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**FOUNDATION INVESTIGATION AND DESIGN REPORT  
DINGMAN CREEK CULVERT EXTENSION  
HIGHWAY 401 FROM 1.0 KILOMETRES WEST OF HIGHWAY 402  
TO 1.0 KILOMETRES EAST OF WELLINGTON ROAD  
GWP 476-89-00, AGREEMENT NO. 3005-A-000399  
MINISTRY OF TRANSPORTATION - SOUTHWESTERN REGION**

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## **PART A – FOUNDATION INVESTIGATION REPORT**

**DINGMAN CREEK CULVERT EXTENSION  
HIGHWAY 401 FROM 1.0 KILOMETRES WEST OF  
HIGHWAY 402 TO 1.0 KILOMETRES EAST OF WELLINGTON ROAD  
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MINISTRY OF TRANSPORTATION – SOUTHWESTERN REGION**

## **1.0 INTRODUCTION**

Golder Associates Ltd. (Golder Associates) has been retained by Delcan Corporation (Delcan) on behalf of the Ministry of Transportation, Ontario (MTO) to carry out foundation investigations as part of the detail design work for GWP 476-89-00. The project involves the detail design of the widening and improvements of Highway 401 including the Wellington Road interchange in London, Ontario.

This report addresses the extension of the Dingman Creek culvert identified as Structure Site No. 19-367.

The purpose of the foundation investigation is to determine the subsurface conditions at the locations of the proposed works by drilling boreholes and carrying out in situ testing and laboratory testing on selected samples. The terms of reference for the scope of work are outlined in the MTO's Request for Proposal and in Golder Associates' proposal P41-3017-1 dated July 14, 2004. The work was carried out in accordance with our Quality Control Plan for Foundation Engineering dated September 21, 2004.

The centreline and stations of the alignment were surveyed by others prior to commencing the foundation investigation program. Delcan provided Golder Associates with preliminary drawings for this project in digital format.

## **2.0 SITE DESCRIPTION**

GWP 476-89-00 comprises the detail design of the widening and improvements of Highway 401 from 1.0 kilometres west of Highway 402 to 1.0 kilometres east of Wellington Road and the reconstruction of the Wellington Road interchange in London, Ontario. The location of the project is shown on the Key Plan, Figure 1.

Highway 401 is one of the most important transportation facilities in Ontario, it connects major urban centres in southern Ontario with Quebec and the United States of America. In this section, Highway 401 is a Class I, controlled access, divided rural freeway. From the west limit to Wellington Road, Highway 401 is comprised of four main lanes. From Wellington Road to the east limit, Highway 401 is comprised of five main lanes. From Highway 402 to Wellington Road, Highway 401 is a four-lane cross section (7.50 metres per direction). From Wellington Road easterly, Highway 401 is a six-lane cross section (11.00 metres per direction) except between Station 23+519 and 23+940 where 2 eastbound lanes are present. The median is 6.6 to 7.8 metres wide and the right-of-way (ROW) is 91 metres wide.

The existing Dingman Creek culvert is located beneath Highway 401 at Station 21+990. Based on the background information provided by the MTO, the existing culvert is a three cell box culvert with each cell 6.1 metres wide by 4.3 metres high (20 feet wide by 14 feet high). The projected length of the skewed culvert is 30.5 metres (100 feet). The interior base of the culvert is at elevation 253.59 metres (832.00 feet), it has a base thickness of 0.48 metres (1.58 feet) and is supported on a 0.9 metre (3.0 foot) thick reinforced concrete mat. The underside of the mat is at elevation 252.2 metres (827.4 feet).

Land use adjacent to Dingman Creek is typically agricultural.

### **2.1 Site Geology**

This project lies within the physiographic region of southwestern Ontario known as the Mount Elgin Ridges<sup>1</sup>. The soils generally consist of moraines of clay or silty clay with vales of alluvium consisting of gravel, sand and silt.

Based on the Ontario Department of Mines Preliminary Map P.606 entitled "Pleistocene Geology of the St. Thomas Area (East Half), Southern Ontario", the site lies between the Ingersoll and Westminster moraines. The predominant soils at the site consist of glacial tills deposited by the Erie Lobe of the St. Thomas moraine during the Late Wisconsin period of glaciation. From

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<sup>1</sup> L.J. Chapman and D.F. Putnam: The Physiography of Southern Ontario, Third Edition. Ontario Geological Survey, Special Volume 2, 1984.

Dingman Drive easterly to the east project limit, the soils consist of the Port Stanley silty clay and clayey silt till, which is locally overlain by thin patches of lacustrine silts. At Dingman Creek, deposits of modern alluvium consisting of gravel, sand and silt are present. From Dingman Creek to Westminster Drive, lacustrine or pond deposits of sand and silty sand predominate and are intersected by localized valley trains. West of Westminster Drive, the Port Stanley till is present and is intersected at the west project limit by the Catfish Creek silty sand till.

The underlying bedrock is reported to be limestone of the Dundee Formation of the Hamilton Group of Middle Devonian age. The bedrock surface is estimated to be some 55 metres below ground surface or at about elevation 205 metres.

### 3.0 INVESTIGATION PROCEDURES

The field work for this portion of the investigation was carried out between November 1 and 10, 2004, during which time two boreholes were drilled through the Highway 401 shoulders adjacent to the existing structure.

The locations of the boreholes are shown on the Borehole Location Plan, Drawing 1. The table below summarizes the borehole locations, ground surface elevations at the borehole locations and borehole depths.

<u>BOREHOLE</u>	<u>LOCATION (m)</u>		<u>GROUND SURFACE</u> <u>ELEVATION</u>	<u>BOREHOLE DEPTH</u>
	<u>Northing</u>	<u>Easting</u>	(m)	(m)
201	4751070	481667	258.99	11.13
202	4751104	481661	258.99	11.13

The investigation was carried out using a truck mounted CME 55 power auger supplied and operated by a specialist drilling contractor. In the boreholes, samples of the overburden were obtained at suitable intervals of depth using 50 millimetre outside diameter split spoon sampling equipment in accordance with the standard penetration test (SPT) procedures. The boreholes were terminated 11.1 metres below the exiting ground surface. Groundwater conditions in the boreholes were observed throughout the drilling operations and the boreholes were backfilled in accordance with current MTO procedures and Ontario Regulation 128/03.

The field work was supervised on a full-time basis by experienced members of our engineering staff who located the boreholes in the field, directed the drilling, sampling and in situ testing operations and logged the boreholes. The samples were identified in the field, placed in labeled containers and transported to our London laboratory for further examination and testing. Index and classification tests consisting of water content determinations, grain size distribution analyses and Atterberg limits determinations were carried out on selected samples. The results of the testing are shown on the Record of Borehole sheets and in Appendix A.

The as-drilled borehole locations and ground surface elevations at the borehole locations were determined by members of our staff relative to geodetic datum. The locations of the boreholes are shown on the Record of Borehole sheets and on Drawing 1, attached.

In addition, the results of previous investigations carried out at this site were reviewed. The results of these investigations were reported in:



- Ministry of Transportation, Ontario “Foundation Investigation Report for Dingman Creek Culvert, W.P. 476-89-02, Site 19-367, Highway 401, District 2, London” dated April 13, 1993, boreholes 1 and 2, Geocres No. 40I14-121; and
- Racey, MacCallum and Associates Ltd. Report No. S74/55/T-123-1 entitled “Test Borehole, Station 378+30 on Centre Line of Proposed Highway No. 401 South of London, Ont.” dated July 15, 1955, borehole 101 (formerly borehole 1). Geocres No. 40I14-121.

The results of these investigations were reviewed during the preparation of this report and Records of Boreholes 1, 2 and 101 are provided in Appendix B and included on Drawing 1. The table below summarizes the borehole locations, ground surface elevations at the borehole locations and borehole depths for the previous boreholes:

<u>BOREHOLE</u>	<u>LOCATION (m)</u>		<u>GROUND SURFACE</u> <u>ELEVATION</u>	<u>BOREHOLE DEPTH</u>
	<u>Northing</u>	<u>Easting</u>	(m)	(m)
1	4753056.0	408888.6	255.8	14.2
2	4753062.0	408960.0	255.5	14.2
101	4753065.9	408930.9	257.3	13.9

## **4.0 SUBSURFACE CONDITIONS**

### **4.1 Site Stratigraphy**

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

In summary, the boreholes drilled at the site encountered the Highway 401 shoulder structure and embankment fill underlain by a stiff to hard clayey silt stratum.

The locations and elevations of the boreholes, together with the interpreted stratigraphic profiles, are shown on the attached Drawing 1. A detailed description of the subsurface conditions encountered in the boreholes is provided on the Record of Borehole sheets and in Appendix B.

### **4.2 Soil Conditions**

#### **4.2.1 Pavement Structure and Fill**

The Highway 401 shoulder pavement structure was encountered in boreholes 201 and 202. The pavements consisted of 90 to 180 millimetres of asphalt and 120 to 250 millimetres of granular base.

Beneath the pavement structure in boreholes 201 and 202 at elevations 258.8 and 258.7 metres, respectively, and at ground surface in borehole 2, loose to very dense granular fill materials which varied in gradation from silty sand to sand and gravel were encountered. The fill materials had N values, as determined in the standard penetration testing, of 4 to 54 blows per 0.3 metres. The fill materials had in situ water contents of 4 to 22 per cent with an average water content of 10 per cent. The results of grain size analyses of the granular fill are shown on Figure A-1 and indicate a silty sand fill with some gravel.

#### **4.2.2 Clayey Silt**

Beneath the fill materials in boreholes 201 and 202 at elevations 259.9 and 259.3 metres, beneath the fill in borehole 2 at elevation 253.7 metres, and at ground surface in boreholes 1 and 101 at elevations 255.8 and 257.3 metres, respectively, stiff to hard clayey silt was encountered. All of

the boreholes were terminated in the clayey silt between elevations 241.3 and 250.2 metres. The clayey silt had N values of 7 to 38 blows per 0.3 metres with natural water contents of 15 to 29 per cent with an average water content of about 19 per cent. The N values ranged from 38 blows per 0.3 metres near the surface of the stratum to generally 10 blows per 0.3 metres at depth. The clayey silt had corresponding average plastic and liquid limits of 15 and 29 per cent (respectively) based on thirteen Atterberg limits determinations. The results of the current limits testing are provided on the Plasticity Chart, Figure A-3, and indicated as inorganic clayey silt of low plasticity to clay of intermediate plasticity. Field vane testing carried out in the clayey silt indicated undrained shear strength of 90 kilopascals to greater than 144 kilopascals with a vane sensitivity of 2.

Grain size distribution curves for samples of the clayey silt recovered from the standard penetration testing are provided on Figure A-2.

### 4.3 Groundwater Conditions

Groundwater conditions were observed during and on completion of drilling and sampling. Details of the groundwater conditions encountered are provided on the Record of Borehole sheets and are summarized below.

<u>BOREHOLE</u>	<u>GROUND SURFACE ELEVATION</u> (m)	<u>ENCOUNTERED GROUNDWATER LEVEL</u>					
		<u>June 22, 1955</u>		<u>February 10&amp;11, 1993</u>		<u>November 1&amp;10, 2004</u>	
		<u>Depth</u>	<u>Elevation</u>	<u>Depth</u>	<u>Elevation</u>	<u>Depth</u>	<u>Elevation</u>
		(m)	(m)	(m)	(m)	(m)	(m)
201	258.99						dry
202	258.89					3.96	254.93
1	255.8				not observed		
2	255.5			0.76	254.74		
101	257.3		not observed				

Borehole 201 remained dry during drilling.

Groundwater was encountered at depths of 0.8 to 4.0 metres below ground surface or between elevation 254.7 (February 1993) and 254.9 (November 2004) metres. Water levels were not observed in boreholes 1 and 101.

Groundwater was encountered in borehole 202 at the granular fill/clayey silt interface and that level corresponds well with the measured water level in Dingman Creek. No granular layers which might be potentially water bearing were encountered within the native clayey soils.

The water level in Dingman Creek was at elevation 254.6 metres on November 17, 2005. The groundwater levels are expected to fluctuate seasonally and are expected to be higher during periods of sustained precipitation or during spring melt conditions.

## **5.0 MISCELLANEOUS**

The investigation was carried out using equipment supplied and operated by Aardvark Drilling Inc., an Ontario Ministry of Environment licensed well contractor. The field operations were carried out under the direction of Mr. David J. Mitchell. The laboratory testing was carried out at Golder Associates' London laboratory under the direction of Mr. Chris M. Sewell. The laboratory is an accredited participant in the MTO Soil and Aggregate Proficiency Program and is certified by the Canadian Council of Independent Laboratories for testing Types C and D aggregates. This report was prepared by Mr. Michael E. Beadle, P. Eng. under the direction of the Project Manager, Mr. Philip R. Bedell, P. Eng. This report was reviewed by Mr. Fintan J. Heffernan, P. Eng., the Designated MTO Contact and Quality Control Auditor for this assignment.

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## **PART B – FOUNDATION DESIGN REPORT**

**DINGMAN CREEK CULVERT EXTENSION  
HIGHWAY 401 FROM 1.0 KILOMETRES WEST OF  
HIGHWAY 402 TO 1.0 KILOMETRES EAST OF WELLINGTON ROAD  
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## **6.0 ENGINEERING RECOMMENDATIONS**

### **6.1 General**

This section of the report provides our recommendations on the foundation aspects of the design of the proposed culvert extensions to be constructed at the existing Dingman Creek culvert based on our interpretation of the factual information obtained during the 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 in order 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 methods and scheduling.

It is understood that the culvert will be extended to both the north and south to accommodate a six lane Highway 401 cross section. Based on the background information provided by the MTO, the existing culvert is a three cell box culvert with each cell 6.1 metres wide by 4.3 metres high (20 feet wide by 14 feet high). The projected length of the skewed culvert is 30.5 metres (100 feet). The interior base of the culvert is at elevation 253.59 metres (832.00 feet), it has a base thickness of 0.48 metres (1.58 feet) and is supported on a 0.9 metre (3.0 foot) thick reinforced concrete mat. The underside of the mat is at elevation 252.2 metres (827.4 feet).

### **6.2 Culvert Foundations**

The soil conditions encountered in the current boreholes drilled at the site generally consist of surficial fill materials associated with the Highway 401 platform underlain by clayey silt.

Based on the founding information available for the existing culvert, it is considered that the culvert extensions and associated wing walls will be founded in a similar fashion on a mat foundation at elevation 252.5 metres. The founding soils will consist of stiff to very stiff clayey silt.

The culvert extension foundation, as indicated above, may be designed using a factored geotechnical resistance at ultimate limit states (ULS) of 350 kPa and a geotechnical resistance at serviceability limit states (SLS) of 225 kPa.

It should be noted that the SLS resistance is based on a settlement (deformation) of 25 millimetres for the 2.8 to 6.4 metres wide mat foundation extension which, under free movement conditions, would be differential to the existing structure. The structural design of the culvert extensions should be sufficient to address the resultant deformations. Alternatively, if the extensions are rigidly connected to the existing structure, some local deformations will occur. To analyze these

effects, details of the existing and future foundation loadings on the existing culvert footings are required.

### **6.3 Backfill**

Backfill around the culverts should be carried out as per Ontario Provincial Standard Drawing (OPSD) 802.02. Culvert backfill material should consist of free-draining, non-frost susceptible granular materials such as Ontario Provincial Standard Specifications (OPSS) Granular A or Granular B.

Heavy compaction equipment should not be used adjacent to the walls and roof of the culverts. The height of backfill adjacent to the culvert walls should be maintained equal on both sides of the structures during all stages of backfill placement. Temporary diversion of surface water flow may be required during culvert installation. Adequate erosion protection, such as suitable non-woven geotextile and rip rap, as determined by a hydraulic assessment, should be provided at the inlets and the outlets.

### **6.4 Lateral Earth Pressures for Design**

The lateral pressures acting on the culvert extension will depend on the backfill soils and, where used, the type and method of placement of the backfill materials behind the wall, as well as the subsequent lateral movement of the structure. The following recommendations are made concerning the design of the culvert wall in accordance with the Canadian Highway Bridge Design Code (CHBDC).

Backfill behind the culvert walls should consist of select, free-draining granular fill meeting the specifications of OPSS Granular A or Granular B but with less than 5 per cent passing the No. 200 sieve.

Where backfill soils are placed and compacted behind the walls, a compaction surcharge equal to 16 kPa should be included in the lateral earth pressures for structural design, in accordance with the CHBDC. Compaction equipment should be used in accordance with OPSS 501.06.

The granular fill should be placed in a zone with a width equal to at least 1.2 metres behind the culvert walls. For walls backfilled as noted above, the following parameters (unfactored) may be assumed:



	<u>GRANULAR A</u>	<u>GRANULAR B</u>
Fill unit weight:	22 kN/m <sup>3</sup>	21 kN/m <sup>3</sup>
Coefficients of lateral earth pressure:		
‘active’, $K_a$	0.27	0.31
‘at rest’, $K_o$	0.43	0.47

If the wall support allows lateral yielding (unrestrained structure), active earth pressures may be used in the geotechnical design of the structure. If the culvert wall support does not allow lateral yielding (restrained structure), at-rest pressures should be assumed for geotechnical design. Resistance to sliding between the clayey founding soils and the concrete may be based on an angle of internal friction of 29 degrees. The unfactored coefficient of passive pressure for the portion of the culvert wall and footing below the creek invert may be taken as 3.1.

## 6.5 Construction Considerations

The founding soils are sensitive to disturbance and softening due to water seepage and/or ponding. If cast-in-place culvert extensions are to be constructed, placement of a working slab of lean concrete will be required at the base of the culvert excavations for the footing area. Exposure without protection of the mud coat will result in softening of the founding soils. The cleaned excavation base should be inspected by qualified geotechnical personnel prior to placing the working slab. It is recommended that the footing excavation be carried out such that the final 0.5 metres of excavation is completed with the geotechnical personnel on site and the working slab be placed immediately after footing inspection.

Erosion protection for the culvert/wing wall backfill should be provided, as appropriate. Consideration could be given to using suitable non-woven geotextile and rip rap, as required, to provide erosion protection based on hydraulic requirements. If granular bedding materials are used, an upstream clay seal and/or a cut-off wall should be provided to control seepage through the bedding below the culvert extension. The material specification for a clay seal should be in accordance with OPSS 1205. In addition, sediment control such as silt fences and erosion control blankets may be required during construction and diversion of the creek watercourse to mitigate migration of fine soil particles into the water course.

## 6.6 Excavations and Temporary Cut Slopes

Excavations for the culvert extensions will extend through surficial topsoil, fill and clayey silt. Based on the subsurface conditions encountered in the boreholes, the base of excavations will be 5 metres below the measured groundwater level. Temporary open cut slopes should be maintained no steeper than 1 horizontal to 1 vertical.

Surficial water seepage into the excavations should be expected and will be heavier during periods of sustained precipitation. In addition to diverting the existing culvert flows, pumping from well filtered sumps located at the base of the excavations may be required to provide groundwater control during foundation excavations.

The consideration with respect to protection of the founding soils, however, as given in Section 5.5 under the heading Construction Considerations, must be recognized. Sumps should be maintained outside of the actual footing limits. Surface water runoff should be directed away from the excavations at all times. The appropriate Non Standard Special Provision (NSSP) should be included in the contract documents.

Where space is restricted and will not permit open cuts, a temporary support system should be installed to support the sides of the excavation and permit the use of vertical cuts. The temporary support system could consist of soldier piles and lagging where H-piles would be driven to a suitable depth and horizontal lagging installed as the excavation proceeds. Support to the soldier pile and lagging wall system could be in the form of struts and walers in the case of footing excavations or rakers and anchors in the case of roadway protection excavations.

The design of braced soldier pile and lagging walls should be based on a rectangular earth pressure distribution using the design parameters given below. Where the support to the wall is provided by anchors or rakers, the wall design should be based on a triangular earth pressure distribution using the design parameters given below. The raker/anchor support must be designed to accommodate the loads applied from pressures and surcharge pressures from area, line or point loads as well as the impact of sloping ground behind the system.

Unfactored triangular earth pressure distribution ( $p$  in  $\text{kN/m}^2$ ; increasing with depth), can be calculated as follows:

$$p = K_a \gamma H$$

where  $H$  = the height of the excavation at any point in metres  
 $K_a$  = 0.3 for level ground behind excavation  
 $\gamma$  = soil unit weight =  $20 \text{ kN/m}^3$

Unfactored rectangular earth pressure distribution ( $p$  in  $\text{kN/m}^2$ ; constant with depth), can be calculated as follows:

$$p = K_a \gamma H$$

where  $H$  = the height of the excavation  
 $K_a$  = 0.3 for level ground behind excavation  
 $\gamma$  = soil unit weight =  $20 \text{ kN/m}^3$

Passive toe restraint to the soldier piles may be determined using a triangular pressure distribution acting over an equivalent width equal to three times the pile socket diameter. The coefficient of passive lateral earth pressure,  $K_p$ , for the socket within the stiff to very stiff clayey soils may be taken as 3.5. The soil unit weight should be taken as  $20 \text{ kN/m}^3$  and the unit weight of water should be taken as  $9.8 \text{ kN/m}^3$ . A groundwater level corresponding to the high water level, should be assumed.

The temporary excavation support system should be designed and constructed in accordance with MTO's Special Provision 539S01. The lateral movement of the temporary shoring system should meet Performance Level 2 as specified in SP 539S01.

All excavations should be carried out in accordance with the latest edition of the Ontario Occupational Health and Safety Act and Regulations For Construction Projects. The fill materials at this site would be classified as Type 3 soils. The native clayey silt materials would be classified as Type 2 soils.

## **7.0 MISCELLANEOUS**

This report was prepared by Mr. Michael E. Beadle, P. Eng. under the direction of the Project Manager, Mr. Philip R. Bedell, P. Eng. This report was reviewed by Mr. Fintan J. Heffernan, P. Eng., the Designated MTO Contact and Quality Control Auditor for this assignment.

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## 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
SS	Split-spoon
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

### 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

### 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.) split spoon sampler for a distance of 300 mm (12 in.)

#### (b) Cohesive Soils

Consistency	$c_u, s_u$	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

#### Dynamic Cone 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)

A electronic cone penetrometer with a 60° conical tip and a project end area of 10 cm<sup>2</sup> 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.

### 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 <sup>1</sup>
CIU	consolidated isotropically undrained triaxial test with porewater pressure measurement <sup>1</sup>
$D_R$	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 (LV-laboratory vane test)
$\gamma$	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

$\pi$	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

$\gamma$	shear strain
$\Delta$	change in, e.g. in stress: $\Delta \sigma$
$\epsilon$	linear strain
$\epsilon_v$	volumetric strain
$\eta$	coefficient of viscosity
$\nu$	poisson's ratio
$\sigma$	total stress
$\sigma'$	effective stress ( $\sigma' = \sigma - u$ )
$\sigma'_{vo}$	initial effective overburden stress
$\sigma_1, \sigma_2, \sigma_3$	principal stress (major, intermediate, minor)
$\sigma_{oct}$	mean stress or octahedral stress $= (\sigma_1 + \sigma_2 + \sigma_3)/3$
$\tau$	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
$\gamma'$	unit weight of submerged soil ( $\gamma' = \gamma - \gamma_w$ )
$D_R$	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

#### (a) Index Properties (continued)

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)

#### (b) 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

#### (c) Consolidation (one-dimensional)

$C_c$	compression index (normally consolidated range)
$C_r$	recompression index (over-consolidated range)
$C_s$	swelling index
$C_a$	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
$\sigma'_p$	pre-consolidation pressure
OCR	over-consolidation ratio $= \sigma'_p / \sigma'_{vo}$

#### (d) Shear Strength

$\tau_p, \tau_r$	peak and residual shear strength
$\phi'$	effective angle of internal friction
$\delta$	angle of interface friction
$\mu$	coefficient of friction $= \tan \delta$
$c'$	effective cohesion
$c_u, s_u$	undrained shear strength ( $\phi = 0$ 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
  - \* density symbol is  $\rho$ . Unit weight symbol is  $\gamma$  where  $\gamma = \rho g$  (i.e. mass density x acceleration due to gravity)

[illegible]

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to Sensitivity      ○<sup>3%</sup> STRAIN AT FAILURE

**RECORD OF BOREHOLE No 202**

1 OF 1

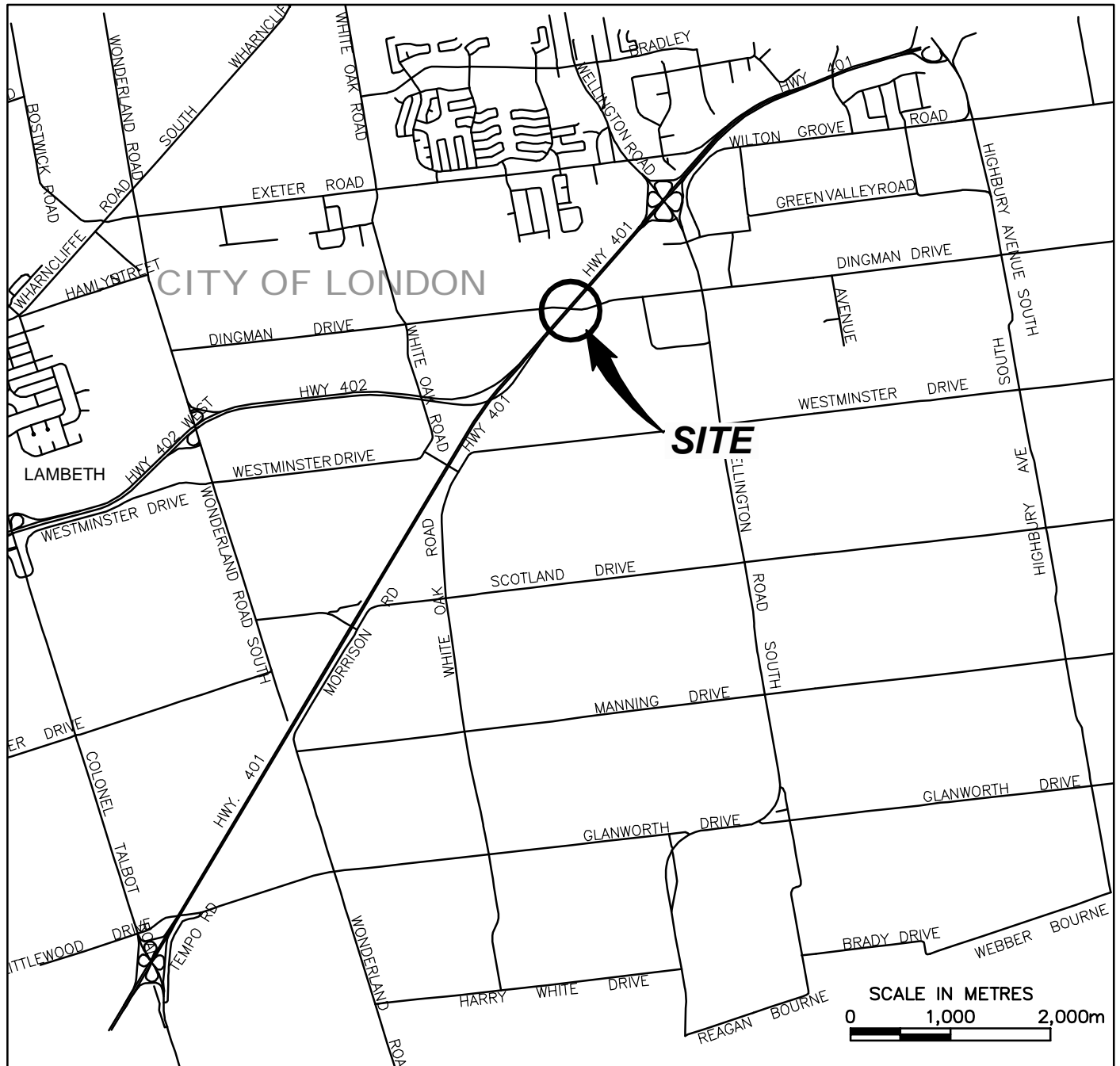
**METRIC**

PROJECT 04-1130-229-2  
G.W.P. 476-89-00 LOCATION N 4751104.4 ; E 481661.1 ORIGINATED BY RC  
DIST HWY 401 BOREHOLE TYPE POWER AUGER (HOLLOW STEM) COMPILED BY BG  
DATUM GEODETIC DATE November 10, 2004 CHECKED BY

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT w <sub>p</sub>	NATURAL MOISTURE CONTENT w	LIQUID LIMIT w <sub>L</sub>	UNIT WEIGHT  γ  kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)  GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa									
								○ UNCONFINED      + FIELD VANE ● QUICK TRIAXIAL    × LAB VANE									
								WATER CONTENT (%)									
258.89	PAVEMENT SURFACE						20	40	60	80	100						
0.09	ASPHALT																
0.21	(FILL) crushed sand and gravel Brown																
	(FILL), sand and gravel, trace silt Dense Brown		1	SS	38							○					
257.52																	
1.37	(FILL), silty sand, some gravel with clayey silt products Very loose to compact Brown		2	SS	10							○				21 65 14 0	
			3	SS	13							○					
			4	SS	13							○					
			5	SS	4							○					
254.71																	
4.18	CLAYEY SILT, trace sand, trace gravel Very stiff to hard Brown becoming grey at about 6.0m depth		6	SS	36							○				0 7 51 42	
			7	SS	32							○					
			8	SS	19							○					
252.03																	
6.86	CLAYEY SILT, trace sand, trace gravel Stiff to very stiff Grey		9	SS	16							○				0 3 62 35	
			10	SS	15							○					
			11	SS	12							○					
247.76																	
11.13	END OF BOREHOLE																
	Groundwater encountered in borehole at about elev. 254.93m November 10, 2004																


+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to Sensitivity ○ 3% STRAIN AT FAILURE





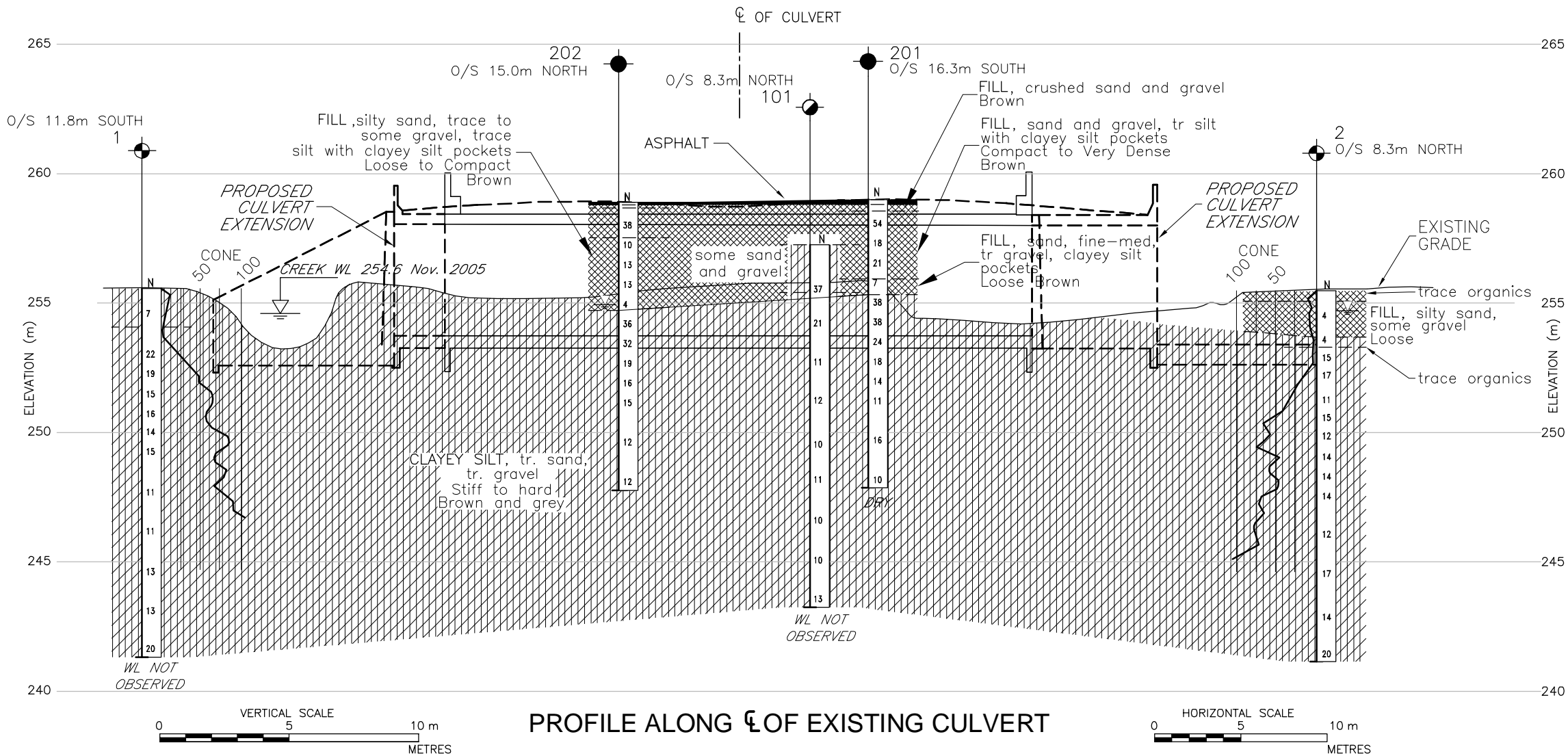
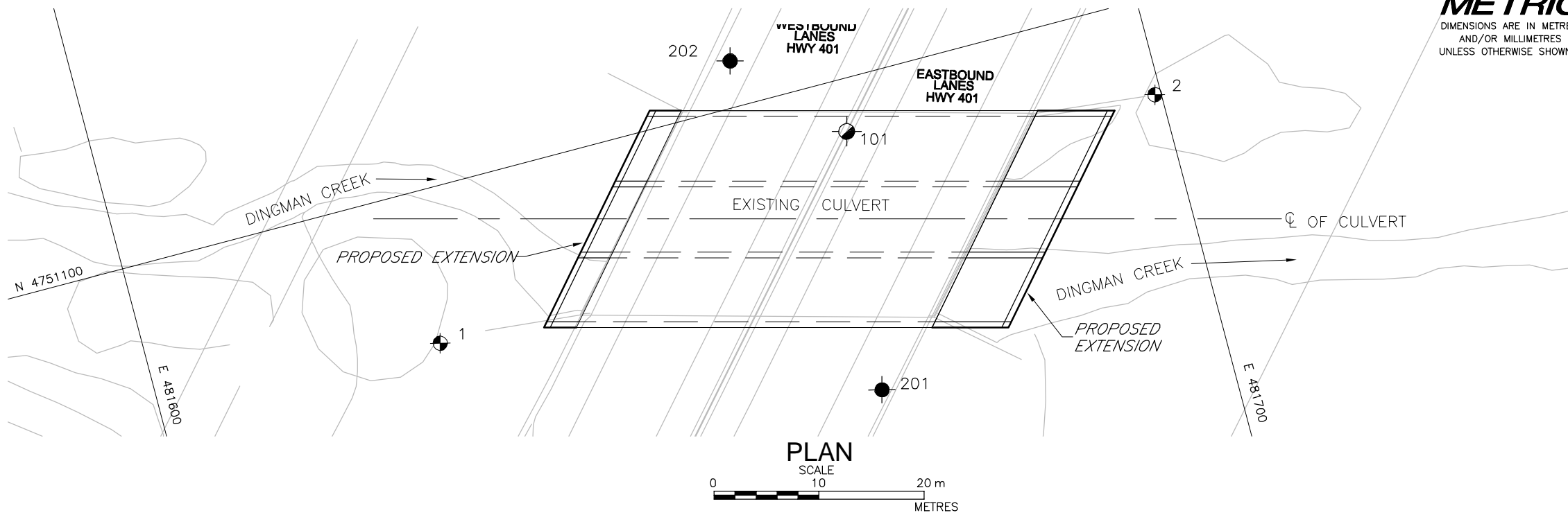
Feb 22, 2006 - 10:20pm

Drawing file: 041130229-2-F001-dc.dwg

PROJECT	DINGMAN CREEK CULVERT EXTENSION HIGHWAY 401 WP. 476-89-00		
TITLE	KEY PLAN		
 Golder Associates LONDON, ONTARIO	PROJECT No.041-130-229-2	FILE No. 041130229-2-F001	
	DESIGN		SCALE N.T.S. REV. 0
	CADD	WDF/DCH Feb. 16/06	
	CHECK		
	REVIEW		
FIGURE 1			

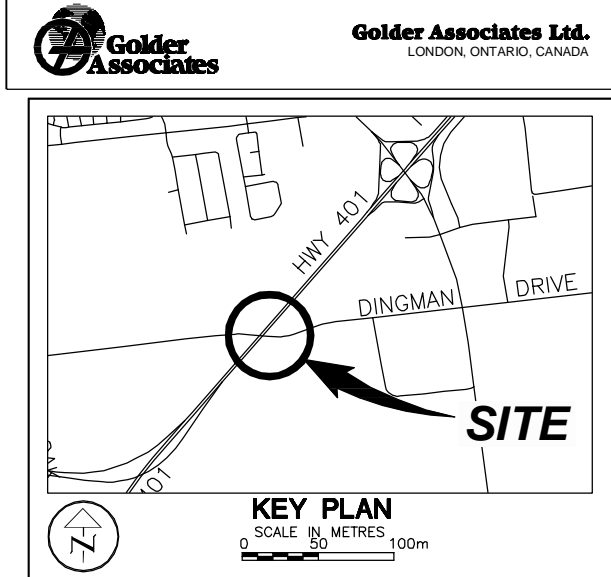
D size dwg 24" x 36" 11" x 17" plot half scale  
1 = 1 metric

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



DIST 1 HWY. 401  
CONT. No.  
WP No. 476-89-00

**DINGMAN CREEK  
CULVERT EXTENSION**  
BOREHOLE LOCATIONS & SOIL STRATA



LEGEND	
	Borehole (Current Investigation)
	Borehole (Previous Investigation GEOCRES 40114-121)
	Borehole and Cone (Previous Investigation GEOCRES 40114-121)
	Blows/0.3m (Std. Pen. Test, 475 j/blow)
	WL during drilling
	Blows/0.3m (60° Cone, 475 J/blow)
	Borehole dry during drilling

No.	ELEVATION (metres)	CO-ORDINATES (UTM NAD83, ZONE 17)	
		NORTHING	EASTING
CURRENT			
201	258.99	4 751 070.4	481 667.1
202	258.89	4 751 104.4	481 661.1
GEOCRES No. 40114-121			
1	255.80	4 751 085.4	481 627.5
2	255.50	4 751 090.9	481 699.4
101	257.30	4 751 095.0	481 670.1

**NOTES**

The boundaries between soil strata have been established only at Borehole locations. Between Boreholes the boundaries are assumed from geological evidence.

This drawing is for subsurface information only. The proposed structure details are shown for illustration purposes only and may not be consistent with the final design configuration as shown elsewhere in the Contract Documents.

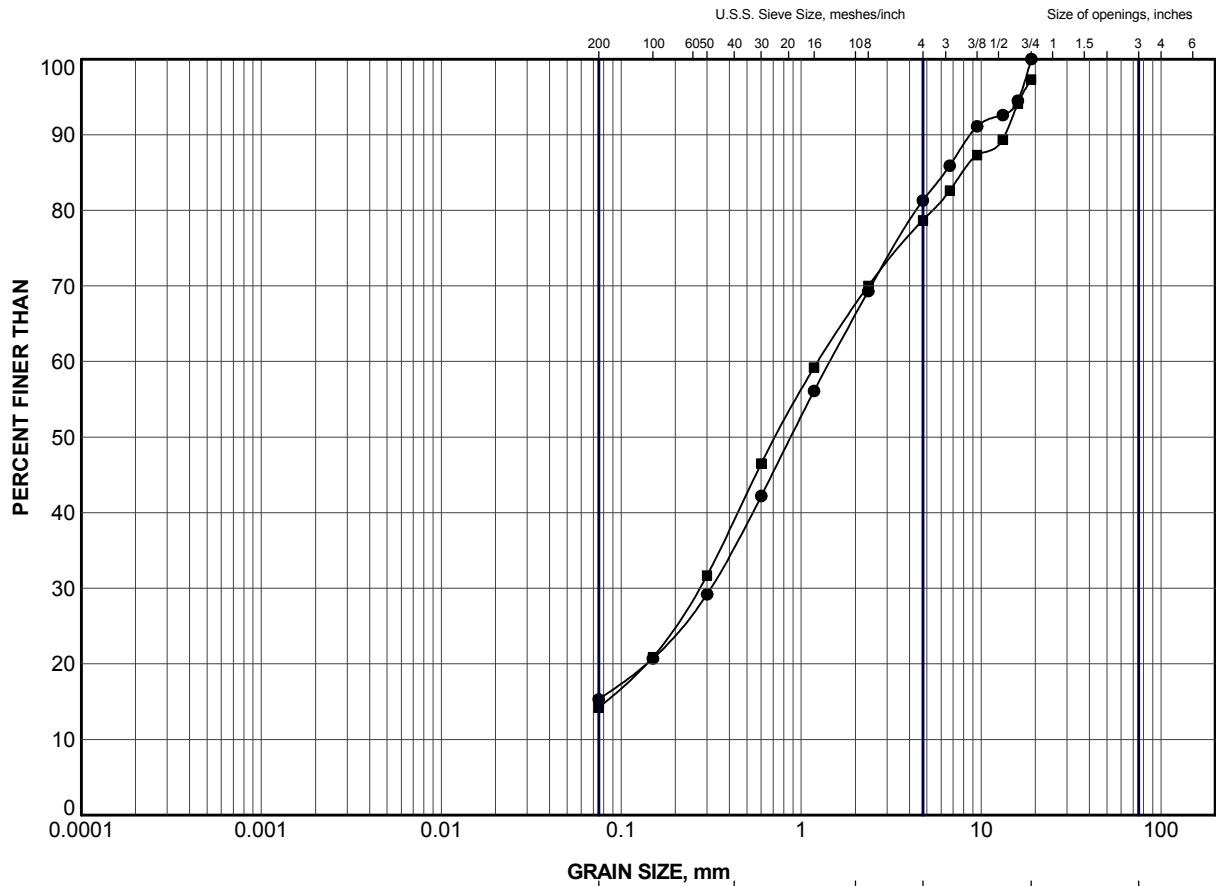
Borehole locations from previous investigations are approximate.

**REFERENCES**

Drawing Supplied by: Delcan entitled: Highway no. 401 geographic Township of Westminster County of Middlesex 19+761.880 to 25+400.000 scale 1:1000, Dated Feb. 2005 prepared for the Ministry of Transportation

Geocres No. 40114-138		PROJECT NO.: 04-1130-229-2-2	
HWY. No. 401	CHKD: -	DATE: Feb. 14/06	DWG. 1
SUBM'D. -	CHKD. -	APPD. -	
DRAWN: DCH	CHKD. -		


**APPENDIX A**  
**LABORATORY TEST DATA**

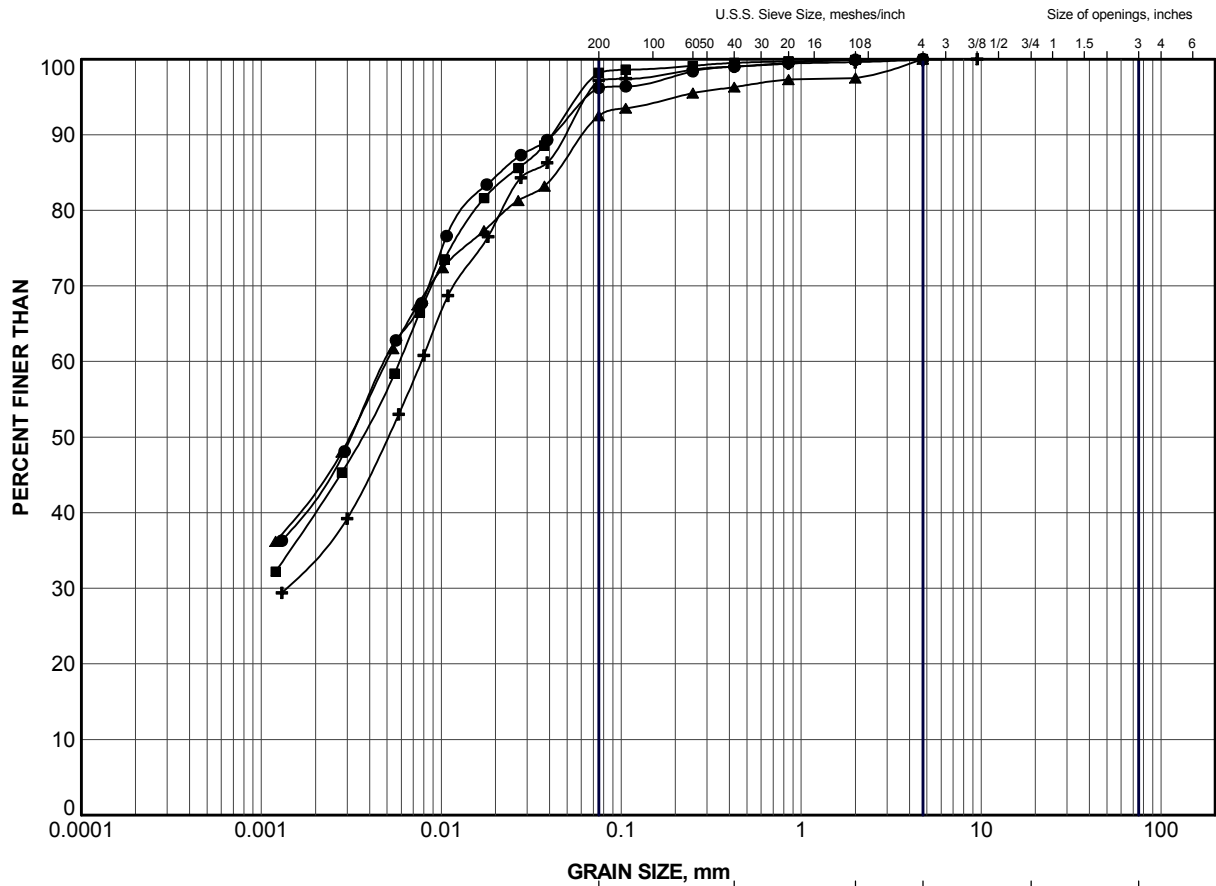


CLAY AND SILT	SAND SIZE, mm					Cobble Size
	fine	medium	coarse	fine	coarse	
	SAND SIZE			GRAVEL SIZE		

#### LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEV (m)
●	201	1	258.0
■	202	2	257.1


PROJECT				DINGMAN CREEK EXTENSION HIGHWAY 401 GWP 476-89-00			
TITLE				GRAIN SIZE DISTRIBUTION FILL			
PROJECT No.		04-1130-229-2		FILE No.		041130229-2-DC.GPJ	
DRAWN		WDF		SCALE		N/A	
CHECK				REV.			
Feb 15/06							
 <b>Golder Associates</b> LONDON, ONTARIO				<b>FIGURE A-1</b>			

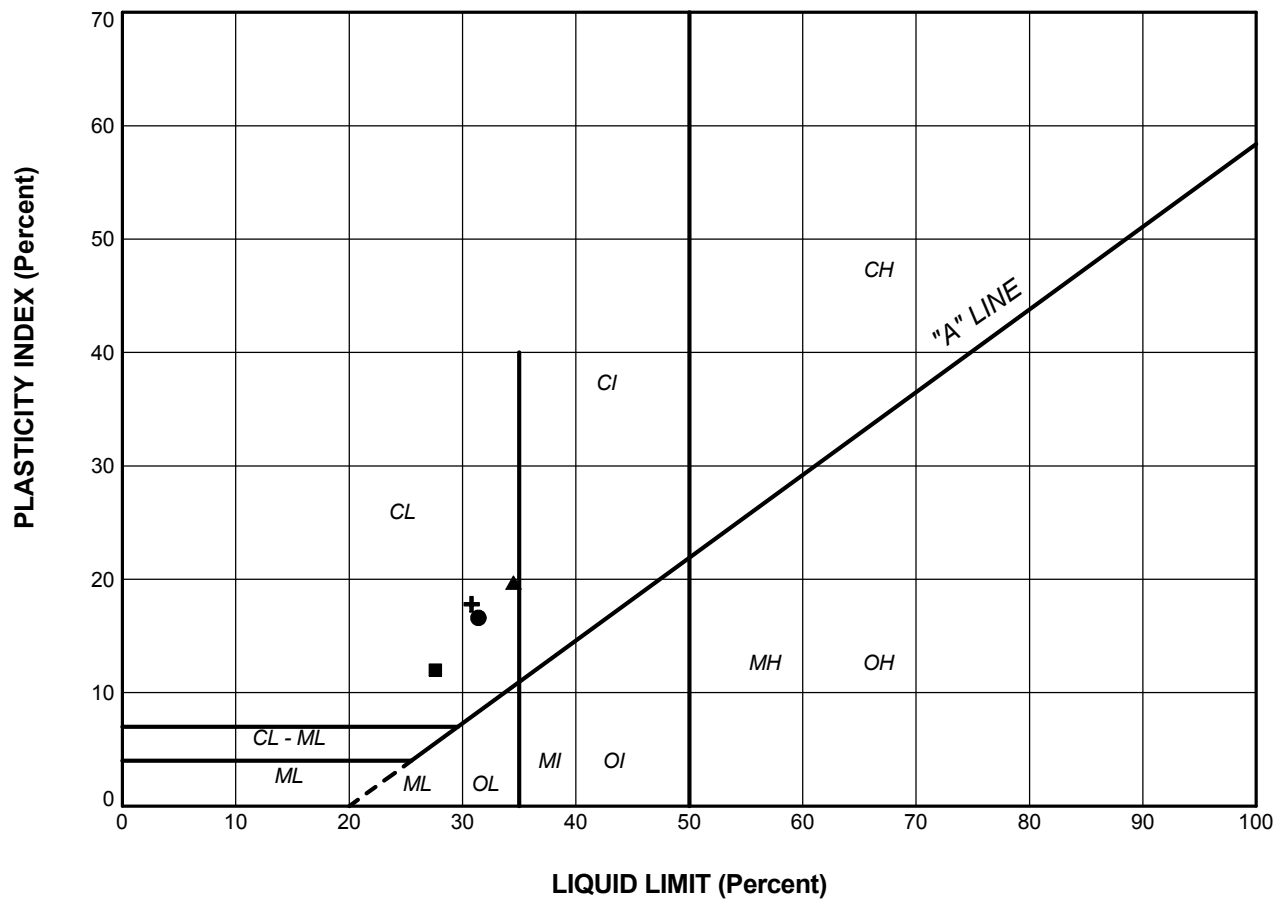


CLAY AND SILT	fine	medium	coarse	fine	coarse	Cobble Size
	SAND SIZE			GRAVEL SIZE		

#### LEGEND


SYMBOL	BOREHOLE	SAMPLE	ELEV (m)
●	201	6	254.2
■	201	10	251.1
▲	202	6	254.1
+	202	9	251.8

PROJECT				DINGMAN CREEK EXTENSION HIGHWAY 401 GWP 476-89-00			
TITLE				GRAIN SIZE DISTRIBUTION CLAYEY SILT			
PROJECT No.		04-1130-229-2		FILE No.		041130229-2-DC.GPJ	
DRAWN		WDF		SCALE		N/A	
CHECK				REV.			
Feb 15/06							
 <b>Golder Associates</b> LONDON, ONTARIO				<b>FIGURE A-2</b>			



### LEGEND

SYMBOL	BOREHOLE	SAMPLE	LL(%)	PL(%)	PI
●	201	6	31.4	14.8	16.6
■	201	9	27.6	15.6	12.0
▲	202	7	34.5	14.8	19.7
+	202	10	30.8	13.0	17.8

PROJECT		DINGMAN CREEK EXTENSION HIGHWAY 401 GWP 476-89-00	
TITLE		PLASTICITY CHART	
PROJECT No. 04-1130-229-2		FILE No. 041130229-2-DC.GPJ	
DRAWN	WDF	Feb 15/06	SCALE N/A
CHECK			REV.
 <b>Golder Associates</b> LONDON, ONTARIO			<b>FIGURE A-3</b>

**APPENDIX B**

**RECORDS OF PREVIOUS BOREHOLES**

# RECORD OF BOREHOLE No 1

1 OF 1

METRIC

W.P. 476 - 89 - 02 LOCATION Co-ords: N 4 753 056.0; E 408 888.6 ORIGINATED BY M V  
DIST 2 HWY 401 BOREHOLE TYPE CONTINUOUS FLIGHT HOLLOW STEM AUGER & CONE TEST COMPILED BY M V  
DATUM GEODETTIC DATE 93 02 10 CHECKED BY P P

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100	PLASTIC LIMIT W <sub>p</sub>	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W <sub>L</sub>	UNIT WEIGHT γ	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	'N' VALUES								
255.8	Ground Surface												
0.0						*							
	Trace of Sand		1	SS	7								
			2	SS	22								
			3	SS	19								
			4	SS	15								
			5	SS	16								
			6	SS	14								
			7	SS	15								
	CLAYEY SILT, Very Stiff to Stiff		8	SS	11								
			9	SS	11								
			10	SS	13								
			11	SS	13								
			12	SS	20								
241.6	End of Borehole												
14.2	Note: Water Level Not Observed												

( GECRES No. 40114-121 )

255

254

253

252

251

250

249

248

247

246

245

244

243

242

+3

120/28cm



# RECORD OF BOREHOLE No 2

1 OF 1

METRIC

W.P. 476 - 89 - 02 LOCATION Co-ords: N 4 753 062.0; E 408 960.0 ORIGINATED BY M V  
DIST 2 HWY 401 BOREHOLE TYPE CONTINUOUS FLIGHT HOLLOW STEM AUGER & CONE TEST COMPILED BY M V  
DATUM GEODETIC DATE 93 02 11 CHECKED BY P P

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT W <sub>P</sub>	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W <sub>L</sub>	UNIT WEIGHT γ	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	'N' VALUES			20	40					
255.5	Ground Surface													
0.0	Trace of Organics													
	SILTY SAND, Some Gravel, Loose, ( Fill )		1	SS	4									
253.7			2	SS	4									
1.8	Trace of Organics		3	SS	15									
			4	SS	17									
			5	SS	11									
			6	SS	15									
			7	SS	12									
			8	SS	14									
	CLAYEY SILT, Very Stiff to Stiff		9	SS	14									
			10	SS	14									
			11	SS	12									
			12	SS	17									
			13	SS	14									
			14	SS	20									
241.3														
14.2	End of Borehole													

( GEOCRETS No. 40114-121 )

# RECORD OF BOREHOLE No 101

1 OF 1

METRIC

W.P. 476 - 89 - 02 LOCATION Co-ords: N 4 753 065.9; E 408 930.9 ORIGINATED BY R Mac&A  
DIST 2 HWY 401 BOREHOLE TYPE WASHBORING COMPILED BY M V  
DATUM GEODETTIC DATE 55 06 22 CHECKED BY P P

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT			PLASTIC LIMIT W <sub>P</sub>	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W <sub>L</sub>	UNIT WEIGHT γ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL		
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	'N' VALUES			20 40 60 80 100									
								SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE 20 40 60 80 100									
257.3	Ground Surface																
0.0	Same Sand and Gravel  																

( GEOCRETS No. 40114-121 )