ft.
Very loose	0 to 4
Loose	4 to 10
Compact	10 to 30
Dense	30 to 50
Very dense	over 50

(b) Cohesive Soils

Consistency	c_u, s_u	
	kPa	psf
Very soft	0 to 12	0 to 250
Soft	12 to 25	250 to 500
Firm	25 to 50	500 to 1,000
Stiff	50 to 100	1,000 to 2,000
Very stiff	100 to 200	2,000 to 4,000
Hard	over 200	over 4,000

IV. SOIL TESTS

w	water content
w_p	plastic limit
w_l	liquid limit
C	consolidation (oedometer) test
CHEM	chemical analysis (refer to text)
CID	consolidated isotropically drained triaxial test[1]
CIU	consolidated isotropically undrained triaxial test with porewater pressure measurement[1]
D_R	relative density (specific gravity, G_S)
DS	direct shear test
M	sieve analysis for particle size
MH	combined sieve and hydrometer (H) analysis
MPC	Modified Proctor compaction test
SPC	Standard Proctor compaction test
OC	organic content test
SO_4	concentration of water-soluble sulphates
UC	unconfined compression test
UU	unconsolidated undrained triaxial test
V	field vane test (LV-laboratory vane test)
γ	unit weight

Note:
1. Tests which are anisotropically consolidated prior to shear are shown as CAD, CAU.

LIST OF SYMBOLS

Unless otherwise stated, the symbols employed in the report are as follows:

I. GENERAL

π = 3.1416
ln x, natural logarithm of x
$\log_{10}$ x or log x, logarithm of x to base 10
g acceleration due to gravity
t time
F factor of safety
V volume
W weight

II. STRESS AND STRAIN

γ shear strain
Δ change in, e.g. in stress: $\Delta\,\sigma$
ε linear strain
ε_v volumetric strain
η coefficient of viscosity
ν Poisson's ratio
σ total stress
σ' effective stress ($\sigma' = \sigma$ -u)
σ'_{vo} initial effective overburden stress
$\sigma_1,\sigma_2,\sigma_3$ principal stresses (major, intermediate, minor)
σ_{oct} mean stress or octahedral stress $= (\sigma_1 + \sigma_2 + \sigma_3)/3$
τ shear stress
u porewater pressure
E modulus of deformation
G shear modulus of deformation
K bulk modulus of compressibility

III. SOIL PROPERTIES

(a) Index Properties

$\rho(\gamma)$ bulk density (bulk unit weight*)
$\rho_d(\gamma_d)$ dry density (dry unit weight)
$\rho_w(\gamma_w)$ density (unit weight) of water
$\rho_s(\gamma_s)$ density (unit weight) of solid particles
γ' unit weight of submerged soil ($\gamma' = \gamma$-γ_w)
D_R relative density (specific gravity)of solid particles ($D_R = \rho_s / \rho_w$) (formerly G_s)
e void ratio
n porosity
S degree of saturation

* Density symbol is ρ. Unit weight symbol is γ where $\gamma = \rho g$ (i.e. mass density x acceleration due to gravity)

(a) Index Properties (con't.)

w water content
w_l liquid limit
w_p plastic limit
I_P plasticity Index = $(w_l - w_p)$
w_S shrinkage limit
I_L liquidity index = $(w - w_p) / I_p$
I_C consistency index = $(w_l - w) / I_p$
e_{max} void ratio in loosest state
e_{min} void ratio in densest state
I_D density index = $(e_{max} - e) / (e_{max} - e_{min})$ (formerly relative density)

(c) Hydraulic Properties

h hydraulic head or potential
q rate of flow
v velocity of flow
i hydraulic gradient
k hydraulic conductivity (coefficient of permeability)
j seepage force per unit volume

(d) Consolidation (one-dimensional)

C_c compression index (normally consolidated range)
C_r recompression index (overconsolidated range)
C_S swelling index
C_α coefficient of secondary consolidation
m_v coefficient of volume change
c_v coefficient of consolidation
T_v time factor (vertical direction)
U degree of consolidation
σ'_p pre-consolidation pressure
OCR Overconsolidation ratio $=\sigma'_p/\sigma'_{vo}$

(e) Shear Strength

τ_p, τ_r peak and residual shear strength
ϕ' effective angle of internal friction
δ angle of interface friction
μ coefficient of friction = tan δ
c' effective cohesion
c_u,s_u undrained shear strength (ϕ = 0 analysis)
p mean total stress $(\sigma_1 + \sigma_3)/2$
p' mean effective stress $(\sigma'_1 + \sigma'_3)/2$
q $(\sigma_1 - \sigma_3)/2$ or $(\sigma'_1 - \sigma'_3)/2$
q_u compressive strength $(\sigma_1 - \sigma_3)$
S_t sensitivity

Notes: 1. $\tau = c' + \sigma' \tan \phi'$
2. Shear strength = (Compressive strength)/2

M8033014.BHS

PROJECT: 971-8033

RECORD OF BOREHOLE 97-14

LOCATION: N 5025772.97; E 326886.74

BORING DATE: SEPT.5/97

DATUM: GEODETIC

SAMPLER HAMMER, 63.5kg; DROP, 760mm

PENETRATION TEST HAMMER, 63.5kg; DROP, 760mm

DEPTH SCALE METRES | BORING METHOD | SOIL PROFILE (DESCRIPTION, STRATA PLOT, ELEV. DEPTH (m)) | SAMPLES (NUMBER, TYPE, BLOWS/0.3m) | DYNAMIC PENETRATION RESISTANCE, BLOWS/0.3m (60, 120, 180, 240) | SHEAR STRENGTH Cu, kPa (nat V - +, rem V - ⊕, Q - ●, U - ○) | HYDRAULIC CONDUCTIVITY, k, cm/s | WATER CONTENT, PERCENT (Wp, W, Wl; 10, 20, 30, 40) | ADDITIONAL LAB. TESTING | PIEZOMETER OR STANDPIPE INSTALLATION

Boring method: BOMBARDIER CME-55 HOLLOW STEM AUGERS

Description	Elev. (m)	Depth (m)
GROUND SURFACE	289.48	0.00
Wood chips (FILL)	287.81	1.67
Silty Sand, trace organics Very loose to loose Greenish grey Moist to wet 100mm thick peat layers at 1.8m and 2.7m depth	286.58	2.90
Sand, fine to medium, trace silt Very loose to loose Greenish brown to grey Wet	283.78	5.70
Silty Sand Very loose to loose Grey Wet	279.38	10.10
Sand and Silt to Silty Sand, interlayered Very loose Grey Wet	277.78	11.70
Sand, fine, trace to some silt Very loose Grey Wet	269.68	19.80

Sample Number	Type	Blows/0.3m	Additional Lab. Testing
1	50 DO	2	
2	50 DO	6	
3	50 DO	2	MH
4	50 DO	1	
5	50 DO	6	
6	50 DO	2	
7	50 DO	2	
8	50 DO	WH	
9	50 DO	WH	
10	50 DO	WH	

Depth scale: 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20

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DATA INPUT. PS dec.18/97

DEPTH SCALE
1 to 100

Golder Associates

LOGGED: MSB
CHECKED: DC

SOILM6

PROJECT: 971-8033

RECORD OF BOREHOLE 97-14

LOCATION: N 5025772.97; E 326886.74

BORING DATE: SEPT.5/97

DATUM: GEODETIC

SAMPLER HAMMER, 63.5kg; DROP, 760mm

PENETRATION TEST HAMMER, 63.5kg; DROP, 760mm

DEPTH SCALE METRES	BORING METHOD	SOIL PROFILE: DESCRIPTION	ELEV. DEPTH (m)	SAMPLES: NUMBER	TYPE	BLOWS/0.3m	WATER CONTENT, PERCENT (Wp / W / Wl)
20	BOMBARDIER CME-55 HOLLOW STEM AUGERS	CONTINUED FROM PREVIOUS PAGE					
21.5		Silt with some sand Very loose Grey Wet		11	50 DO	WH	~29
24.5				12	50 DO	WH	~27
27.40		Borehole advanced without sampling to 35.0m due to sand and silt blowing back into augers.	262.08 27.40				
35.00		END OF BOREHOLE Dynamic cone penetration test was carried out to practical refusal to further cone penetration encountered at 43.9m depth.	254.48 35.00				
40		CONTINUED ON NEXT PAGE					

Column headings also printed: STRATA PLOT; DYNAMIC PENETRATION RESISTANCE, BLOWS/0.3m (60, 120, 180, 240); SHEAR STRENGTH Cu, kPa (nat V - +, Q - ●, rem V - ⊕, U - ○); HYDRAULIC CONDUCTIVITY, k, cm/s; WATER CONTENT, PERCENT (10, 20, 30, 40); ADDITIONAL LAB. TESTING; PIEZOMETER OR STANDPIPE INSTALLATION

DEPTH SCALE 1 to 100

Golder Associates

LOGGED: MSB

CHECKED: DC

M8033014.BHS

DATA INPUT: PS dec.18/97

SOILM6

PROJECT: 971-8033

RECORD OF BOREHOLE 97-14

LOCATION: N 5025772.97; E 326886.74

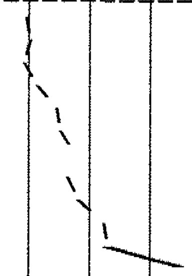
BORING DATE: SEPT.5/97

DATUM: GEODETIC

SAMPLER HAMMER, 63.5kg; DROP, 760mm

PENETRATION TEST HAMMER, 63.5kg; DROP, 760mm

DEPTH SCALE METRES	BORING METHOD	SOIL PROFILE: DESCRIPTION	STRATA PLOT	ELEV. / DEPTH (m)	SAMPLES: NUMBER	TYPE	BLOWS/0.3m	DYNAMIC PENETRATION RESISTANCE, BLOWS/0.3m (60, 120, 180, 240); SHEAR STRENGTH Cu, kPa (nat V - + Q - ●; rem V - ⊕ U - ○)	HYDRAULIC CONDUCTIVITY, k, cm/s; WATER CONTENT, PERCENT Wp ⊢—○W—⊣ Wl (10, 20, 30, 40)	ADDITIONAL LAB. TESTING	PIEZOMETER OR STANDPIPE INSTALLATION
40	BOMBARDIER CME-55 HOLLOW STEM AUGERS	CONTINUED FROM PREVIOUS PAGE									
42											
44		END OF DYNAMIC CONE PENETRATION TEST		245.59 / 43.89							
46											
48											
50											
52											
54											
56											
58											
60											



DEPTH SCALE

1 to 100

Golder Associates

LOGGED: MSB

CHECKED: DC

DATA INPUT: PS dec.16/97

SOILM6

M6033015.BHS

PROJECT: 971-8033

RECORD OF BOREHOLE 97-15

SHEET 1 OF 3

LOCATION: N 5025796.321; E 326949.693

BORING DATE: SEPT.7/97

DATUM: GEODETIC

SAMPLER HAMMER, 63.5kg; DROP, 760mm

PENETRATION TEST HAMMER, 63.5kg; DROP, 760mm

DEPTH SCALE METRES | BORING METHOD | SOIL PROFILE: DESCRIPTION | STRATA PLOT | ELEV. DEPTH (m) | SAMPLES: NUMBER | TYPE | BLOWS/0.3m | DYNAMIC PENETRATION RESISTANCE, BLOWS/0.3m (60 120 180 240); SHEAR STRENGTH Cu, kPa (nat V - + Q - ●; rem V - ⊕ U - O) | HYDRAULIC CONDUCTIVITY, k, cm/s; WATER CONTENT, PERCENT Wp W Wl (10 20 30 40) | ADDITIONAL LAB. TESTING | PIEZOMETER OR STANDPIPE INSTALLATION

Boring method: BOMBARDIER CME-55, HOLLOW STEM AUGERS

Depth (m)	Description	Elev. / Depth (m)	Sample No.	Type	Blows/0.3m	Additional Lab. Testing	Remarks
0	GROUND SURFACE	288.83					
	Silty Sand, trace organics Very loose Brown Moist	0.00	1	50 DO	1		
	Sand, fine to medium, some silt to silty sand, trace peat Very loose Greenish brown Moist to wet -300mm of very loose, wet, dark brown peat noted at 1.8m depth.	288.07 0.76	2	50 DO	4		
2			3	50 DO	1	M	▽
			4	50 DO	2		
	Sand, fine to coarse, some silt Very loose Brown to grey Wet -150mm of wood fragments at 4.7m depth	285.88 2.95	5	50 DO	1		
4			6	50 DO	2		
6			7	50 DO	3		
8			8	50 DO	1		
			9	50 DO	1		
10	Silty Sand Very loose Grey Wet	278.63 10.20	10	50 DO	2		
12			11	50 DO	2		
14							
16			12	50 DO	2		
18	-trace organics noted below approx. 18m depth		13	50 DO	3		>52.7
20	CONTINUED ON NEXT PAGE						

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DATA INPUT: PS dec 18/97

PROJECT: 971-8033

LOCATION: N 5025796.321; E 326949.693

SAMPLER HAMMER, 63.5kg; DROP, 760mm

RECORD OF BOREHOLE 97-15

BORING DATE: SEPT.7/97

DATUM: GEODETIC

PENETRATION TEST HAMMER, 63.5kg; DROP, 760mm

BORING METHOD: BOMBARDIER CME-55 HOLLOW STEM AUGERS

DEPTH SCALE METRES	DESCRIPTION	ELEV. / DEPTH (m)	SAMPLE NUMBER	TYPE	BLOWS/0.3m	WATER CONTENT, PERCENT	PIEZOMETER OR STANDPIPE INSTALLATION
20	CONTINUED FROM PREVIOUS PAGE						
	Silty Sand Very loose Grey Wet						
			14	50 DO	WH	~28	
22		265.97 22.86					
24	Silt, trace sand, trace clay Very loose to loose Grey Wet		15	50 DO	9		
26							
28			16	50 DO	5		
30			17	50 DO	WH		
32		255.91 32.92					
	Silty Clay, trace sand Soft to firm Grey Wet		18	50 DO	4	Wp ~20, W ~36	Note: Water level in open borehole at 1.8m depth on completion of drilling.
34	END OF BOREHOLE	254.69 34.14					
36							
38							
40	CONTINUED ON NEXT PAGE						

DYNAMIC PENETRATION RESISTANCE, BLOWS/0.3m (60, 120, 180, 240)

SHEAR STRENGTH Cu, kPa — nat V - + Q - ● ; rem V - ⊕ U - O

HYDRAULIC CONDUCTIVITY, k, cm/s

WATER CONTENT, PERCENT — Wp, W, Wl (10, 20, 30, 40)

ADDITIONAL LAB. TESTING

DEPTH SCALE 1 to 100

Golder Associates

LOGGED: MSB

CHECKED: AMP

PROJECT: 971-8033

LOCATION: N 5025796.321; E 326949.693

SAMPLER HAMMER, 63.5kg; DROP, 760mm

RECORD OF BOREHOLE 97-15

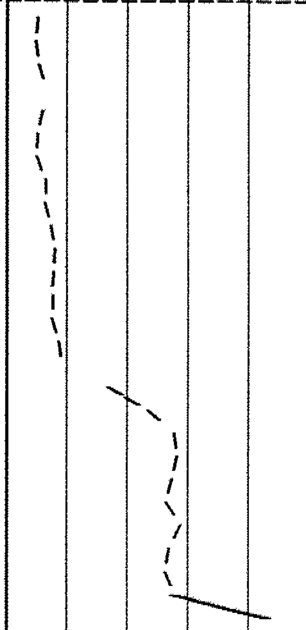
BORING DATE: SEPT.7/97

SHEET 3 OF 3

DATUM: GEODETIC

PENETRATION TEST HAMMER, 63.5kg; DROP, 760mm

DEPTH SCALE METRES	BORING METHOD	SOIL PROFILE: DESCRIPTION	STRATA PLOT	ELEV. DEPTH (m)	SAMPLES: NUMBER	TYPE	BLOWS/0.3m	DYNAMIC PENETRATION RESISTANCE, BLOWS/0.3m (60 120 180 240); SHEAR STRENGTH Cu, kPa (nat V - + Q - ●; rem V - ⊕ U - ○)	HYDRAULIC CONDUCTIVITY, k, cm/s; WATER CONTENT, PERCENT Wp W Wl (10 20 30 40)	ADDITIONAL LAB. TESTING	PIEZOMETER OR STANDPIPE INSTALLATION
40		CONTINUED FROM PREVIOUS PAGE									
42											
44											
46											
48		END OF DYNAMIC CONE PENETRATION TEST		240.31 48.52							
50											
52											
54											
56											
58											
60											



DEPTH SCALE

1 to 100

Golder Associates

LOGGED: MSB

CHECKED: AMP

M8033015.BHS

DATA INPUT: PS dec 18/97

SOILM6

M5033016.BHS

PROJECT: 971-8033

RECORD OF BOREHOLE 97-16

LOCATION: N 5025778.436; E 326921.667

BORING DATE: SEPT.9/97

DATUM: GEODETIC

SAMPLER HAMMER, 63.5kg; DROP, 760mm

PENETRATION TEST HAMMER, 63.5kg; DROP, 760mm

DYNAMIC PENETRATION RESISTANCE, BLOWS/0.3m: 30, 60, 90, 120

SHEAR STRENGTH Cu, kPa: nat V - + ; rem V - ⊕ ; Q - ● ; U - ○

HYDRAULIC CONDUCTIVITY, k, cm/s

WATER CONTENT, PERCENT: Wp ⊢—○W—⊣ Wl; 10, 20, 30, 40

BORING METHOD: BOMBARDIER CME-55, HOLLOW STEM AUGERS

DEPTH SCALE METRES	SOIL PROFILE DESCRIPTION	ELEV. / DEPTH (m)
0	GROUND SURFACE	289.45 / 0.00
0 – 5.60	Sand, trace silt Very loose to loose Brown Moist becoming wet below 2.4m depth -becoming grey with trace organics and trace gravel	283.85 / 5.60
5.60 – 7.16	Silt, trace sand Very loose Brownish grey Wet	282.29 / 7.16
7.16 – 8.50	Sand, fine to coarse, trace silt Very loose Grey Wet	280.95 / 8.50
8.50 – 10.00	Silty Sand Very loose Grey Wet	279.45 / 10.00
10.00 – 15.00	Silty Sand Very loose Grey Wet	274.45 / 15.00
15.00 – 20	Silt, trace clay and trace sand Very loose to loose Grey Wet	

SAMPLE NUMBER	TYPE	BLOWS/0.3m	ADDITIONAL LAB. TESTING
1	50 DO	7	
2	50 DO	9	
3	50 DO	3	M
4	50 DO	1	
5	50 DO	2	
6	50 DO	1	
7	50 DO	3	
8	50 DO	3	
9	50 DO	3	
10	50 DO	4	
11	50 DO	8	
12	50 DO	WH	

PIEZOMETER OR STANDPIPE INSTALLATION: BENTONITE SEAL; NATIVE BACKFILL; GRAVEL; NATIVE BACKFILL; BENTONITE SEAL; GRAVEL; NATIVE BACKFILL

NOTE:
Water level in open borehole at 2.4m depth on completion of drilling.

Water level in deep and shallow piezometers at 3.6m depth on Sept.12/97.

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DATA INPUT: PS dec.18/97

DEPTH SCALE 1 to 100

Golder Associates

LOGGED: MSB

CHECKED: DC

SOILM6

M6033016.BHS

PROJECT: 971-8033

RECORD OF BOREHOLE 97-16

LOCATION: N 5025778.436; E 326921.667

BORING DATE: SEPT.9/97

DATUM: GEODETIC

SAMPLER HAMMER, 63.5kg; DROP, 760mm

PENETRATION TEST HAMMER, 63.5kg; DROP, 760mm

DEPTH SCALE METRES | BORING METHOD | SOIL PROFILE (DESCRIPTION, STRATA PLOT, ELEV. DEPTH (m)) | SAMPLES (NUMBER, TYPE, BLOWS/0.3m) | DYNAMIC PENETRATION RESISTANCE, BLOWS/0.3m (30, 60, 90, 120) | SHEAR STRENGTH Cu, kPa (nat V - +, Q - ●, rem V - ⊕, U - O) | HYDRAULIC CONDUCTIVITY, k, cm/s | WATER CONTENT, PERCENT (Wp, W, Wl; 10, 20, 30, 40) | ADDITIONAL LAB. TESTING | PIEZOMETER OR STANDPIPE INSTALLATION

Boring method: BOMBARDIER CME-55, HOLLOW STEM AUGERS

CONTINUED FROM PREVIOUS PAGE

Depth (m)	Description	Elev. / Depth (m)
20 – 32.60	Silt, trace clay and trace sand Very loose to loose Grey Wet	256.85 32.60
32.60 – 35.20	Silty Clay, trace sand Firm Grey Wet	254.25 35.20
35.20 – 38.30	Silt, trace clay, trace sand Dense Grey Wet	251.15 38.30
38.30 – 40	Clayey Silt to Silty Clay, some sand and silt seams Very stiff to hard Grey Wet 150mm thick layer of coarse sand at 39.6m depth	

Sample Number	Type	Blows/0.3m
12a	50 DO	WH
13	50 DO	10
14	50 DO	4
15	50 DO	1
16	50 DO	7
17	50 DO	33
18	50 DO	19

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DATA INPUT: PS dec.18/97

DEPTH SCALE

1 to 100

Golder Associates

LOGGED: MSB

CHECKED: DC

SOILM6

M8033016.BHS

PROJECT: 971-8033

RECORD OF BOREHOLE 97-16

SHEET 3 OF 3

LOCATION: N 5025778.436; E 326921.667

BORING DATE: SEPT.9/97

DATUM: GEODETIC

SAMPLER HAMMER, 63.5kg; DROP, 760mm

PENETRATION TEST HAMMER, 63.5kg; DROP, 760mm

DEPTH SCALE METRES	BORING METHOD	SOIL PROFILE: DESCRIPTION	STRATA PLOT	ELEV. DEPTH (m)	SAMPLES: NUMBER	TYPE	BLOWS/0.3m	DYNAMIC PENETRATION RESISTANCE, BLOWS/0.3m (30, 60, 90, 120); SHEAR STRENGTH Cu, kPa (nat V - +, Q - ●, rem V - ⊕, U - ○)	HYDRAULIC CONDUCTIVITY, k, cm/s; WATER CONTENT, PERCENT (Wp, W, Wl; 10, 20, 30, 40)	ADDITIONAL LAB. TESTING	PIEZOMETER OR STANDPIPE INSTALLATION
40	BOMBARDIER CME-55 HOLLOW STEM AUGERS	CONTINUED FROM PREVIOUS PAGE			18	50 DO	19				
		Clayey Silt to Silty Clay, some sand and silt seams Very stiff to hard Grey Wet			19	50 DO	35		Wp I, W ○		
					20	50 DO	30				
					21	50 DO	39				
		(inferred based on observations of auger cuttings during drilling operations)									
		END OF BOREHOLE		230.02 59.43							

DEPTH SCALE 1 to 100

Golder Associates

LOGGED: MSB

CHECKED: DC

DATA INPUT: PS dec.18/97

SOILM6

PROJECT: 971-8033

LOCATION: N 5025763.453; E 326873.353

SAMPLER HAMMER, 63.5kg; DROP, 760mm

RECORD OF CONE TEST CT97-3

BORING DATE: SEPT.4/97

DATUM: GEODETIC

PENETRATION TEST HAMMER, 63.5kg; DROP, 760mm

DEPTH SCALE METRES	BORING METHOD	SOIL PROFILE: DESCRIPTION	STRATA PLOT	ELEV. DEPTH (m)	SAMPLES: NUMBER	TYPE	BLOWS/0.3m	DYNAMIC PENETRATION RESISTANCE, BLOWS/0.3m (50, 100, 150, 200); SHEAR STRENGTH Cu, kPa (nat V - +, Q - ●, rem V - ⊕, U - O)	HYDRAULIC CONDUCTIVITY, k, cm/s; WATER CONTENT, PERCENT (Wp, W, Wl; 10, 20, 30, 40)	ADDITIONAL LAB. TESTING	PIEZOMETER OR STANDPIPE INSTALLATION
0	BOMBARDIER CME-55	GROUND SURFACE		289.33 0.00							
		For soil stratigraphy refer to Borehole 97-14.									
2											
4											
6											
8											
10											
12											
14											
16											
18											
20		CONTINUED ON NEXT PAGE									

DEPTH SCALE

1 to 100

Golder Associates

LOGGED: MSB

CHECKED: AMP

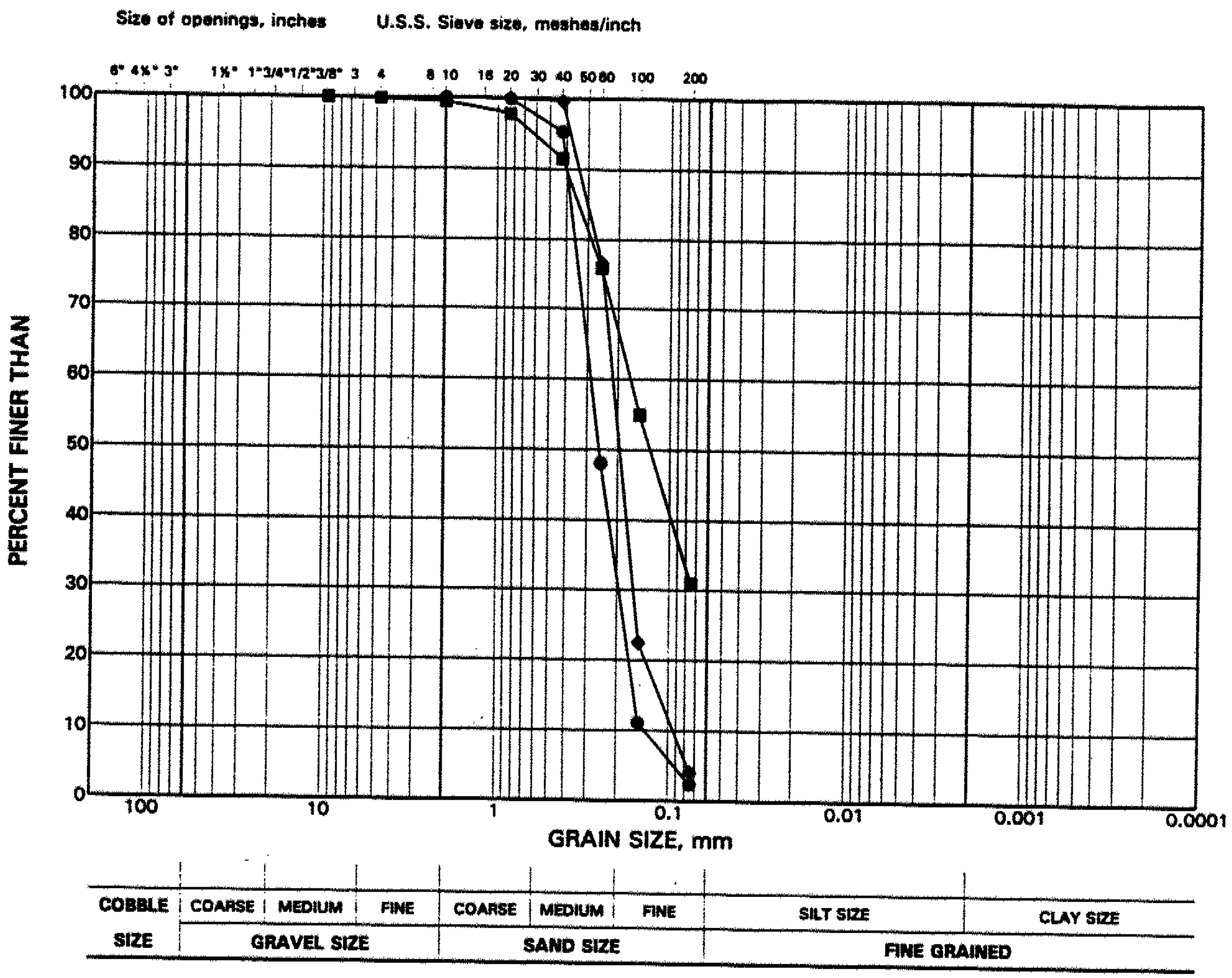
M8033CT3.BHS

DATA INPUT: PS DEC.18/97

SMPROBE

GRAIN SIZE DISTRIBUTION
SAND TO SILTY SAND

FIGURE 1



LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	97-14	3	286.1
■	97-15	3a	287.0
◆	97-16	3b	286.9

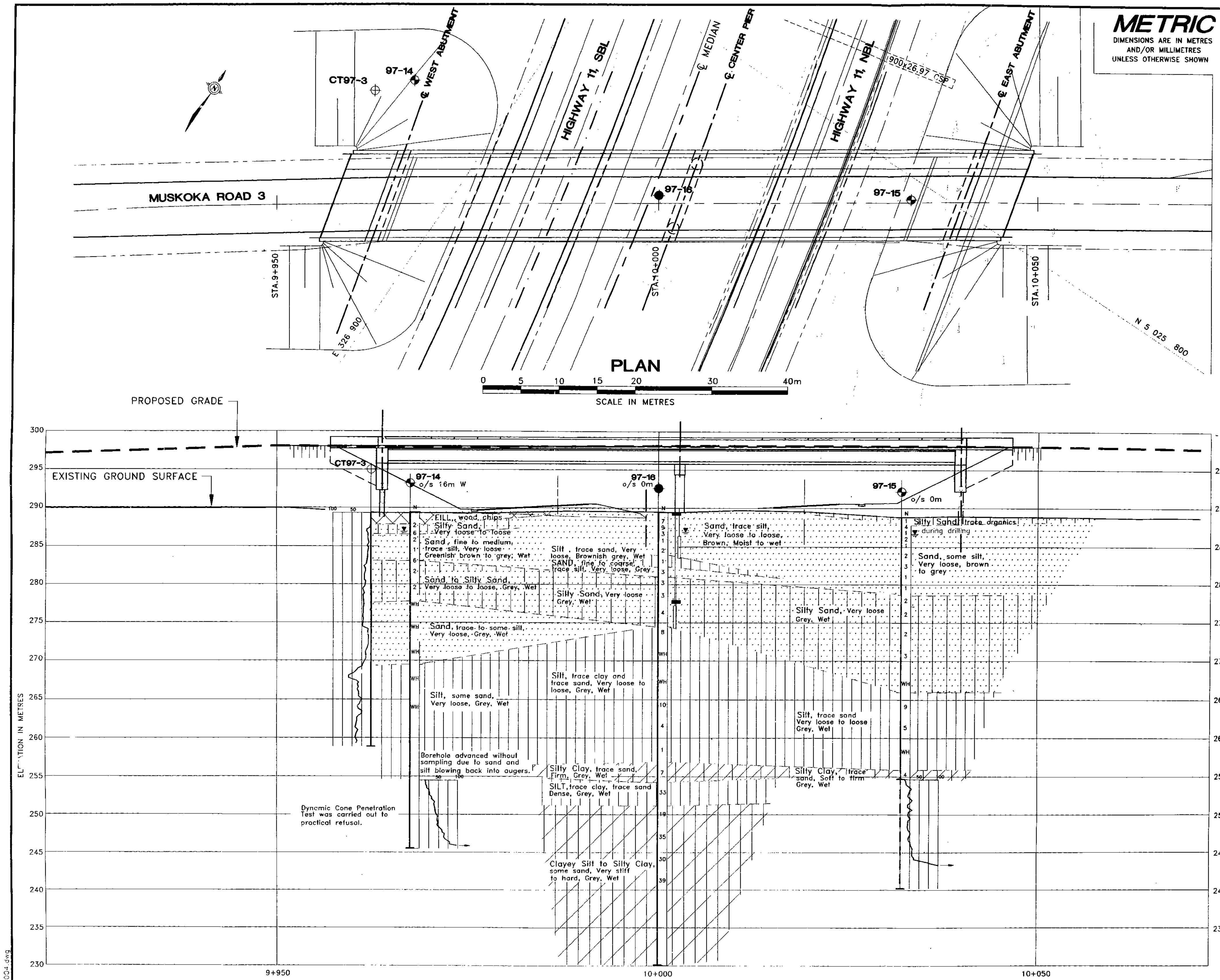
METRIC
DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN

CONT. No.
WP No. 454-93-00

HIGHWAY No. 11 UNDERPASS AT MUSKOKA ROAD 3
BORE HOLE LOCATIONS & SOIL STRATA

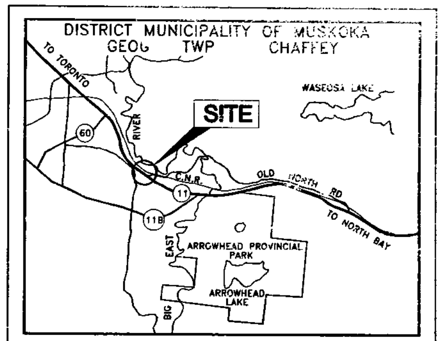
SHEET

Golder Associates
Golder Associates Ltd.
MISSISSAUGA, ONTARIO, CANADA



PROFILE ALONG MUSKOKA ROAD 3 AT HIGHWAY 11

SCALE IN METRES



KEY PLAN

SCALE, km

LEGEND

- ● Bore Hole
- ⊕ Dynamic Cone Penetration Test (Cone)
- Bore Hole & Cone
- N — Blows/0.3m (Std. Pen. Test, 475 j/blow)
- Cone — Blows/0.3m (60° Cone, 475 j/blow)
- WL at time of investigation 1997 08

No.	ELEVATION	LOCATION NORTHING	LOCATION EASTING
97-14	289.48	5025772.97	326886.74
97-15	288.83	5025796.32	326949.69
97-16	289.45	5025778.44	326921.67
CT97-3	289.33	5025786.97	326883.10

NOTES

The boundaries between soil strata have been established only at Bore Hole locations. Between Bore Holes the boundaries are assumed from geological evidence.

NO.	DATE	BY	REVISION
A	97/09/12	AMP	ISSUED FOR REVIEW

Geocres No.

HWY. No. 11	PROJECT NO.: 971-8033		DIST. 52
SUBM'D. AMP	CHKD: ASP	DATE: 1997 08 15	SITE 42-317
DRAWN: MHW	CHKD. AMP	APPD.	DWG. M8033004

ACAD FILE VB033004.dwg