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ENGINEERING MATERIALS OFFICE  
FOUNDATION DESIGN SECTION

WP 325-89-01. DIST 4

HWY Q.E.W. STR SITE 13-351

Jordan Harbour (Twenty Mile Creek)  
North Service Road Bridge

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# **FOUNDATION INVESTIGATION REPORT**

## **FOR**

**Jordan Harbour (Twenty Mile Creek) -**

**North Service Road Bridge**

**W.P. 325-89-01, Site 13-351**

**District 4, Burlington**

## **INTRODUCTION**

This report summarizes the results of a foundation investigation conducted at the proposed Jordan Harbour (Twenty Mile Creek) - North Service Road bridge. It has been proposed to construct a five span structure that will carry the North Service Road over the Twenty Mile Creek immediately adjacent to Lake Ontario. In view of the close proximity to Lake Ontario, approach fills and shoreline protection will encroach into the waters of the lake.

## **SITE DESCRIPTION AND GEOLOGY**

The site is located immediately north of the Twenty Mile Creek - QEW crossing adjoining Lake Ontario in the Town of Lincoln, Regional Municipality of Niagara. The site is situated between Victoria Ave and Jordan Road approximately ten kilometres west of the City of St. Catharines. The Jordan Harbour is present south of the site and its waters flow into Lake Ontario via the Twenty Mile Creek.

The site conditions have undergone significant changes within the time period in which the foundation investigation has taken place. Originally, the shoreline was populated with tall deciduous trees but as a result of recent construction activity at the site, these trees have been removed. New fill material including shoreline protection materials (armour stone, rip rap) were being placed at the time of the most recent investigation in September, 1993. Previous armour stone placed along the Twenty Mile Creek is also evident at the site. In addition, a pronounced breakwater rockfill wall is located within Lake Ontario adjacent to the each approach embankment area. This breakwater structure apparently has been recently constructed by the Beacon Hotel management to safeguard the hotel which is located north of the existing North Service Road just east of the site area.

The two existing QEW-Twenty Mile Creek structures are three span steel structures that carry two lane WBL and EBL respectively. Both structures have undergone considerable deterioration. It is understood that the existing structures are founded on concrete caissons bearing on bedrock.

The land surrounding the site is generally flat with grade increases in both west and east directions. The approach embankment fills to the existing structures reveal their slopes superimposed on the natural ground surface at the site.

The primary industry within the site area is agricultural and the area is reknown for its fruit growing. Orchards and vineyards are present within the generally site area, although not at the specific site location. Soil conditions and the regional climate allow grapes, peaches, cherries and pears to be grown extensively in the area. Motel accommodations and restaurants are also located within the area.

Physiographically, the site is located within the region known as the "Iroquois Plain". The Iroquois Plain is the product of the advance and retreat of the Wisconsinan ice sheet which covered the area during the Pleistocene epoch (over 12,000 years ago). The lowland bordering Lake Ontario, was inundated by the glacial lake called Lake Iroquois when the last glacier was receding at the site. Conditions in the old lake plain vary greatly within the Iroquois Plain. At the site location, the former lake bottom consisted of an organic silt deposit which is underlain by undulating till plains and overlain by glaciofluvial sands to silty sands.

The overburden at the site is underlain by shale bedrock of the Queenston Formation at an elevation ranging from approximately 56 m to 63.7 m. The bedrock appears to slope downward in an easterly direction and the overburden thickness ranges from approximately 8 metres to 18.7 metres.

## **INVESTIGATION PROCEDURE**

### **General**

The subsurface investigation conducted at the site was executed during several different mobilizations spanning time periods between 1965 and 1993. The borehole identification number groups that signify the five separate mobilizations that occurred at the site are summarized in Table 1 below. In each case, the physical and mechanical properties of the soil and/or rock were obtained both by in situ and laboratory testing as discussed below.

Table 1 - Investigation Time Periods			
BH Group #	BH	# of BH's	Time Period
1	1-4 incl.	4	65 11 02-09
2	101-104 incl.	4	92 06 29-92 07 03
3	201-208 incl.	8	93 09 20-23
4	301-302 incl.	4	93 08 12-13
5	401-409 incl.	9	93 06 07-15

The original field investigation at the site occurred in 1965, when a total of twenty-one boreholes were advanced for the proposed widening of the QEW structures at that time. Four of these boreholes were advanced in the vicinity of the NSR and have therefore been included in this report.

Since the original field investigation, four further investigations have been conducted between June 1992 and September 1993. Three of these investigations (Groups #2, 4 and 5) were coordinated to retrieve subsoil information within and also beyond the NSR-Twenty Mile Creek for the QEW-Twenty Mile Creek structure replacements. One of the investigations (Group 3) was planned and implemented specific to the NSR structure. A total of twenty-five boreholes have been advanced during the more recent investigations.

### **Field Investigation**

The fieldwork for the original investigation in 1965 was carried out using both a diamond drill unit adapted for soil sampling purposes, and a Pennsylvania continuous flight drill auger which were conventional at the time. The more recent investigations were carried out employing track mounted diesel drilling units equivalent to a CME 55 and equipped with hollow stem augers to advance the boreholes. The fieldwork consisted of the advancement of several sampled boreholes as mentioned earlier and also five dynamic cone penetration tests advanced to depths ranging from 1.2 m to 20.3 m.

Samples were retrieved at 0.7, 1.5 and 3 m intervals. Disturbed subsoil samples were retrieved using a standard 50.8 mm O.D. split spoon sampler driven in accordance with the Standard Penetration Test (SPT-ASTM D1586). Relatively undisturbed samples of the

organic silt at the site were also retrieved using 57 mm and 73 mm diameter thin wall samples. The thin wall sampler was pushed either manually or hydraulically in accordance with the procedures outlined in ASTM D1587.

All subsoil samples were identified in the field and then properly sealed to preserve natural moisture contents in the soil. Disturbed samples were placed in sealed plastic containers and thin wall samples were capped and waxed. The samples were then transported to the laboratory where additional visual classifications were carried out and pertinent laboratory tests were conducted as described in the next section below.

In situ vane tests were also carried out to determine the undrained shear strength at selected intervals between the subsoil sample retrieval. The test was carried out in accordance with ASTM D2573 employing the standard MTO 'N' vane. Remoulded shear strengths were also obtained allowing the determination of soil sensitivity. Two boreholes (301B and 302B) were advanced strictly to conduct in situ vane tests.

Rock core was also retrieved at the proposed structure foundation locations using conventional rock coring techniques and a NXL core barrel. The rock core was identified in the field and physical index properties were determined by visual examination and also by measurement of rock quality designations (RQD's) and core recovery. All rock core were placed in standard rock core boxes and carefully transported to the laboratory for detailed rock logging (see Laboratory Analyses).

Groundwater levels were determined by monitoring the water levels in the open boreholes throughout the duration of the field investigation. All boreholes were backfilled upon completion of the fieldwork.

The survey related to the location and elevation of the individual boreholes was provided by Central Region Survey and Plans and MTO Construction staff.

### **Laboratory Analyses**

All subsoil samples were carefully visually examined in the laboratory in accordance with the procedures outlined in the Visual Method described in Chapter 2 of the MTO Soil Classification Manual. The behaviour, gradation and other pertinent physical properties and the mechanical properties of the soil (strength, compressibility) were determined by conducting the appropriate laboratory tests on representative samples. These tests are tabulated in Table 2 below.

Table 2 - Physical/ Mechanical Property Testing	
Physical Property Tests	Mechanical Property Tests
1) Atterberg Limit Tests	1) Consolidation Test
2) Particle Size Analysis	2) Unconfined Compression
3) Natural Moisture Contents	3) Quick Triaxial
4) Bulk Unit Weights	
5) Organic Content	



Sample preparation and laboratory tests were conducted in accordance with the respective procedures outlined in the MTO Laboratory Testing Manual and as described in Chapter 3 of the MTO Soil Classification Manual.

As mentioned earlier, detailed rock core logs were produced by an in-house resident geologist and "Rock Core Descriptions" for all rock core retrieved are contained in the Appendix to this report. The descriptions include rock colour, strength, jointing, bedding and composition.

Laboratory test results on subsoil samples have been summarized below in the subsequent section of this report entitled "Subsurface Conditions", and are illustrated on the corresponding boreholes and figures included in the Appendix of this report. Rock core recoveries and rock quality designations are summarized both in the Rock Core Descriptions and on individual borehole logs.

## **SUBSURFACE CONDITIONS**

### **General**

In general, subsurface conditions are uniform across the site. The native subsoils consist of an uppermost deposit of sand to silty sand with traces to some gravel. This deposit is brown to grey in colour and has a thickness ranging from 4.0 m to 9.3 m but generally is within 4.6 to 7 m. The deposit has a very loose to dense range of denseness but is generally loose to compact.

The cohesionless sand to silty sand with gravel deposit is underlain by an organic silty clay to clay deposit. The organic silty clay to organic clay has a thickness ranging upto 10.7 m with thicknesses increasing in an easterly direction. As shown on Dwg. No. 3258901-A, however, the organic silty clay to organic clay stratum eventually disappears in both easterly and westerly directions. Based on in situ and laboratory testing of the organic silty clay to clay, this material can be categorized as having a firm to very stiff consistency.

The organic silty clay to clay is underlain by glacial till deposits consisting of either a heterogeneous mixture of silt, sand and gravel or a heterogeneous mixture of clayey silt, sand and gravel. These deposits are of a thickness ranging from 0.4 m to 4.9 m. At BH 205 (Pier #3), both deposits were encountered with the cohesive heterogeneous mixture of clayey silt, sand and gravel overlying the cohesionless heterogeneous mixture of silt, sand and gravel. The total thickness of the deposits is 4.6 m at this location. The consistency/ denseness of these deposits is generally hard and very dense respectively.

Various types of fill material are also present across the site. A sand and gravel fill material of approximately 1.5 m thickness exists at the west abutment and Piers #1 and #2 locations. This material is brown and compact. At Pier #3, the native subsoil is overlain by an irregular mixture of sand, gravel, cobbles and boulders. The thickness of the fill material at this location was in the order of 3 m. Penetration through this fill material was extremely difficult and time consuming employing hollow stem augering

techniques. Boreholes in this area were strategically positioned to avoid the armour stone located in the area. The armour stone would have definitely prevented auger penetration.

At the east abutment and Pier #4 location, approximately 3.0 m of an irregular mixture of clayey silt, sand and gravel, placed as part of the preloading of the east approach embankment exists. This material is grey and of firm to stiff consistency.

The extent and thickness of the fill material is subject to change as a result of fill placement proposed at the approach embankment areas as part of the preloading and surcharging scheme adopted at the site (see "Recommendations" in this report).

A plan of the site illustrating the locations and elevations of the boreholes is shown on Dwg. No. 3258901-A in the Appendix. A subsoil stratigraphical profile illustrating the subsurface conditions at the site is also provided. The boundaries between the various soil types, in situ and laboratory test results as well as groundwater levels established at the time of investigation are shown on the stratigraphical profile and also on the individual Record of Borehole sheets in the Appendix. A detailed description of the subsurface conditions is given below.

#### **Sand to Silty Sand, trace/ some Gravel**

The surficial native deposit at the site consists of a cohesionless sand to silty sand with traces to some gravel. This deposit underlies the fill material which is present at some

locations across the site. The thickness of this deposit ranges from 4 m to 9.3 m, but generally the deposit has a thickness ranging from 4.6 m to approximately 7 m. The deposit has been oxidized to varying depths ranging from being completely unoxidized and hence completely grey in colour to partially oxidized and brown to depths ranging from approximately 1.5 m to 6 m.

Figure 1 in the Appendix illustrates a grain size distribution envelope of the deposit derived from mechanical sieve analysis of representative samples across the site. As the envelope reveals, the main component of the deposit is the sand that ranges from fine to coarse. The envelope also illustrates traces/ some fine to coarse gravel sizes ranging from approximately 1 to 28% of the deposit. Silt percentages range from approximately 6% (traces) to 50% (silty sand).

This cohesionless deposit is for the most part submerged below the groundwater table and hence during the drilling and sampling process was subjected to conditions of unbalanced hydrostatic head. To prevent soil cave-in and sloughing at the base of the borehole, a constant hydrostatic force was required. This was achieved by supplying a constant head of water using pumps and hoses.

The 'N' values derived from the SPT conducted in this deposit ranged from 4 blows/ 0.3 m to 37 m blows/ 0.3 m indicating a very loose to dense state of denseness. However, in general, 'N' values were in the 5 blows/ 0.3 m to 25 blows/ 0.3 m suggesting a loose

to compact state of denseness. The larger 'N' values may have been a product of the coarser gravel sizes in the deposits.

### **Organic Silty Clay to Organic Clay**

The surficial native sand to silty sand deposit is underlain by an organic silty clay to organic clay stratum which is present across most of the site. The organic silty clay to organic clay stratum extent was defined between approximate stations 21+495 and 21+950. The surface of this stratum was encountered at an elevation ranging from 67.8 m to 70.1 m and its thickness ranged from 3.7 m to 10.7 m with the thickness increasing in the easterly direction.

A grain size distribution envelope produced by mechanical sieve and hydrometer analysis for this stratum is shown on Figure 2 in the Appendix. The envelope clearly illustrates that the material is fine grained with particle sizes less than 75 micrometres. The clay fraction ranges from approximately 10% to 20% but generally, the clay fraction ranges between 10% and 15%. Silt percentages range from approximately 78% to 90%.

Occasional layers of peat and organic inclusions of partially decomposed timber are also present within the soil matrix of this stratum. The organic content varies between 2 and 18.2% by weight but generally the organic content is in the 6 to 10% range. The organic inclusions and soil material are dark grey to blackish grey in colour.

In accordance with the MTO Soil Classification system, a deposit with gradations of this nature is categorized by its behaviour and hence Atterberg Limit Tests were conducted to evaluate the plasticity of the soil. The results of these tests are illustrated on Figure 3 and summarized in Table 3 below. Natural moisture contents and unit weights of the soil are also included in Table 3 below. Natural moisture contents were determined by oven drying whereas Atterberg Limits were determined by air drying the samples prior to testing.

Table 3 - Organic Silty Clay to Clay		
	Range	# of Tests
Plastic Limit ( $w_p\%$ )	32-45	18
Liquid Limit ( $w_L\%$ )	41-71	18
Plasticity Index ( $I_p\%$ )	11-30	18
Liquidity Index ( $I_L\%$ )	0.8-1.4	18
Natural Moisture Content ( $w\%$ )	45-117	21
Unit Weight ( $kN/m^3$ )	14,9-19.2	5

Table 4 below provides the results of Atterberg Limit Tests in which sample air drying was compared to sample oven drying.

Table 4 - Air Drying vs. Oven Drying						
Sample	Plastic Limit ( $w_p$ %)		Liquid Limit ( $w_L$ %)		Plasticity Index ( $I_p$ %)	
	Air	Oven	Air	Oven	Air	Oven
BH 101, SS9	38	36	63	54	25	18
BH 101, SS11	72	70	103	86	31	16
BH 103, SS9	46	42	74	59	28	17

The results tabulated in Table 3 and 4 and illustrated on Figure 3 clearly reveal that the soil exhibits an intermediate to high plasticity and behaves as an organic silty clay to an organic clay. Atterberg Limits were smaller for the oven dried samples than for the air dried samples confirming the presence and influence of the organic material in the soil.

The liquidity index for the soil ranges from 0.8 to 1.4 but in general, the liquidity index exceeds unity. This indicates that the natural moisture content of the soil exceeds the liquid limit. Natural moisture contents range from 45% to 117%.

The unit weight of the soil ranges from  $14.9 \text{ kN/m}^3$  to  $19.2 \text{ kN/m}^3$ , but generally the unit weights are less than  $16 \text{ kN/m}^3$ .

The undrained shear strength of the organic silty clay to organic clay was determined by in situ vane tests and laboratory unconfined compression and undrained unconsolidated (quick triaxial) tests and the results are tabulated in Table 5.

Table 5 - Undrained Shear Strength ( $c_u$ ) (kPa)		
	Range	# of Tests
Vane Test	70-> 100	33
Unconfined Compression Test	30-58	3
Undrained Unconsolidated	51-82	2

The results reveal an undrained shear strength ranging from 30 kPa to in excess of 100 kPa. It is believed that the lower undrained shear strength values observed in the unconfined compression test may be a reflection of sample disturbance induced. An undrained shear strength of 60 kPa to 100 kPa is considered as an accurate representative range of the undrained shear strength of this material and consequently the material can be described as having a stiff to very stiff consistency.

The sensitivity of the soil ranged from 2 to 3 indicating a soil of low sensitivity.



SPT 'N' values recorded in this material ranged from 1 blow/ 0.3 m to 14 blows/ 0.3 m. However, in general, there was very little resistance offered by the soil to the split spoon sampler penetration and 'N' values were usually less than 5 blows/ 0.3 m.

The compressibility characteristics of the organic silty clay to organic clay stratum were determined by conducting one dimensional consolidation tests on representative samples of the material. Figures 4a and 4b illustrate the results of oedometer tests in which samples were subjected to an external loading with a load increment ratio of one and double drainage. The consolidation curves are plotted on semi-logarithmic paper with the void ratio ( $e$ ) plotted against the applied load ( $\log p$ ). This form of plotting the load-deformation properties of the soil has the advantage of enabling the determination of the preconsolidation pressure ( $p_c$ ) which is defined as the maximum pressure that the soil has experienced in its stress history. Considerable consolidation settlements can occur once the threshold preconsolidation pressure is exceeded.

The consolidation curves reveal preconsolidation pressures ranging from 128 kPa to 142 kPa. The effective overburden pressures of the samples tested ranged from approximately 57 kPa to 67 kPa. It can therefore be concluded that the soil has been preconsolidated in the past to an effective pressure approximately 60 to 85 kPa in excess of the existing overburden pressure. Compression indices of the material ranged from 0.4 to 1.4.

Attempts were made to compute the coefficient of consolidation ( $c_v$ ) using Taylor's Root time method and oedometer dial gauge readings. However, this method produced irregular and inconsistent results. The results have therefore been considered as unacceptable for application in engineering calculations.

### **Deposits of Glacial Till Origin**

#### **General**

The organic silty clay to clay is underlain by deposits of glacial till origin, namely a heterogeneous mixture of clayey silt, sand and gravel or a cohesionless heterogeneous mixture of silt, sand and gravel. At BH 205, the cohesionless heterogeneous mixture of silt, sand and gravel is overlain by the cohesive heterogeneous mixture of clayey silt, sand and gravel. Both deposits are irregular and unstratified and occur randomly across the site, generally overlying the bedrock. Detailed descriptions of these deposits are given below.

#### **Heterogeneous Mixture of Clayey Silt Sand and Gravel (Glacial Till)**

The heterogeneous mixture of clayey silt, sand and gravel has a thickness ranging from 0.4 m to 4.9 m and varies in colour from brown to grey to red. Figure 5 in the Appendix illustrates a grain size distribution envelope of this deposit revealing that the deposit is broadly graded containing a wide range of particle sizes. The main component of this unsorted deposit is the clayey silt material. The envelope reveals that the fine grained portions (less than 75 micrometres) contribute upto 85% of the deposit. This material

essentially binds the coarser sands and gravels within the deposit. Boulders and cobbles, although not encountered, are characteristic components of glacial till deposits and hence can occur in this deposit.

Atterberg Limit Tests were carried out to define the behaviour and plasticity of the fine grained portion of the soil (less than 425 micrometres) and the results are plotted on Figure 6. A summary of the indices is provided in Table 6 below. Natural Moisture Contents have also been included in the table.

Table 6 - Heterogeneous Mixture of Clayey Silt, Sand and Gravel (Glacial Till)		
	Range %	# of Tests
Natural Moisture Content (w%)	11-25	8
Liquid Limit ( $w_L$ %)	20-37	8
Plastic Limit ( $w_p$ %)	3-21	8
Plastic Index ( $I_p$ %)	4-16	8

The test results reveal that the fine grained portion of the deposit is predominantly of low plasticity and hence is classified as clayey silt. The test results also reveal that zones of heterogeneous mixture of silt, sand and gravel are also present within the deposit.

Natural moisture contents are generally less than or equivalent to the plastic limit of the soil indicating that the soil is in a plastic to semi-solid state.

Standard Penetration Tests (SPT) carried out in this deposit revealed 'N' values ranging from 6 blows/ 0.3 m to 100 blows/ 0.3 and hence the material can be categorized as having a stiff to hard consistency.

**Heterogeneous Mixture of Silt, Sand and Gravel (Glacial Till)**

The heterogeneous mixture of silt, sand and gravel has a thickness ranging from 0.4 m to 1.6 m and generally is red in colour. The deposit is unsorted, unstratified and broadly graded containing a wide range of particle sizes ranging from silt to gravel. Boulders and cobbles although not encountered during the investigation are characteristic components of glacial till deposits and hence can exist in this deposit. This cohesionless deposit is generally underlain by bedrock.

Standard Penetration Tests (SPT) carried out in this deposit revealed 'N' values ranging from 18 blows/ 0.3 m to 106 blows/ 0.13 m indicating a denseness ranging from compact to very dense. In general, 'N' values exceeded 100 blows/ 0.3 m and hence it is suspected that the lower 'N' values recorded may have been attributable to sample disturbance. Consequently, it is concluded that this deposit is generally of very dense denseness.

**Bedrock**

The overburden at the site is underlain by bedrock of the Queenston Shale Formation at an Elevation ranging from 67.9 m to 56.0 m. The bedrock surface appears to slope downward in an easterly direction.

The bedrock consists of a greyish red shale with interbedded greenish grey siltstone. In general, the surficial metre or so has been slightly to moderately weathered. Occasional clay seams of 50 to 100 mm thickness were present within the weathered zone. The weathered rock is underlain by sound, competent and unweathered rock.

Samples of the rock were retrieved by conventional rock coring techniques using an NXL core barrel. Up to 3.5 metres of rock core was retrieved at various borehole locations across the site. Split spoon samples were also retrieved albeit with considerable penetration resistance at some locations where augering techniques were used to penetrate the weathered rock.

Physical and mechanical properties of the rock were determined by physical examination and by core recovery and rock quality designation (RQD) measurement conducted in situ. Detailed rock core designations produced by our resident geologist provide a summary of these properties and are located within the Appendix under the heading "Rock Core Descriptions".

The shale bedrock with interbedded siltstone is very fine grained and contains very thin to thin horizontal bedding. The rock contains moderately close to extremely close spaced fractures that are flat, dipping to near vertical, planar to undulating and smooth. The rock is an extremely friable material with a very low slaking durability. Rock strength as determined by index property examination in the laboratory is generally very weak to weak.

Rock core recoveries in the slightly to moderately weathered rock ranged from 90% to 100% and RQD's ranged from 0% to 45%. In the unweathered rock, recoveries were generally 100% and RQD's ranged from 0% to 97%. The 0% RQD for the unweathered rock appears to be an anomaly in comparison to the RQD's determined elsewhere at the site. A lower limit of 32% may therefore be more appropriate. Based on these observations, it can be concluded that the weathered rock is of very poor to poor quality and the unweathered rock ranges from poor to excellent quality. In general, however, the unweathered rock can be considered to have a fair to excellent quality.

### **GROUNDWATER CONDITIONS**

Observation of the groundwater level was carried out by measuring the water level in the open boreholes throughout the duration of the field investigation. Particular attention was given to avoiding non-representative water levels produced by the drilling water.

At the time of the most recent investigation, the groundwater elevation ranged from approximately 73 m to 75 m which for all practical purposes can be assumed to be approximately equal to the lake level.

Groundwater levels, in general, are subject to seasonal fluctuations and hence can vary from the values given in this report.

## **DISCUSSION AND RECOMMENDATIONS**

### **General**

It is proposed to construct a five (5) span structure that will carry the North Service Road (NSR) over the Twenty Mile Creek immediately north of the QEW and south of Lake Ontario. As shown on Dwg. No. 3258901-A, three piers and the west abutment are to be located west of the Twenty Mile Creek and a single pier and the east abutment is to be located east of the Twenty Mile Creek. The proposed span lengths from west to east are 27.5 m - 28.5 m - 28.5 m - 28.5 m - 27.5 m. It is understood that prestressed concrete girders have been designed to support the 225 mm concrete deck and asphaltic and waterproofing system. The NSR is to be approximately 13.6 m in width and will be a two lane roadway with extra wide shoulders and a sidewalk. A 2810 mm vertical clearance has been designed to provide the necessary navigation clearance between Piers #3 and #4 which is the span over the Twenty Mile Creek.

Encroachment into the Lake Ontario will be required at the west approach to facilitate the construction of the approach embankment. The proposed profile grade varies from 79.3 m to 79.9 m within and immediately adjacent to the structure. The original ground surface at the site varies from approximately 75.6 m to 77.4 m. Therefore fill heights in the order of magnitude of 3 to 4 metres will be required at the approaches to the structures.



A plan illustrating the proposed structure including the proposed structure foundation locations is shown on Dwg. No. 3258901-A in the Appendix. The proposed profile grade superimposed on a longitudinal stratigraphical section across the site is also included on the drawing.

The subsurface conditions at the site as described earlier consist of native sands to silty sands with traces/ some gravel underlain by organic silty clays to organic clays, which in turn are underlain by deposits of glacial till origin. Overburden at the site is underlain by shale bedrock of the Queenston Formation. The organic silty clays to organic clays are materials that control the slope stability and settlement requirements at the site. In view of the significant influence that slope stability and settlements have on the arrangement and positioning of the structure, recommendations pertaining to these two geotechnical considerations are given firstly in this report. Recommendations pertaining to the design and construction of structure foundations, and backfill to the structure are then provided.

## **SETTLEMENT OF APPROACH EMBANKMENT**

### **General**

Settlements of the native subsoils at the site will occur as the result of the proposed embankment loading. Soil displacement can occur as a result of elastic compression, and/ or primary consolidation and/ or secondary compression. All soils experience elastic settlements. These settlements, however, are instantaneous and usually occur during the construction period. Consequently, elastic settlements do not induce maintenance

problems. Primary consolidation and secondary compression, on the other hand, are time dependent, and hence soils susceptible to these types of settlements must be engineered to avoid excessive post construction settlements and the maintenance problems that can result. At the site, the organic silty clay to organic clay stratum will settle as a result of primary consolidation and secondary compression. A prediction of the settlements induced in the organic silty clay to clay as well as the other native subsoils at the site are discussed below.

Settlements within the embankment fill proper itself can also be expected in addition to the settlement of the native subsoils. The settlement characteristics of different fill materials are described below.

The two important aspects of settlement that must be addressed are magnitude and time rate. The magnitude of settlement is a function of the compressibility characteristics of the soil, the soil thickness and the magnitude of the embankment loading. The time rate is a function of the drainage conditions, the permeability of the soil, the soil compressibility characteristics and the soil thickness.

All the settlement considerations, with particular emphasis on the organic silty clay to organic clay are discussed below. Recommendations are then given to solve the settlement problem.

## **Settlement Considerations**

### **Primary Consolidation and Secondary Compression**

The organic silty clay to organic clay at the site will undergo primary consolidation and secondary compression settlements as a result of embankment loadings exceeding the preconsolidation pressure of the soil which is as low as 60 kPa at the site. With fill heights exceeding 3 metres at the site, and using a normal weight fill material (unit weight  $\geq 20 \text{ kN/m}^3$ ), primary consolidation and secondary compression settlements can be expected.

Figure 7 in the Appendix illustrates anticipated primary consolidation settlements for different fill heights. One-dimensional consolidation theory was used to compute the settlements. The load deformation curves illustrated on Figures 4a and 4b were used to determine the void ratio change (deformation) as a result of the proposed loadings and Osterberg's (1957) stress distribution curves were used to determine the influence of the embankment loading on the native subsoil. Settlements in the order of 175 mm and 250 mm have been predicted for a four metre embankment at the west and east approach embankment respectively.

The time rate of primary consolidation of the organic silty clay to organic clay stratum was predicted using Terzaghi's theory of one dimensional consolidation and the results are shown on Figures 8a and 8b. Double drainage to the overlying sands and underlying deposits of glacial till origin was assumed. The coefficient of consolidation ( $c_v = 3\text{m}^2/\text{yr}$ )

that was used in the calculations was based on values previously determined for similar subsoils for the specified loadings.

The results of the time-rate calculations reveal that it takes approximately 42 months to achieve 90% degree of consolidation. It takes approximately 10 months to achieve 50% degree of consolidation. Therefore, for a four metre embankment, after 10 months of embankment loading, 125 mm and approximately 85 mm of primary consolidation settlement would be outstanding at the east approach and west approach respectively.

Secondary compression is thought to be due to the gradual readjustment of soil mineral particles into a more stable configuration. Hence, as the pore pressures generated as a result of embankment loading dissipate, the particles rearrange themselves closer together decreasing the void ratio in the process. The magnitude of secondary compression is difficult to predict but it is not expected to be of significant magnitude (less than 5% of the primary consolidation). Furthermore, it is presumed that primary consolidation and secondary compression proceed simultaneously from the time of loading and consequently, some of the secondary compression can occur during the primary consolidation period.

#### **Elastic Settlements of Native Subsoils**

The elastic settlements of the native subsoils at the site were predicted using Steinbrenner's solution (1934). Moduli of elasticity for the sand, organic silty to clay and

glacial tills assumed in the calculations are given below in Table 7 below. Stress distribution influence factors were taken as a function of the embankment geometry and subsoil thickness.

Table 7 - Moduli of Elasticity	
Soil	Modulus of Elasticity ( $E_s$ ) (MPa)
Sands	40
Organic Silty Clay to Clay	75
Glacial Tills	250

Based on the calculations, up to 50 mm of elastic settlement of the native subsoils can be realized as a result of embankment loadings produced by fill heights ranging from 3 to 8 metres. These settlements, however, are expected to be instantaneous and should occur during the construction period.

#### **Settlements within Embankment Fill Proper**

Settlements within the embankment fill material itself are also anticipated as the result of internal stresses induced by the self weight of the material. The magnitude and time

rate of this settlement is a function of the embankment height and the composition of the fill. Settlements expected within cohesive and non-cohesive earth fills, and also rock fills are discussed below.

For earth fills up to approximately 7 metres, the total settlement within the embankment proper is expected to be approximately 0.5% of the fill height. Therefore, for fill heights ranging from 3 metres to 7 metres, total settlements in the order of magnitude of 15 mm to 35 mm can be expected.

For rock fills, on the other hand, slightly greater settlements can be expected as a result of particle breakage caused by contact forces and particle reorientation within the rock fill. In general, rock fill embankments have shown settlement equivalent to approximately 1% of the fill heights. Therefore, for fill heights ranging from 3 metres to 7 metres, total settlements in the order of 30 mm to 70 mm can be expected.

Settlements within the earth fill should occur almost instantaneously and hence should occur during or immediately following construction for a granular material. Settlements of cohesive fill embankments will be more time dependent and anticipated to be realized within a three (3) month time period following placement.

Settlements within the rock fill material will be time dependent. However, for the fill thickness proposed at the site, it is expected that post construction settlements will not be significant.

### **Settlement Recommendations**

#### **General**

In consideration of the predicted settlements, various alternatives are provided to minimize post construction settlement problems. The options discussed below include:

- (1) Surcharging and Preloading
- (2) Lightweight Fill Material
- (3) Wick Drains
- (4) Spanning the Organic Silty Clay to Clay Deposit

The option that proves to be the most technically feasible, cost effective and environmentally viable and also satisfies construction scheduling constraints shall be chosen.

#### **1) Surcharge and Preload**

If construction scheduling permits, post construction settlements can be minimized by preloading and surcharging. In general, for example, it is predicted that an embankment surcharge of 2 metres in thickness and assuming a unit weight of fill of  $20 \text{ kN/m}^3$ , allowed

to preload for six months can accelerate the consolidation settlements to approximately 70 to 75% of the total anticipated settlements. For a nine month, 2 metre surcharge preload, approximately 75% to 90% of the total anticipated settlement can be realized. In addition within the six or nine month preloading period, it is expected that all elastic settlements of the native subsoils and fill materials will be realized.

Figure 9 in the Appendix illustrates graphically the procedure used to determine the rate of acceleration. As an example, a four metre embankment is surcharged with two metres of additional fill for nine months. Initially, the progress of settlement will occur along the curve for the surcharge (6 m fill height). After the surcharge is removed the progress of settlement will follow the time-rate pattern predicted for the original 4 metre fill height (refer to match points X and Y on Figure 9). The figure illustrates that the settlement has been accelerated by approximately 16 months (75% consolidation). Therefore an outstanding consolidation settlement of approximately 50 mm remains.

When additional surcharge load is placed, the stability of the embankment must be analyzed to ensure that no slope stability problems are triggered as a result of the additional loading. Slope stability is discussed in detail in the next section of this report. As mentioned in this section, for proposed surcharge fill heights up to eight metres constructed at 1H:1V or flatter, no global stability problems are anticipated. Figure 10 in the Appendix illustrates a typical surcharge load geometry.



## 2) Lightweight Fill

Total settlements can be significantly reduced if a lightweight fill material is used as a replacement for normal weight fill material. As mentioned earlier, the organic silty clay to clay is the stratum that is the most problematic because of consolidation settlements that can occur. As discussed earlier, this soil has been preconsolidated approximately a minimum of 60 kPa in excess of the existing overburden pressure. Therefore the application of a lighter weight fill material will result in being able to construct embankments of greater height without consolidation settlements.

Two types of lightweight material that can be considered is blast furnace slag or expanded or extruded polystyrene. A  $\frac{3}{8}$ " structural coarse slag can be placed and compacted at an in situ unit weight of  $11.5 \text{ kN/m}^3$  and the polystyrene has a unit weight as low as  $0.4 \text{ kN/m}^3$ . The slag material can therefore be used to construct embankments to a height of approximately five metres without any consolidation settlements and the polystyrene can be used to construct embankments of even greater heights without consolidation settlements.

A number of design and construction considerations must be addressed in employing the lightweight fill materials. Physical, chemical and mechanical properties of these materials are design considerations that need to be evaluated and include grain size, crushing characteristics and chemical composition for the slag material and compressive and flexural strength, flammability, buoyancy problems and biodegradability and wetness for

the polystyrene. Construction considerations include avoiding overcompacting the slag material and for the polystyrene subgrade preparation, drainage and installing the polystyrene with maximum staggered joints. These are all details that have been previously considered and resolved successfully on other MTO projects.

Table 8 below provides some approximate costs for the supply of the slag and the polystyrene. These costs can be used to produce preliminary estimates.

Table 8 - Lightweight Fill Costs		
Material	Supply	Transportation
Water Cooled Pelletized Slag	\$25/ m <sup>3</sup>	\$0.07/ km/ tonne
Polystyrene - Extruded	\$200/ m <sup>3</sup>	(included in supply)
- Expanded	\$100/ m <sup>3</sup>	

### 3) Wick Drains

Wick drains are vertical drains manufactured from geosynthetic material that can be installed at close spacing to increase the rate of consolidation of the organic silty clay to organic clay. The wick drains expedite the consolidation process much faster than the conventional surcharge and preloading because the radial drainage is quicker because of the shorter drainage path and the fact that the coefficient of consolidation in the horizontal direction ( $c_h$ ) is greater than the coefficient of consolidation in the vertical direction ( $c_v$ ).

Although wick drains have not been previously incorporated in MTO embankment design, wick drains have been successfully employed in highway embankment design and large dam designs across the United States and in western Canada where subsoil conditions were generally similar to the conditions present at the Jordan Harbour site. Our office, consequently, is confident that a value engineering wick drain design can be successful at the Jordan Harbour site.

Based on our calculations, it is expected that for wick drains installed to Elevation 60 m and at a 2 metre triangular grid spacing, 90% degree of consolidation can be achieved within three months with a two metre surcharge load placed on the final embankment height. A typical section that illustrates the wick drain-surcharge load combination is given in Figure 11. The figure illustrates the embankment foundation containing the wick drains, a 0.5 metre drainage blanket and working pad consisting of Granular 'A' or Granular 'B' material and the final embankment and surcharge embankment geometrics. As discussed previously, embankment materials shall be placed and compacted in accordance with OPSS 501 series.

Wick drains consist of a flexible plastic core surrounded by a filter fabric jacket. They are about 100 mm wide and 2 to 6 mm thick. The core is ribbed, studded or channelled to maximize water flow capacity and the filter allows passage of groundwater into the drain

core while preventing soil migration. Some proprietary wick drain products include Alidrains and Mebradrains. Our office can coordinate standard drawings, and NSSP for these products.

Wick drains are typically installed by means of a mandrel which is pushed through the soil to the desired depth. The wick drain is shipped in rolls and threaded through a mast and into the mandrel. Consequently, as the mandrel is pushed, the wick drain is also simultaneously pushed to the design tip elevation. There are various means of driving the mandrel including a cable pull crane and hydraulic backhoes.

In view of the surficial sand to silty sand with some gravel deposit overlying the organic silty clay deposit, preaugering through this material will be required to facilitate the installation of the wick drains. In view of the cohesionless nature of these soils submerged below the groundwater table, conditions of unbalanced hydrostatic head will result and hence, the Contractor will have to control any soil cave-in or sloughing in the preaugered hole.

Typical costs for the supply and installation of the wick drains at the Jordan Harbour site were ascertained by contacting various specialized contractors and suppliers in the industry. These costs are summarized in Table 9 below.

Table 9 - Wick Drains Supply/ Installation Costs
\$25/ m <sup>2</sup> (Embankment Area)

4) Spanning the Organic Silty Clay to Clay Deposit

Alternatively, consideration may be given to eliminating fill placement entirely within the area that contains the organic silty clay to clay by spanning the deposit with a structure. The organic silty clay to organic clay extends from Station 21+495 to Station 21+950 at the site.

### **STABILITY OF APPROACH EMBANKMENTS**

#### **General**

The design of approach embankments as proposed at the site must be designed to avoid instabilities in both the longitudinal direction and also the transverse direction. The procedure conventionally involves satisfying two major criteria:

- (1) Global Stability
- and (2) Internal (Surficial) Stability

Global stability calculations involve conducting two-dimensional analyses to determine whether the applied embankment loading will induce a deep seated slip failure surface within the native subsoil which will manifest itself in a "global" slip surface movement within the embankment. Many factors must be considered in this analyses including embankment geometry, height and load; external loadings; overall geometry of embankment and natural ground surface, for instance the influence of scouring at the toe of an embankment fill, the properties and behaviour of the native subsoils and the groundwater and surface water conditions at the site.

Internal stability, on the other hand, concentrates on the stability of the embankment within the embankment proper itself. Internal embankment stability involves the assessment of seepage forces; erosional forces; embankment materials, construction and geometry. At the site, the Lake Ontario waves are a major factor in evaluating the internal stability of the approach embankments.

Specific recommendations to safeguard against global and internal instabilities of the approach embankments at the site are given below.

### **Global Stability**

The critical condition examined in the evaluation of the global stability of embankment fills as proposed at the site location is the short term (undrained) condition and consequently a total stress analysis was conducted. In all cases, stability computations were carried out using an in house MTO-slope application software package which is based on Sarma's method of limiting equilibrium. The formulation of Sarma's method is described in a paper entitled "Stability Analysis of Embankments and Slopes", Sarma, S.K. (1973), Geotechnique 23, No. 3, pp. 423-433.

The process of stability analyses involves the selection of pertinent shear strength parameters and physical soil properties such as unit weight, inputting the subsurface and groundwater conditions and then designing a surface geometry that produces an acceptable factor of safety of 1.3 using the MTO slope program. At the east approach,

scouring of the channel must be considered in the overall global stability. A channel width of 27 m and a scour depth (channel elevation) of 70.5 m was used in the analyses. The top of embankment elevation used in the analyses was 81.5 m which includes an additional surcharge thickness on the surface of the final NSR grade.

Figure 12 in the Appendix illustrates the overall geometry, the subsurface conditions and relevant subsoil parameters used in the stability analyses. Both circular and composite failure surfaces were evaluated and a critical slip surface was searched. The results of the analyses reveal that a 38.5 metre offset between the centreline of the channel and the east abutment is required to satisfy global stability requirements. The geometry of the offset shall consist of 2H:1V slopes and a minimum seven(7) metre berm at an elevation of approximately 76 m.

It is prudent that the approach embankments be protected against long term channel erosion that can result from the wave action of the Lake Ontario. Channel armouring shall therefore be placed for a minimum width of the structure within the channel area.

At the west approach, slope stability analyses were conducted for fill heights up to eight metres employing the same soil parameters and groundwater conditions used in the east approach analyses. A four metre organic silty clay to organic clay layer thickness was used in the computations. The results reveal that no global instabilities will occur for slopes constructed at 1.25H:1V or flatter.

### **Internal Stability**

A shoreline protection scheme will be required where approach embankments are located adjacent to Lake Ontario to preserve the internal stability of the embankment from the erosive wave action. Figure 13 in the Appendix illustrates the proposed slope treatment that consists of armour stone and a minimum 0.6 m rip rap (OPSS 1004.05.06) placed at a 1.25H:1V slope or flatter. To prevent soil migration, it is recommended as shown on the figure that minimum 300 mm thick layers of granular A or B (OPSS 1010) and 19-26 mm crushed (OPSS 1004.05.07) be placed as filter materials between the embankment and the coarser rip rap material.

In the areas where encroachment into the lake is required, it is recommended that a bedding material consisting of rip rap be placed to facilitate the shoreline protection construction. The shoreline protection scheme is applicable for fill heights up to ten (10) metres which is in the range at the site.

Any slope that does not require shoreline protection at the site still requires internal instability protection. It is therefore recommended that any such slope be designed to satisfy the following guidelines:

#### **1 - Earth Fills**

- 1.1 Earth fills up to eight (8) metres in height shall be constructed at 2H:1V slopes or flatter.



- 1.2 Earth fills exceeding eight (8) metres shall be constructed at 2H:1V slopes with a nominal two (2) metre midheight berm constructed with a 2% gradient towards the toe of the embankment to promote surface runoff or alternatively at 2.5H:1V slopes.

## **2 - Rock Fills**

- 2.1 Rock fills up to ten (10) metres in height shall be constructed at 1.25H:1V or flatter slopes.

Normal slope vegetation cover shall be established as per conventional MTO standards as soon as possible to provide surface erosion protection for the slopes above the rock protection and where applicable elsewhere at the site.

## **Embankment Construction**

Embankment material and construction shall conform to OPSS 212 and OPSS 206 series respectively. The embankment material shall be compacted as outlined in OPSS 501 series.

All softened and/or organic material should be excavated for their full depth within the plan limits prior to fill placement.

**Embankment Settlement Monitoring Instrumentation**

In view of the compressible nature of the organic silty clay to organic clay stratum at the site and to minimize post construction maintenance, confirmation of the magnitude and time rate settlement is certainly warranted. Consequently, it is recommended that an instrumentation program be arranged and coordinated by this office to monitor the magnitude and time rate settlement of the compressible silty clay.

The selection, design and installation procedures for this instrumentation can be provided by this office.

**STRUCTURE FOUNDATIONS****General**

Boreholes 201 to 208 inclusive (eight boreholes) were advanced specifically to retrieve subsurface data to facilitate the design and construction of the structure foundations. The boreholes were planned and advanced for a seven span structure illustrated on a general arrangement drawing submitted to our office by the structural section on September 16, 1993. It was later disclosed that the five span structure as mentioned previously would indeed represent the final span arrangement. Although the foundation investigation was planned originally for the seven span scheme, the results of this investigation were also applicable to the revised five span scheme. This explains why some of the boreholes do not coincide with the proposed structure foundation locations.

A further additional explanation for the fact that the boreholes do not necessarily coincide with the structure foundation locations is that the site conditions did not permit borehole advancement at the exact proposed pier #3 and #4 locations. The existing Lake Ontario and Twenty Mile Creek and the presence of large armour stone used for shoreline protection prevented borehole advancement at these locations.

The surficial soils at the site and general site conditions render shallow foundations as an unsuitable option at the site. It is therefore necessary to support all structure foundations on deep foundations founded on or in bedrock. Deep foundations can consist of either concrete caissons installed in preaugered holes or driven steel H-piles. Recommendations for the design and construction of the deep foundation units are given below. The option that proves to be the most economical and technically feasible shall be selected.

### **Design Considerations**

#### **Concrete Caissons**

All structure foundations can be supported on concrete caissons socketed into the shale bedrock with interbedded siltstone formation. It is recommended that the caissons be founded on unweathered rock at or below the elevations provided in Table 10 below. To facilitate the design of the concrete caissons, a vertical factored capacity at U.L.S. equivalent to 3500 kPa can be employed. Due to the unyielding nature of the bedrock, the Serviceability Limit State (SLS) will not govern the design because the stresses

required to induce detrimental settlements at the S.L.S. will exceed the factored capacity at U.L.S. Reductions of axial capacities for inclined loadings shall conform to factors provided in Section 6-8.3.4.3 of the O.H.B.D.C.

Table 10 - Caisson Founding Elevation	
Structure	Foundation Elevation (m)
West Abutment	62
Pier #1	62
Pier #2	61.5
Pier #3	60.5
Pier #4	57.5
East Abutment	58

In view of the anticipated settlements at the approach embankments, downdrag forces or negative skin friction must be accounted for in the design of the caissons at the abutment locations. Downdrag forces expected for different caisson diameters at the U.L.S. are given in Table 11 below.

Table 11 - Downdrag Forces on Concrete Caissons (kN)		
Caisson Diameter (m)	West Abutment	East Abutment
0.9	750	1000
1.2	950	1350
1.5	1200	1700
1.8	1450	2050

The designer can use the bearing capacity provided to select the size of the caisson and the respective ultimate capacity. For instance, a 1.2 m diameter caisson will yield a load capacity equivalent to approximately 4000 kN at U.L.S. for a bearing capacity of 3500 kPa at the piers.

The lateral resistance for vertical or battered concrete caissons can be computed in accordance with Section 6-8.3.8 of the O.H.B.D.C. and using the data given in Table 12 below. Specific soil thickness/ depths can be obtained from the individual borehole logs. Caissons can be socketed into the bedrock to augment the lateral resistance. A minimum 0.5 m of socket into rock is required. Battered caissons are limited to a maximum 1H:4V due to construction limitations.

Table 12 - Horizontal Resistance Design Parameters

Soil/ Rock	Unfactored Strength Parameters Angle of Internal Friction ( $\phi$ )	Undrained Shear Strength ( $C_u$ ) (kPa)	Unconfined Compressive Strength ( $q_u$ ) (kPa)	Bulk Unit Weight $\gamma$ (kPa)
Fill Material	30°	-	-	20
Sand to Silty Sand	30°	-	-	20
Organic Silt	-	80	-	15
Cohesive Till	-	200	-	15
Cohesionless Till	35°	-	-	20
Weathered Bedrock	-	-	1,000	20
Unweathered Bedrock	-	-	10,000	22

Submerged unit weights are to be used below the groundwater table. Pile caps shall be protected against frost penetration by providing a minimum 1.2 m earth cover or equivalent frost protection.

### **Driven Steel H-piles**

Alternatively, all structure foundations can be founded on steel H-piles driven to the bedrock surface as identified in Table 13 below. For purposes of the O.H.B.D.C., the steel H-piles can be designed employing the axial capacities tabulated in Table 13 below.

Table 13 - Driven Steel H-Piles			
Structure	Pile Type	Factored Axial Capacity at U.L.S. (kN)	Axial Capacity at S.L.S (kN)
Piers	HP310 x 110	1600	1150
	HP310 x 79	1150	890
Abutments	HP310 x 110	1600	1150
	HP310 x 79	1150	890

Downdrag forces must also be considered in the design of driven steel H-piles at the abutment locations. The magnitude of the downdrag forces on the steel H-piles is given in Table 14 below. As mentioned earlier, downdrag forces are applicable at the U.L.S.

Table 14 - Downdrag Forces on Steel H-piles	
Structure	Downdrag Forces (kN)
West Abutment	450
East Abutment	600

Across the site, the cohesionless heterogeneous mixture of silt, sand and gravel or cohesive heterogeneous mixture of clayey silt, sand and gravel overlying the bedrock may prevent pile penetration and hence the piles may not reach the bedrock surface. Therefore, the pile installation shall be carefully monitored to confirm this potential occurrence. The Hiley Dynamic Formula as shown on Dwg. No. SS103-11 can be used to verify the pile capacity and acceptability of the pile driven into the overlying till deposit. The pile installation shall be controlled using an ultimate capacity of 3450 kN and 2670 kN for HP310x110 and HP310x79 piles respectively.

Axial capacities provided in Table 4 are for vertical piles only. Reductions of axial capacities for inclined loadings shall conform to factors provided in Section 6-8.3.4.3 of the O.H.B.D.C.

It is recommended that to facilitate the pile driving process, all piles be equipped with reinforced tips.



The lateral resistance for both vertical and battered piles shall be computed in accordance with Section 6.8.3.8 of the O.H.B.D.C. Pertinent unfactored soil parameters to facilitate the design of vertical piles are given in Table 12.

Pile caps shall be protected against frost penetration by providing a minimum 1.2 m earth cover or equivalent frost protection.

### **Construction Considerations**

#### **Caisson Construction**

Caisson construction within augered holes penetrating the cohesionless sand to silty sand with some gravel submerged below the groundwater table will require a dewatering system. This is for the reason that soil sloughing and cave-in will result due to the unbalanced hydrostatic head condition produced during construction. One method of controlling this condition is to construct the caisson within a temporary steel liner installed to the full depth of the submerged cohesionless soils to prevent soil cave-ins. After the liner has been cleared out, concrete shall be placed in the dry by bailing out the water or alternatively by tremie methods.

Alternatively, mud drilling and tremie techniques can also be used to control conditions of unbalanced head conditions. In employing this technique, the quality of the bentonite slurry (density, viscosity) should be kept under constant control to ensure that it performs satisfactorily.

The proposed method of caisson installation shall be in accordance with OPSS 903.07.03 and subject to review by this office. It is prudent that the contractor submit a caisson construction installation procedure for approval as outlined in OPSS 902.04.01. A NSSP addressing caisson materials, construction procedure and inspection should be included in the contract documents.

It is also recommended that a NSSP be included in the contract documents that states that the cohesionless sand to silty sand with some gravel submerged below the prevailing groundwater is subjected to conditions of unbalanced hydrostatic head and hence can boil.

### **Rockfill Removal**

Rockfill present at the proposed pier #3 location must be removed prior to foundation construction to facilitate the installation of the deep foundation units. Large armour stone are visible at these locations and the contractor shall be advised of the presence of these large rock sizes at the proposed foundation locations. The depth of the rockfill can be determined from the borehole logs and visual inspection which should be encouraged. For estimating purposes, it can assumed that three (3) metres of rockfill exists at pier #3.

### **Temporary Dewatering Enclosure**

Any foundation excavation/ construction within the Lake Ontario or the Twenty Mile Creek will have to be carried out within a temporary interlocking steel sheeting enclosure

(cofferdam). Any pile cap construction within the native surficial sand to silty sand with some gravel deposit below the prevailing groundwater table will also require similar dewatering measures. The steel sheeting shall be driven to a depth below the base of the excavation equivalent to the unbalanced hydrostatic head above this level. Once the water tight enclosure is formed, water can be discharged in an environmentally accepted manner using conventional pumping methods.

A NSSP shall be included in the contract documents that specifies the temporary dewatering enclosure.

#### **Foundation Scour Protection**

The channel armouring shall be adequately extended to protect piers #3, #4 and #5 located partially or entirely in Lake Ontario or Twenty Mile Creek.

#### **BACKFILL TO STRUCTURE**

##### **Material**

It is recommended that Granular 'A' or Granular 'B' material be placed within a wedge behind the abutments bounded by a plane rising at 60° to horizontal as shown in Figure 6.9.6.1 of the O.H.B.D.C. The application of granular material combined with weep holes in the abutment walls or pipe subdrains to drain any accumulation of water in the backfill will prevent hydrostatic pressure build-up.

Design parameters of the soil are given in Table 15 below. Computations of lateral earth pressure shall be in accordance with Section 6-6.1.2 of the O.H.B.D.C.

Table 15 - Backfill Properties		
	Granular 'A'	Granular 'B'
Angle of Internal Friction ( $\phi$ ) Factored	35°	30°
Unit Weight (kN/m <sup>3</sup> ), $\gamma$	22.8	21.2
*Coefficient of Active Earth Pressure ( $K_a$ )		
- S.L.S.	0.27	0.33
- U.L.S.	0.33	0.41
*Coefficient of Earth Pressure at Rest ( $K_o$ )		
- S.L.S.	0.43	0.50
- U.L.S.	0.50	0.58

\*These earth pressure coefficients apply to horizontal backfill surfaces only.

The appropriate consideration shall be given to account for sloping backfill.

The coefficient of earth pressure at rest shall be applied for rigid and unyielding walls.

### **Backfilling and Compaction**

The backfill shall be placed in 300 mm lifts in accordance with OPSS 902 series and compacted to achieve the target maximum dry density as outlined in OPSS 501 series.

Heavy vibratory equipment should be avoided in the backfill construction adjacent to the structure. It is therefore recommended that hand compaction equipment be employed in backfilling behind the abutment within a lateral distance equal to the current height of fill above the wall footing, in order to minimize deflection or possible damage of the wall.

### **MISCELLANEOUS**

The fieldwork for this investigation was carried out under several different mobilizations as summarized below.

BH's	Time Period	Supervisor(s)	Contractor
1-4	November, 1965	R. Magi, F. Wang	Dominion Soil Inc.
101-104	June/ July 1992	M. Vasavithasan	Malone's Soil Samples
201-208	September 1993	T. Sangiuliano	Malone's Soil Samples
301-302	August 1993	M. Vasavithasan	Malone's Soil Samples
401-409	June 1993	M. Vasavithasan	Malone's Soil Samples

Logging of rock core in the laboratory was carried out by D. Williams, Petrographer.

The project was carried out by T. Sangiuliano and M. Vasavithasan under the general supervision of P. Payer, Senior Foundation Engineer. The report was written by T. Sangiuliano, reviewed by P. Payer and approved by M. Devata, Chief Foundation Engineer.



A handwritten signature in black ink, appearing to read 'T. Sangiuliano'.

T. Sangiuliano, P.Eng.

Foundation Engineer



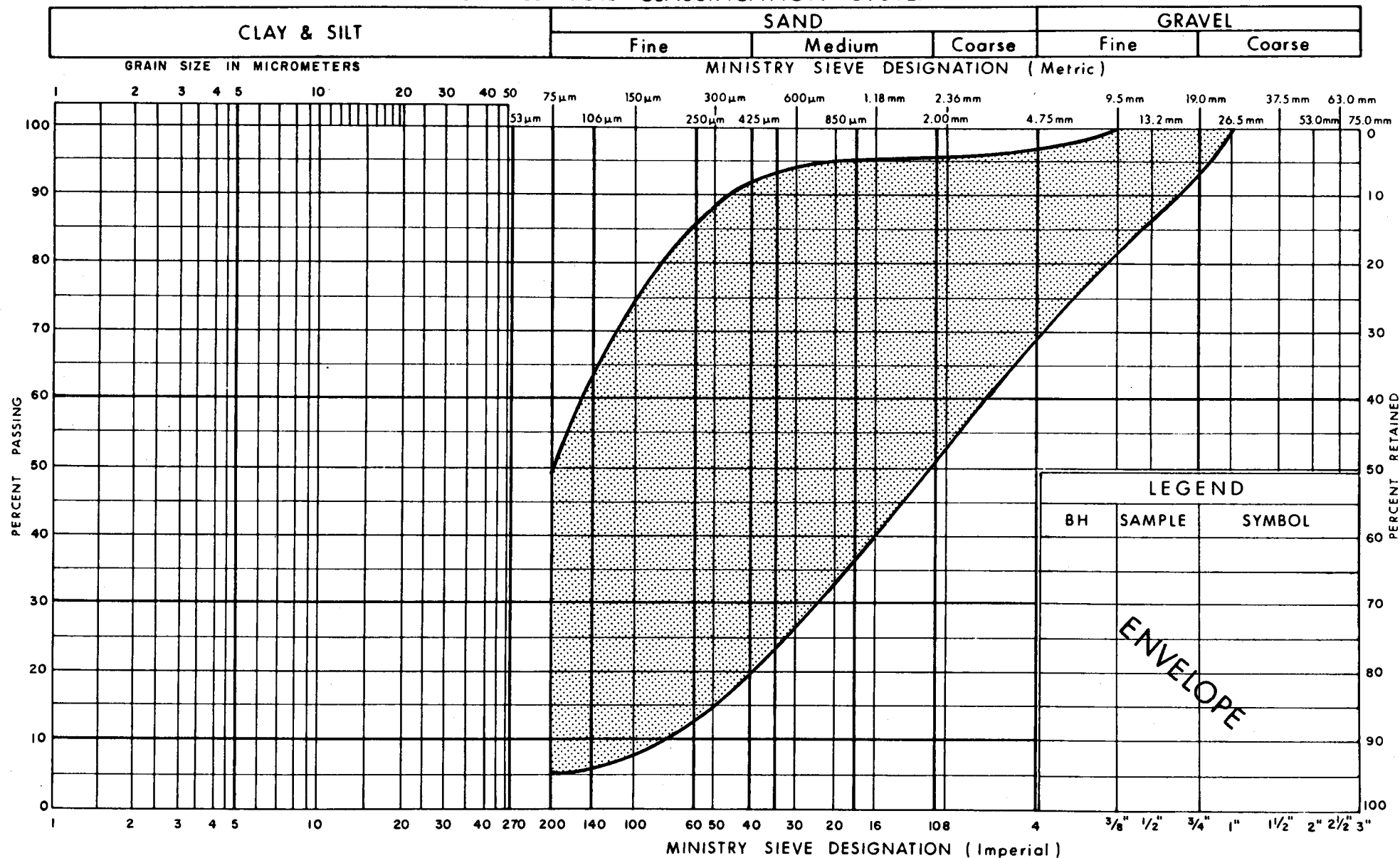
A handwritten signature in black ink, appearing to read 'M. Devata'.

M. Devata, P.Eng.

Chief Foundation Engineer

## APPENDIX

## UNIFIED SOIL CLASSIFICATION SYSTEM



Ministry of  
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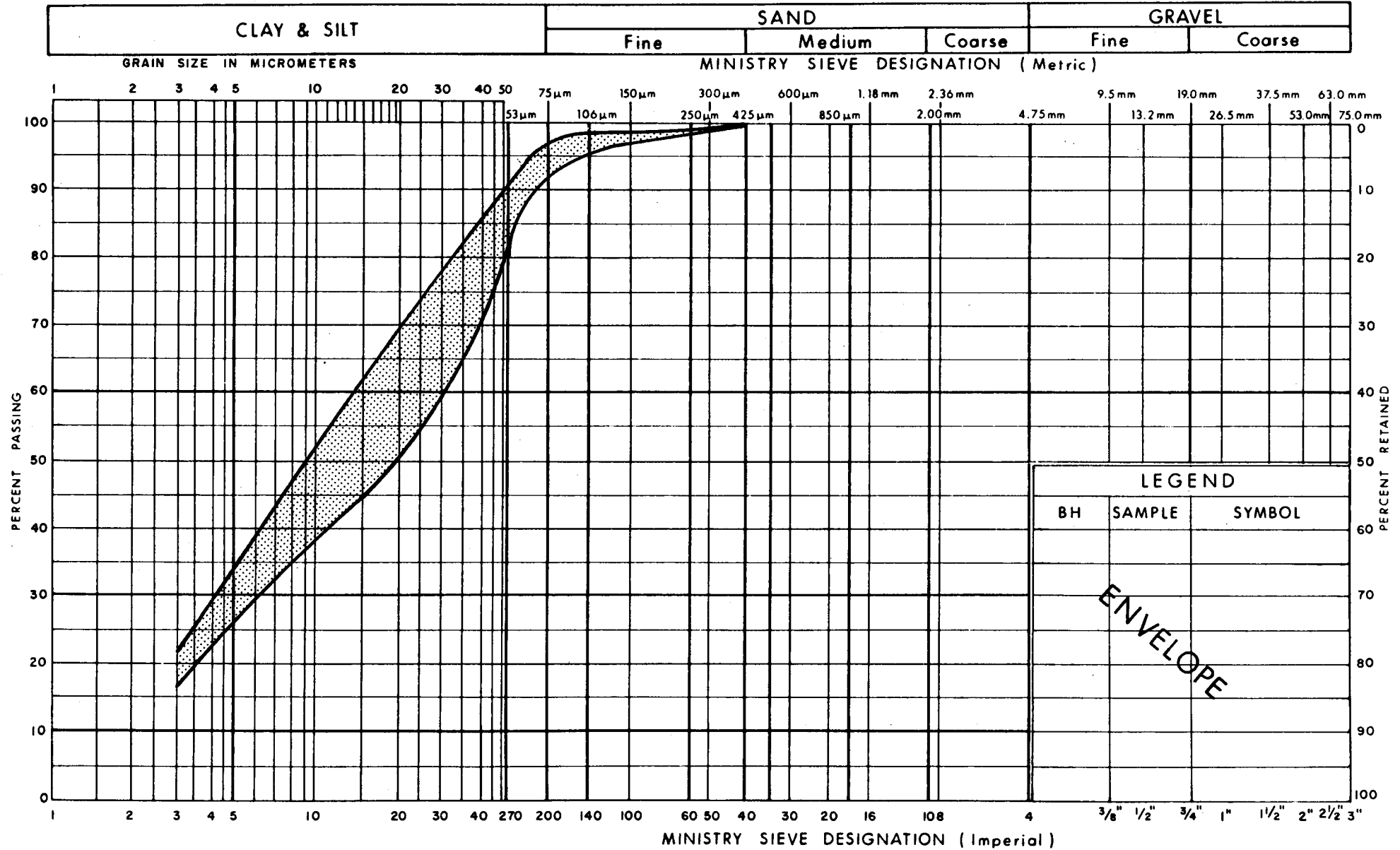
**GRAIN SIZE DISTRIBUTION**  
SAND TO SILTY SAND, TRACE / SOME GRAVEL

FIG No 1

WP 325-89-01



## UNIFIED SOIL CLASSIFICATION SYSTEM

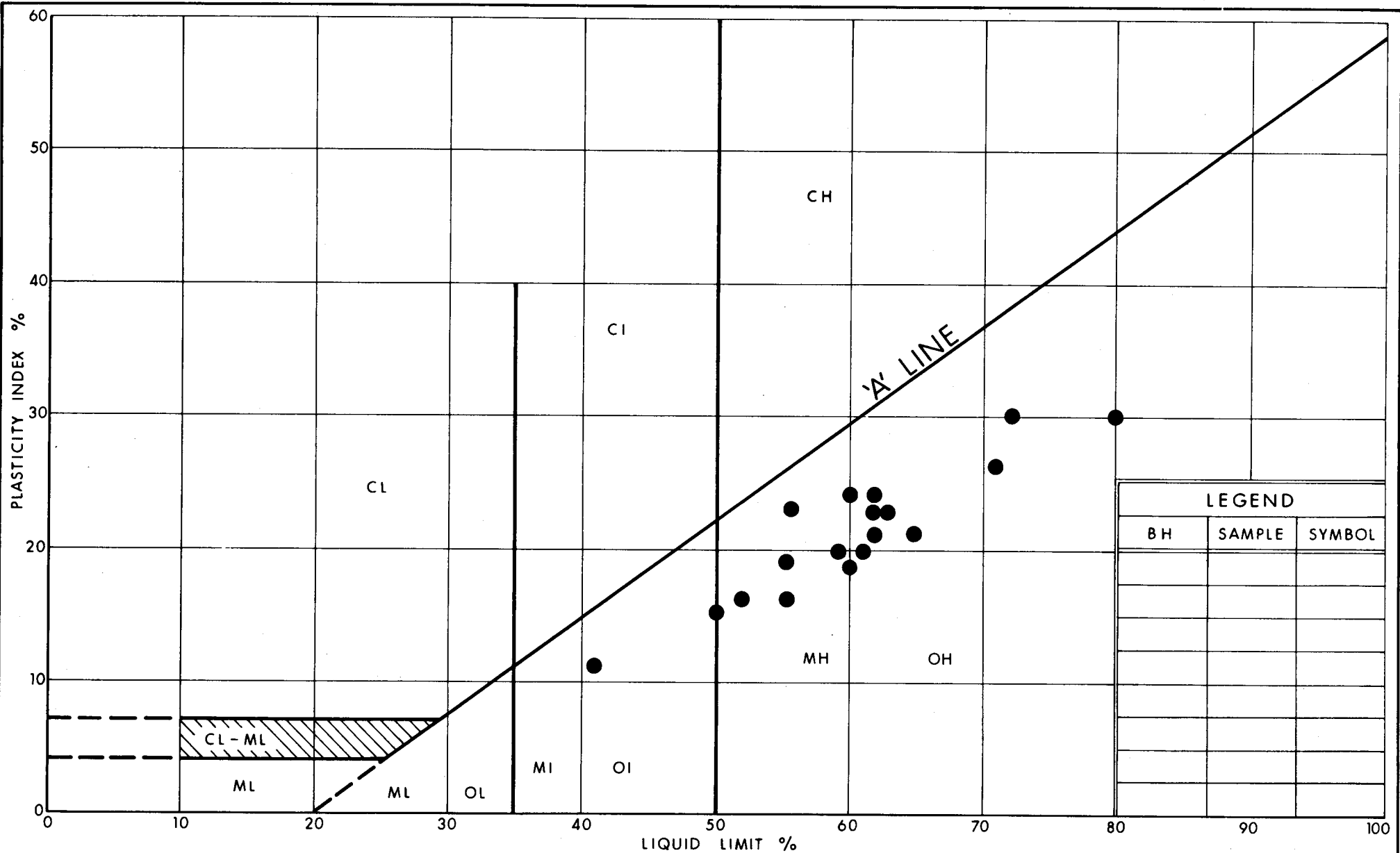

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Transportation

## GRAIN SIZE DISTRIBUTION

### ORGANIC SILTY CLAY TO ORGANIC CLAY

FIG No 2

W P 325-89-01



Ontario

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Transportation

# PLASTICITY CHART

## ORGANIC SILTY CLAY TO CLAY

FIG No 3

W P 325-89-01

# VOID RATIO - PRESSURE CURVES

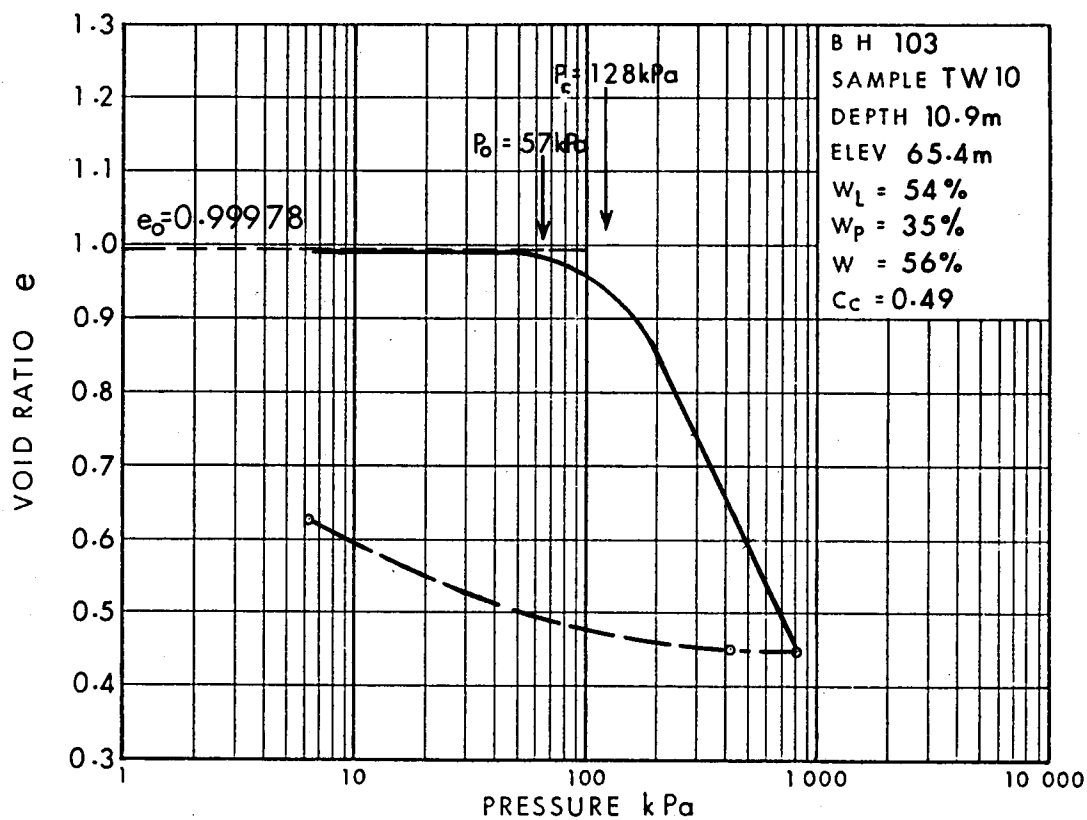
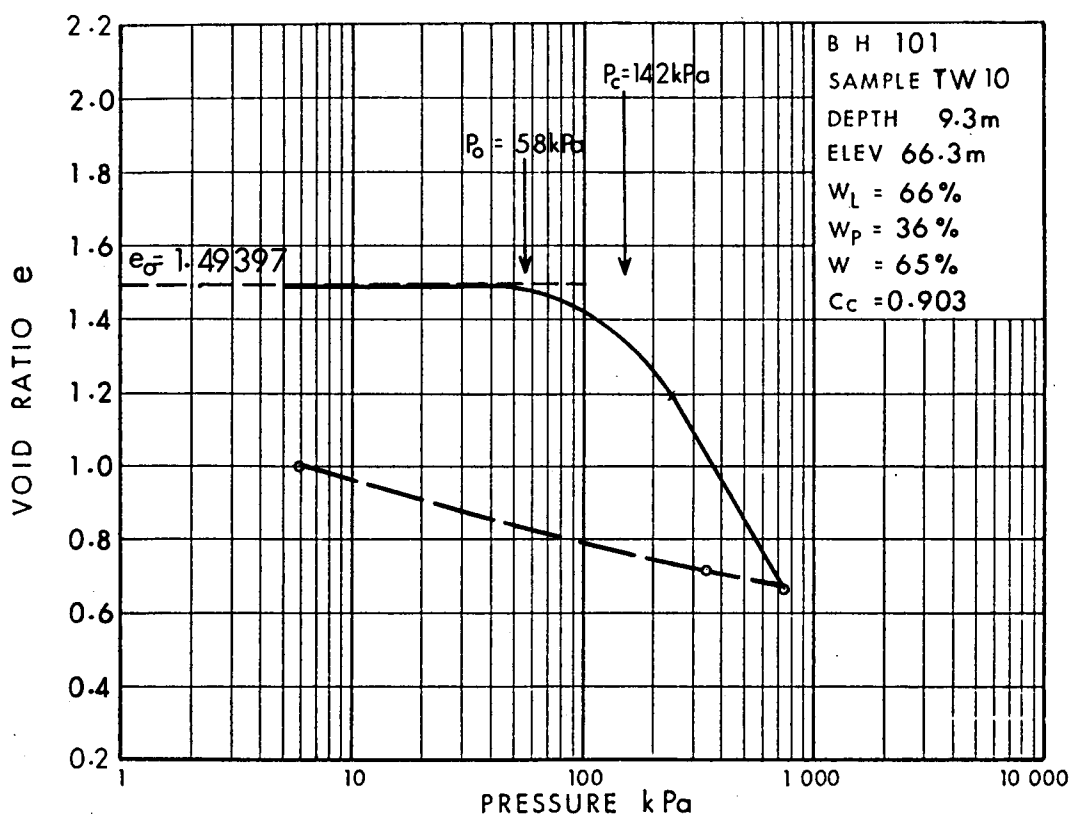


Fig 4a

W P 325-89-01

# VOID RATIO - PRESSURE CURVES

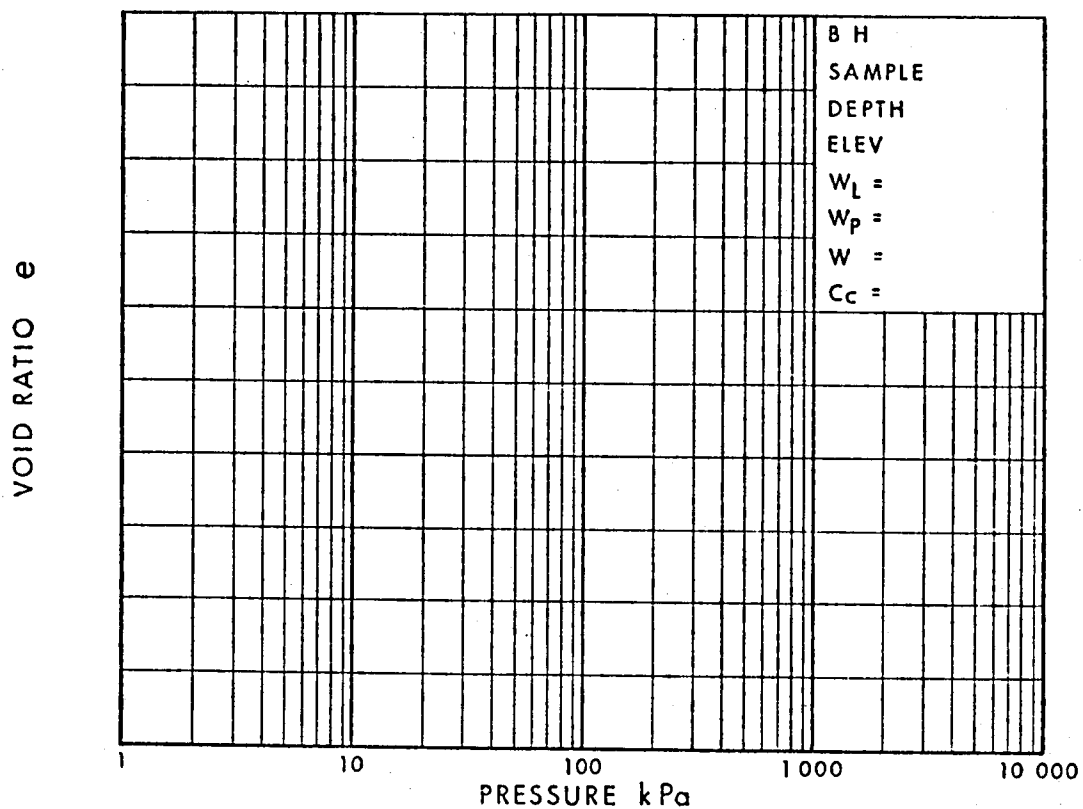
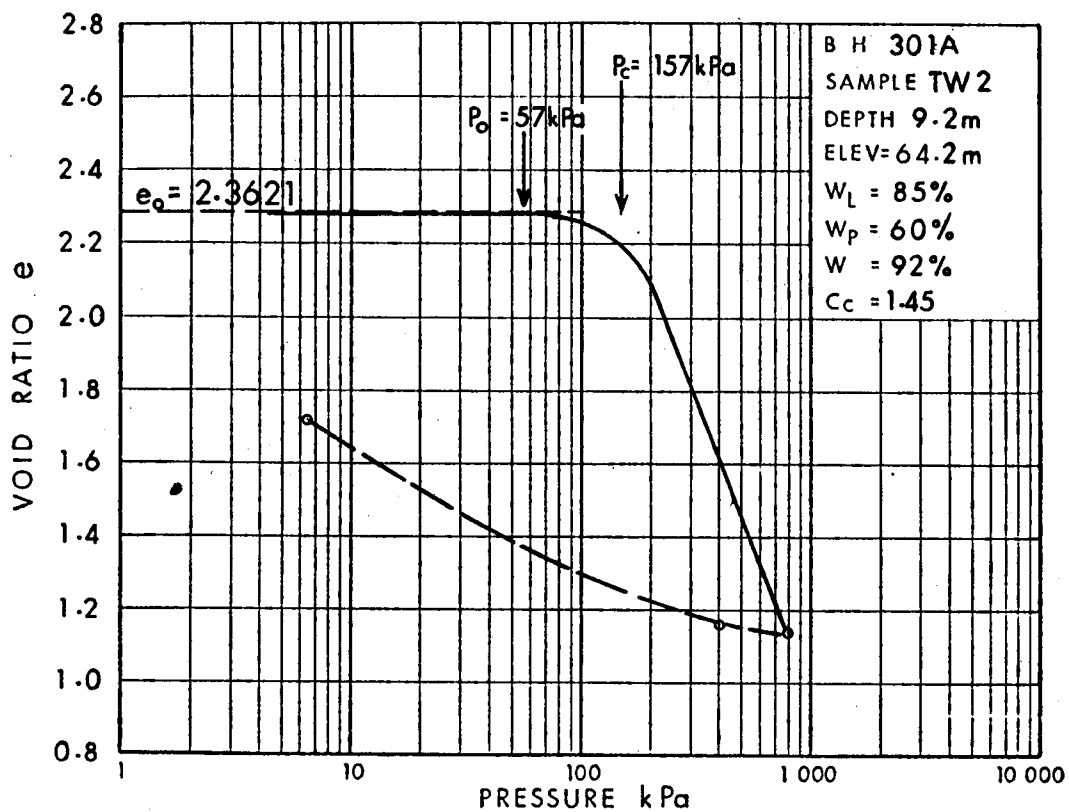
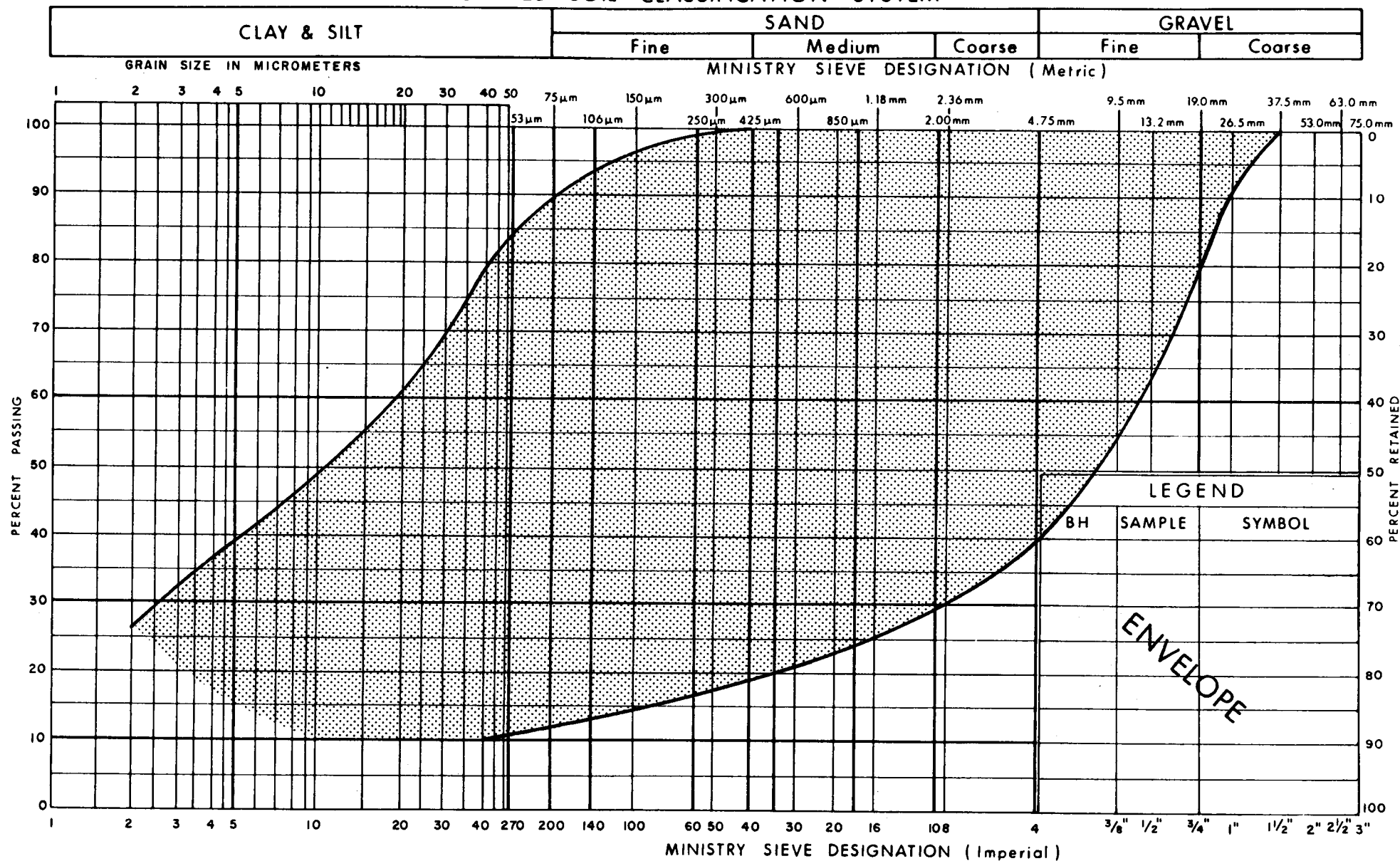


Fig 4b

W P 325-89-01

## UNIFIED SOIL CLASSIFICATION SYSTEM



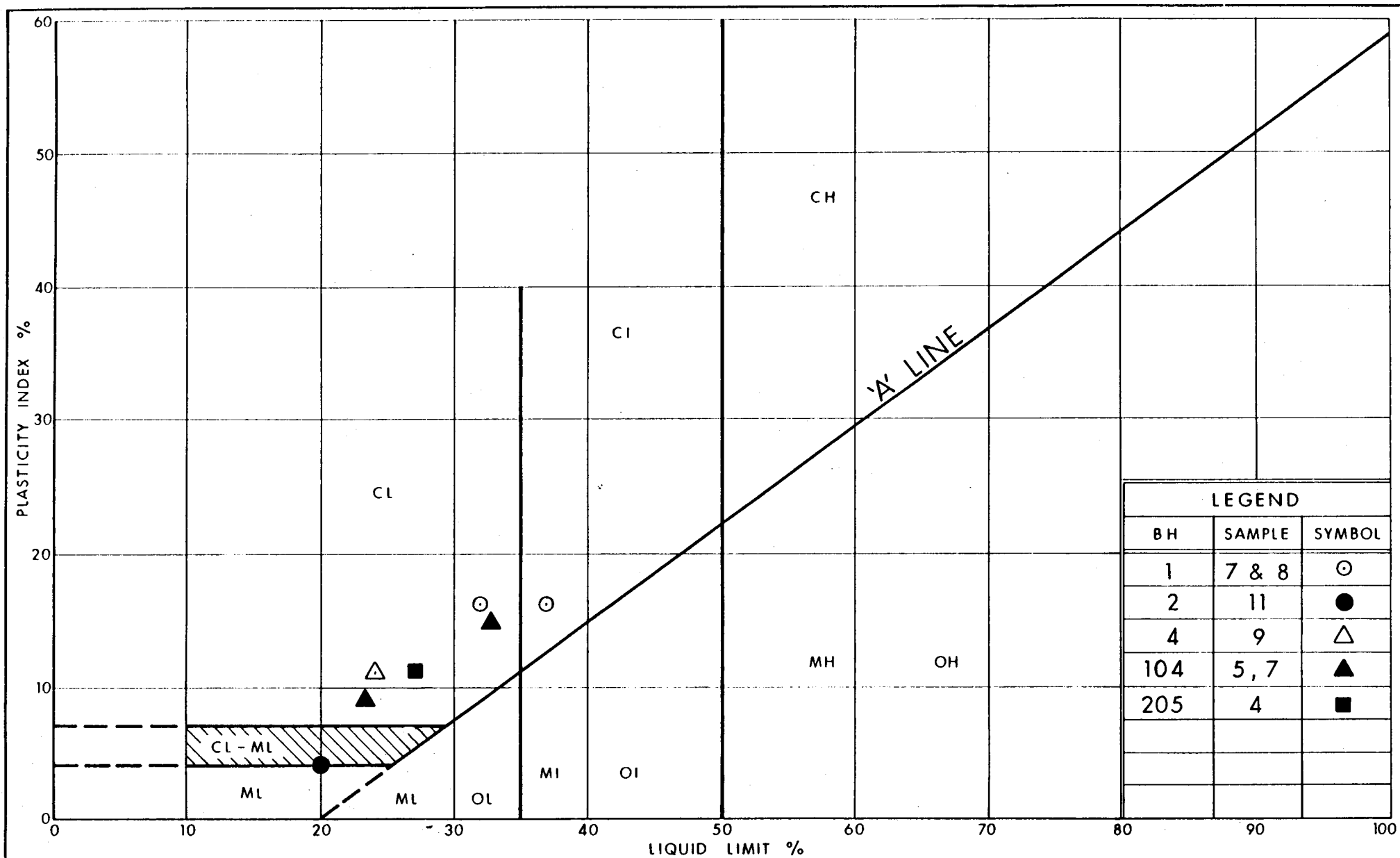
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## GRAIN SIZE DISTRIBUTION

### HET MIXTURE OF CLAYEY SILT, SAND & GRAVEL

FIG No 5

W P 325-89-01



Ministry of  
Transportation

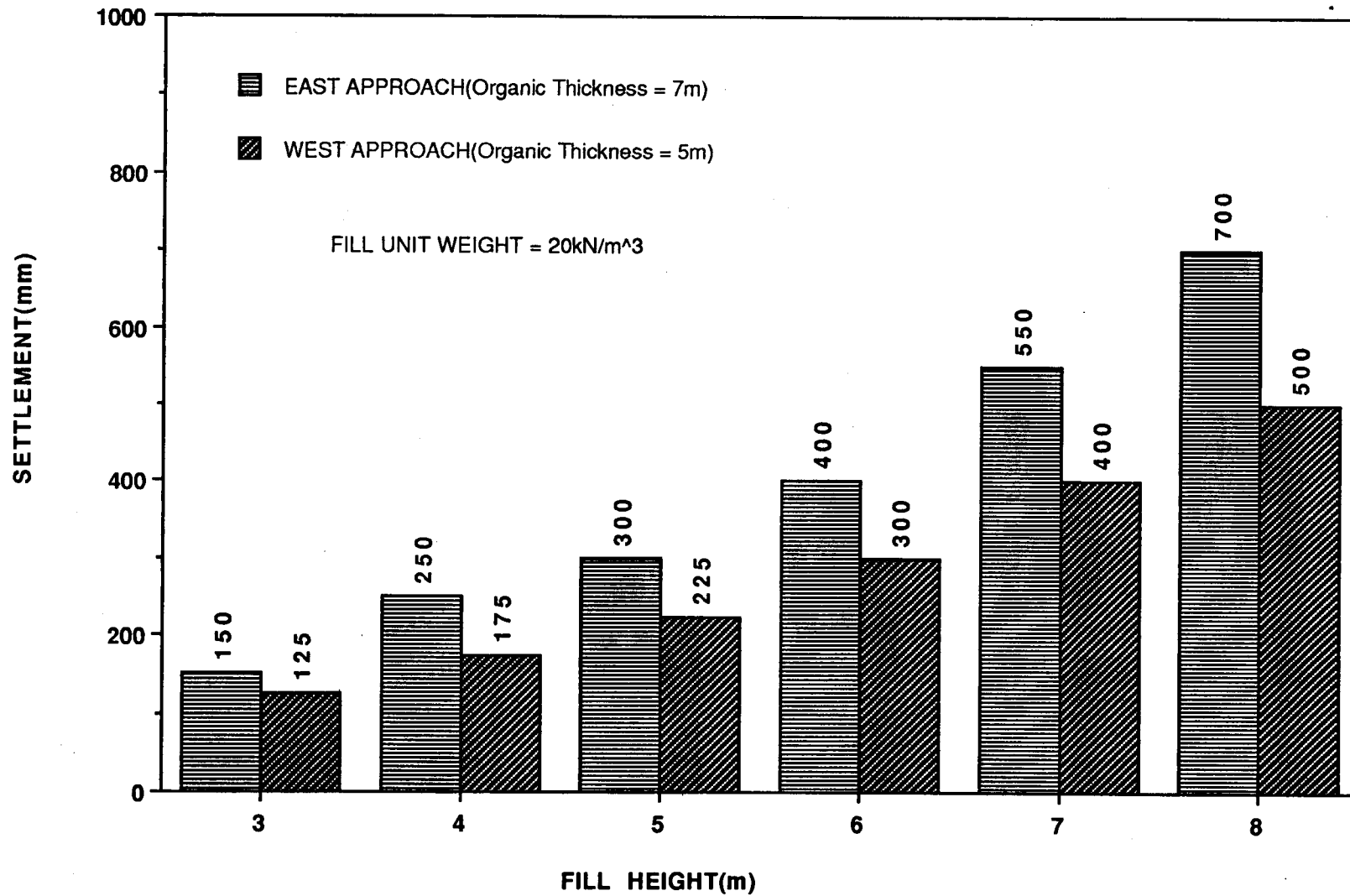
Ontario

# PLASTICITY CHART HET MIXTURE OF CLAYEY SILT, SAND & GRAVEL

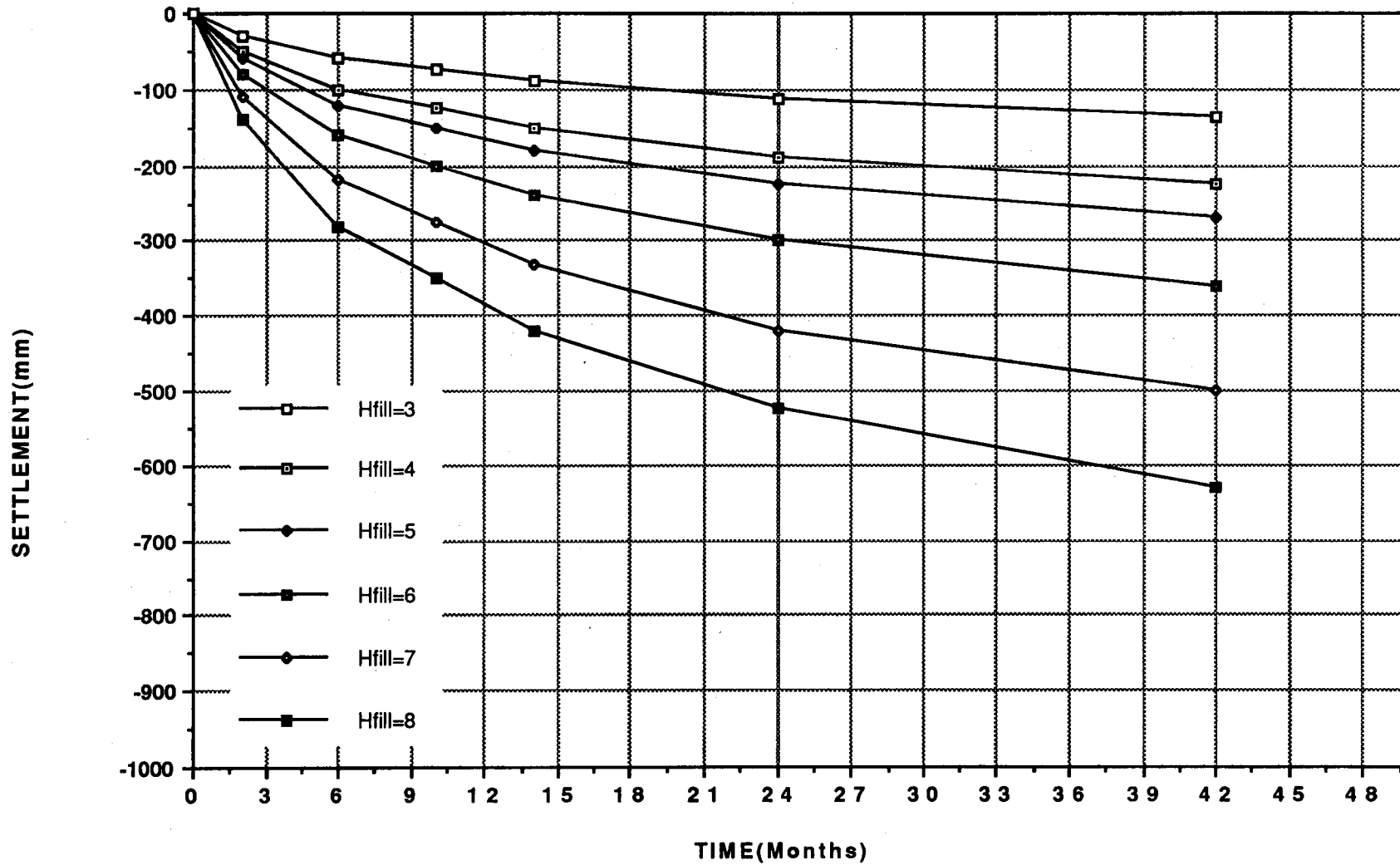
FIG No 6

W P 325-89-01

**FIGURE 7**  
**APPROACH EMBANKMENT SETTLEMENT**  
**NSR/JORDAN HARBOUR(WP 325-89-01)**



**FIGURE 8a**  
**SETTLEMENT VS TIME - EAST APPROACH**  
**( $C_v = 3 \text{ m}^2/\text{yr}$ )**



$U = 20\%$

40%

50%

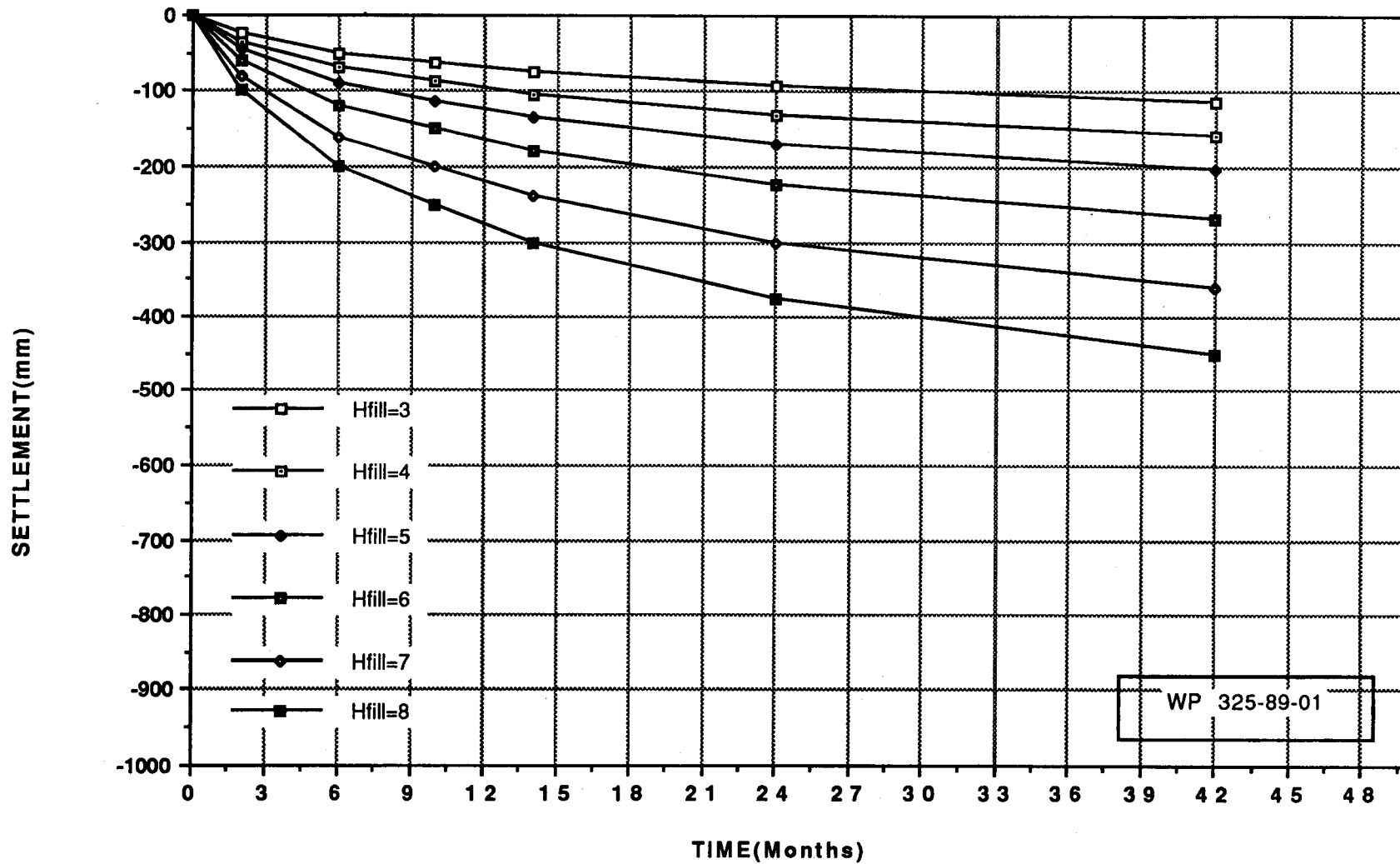
60%

75%

90%



FIGURE 8b  
SETTLEMENT VS TIME - WEST APPROACH  
( $C_v = 3 \text{ m}^2/\text{yr}$ )



U = 20%

40%

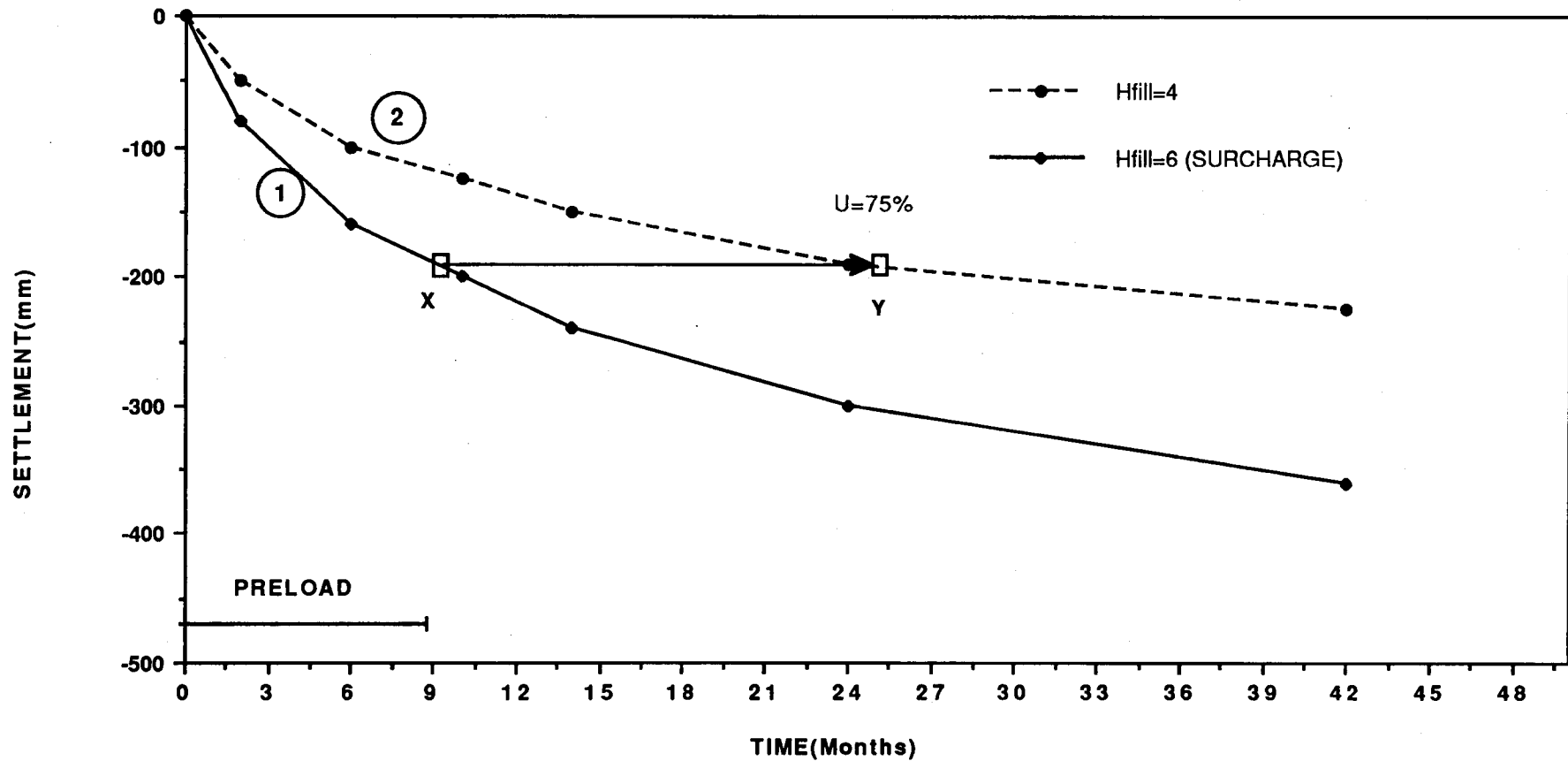
50%

60%

75%

90%

**FIGURE 9  
PRELOAD-SURCHARGE EXAMPLE  
EAST APPROACH**

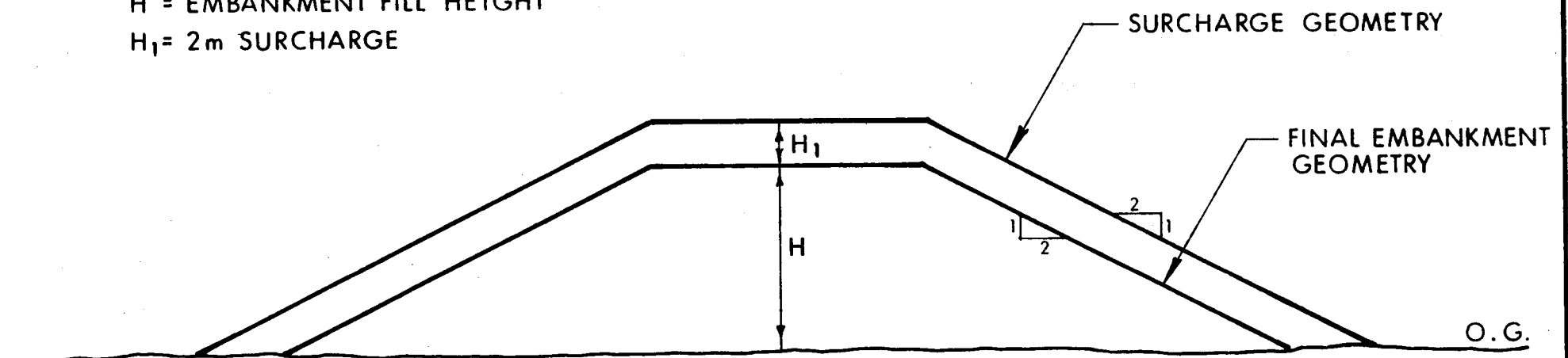


**PROCEDURE**

1. PRELOAD WITH SURCHARGE
2. INITIALLY SETTLEMENT WILL PROGRESS ALONG CURVE 1(SURCHARGE)
3. REMOVE SURCHARGE AFTER PRELOADING PERIOD(PT X)
4. IDENTIFY MATCH POINT(PT Y) ON CURVE 2
5. SETTLEMENT WILL PROGRESS ALONG CURVE 2(FINAL GRADE)

Figure 10 - SURCHARGE LOAD GEOMETRY

H = EMBANKMENT FILL HEIGHT  
 $H_1 = 2\text{m}$  SURCHARGE

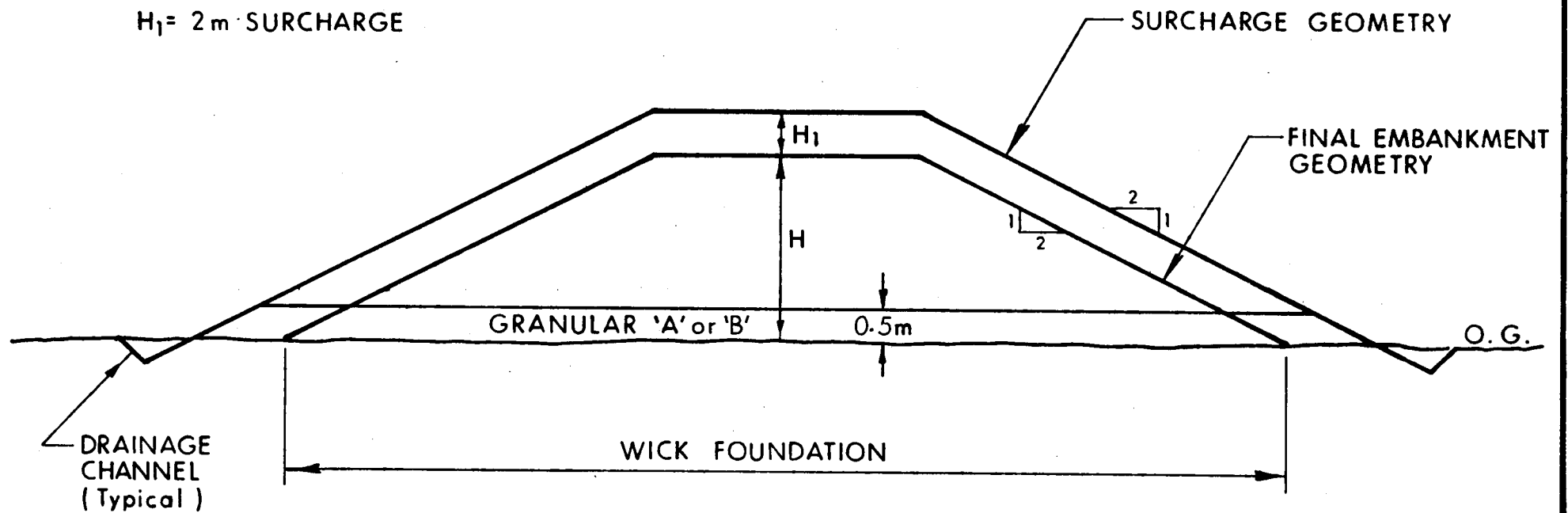


NOT TO SCALE

### Figure 11 - WICK DRAIN DESIGN

H = EMBANKMENT FILL HEIGHT

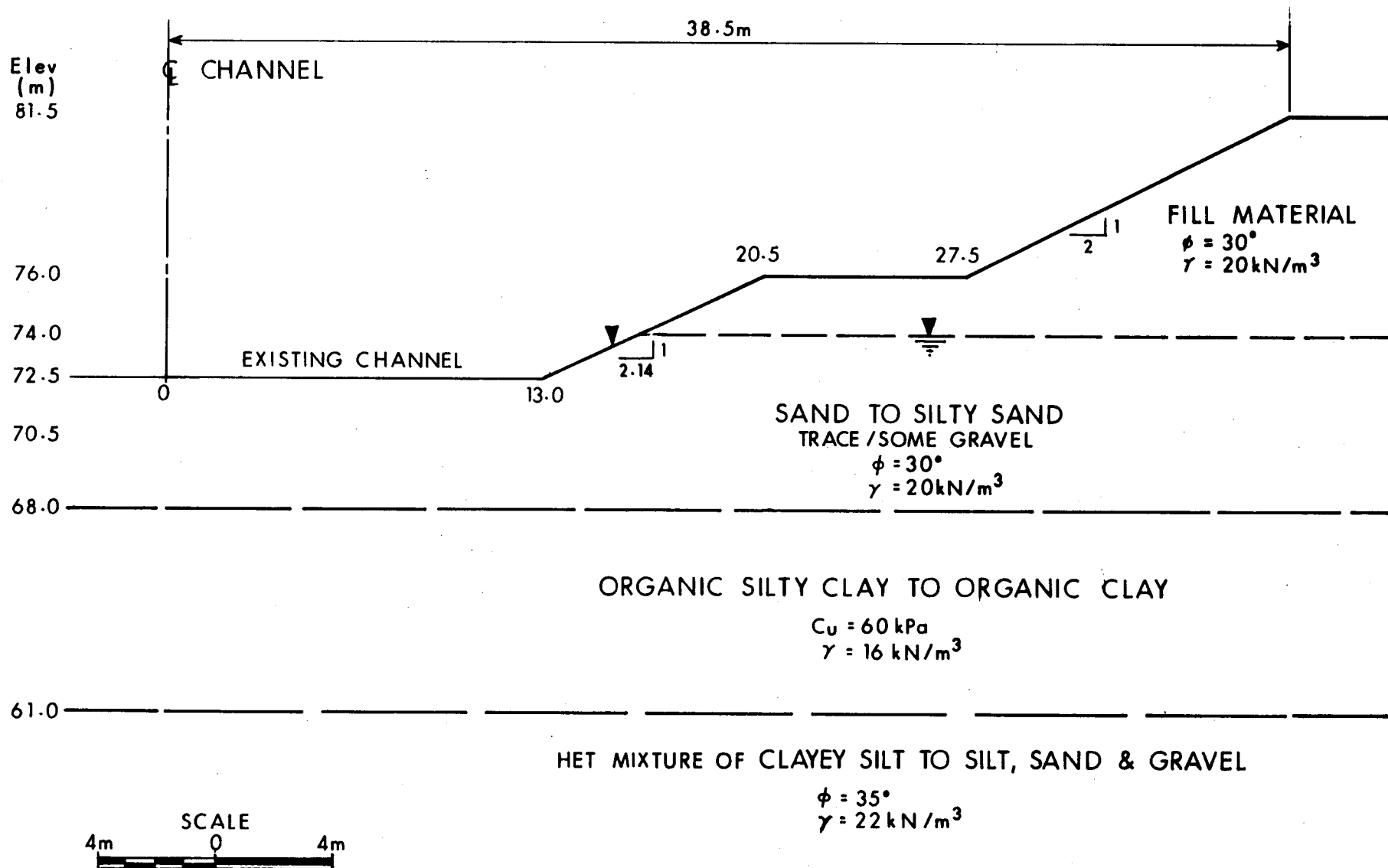
$H_1 = 2 \text{ m} \cdot \text{SURCHARGE}$



**NOT TO SCALE**

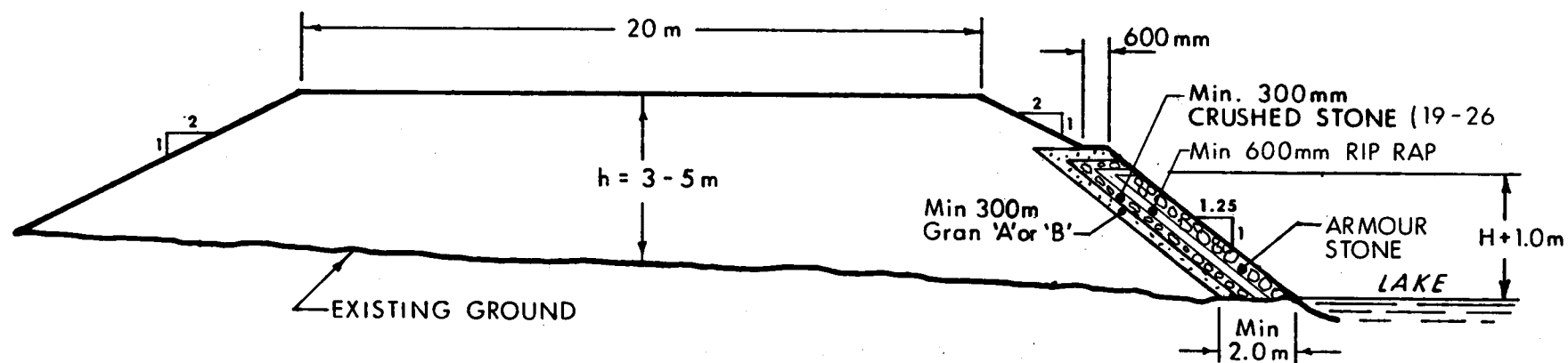
## Figure 12 - Slope Stability Analyses

(EAST APPROACH EMBANKMENT)



WP 325-89-01

h = Height of embankment (Varies)  
H = Maximum wave height expected



SHORELINE PROTECTION SCHEME  
NORTH SERVICE ROAD, JORDAN HARBOUR

WP 325 - 89 - 01

Figure 13

## EXPLANATION OF TERMS USED IN REPORT

**N VALUE:** THE STANDARD PENETRATION TEST (SPT) N VALUE IS THE NUMBER OF BLOWS REQUIRED TO CAUSE A STANDARD 51mm O.D SPLIT BARREL SAMPLER TO PENETRATE 0.3m INTO UNDISTURBED GROUND IN A BOREHOLE WHEN DRIVEN BY A HAMMER WITH A MASS OF 63.5kg, FALLING FREELY A DISTANCE OF 0.76m. FOR PENETRATIONS OF LESS THAN 0.3m N VALUES ARE INDICATED AS THE NUMBER OF BLOWS FOR THE PENETRATION ACHIEVED. AVERAGE N VALUE IS DENOTED THUS  $\bar{N}$ .

**DYNAMIC CONE PENETRATION TEST:** CONTINUOUS PENETRATION OF A CONICAL STEEL POINT (51mm O.D. 60° CONE ANGLE) DRIVEN BY 475 J IMPACT ENERGY ON 'A' SIZE DRILL RODS. THE RESISTANCE TO CONE PENETRATION IS MEASURED AS THE NUMBER OF BLOWS FOR EACH 0.3m ADVANCE OF THE CONICAL POINT INTO THE UNDISTURBED GROUND.

SOILS ARE DESCRIBED BY THEIR COMPOSITION AND CONSISTENCY OR DENSENESS.

**CONSISTENCY:** COHESIVE SOILS ARE DESCRIBED ON THE BASIS OF THEIR UNDRAINED SHEAR STRENGTH ( $c_u$ ) AS FOLLOWS:

$c_u$ (kPa)	0 - 12	12 - 25	25 - 50	50 - 100	100 - 200	> 200
	VERY SOFT	SOFT	FIRM	STIFF	VERY STIFF	HARD

**DENSENESS:** COHESIONLESS SOILS ARE DESCRIBED ON THE BASIS OF DENSENESS AS INDICATED BY SPT N VALUES AS FOLLOWS:

N (BLOWS/0.3m)	0 - 5	5 - 10	10 - 30	30 - 50	> 50
	VERY LOOSE	LOOSE	COMPACT	DENSE	VERY DENSE

ROCKS ARE DESCRIBED BY THEIR COMPOSITION AND STRUCTURAL FEATURES AND / OR STRENGTH.

**RECOVERY:** SUM OF ALL RECOVERED ROCK CORE PIECES FROM A CORING RUN EXPRESSED AS A PERCENT OF THE TOTAL LENGTH OF THE CORING RUN.

**MODIFIED RECOVERY:** SUM OF THOSE INTACT CORE PIECES, 100mm+ IN LENGTH EXPRESSED AS A PERCENT OF THE LENGTH OF THE CORING RUN. THE ROCK QUALITY DESIGNATION (RQD), FOR MODIFIED RECOVERY, IS:

RQD (%)	0 - 25	25 - 50	50 - 75	75 - 90	90 - 100
	VERY POOR	POOR	FAIR	GOOD	EXCELLENT

**JOINTING AND BEDDING:**

SPACING	50mm	50 - 300mm	0.3m - 1m	1m - 3m	> 3m
JOINTING	VERY CLOSE	CLOSE	MOD. CLOSE	WIDE	VERY WIDE
BEDDING	VERY THIN	THIN	MEDIUM	THICK	VERY THICK

## ABBREVIATIONS AND SYMBOLS

### FIELD SAMPLING

S S	SPLIT SPOON	T P	THINWALL PISTON
W S	WASH SAMPLE	O S	OSTERBERG SAMPLE
S T	SLOTTED TUBE SAMPLE	R C	ROCK CORE
B S	BLOCK SAMPLE	P H	T W ADVANCED HYDRAULICALLY
C S	CHUNK SAMPLE	P M	T W ADVANCED MANUALLY
T W	THINWALL OPEN	F S	FOIL SAMPLE

### STRESS AND STRAIN

$u_w$	kPa	PORE WATER PRESSURE
$r_u$	1	PORE PRESSURE RATIO
$\sigma$	kPa	TOTAL NORMAL STRESS
$\sigma'$	kPa	EFFECTIVE NORMAL STRESS
$\tau$	kPa	SHEAR STRESS
$\sigma_1, \sigma_2, \sigma_3$	kPa	PRINCIPAL STRESSES
$\epsilon$	%	LINEAR STRAIN
$\epsilon_1, \epsilon_2, \epsilon_3$	%	PRINCIPAL STRAINS
E	kPa	MODULUS OF LINEAR DEFORMATION
G	kPa	MODULUS OF SHEAR DEFORMATION
$\mu$	1	COEFFICIENT OF FRICTION

### MECHANICAL PROPERTIES OF SOIL

$m_v$	kPa <sup>-1</sup>	COEFFICIENT OF VOLUME CHANGE
$C_c$	1	COMPRESSION INDEX
$C_s$	1	SWELLING INDEX
$C_\alpha$	1	RATE OF SECONDARY CONSOLIDATION
$c_v$	m <sup>2</sup> /s	COEFFICIENT OF CONSOLIDATION
H	m	DRAINAGE PATH
$T_v$	1	TIME FACTOR
U	%	DEGREE OF CONSOLIDATION
$\sigma'_{vo}$	kPa	EFFECTIVE OVERBURDEN PRESSURE
$\sigma'_p$	kPa	PRECONSOLIDATION PRESSURE
$\tau_f$	kPa	SHEAR STRENGTH
$c'$	kPa	EFFECTIVE COHESION INTERCEPT
$\phi'$	-°	EFFECTIVE ANGLE OF INTERNAL FRICTION
$c_u$	kPa	APPARENT COHESION INTERCEPT
$\phi_u$	-°	APPARENT ANGLE OF INTERNAL FRICTION
$\tau_R$	kPa	RESIDUAL SHEAR STRENGTH
$\tau_r$	kPa	REMOULDED SHEAR STRENGTH
$S_t$	1	SENSITIVITY = $\frac{c_u}{\tau_r}$

### PHYSICAL PROPERTIES OF SOIL

$\rho_s$	kg/m <sup>3</sup>	DENSITY OF SOLID PARTICLES	e	1, %	VOID RATIO	$e_{min}$	1, %	VOID RATIO IN DENSEST STATE
$\gamma_s$	kn/m <sup>3</sup>	UNIT WEIGHT OF SOLID PARTICLES	n	1, %	POROSITY	$I_D$	1	DENSITY INDEX = $\frac{e_{max} - e}{e_{max} - e_{min}}$
$\rho_w$	kg/m <sup>3</sup>	DENSITY OF WATER	w	1, %	WATER CONTENT	D	mm	GRAIN DIAMETER
$\gamma_w$	kn/m <sup>3</sup>	UNIT WEIGHT OF WATER	$S_r$	%	DEGREE OF SATURATION	$D_n$	mm	n PERCENT - DIAMETER
$\rho$	kg/m <sup>3</sup>	DENSITY OF SOIL	$w_L$	%	LIQUID LIMIT	$C_u$	1	UNIFORMITY COEFFICIENT
$\gamma$	kn/m <sup>3</sup>	UNIT WEIGHT OF SOIL	$w_p$	%	PLASTIC LIMIT	h	m	HYDRAULIC HEAD OR POTENTIAL
$\rho_d$	kg/m <sup>3</sup>	DENSITY OF DRY SOIL	$w_s$	%	SHRINKAGE LIMIT	q	m <sup>3</sup> /s	RATE OF DISCHARGE
$\gamma_d$	kn/m <sup>3</sup>	UNIT WEIGHT OF DRY SOIL	$I_p$	%	PLASTICITY INDEX = $\frac{w_L - w_p}{w - w_p}$	v	m/s	DISCHARGE VELOCITY
$\rho_{sat}$	kg/m <sup>3</sup>	DENSITY OF SATURATED SOIL	$I_L$	1	LIQUIDITY INDEX = $\frac{w - w_p}{I_p}$	i	1	HYDRAULIC GRADIENT
$\gamma_{sat}$	kn/m <sup>3</sup>	UNIT WEIGHT OF SATURATED SOIL	$I_C$	1	CONSISTENCY INDEX = $\frac{w_L - w}{I_p}$	k	m/s	HYDRAULIC CONDUCTIVITY
$\rho'$	kg/m <sup>3</sup>	DENSITY OF SUBMERGED SOIL	$e_{max}$	1, %	VOID RATIO IN LOOSEST STATE	j	kn/m <sup>3</sup>	SEEPAGE FORCE
$\gamma'$	kn/m <sup>3</sup>	UNIT WEIGHT OF SUBMERGED SOIL						

# RECORD OF BOREHOLE No 1

1 OF 1

METRIC

W.P. 325- 89 - 01 LOCATION CO - ORDS: N 4 782 671; E 314 876 ORIGINATED BY R M  
DIST 4 HWY QEW BOREHOLE TYPE PENNDRILL COMPILED BY M V  
DATUM GEODETIC DATE 85 11 09 CHECKED BY P P

SOIL PROFILE		SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					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		
78.5	Ground Surface												
0.0			1	SS	8								
			2	SS	16								
	SILTY SAND, Occasional Gravel, Loose to Dense		3	SS	33								
			4	SS	31								
			5	SS	10								
68.6			6	SS	15								
7.9	Heterogeneous Mixture of CLAYEY SILT, SAND and GRAVEL, Hard ( Glacial Till )		7	SS	78								
			8	SS	92	/10cm							
64.3			9	SS	100	/5cm							
12.2	End of Borehole * Note: Formerly BH# 9 of 65 - F - 113												



# RECORD OF BOREHOLE No 2

1 OF 1

METRIC

W.P. 325-89-01 LOCATION CO - ORDS: N 4 782 607; E 315 020 ORIGINATED BY R M  
DIST 4 HWY QEW BOREHOLE TYPE WASHBORING COMPILED BY M V  
DATUM GEODETIC DATE 65 11 02 CHECKED BY P P

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			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							WATER CONTENT (%)		
								20 40 60 80 100							20 40 60		
78.1	Ground Surface																
0.0	SILTY SAND, Occasional Gravel, Compact to Dense		1	SS	37		74								19.2	Org. = 12.5%	
			2	SS	36												
			3	SS	26												
			4	SS	38												
			5	SS	14												
70.0	Organic Silt Clay to Clay Firm to Stiff		6	TW	PM		70										
8.1			7	TW	PM		68										
			8	TW	PM		66										
65.4	Heterogeneous Mixture of CLAYEY SILT, SAND and GRAVEL, Very Stiff to Hard ( Glacial Till )		9	SS	26		66										
10.7			10	SS	95	/15cm	64										
			11	SS	100	/8cm	62										
			12	SS	100	/8cm											
60.5	End of Borehole																
15.6																	
	Note: Formerly BH# 2 of 65 - F - 113																

# RECORD OF BOREHOLE No 3

1 OF 1 METRIC

W.P. 325-89-01 LOCATION CO - ORDS: N 4 782 552; E 315 127 ORIGINATED BY R M  
 DIST 4 HWY QEW BOREHOLE TYPE PENNDRIILL COMPILED BY M V  
 DATUM GEODETIC DATE 65 11 04 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					
76.2	Ground Surface												
0.0													
	SILTY SAND, Occasional Gravel, Compact		1	SS	16								
			2	SS	15								
			3	SS	13								
			4	SS	20								
			5	SS	26								
			6	SS	16								
66.9			7	SS	9								
9.3	Organic Silty Clay to Clay Occasional Gravel, Stiff to Very Stiff		8	SS	11								
			9	SS	12								
			10	SS	14								
			11	SS	18								
60.4	Heterogeneous Mixture of CLAYEY SILT, SAND and GRAVEL, Hard ( Glacial Till )		12	SS	100	/13cm							
15.8			13	SS	100	/10cm							
			14	SS	100	/3cm							
56.1													
20.1	End of Borehole Note: Formerly BH# 4 of 65 - F - 113												

# RECORD OF BOREHOLE No 4

1 OF 1

METRIC

W.P. 325- 89 - 01 LOCATION CO - ORDS: N 4 782 479; E 315 266 ORIGINATED BY R M  
DIST 4 HWY QEW BOREHOLE TYPE PENNDRILL COMPILED BY M V  
DATUM GEODETIC DATE 65 11 08 CHECKED BY P P

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT NATURAL MOISTURE CONTENT			UNIT WEIGHT $\gamma$ 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	W <sub>P</sub>	W	W <sub>L</sub>		
78.2	Ground Surface																
0.0	SILTY SAND With Gravel ( Fill )																
0.6			1	SS	17												
	SILTY SAND, Occasional Gravel, Loose to Compact		2	SS	24												
			3	SS	23												
			4	SS	8												
70.1																	
6.1	Organic Silty Clay to Clay  Firm to Stiff		5	SS	5												
			6	SS	9												
			7	TW	PM												
64.6			8	SS	10												
11.6	Heterogeneous Mixture of CLAYEY SILT, SAND and GRAVEL, Organic Silty Clay to Clay Hard ( Glacial Till )		9	SS	130	/15cm											
			10	SS	148	/15cm											
60.5			11	SS	115	/15cm											
15.7	End of Borehole Note: Formerly BH# 6 of 65 - F - 113																

# RECORD OF BOREHOLE No 101

1 OF 1

METRIC

W.P. 325-89-01 LOCATION CO - ORDS: N 4 782 565; E 315 178 ORIGINATED BY M V  
DIST 4 HWY QEW BOREHOLE TYPE HOLLOW STEM AUGER, NW CASING & CONE TEST COMPILED BY M V  
DATUM GEODETIC DATE 92 06 29 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 60 80 100	20 40 60 80 100					
75.6	Ground Surface													
0.0														
			1	SS	8									20 71 (9)
			2	SS	4									
			3	SS	7									
			4	SS	12									
			5	SS	12									
			6	SS	16									
			7	SS	6									
			8	SS	5									
68.4														
7.2			9	SS	3									Org. = 7.2%
			10	TW	PH								14.9	Org. = 9.6%
			11	SS	3									
			12	SS	5									
			13	SS	4									
60.0			14	SS	10									
15.6			15	SS	106	/13cm								
58.4			16	SS	106	/6cm								
17.2														
57.2														
18.4														

# RECORD OF BOREHOLE No 102

1 OF 1

METRIC

W.P. 325- 89 - 01 LOCATION CO - ORDS: N 4 782 608; E 315 036 ORIGINATED BY M V  
DIST 4 HWY QEW BOREHOLE TYPE HOLLOW STEM AUGER, NW CASING & CONE TEST COMPILED BY M V  
DATUM GEODETIC DATE 92 06 30 CHECKED BY P P

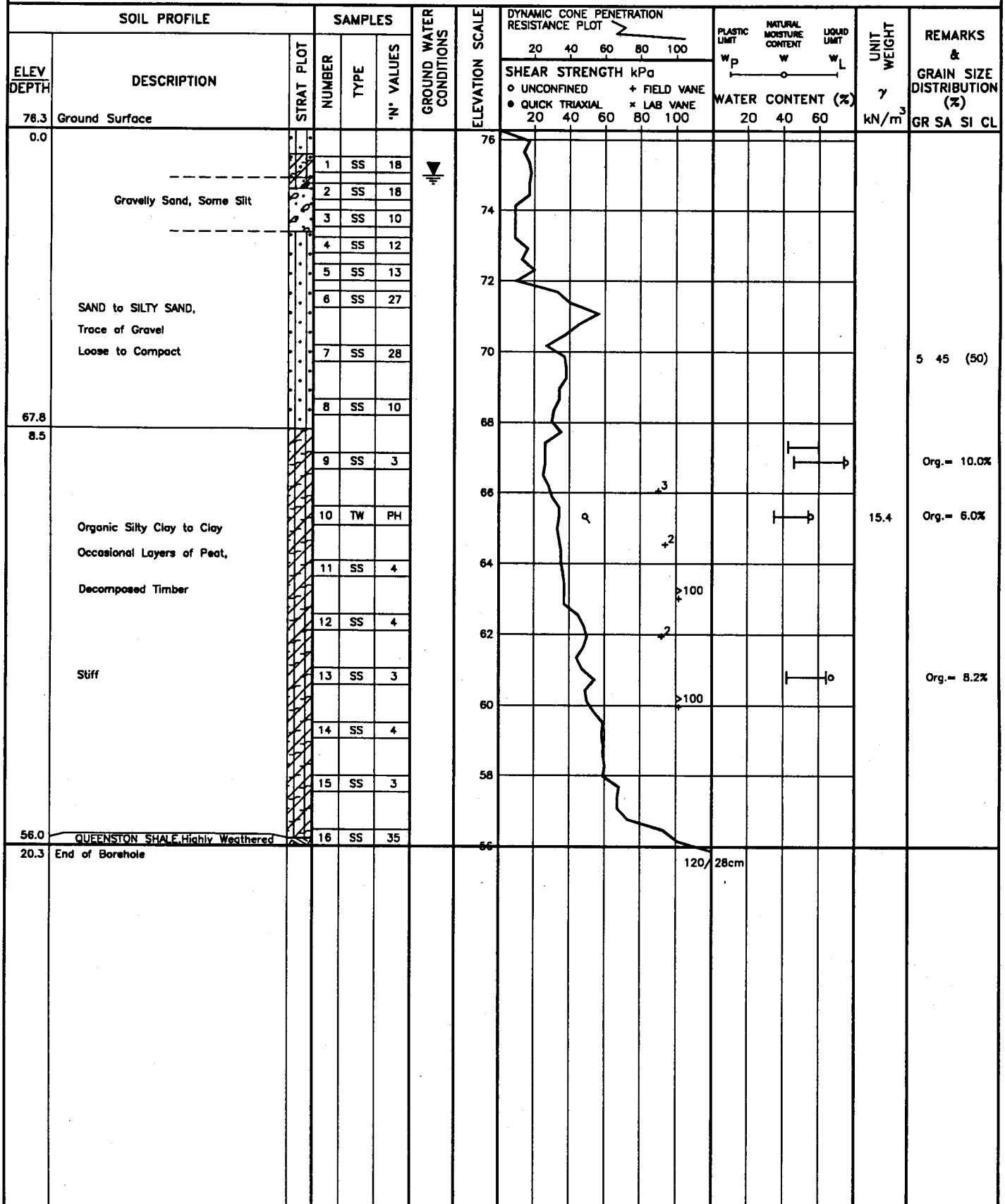
SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT W <sub>P</sub>	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W <sub>L</sub>	UNIT WEIGHT γ	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	'N' VALUES			20	40	60	80	100					
77.1	Ground Surface																
0.0	Organics		1	SS	5	*	76										
	SAND to SILTY SAND, Trace of Gravel, Loose to Compact		2	SS	10		74										
			3	SS	23		72										
	Sandy Silt		4	SS	12		70										4 83 (13)
70.1	Organic Silty Clay to Clay		5	SS	4		68										Org. = 6.4%
7.0	Occasional Layers of Peat, Stiff		6	SS	3		66										
66.1			7	TW	PH		64										
11.0	Het. Mix. of GRAVEL, SAND & SILT Compact ( Glacial Till )		8	SS	18												
65.1			9	SS	88												
12.0	QUEENSTON SHALE, Highly Weathered		10	SS	100	/20cm											
63.2																	
13.9	End of Borehole																
	Note: Water Level Not Established																

# RECORD OF BOREHOLE No 103

1 OF 1

METRIC

W.P. 325- 89 - 01 LOCATION CO - ORDS: N 4 782 656; E 314 942 ORIGINATED BY M V  
 DIST 4 HWY QEW BOREHOLE TYPE HOLLOW STEM AUGER, NW CASING & CONE TEST COMPILED BY M V  
 DATUM GEODETIC DATE 92 07 02 CHECKED BY P P



# RECORD OF BOREHOLE No 104

1 OF 1

METRIC

W.P. 325- 89 - 01 LOCATION CO - ORDS: N 4 782 698; E 314 849 ORIGINATED BY M V  
DIST 4 HWY QEW BOREHOLE TYPE HOLLOW STEM AUGER & CONE TEST COMPILED BY M V  
DATUM GEODETIC DATE 92 07 03 CHECKED BY P P

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT				UNIT WEIGHT $\gamma$ 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	20 40 60 80 100	20 40 60 80 100	20 40 60 80 100		
75.7	Ground Surface												
0.0	SAND to SILTY SAND, Some Gravel,		1	SS	7								
			2	SS	23								
	Gravelly Sand, Some Silt		3	SS	22								
			4	SS	8								
71.7	Loose to Compact												
4.0	Heterogeneous Mixture of Clayey Silt, Sand and Gravel (Glacial Till)		5	SS	6								
	Firm to Stiff		6	SS	8								
67.9			7	SS	109								
7.8	QUEENSTON SHALE, Highly Weathered		8	SS	147	/25cm							
66.1													
9.6	End of Borehole												

## 1 OF 1

METRIC

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

[illegible]



# RECORD OF BOREHOLE No 202

1 OF 1

METRIC

W.P. 325-89-01 LOCATION Co-ords: N 4 782 625.4 E 315 005.4 ORIGINATED BY TS  
DIST 4 HWY QEW BOREHOLE TYPE HS Auger, NW Casing, NXL Core COMPILED BY TS  
DATUM Geodetic DATE 93 09 21 CHECKED BY PP

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>	WATER CONTENT (%)	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						
77.4	Ground Surface																	
0.0	Sand and Gravel (Fill Material) Brown, Compact						77											
75.9																		
1.5	Sand to Silty Sand some Gravel		1	SS	14		75											28 66 (6)
			2	SS	32		73											
	Brown, Compact to Dense		3	SS	4		71											
	Grey, Very Loose																	
69.8			4	SS	2		69											
7.6	Organic Silty Clay to Clay Grey, Firm to Very Stiff		5	SS	2		67											Org.= 7% 0 2 86 12
			6	SS	2		65											Org.= 8% 0 5 82 13
65.2			7	SS	10		63											
12.2	Heterogeneous Mixture of Clayey Silt, Sand and Gravel (Glacial Till)		8	SS	80	/8cm	61											0 1 78 21
63.5	Red, Hard		9	RC	REC	= 100%												RQD = 0%
13.9	Shale Bedrock with interbedded Siltstone Slightly to Moderately Weathered Unweathered		10	RC	REC	= 100%												RQD = 0%
60.4	Red with interbedded Grey, Very Weak to Weak																	
17.0	End of Borehole																	
	* 93 09 22																	

# RECORD OF BOREHOLE No 203

1 OF 1

METRIC

W.P. 325-89-01 LOCATION Co-ords: N 4 782 618.6 E 315 028.1 ORIGINATED BY TS  
DIST 4 HWY QEW BOREHOLE TYPE HS Auger, NW Casing, NXL Core COMPILED BY TS  
DATUM Geodetic DATE 93 09 20-21 CHECKED BY PP

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>	WATER CONTENT (%)	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						
78.0	Ground Surface																	
0.0	Sand to Silty Sand, some Gravel																	
	Brown																	
	Grey		1	SS	23													
	Compact																	
69.9																		
6.1	Organic Silty Clay to Clay Grey, Firm to Very Stiff		2	SS	2													
			3	SS	2													
64.4																		
11.6	Heterogeneous Mixture of Silt, Sand and Gravel (Glacial Till)		4	SS	119													
63.0	Red, Very Dense		5	SS	81													
13.0	Shale Bedrock with interbedded Siltstone		6	RC	REC	= 98%												RQD = 15%
	Red with interbedded Grey, Very Weak to Weak		7	RC	REC	= 100%												RQD = 93%
59.8	Slightly Weathered Unweathered																	
16.2	End of Borehole																	
	* 93 09 22																	

# RECORD OF BOREHOLE No 204

1 OF 1

METRIC

W.P. 325-89-01 LOCATION Co-ords: N 4 782 603.9 E 315 045.8 ORIGINATED BY TS  
DIST 4 HWY QEW BOREHOLE TYPE HS Auger, NW Casing, NXL Core COMPILED BY TS  
DATUM Geodetic DATE 93 09 21 CHECKED BY PP

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>	WATER CONTENT (%) W	UNIT WEIGHT γ	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	'N' VALUES			20	40	60	80	100						
77.3	Ground Surface																	
0.0	Irregular Mixture of Sand, Gravel, Cobbles and Boulders (Fill Material)						76											
74.3	Brown, Compact						74											
3.0	Brown Grey Sand to Silty Sand, some Gravel Loose to Compact		1	SS	10		72											21 70 (9)
69.7			2	SS	7		70											
7.8	Organic Silty Clay to Clay Grey, Firm to Very Stiff		3	SS	12		68											Org=6.5% 0 3 78 19
65.1			4	SS	1		66											Org=2% 20 28 48 4
12.2	Heterogeneous Mixture of Clayey Silt, Sand and Gravel (Glacial Till)		5	SS	1		64											9 24 50 17
63.4	Red, Hard		6	SS	6		62											
13.9	Shale Bedrock with interbedded Siltstone Slightly to Moderately Weathered Unweathered		7	SS	65													RQD = 0%
60.4	Red with interbedded Grey, Very Weak to Weak		8	SS	60	/3cm												RQD = 73%
16.9	End of Borehole • 93 09 27		9	RC	REC	= 100%												
			10	RC	REC	= 100%												

# RECORD OF BOREHOLE No 205

1 OF 1

METRIC

W.P. 325-89-01 LOCATION Co-ords: N 4 782 593.9 E 315 055.3 ORIGINATED BY TS  
 DIST 4 HWY QEW BOREHOLE TYPE HS Auger, NW Casing, NXL Core COMPILED BY TS  
 DATUM Geodetic DATE 93 09 20 CHECKED BY PP

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>	WATER CONTENT (%) W	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						
77.7	Ground Surface																	
0.0	Irregular Mixture of Sand, Gravel, Boulders and Cobbles (Fill Material)																	
74.6	Brown, Compact		1	SS	80	/8cm												
3.1	Sand to Silty Sand, some Gravel																	
	Brown Grey		2	SS	9													
	Loose to Compact																	
69.5																		
8.2	Organic Silty Clay to Clay Grey, Firm to Very Stiff		3	SS	2													
65.5																		
12.2	Heterogeneous Mixture of Clayey Silt, Sand and Gravel (Glacial Till) Brown, Hard		4	SS	42													0 23 51 26
64.0																		
13.7	Heterogeneous Mixture of Silt, Sand and Gravel (Glacial Till) Siltstone fragments Red, Very Dense		5	SS	71	/15cm												
			6	SS	100	/15cm												
60.9																		
16.8	Severely Weathered Unweathered		7	SS	100	/15cm												
	Shale Bedrock with interbedded Siltstone		8	RC	REC	= 100%												RQD = 97%
	Red with Interbedded Grey, Very Weak to Weak		9	RC	REC	= 100%												RQD = 88%
57.4																		
20.3	End of Borehole																	
	• 93 09 21																	

# RECORD OF BOREHOLE No 206

1 OF 1

METRIC

W.P. 325-89-01 LOCATION Co-ords: N 4 782 591.9 E 315 097.4 ORIGINATED BY TS  
DIST 4 HWY QEW BOREHOLE TYPE HS Auger, NW Casing, NXI Core COMPILED BY TS  
DATUM Geodetic DATE 93 09 22 CHECKED BY PP

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>	WATER CONTENT (%)	UNIT WEIGHT γ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	'N' VALUES			20	40	60	80	100						
78.4	Ground Surface																	
0.0	Irregular Mixture of Sand, Gravel, Cobbles and Boulders (Fill Material)						76											
73.4							74											
3.0	Sand to Silty Sand, some Gravel  Grey, Loose to Compact		1	SS	18		72											1 85 (14)
			2	SS	9		70											
68.8			3	SS	2		68											
7.6	Organic Silty Clay to Clay  Grey, Firm to Very Stiff		4	SS	2		66											Org=7.4% 0 5 83 12
			5	SS	2		64											Org=7% 0 6 82 12
			6	SS	4		62											
			7	SS	2		60											
59.5			8	SS	8		58											
16.9	Heterogeneous Mixture of Clayey Silt, Sand and Gravel (Glacial Till) Grey, Hard		9	SS	100	/10cm	56											
58.1			10	RC	REC	= 100%												RQD = 68%
18.3	Shale Bedrock with interbedded Siltstone  Red with interbedded Grey, Very Weak to Weak Unweathered		11	RC	REC	= 100%	56											RQD = 72%
55.0																		
21.4	End of Borehole  • 93 09 23																	

# RECORD OF BOREHOLE No 207

1 OF 1

METRIC

W.P. 325-89-01 LOCATION Co-ords: N 4 782 581.9 E 315 102.8 ORIGINATED BY TS  
DIST 4 HWY QEW BOREHOLE TYPE HS Auger, NW Casing, NXL Core COMPILED BY TS  
DATUM Geodetic DATE 93 09 23 CHECKED BY PP

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	20 40 60 80 100					
76.2	Ground Surface													
0.0	Irregular Mixture of Clayey Silt, Sand and Gravel (Fill Material) Grey, Firm to Stiff						76							
73.2							74							
3.0	Sand to Silty Sand, some Gravel Grey, Loose to Compact		1	SS	11		72							
			2	SS	5		70							
68.6														
7.6	Organic Silty Clay to Clay Grey, Firm to Very Stiff		3	SS	10		68							
			4	SS	2		66							
							64							
			5	SS	2		62							
			6	SS	3		60							
58.4														
16.8 58.5	Het. Mixt. of Clayey Silt, Sand and Gravel (Glacial Till)		7	SS	15									
17.7	Shale Bedrock with Interbedded Siltstone Slightly to Moderately Weathered Unweathered		8	RC	REC	= 100%	58							RQD = 43%
	Red with interbedded Grey, Very Weak to Weak		9	RC	REC	= 100%	56							RQD = 32%
55.5														
20.7	End of Borehole													

# RECORD OF BOREHOLE No 208

1 OF 1

METRIC

W.P. 325-89-01 LOCATION Co-ords: N 4 782 580.2 E 315 119.5 ORIGINATED BY TS  
 DIST 4 HWY QEW BOREHOLE TYPE HS Auger, NW Casing, NXL Core COMPILED BY TS  
 DATUM Geodetic DATE 93 09 22-23 CHECKED BY PP

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	60	80	100					
77.1	Ground Surface																
0.0	Irregular Mixture of Clayey Silt, Sand and Gravel (Fill Material) Grey, Stiff						78										
74.1							74										13 75 (12)
3.0	Sand to Silty Sand, some Gravel  Grey Loose to Compact		1	SS	8		72										
			2	SS	20		70										14 74 (12)
69.5																	
7.6	Organic Silty Clay to Clay  Grey, Firm to Very Stiff		3	SS	8		68										
			4	SS	5		66										Org=9.4% 0 0 91 9
							64										
			5	SS	4		62										Org=10.2% 0 0 90 10
			6	SS	4		60										
			7	SS	4												
58.8																	
18.3	**		8	SS	53		58										RQD = 60%
18.7	Shale Bedrock with interbedded Siltstone  Red with interbedded Grey, Very Weak to Weak Unweathered		9	RC	REC	= 100%	56										RQD = 43%
55.3			10	RC	REC	= 100%											
21.8	End of Borehole  • 93 09 23  ** Heterogeneous Mixture of Clayey Silt, Sand, Gravel, Cobbles and Boulders (Glacial Till)  Grey, Hard																

# RECORD OF BOREHOLE No 301A

1 OF 1

METRIC

W.P. 325-89-01 LOCATION Co-ords: N 4 782 565 ; E 315 179.5 ORIGINATED BY MV  
 DIST. 4 HWY QEW BOREHOLE TYPE HS Auger COMPILED BY TS  
 DATUM Geodetic DATE 93 08 11 CHECKED BY PP

SOIL PROFILE		SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT NATURAL MOISTURE CONTENT			UNIT WEIGHT	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE			20	40	60	80	100	W <sub>p</sub>	W	W <sub>L</sub>		
75.8	Ground Surface															
0.0	Sand to Silty Sand, some Gravel															
	Grey, Very Loose to Compact															
			1	SS	5											
			2	SS	5											
67.2			3	SS	2											
8.4			4	SS	2											
	Organic Silty Clay to Clay		5	TW	PH											
	Blackish Grey, Stiff to Very Stiff															
			6	TW	PH											
			7	SS	3											
			8	TW	PH											
60.1			9	SS	2											
15.7	End of Borehole															
	* 93 08 11															
	** Silt															



# RECORD OF BOREHOLE No 301B\* 1 OF 1 METRIC

W.P. 325-89-01 LOCATION Co-ords: N 4 782 565 : E 315 180 ORIGINATED BY MV  
 DIST 4 HWY QEW BOREHOLE TYPE HS Auger, Vane Testing COMPILED BY TS  
 DATUM Geodetic DATE 93 08 11 CHECKED BY PP

SOIL PROFILE		SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					UNIT WEIGHT 7 KN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE			20	40	60	80	100		
75.6	Ground Surface												
0.0	Probable Sand to Silty Sand, some Gravel  Grey, Very Loose to Compact					74							
						72							
						70							
67.2						68							
8.4	Probable Organic Silty Clay to Clay Blackish Grey,  Stiff to Very Stiff					66				+3			
						64				+3			
						62				+3			
						60				+2			
59.9													
15.7	End of Borehole * see BH 301A for detailed soils information												

# RECORD OF BOREHOLE No 302A 1 OF 1 METRIC

W.P. 325-89-01 LOCATION Co-ords: N 4 782 654 : E 314 946 ORIGINATED BY MV  
 DIST 4 HWY QEW BOREHOLE TYPE HS Auger COMPILED BY TS  
 DATUM Geodetic DATE 93 08 13 CHECKED BY PP

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					UNIT WEIGHT $\gamma$ 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		
78.3	Ground Surface													
0.0	Sand to Silty Sand, some Gravel  Grey, Loose													
			1	SS	9									
67.3			2	SS	6									
9.0	Organic Silty Clay to Clay  Blackish Grey, Stiff to Very Stiff		3	SS	2									
			4	TW	PH									
			5	TW	PH									
			6	TW	PH									
			7	TW	PH									
			8	TW	PH									
			9	TW	PH									
			10	SS	3									
			11	SS	3									
			12	SS	1									
58.9			13	SS	4									
58.3	Silt		14	SS	1									
18.0	End of Borehole  * 93 08 13													

RECORD OF BOREHOLE No 302B\* 1 OF 1 METRIC

W.P. 325-89-01 LOCATION Co-ords: N 4 782 655 : E 315 943 E 314 943 ORIGINATED BY MV  
DIST 4 HWY QEW BOREHOLE TYPE HS Auger, Vane Testing COMPILED BY TS  
DATUM Geodetic DATE 93 08 16-17 CHECKED BY PP

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					
78.3																	
0.0	Probable Sand to Silty Sand, some Gravel																
67.3			1	SS	4												
9.0	Probable Organic Silty Clay to Clay																
	Stiff to Very Stiff																
58.9			2	SS	3												
58.3																	
18.0	End of Borehole * see BH 302A for detailed soils information																

# RECORD OF BOREHOLE No 401

1 OF 1

METRIC

W.P. 325-89-01 LOCATION Co-ords: N 4 782 664.5 E 314 909.9 ORIGINATED BY MV  
 DIST 4 HWY QEW BOREHOLE TYPE HS Auger, Dynamic Cone Penetration Test COMPILED BY TS  
 DATUM Geodetic DATE 93 06 07-08 CHECKED BY PP

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						60	80	100	20
78.2	Ground Surface																	
0.0																		
	Brown, Very Loose		1	SS	2													
	Grey, Compact																	
	Sand to Silty Sand, some Gravel		2	SS	21													
			3	SS	17													
			4	SS	18													
			5	SS	16													
66.8			6	SS	7													
9.4	Organic Silty Clay to Clay		7	SS	13													
	Blackish Grey, Firm to Stiff		8	SS	9													
			9	SS	14													
			10	SS	12													
			11	SS	9													
			12	SS	17													
			13	SS	14													
			14	SS	14													
58.4																		
17.8	Heterogeneous Mixture of Silt, Sand and Gravel (Glacial Till)		15	SS	20													
56.6	Grey, Compact to Dense																	
19.6	Shale Bedrock with Interbedded Siltstone		16	SS	35													
55.8	Moderately Weathered		17	SS	78													
20.6	End of Borehole																	
	* 93 06 08																	

# RECORD OF BOREHOLE No 402

1 OF 1

METRIC

W.P. 325-89-01 LOCATION Co-ords: N 4 782 671.4 E 314 895.5 ORIGINATED BY MV  
 DIST 4 HWY QEW BOREHOLE TYPE HS Auger COMPILED BY TS  
 DATUM Geodetic DATE 93 06 08 CHECKED BY PP

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT $\gamma$ 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	W <sub>p</sub>	W	W <sub>L</sub>		
76.2	Ground Surface																
0.0	Irregular Mixture of Silt, Sand and Gravel (Fill Material)																
74.9	Brown, Compact																
1.3	Brown, Loose		1	SS	8												
	Grey																
	Sand to Silty Sand, some Gravel		2	SS	23												
	Compact to Dense		3	SS	31												
			4	SS	38												
			5	SS	21												
67.2																	
9.0	Organic Silty Clay to Clay		6	SS	11												
	Blackish Grey, Stiff																
			7	SS	11												
			8	SS	8												
			9	SS	9												
			10	SS	21												
60.2																	
16.0	Heterogeneous Mixture of Clayey Silt, Sand and Gravel (Glacial Till)		11	SS	9												
	Grey, Firm		12	SS	7												
59.0																	
56.3	Shale Bedrock - Weathered		13	SS	108	15cm											
19.9	End of Borehole																
	* 93 06 09																

# RECORD OF BOREHOLE No 403

1 OF 1

METRIC

W.P. 325-89-01 LOCATION Co-ords: N 4 782 674.9 E 314 886.4 ORIGINATED BY MV  
 DIST 4 HWY QEW BOREHOLE TYPE HS Auger COMPILED BY TS  
 DATUM Geodetic DATE 93 06 09 CHECKED BY PP

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					
76.3	Ground Surface																
0.0 75.5	Irregular Mixture of Silt, Sand and Gravel(Fill Material)																
0.8	Sand to Silty Sand, some Gravel  Grey Compact Dense to Very Dense		1	SS	11												
			2	SS	10												
			3	SS	53												
			4	SS	32												
68.4	Loose		5	SS	9												
7.9	Organic Silty Clay to Clay  Blackish Grey, Stiff		6	SS	12												
65.5			7	SS	7												
10.8	Heterogeneous Mixture of Clayey Silt, Sand and Gravel (Glacial Till)		8	SS	9												
63.4	Grey, Firm to Stiff		9	SS	76												
12.9	End of Borehole  * 93 06 10  ** Shale Bedrock																

# RECORD OF BOREHOLE No 404

1 OF 1

METRIC

W.P. 325-89-01 LOCATION Co-ords: N 4 782 676.6 E 314 881.6 ORIGINATED BY MV  
DIST 4 HWY QEW BOREHOLE TYPE HS Auger COMPILED BY TS  
DATUM Geodetic DATE 93 06 09-10 CHECKED BY PP

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					UNIT WEIGHT $\gamma$ 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	20 40 60 80 100	20 40 60 80 100	20 40 60 80 100	20 40 60 80 100		
76.3	Ground Surface													
0.0	Irregular Mixture of Silt, Sand and Gravel (Fill Material)						76							
75.2														
1.1	Sand to Silty Sand, some Gravel		1	SS	8		74							
	Grey, Loose to Dense		2	SS	17		72							
			3	SS	32		70							
			4	SS	8		68							
68.8			5	SS	5		66							
7.5	Organic Silty Clay to Clay Blackish Grey, Stiff		6	SS	9		64							
66.9			7	SS	13									
9.4	Heterogeneous Mixture of Clayey Silt, Sand and Gravel (Glacial Till)		8	SS	12									
65.9			9	SS	**									
10.4	Shale Bedrock with Interbedded Siltstone		10	RC	REC = 37%									RQD = 14%
	Moderately Weathered													
	Unweathered													
	Red with interbedded Grey, Weak to Very Weak		11	RC	REC = 85%									RQD = 25%
63.0														
13.3	End of Borehole													
	• 93 06 10													
	** Sampler Bouncing													

# RECORD OF BOREHOLE No 405

1 OF 1

METRIC

W.P. 325-89-01 LOCATION Co-ords: N 4 782 678.0 E 314 877.9 ORIGINATED BY MV  
 DIST 4 HWY QEW BOREHOLE TYPE HS Auger COMPILED BY TS  
 DATUM Geodetic DATE 93 06 10 CHECKED BY PP

SOIL PROFILE		SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT $\gamma$ 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	W <sub>P</sub>	W		
78.3	Ground Surface															
0.0	Irregular Mixture of Silt, Sand and Gravel (Fill Material)															
74.9																
1.4	Sand to Silty Sand, some Gravel  Grey, Loose to Compact		1	SS	7											
			2	SS	12											
			3	SS	18											
69.7			4	SS	7											
6.6	Organic Silty Clay to Clay Blackish Grey, Stiff		5	SS	6											
68.8			6	SS	18											
7.5	Heterogeneous Mixture of Clayey Silt, Sand and Gravel (Glacial Till)															
67.1	Grey, Very Stiff to Hard															
9.2	End of Borehole															



# RECORD OF BOREHOLE No 406

1 OF 1

METRIC

W.P. 325-89-01 LOCATION Co-ords: N 4 782 481.1 E 315 313.9 ORIGINATED BY MV  
 DIST 4 HWY QEW BOREHOLE TYPE HS Auger COMPILED BY TS  
 DATUM Geodetic DATE 93 06 07-08 CHECKED BY PP

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					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	20 40 60 80 100	20 40 60 80 100	20 40 60 80 100	20 40 60 80 100		
76.9	Ground Surface													
0.0	Clayey Silt													
75.6	Brown, Stiff													
1.3			1	SS	19									
	Organic Silt Grey, Firm		2	SS	2									
	Sand to Sandy Silt													
	Grey, Compact		3	SS	18									
71.0														
5.9	Heterogeneous Mixture of Clayey Silt, Sand and Gravel (Glacial Till)		4	SS	41									
			5	SS	41									
	Grey, Hard													
67.6			6	SS	95	/15cm								
9.3	End of Borehole • 93 06 08													

# RECORD OF BOREHOLE No 407

1 OF 1

METRIC

W.P. 325-89-01 LOCATION Co-ords: N 4 782 485.5 E 315 299.7 ORIGINATED BY MV  
 DIST 4 HWY QEW BOREHOLE TYPE HS Auger COMPILED BY TS  
 DATUM Geodetic DATE 93 06 14 CHECKED BY PP

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	60	80	100					
78.5	Ground Surface																
0.0	Clayey Silt																
75.1	Brown, Stiff																
1.4	Organic Silt		1	SS	8												
	Sand to Sandy Silt		2	SS	9												
	Grey, Loose																
71.4			3	SS	5												
5.1	Heterogeneous Mixture of Clayey Silt, Sand and Gravel (Glacial Till)		4	SS	8												
			5	SS	50												
	Grey, Hard		6	SS	62	/15cm											
67.2			7	SS	72	/15cm											
9.3	End of Borehole																
	* 93 06 15																

# RECORD OF BOREHOLE No 408

1 OF 1

METRIC

W.P. 325-89-01 LOCATION Co-ords: N 4 782 491.0 E 315 282.8 ORIGINATED BY MV  
 DIST 4 HWY QEW BOREHOLE TYPE HS Auger COMPILED BY TS  
 DATUM Geodetic DATE 93 06 15 CHECKED BY PP

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					
76.4	Ground Surface																
0.0	Clayey Silt																
75.1	Brown, Very Stiff																
1.3	Trace Organics		1	SS	7												
	Sand to Silty Sand		2	SS	10												
	Grey, Loose to Compact		3	SS	8												
			4	SS	6												
70.5																	
5.9	Organic Silty Clay to Clay		5	SS	6												
68.9	Grey, Stiff		6	SS	10												
7.5	Sandy Silt to Silt		7	SS	11												
	Grey, Very Loose to Loose		8	SS	1												
			9	SS	7												
65.4			10	SS	22												
11.0	Heterogeneous Mixture of																
64.4	Clayey Silt, Sand and Gravel		11	SS	143												
	(Glacial Till)																
12.0	End of Borehole																
	* 93 06 16																

# RECORD OF BOREHOLE No 409

1 OF 1

METRIC

W.P. 325-89-01 LOCATION Co-ords: N 4 782 493.6 E 315 312.8 ORIGINATED BY MV  
DIST 4 HWY QEW BOREHOLE TYPE HS Auger COMPILED BY TS  
DATUM Geodetic DATE 93 06 15 CHECKED BY PP

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
78.3	Ground Surface																	
0.0	Clayey Silt						76											
74.9	Brown, Very Stiff																	
1.4	Sand to Sandy Silt		1	SS	6		74											
	Grey, Very Loose to Loose		2	SS	4													
			3	SS	2		72											
70.6			4	SS	2													
5.7	Organic Silty Clay to Clay		5	SS	5		70											
	Blackish Grey to Grey, Stiff		6	SS	4													
			7	SS	5		68											
67.7			8	SS	5													
8.6	Stiff Hard		9	SS	10		66											
			10	SS	109													
	Heterogeneous Mixture of Clayey Silt, Sand and Gravel (Glacial Till)		11	SS	82	/13cm	64											
	Grey		12	SS														
			13	RC	REC	= 25%	62										RQD = 0%	
							60											
58.4																		
17.9	Shale Bedrock						58											
57.6																		
18.7	End of Borehole * Sampler Bouncing																	

# **ROCK CORE DESCRIPTION** **WP 325-89-01**

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CORE RECOVERY					CORE DESCRIPTION	
BH#	RC#	DEPTH (m)	% CR*	% RQD*	DEPTH (m)	DESCRIPTION
201	5	12.65-14.17	90	45	12.65-15.70	SHALE, greyish red, with interbedded greenish grey SILTSTONE (9%); very fine grained; very weak to weak; unweathered to slightly weathered (moderately weathered, 12.65-13.82 m); fractures moderate to extremely close spaced, flat to dipping, undulating to planar, smooth.
	6	14.17-15.70	100	84		
202	9	13.94-15.47	100	0	13.94-16.99	SHALE, greyish red, with interbedded greenish grey SILTSTONE (6%); very fine grained; very weak to weak; unweathered to slightly weathered (moderately weathered, 13.94-15.14 m); fractures close to extremely close spaced, flat to near vertical, planar to undulating, smooth.
	10	15.47-16.99	100	0		
203	6	13.11-14.63	98	15	13.11-16.15	SHALE, greyish red, with interbedded greenish grey SILTSTONE (4%); very fine grained; very weak to weak; unweathered to slightly weathered (moderately weathered, 13.11-14.20 m); fractures wide to extremely close spaced, flat to near vertical, planar to undulating, smooth.
	7	14.63-16.15	100	93		
204	9	13.89-15.42	100	0	13.89-16.94	SHALE, greyish red, with interbedded greenish grey SILTSTONE (4%); very fine grained; very weak to weak; unweathered to slightly weathered (moderately weathered, 13.89-15.65 m); fractures moderate to extremely close spaced, flat to near vertical, undulating to planar, smooth.
	10	15.42-16.94	100	73		

\*CR = CORE RECOVERY

\*RQD = ROCK QUALITY DESIGNATION

*Note: Depths are approximated where core recovery is less than 100%*  
 Logged by: DAW, Soils and Aggregates Section

# ROCK CORE DESCRIPTION

## WP 325-89-01

Page 2 of 2

CORE RECOVERY					CORE DESCRIPTION	
BH#	RC#	DEPTH (m)	% CR*	% RQD*	DEPTH (m)	DESCRIPTION
205	8	16.92-18.44	100	97	16.92-19.96	SHALE, greyish red, with interbedded greenish grey SILTSTONE (8%); very fine grained; very weak to weak; unweathered to slightly weathered (moderately weathered, 16.92-16.99 m); fractures moderate to extremely close spaced, flat to dipping, planar to undulating, smooth.
	9	18.44-19.96	100	88		
206	10	18.39-19.91	100	68	18.39-21.44	SHALE, greyish red, with interbedded greenish grey SILTSTONE (11%); very fine grained; very weak to weak; unweathered to slightly weathered (moderately weathered, 18.39-18.59 m); fractures moderate to extremely close spaced, flat to near vertical, planar to undulating, smooth.
	11	19.91-21.44	100	72		
207	8	17.68-19.20	100	43	17.68-20.73	SHALE, greyish red, with interbedded greenish grey SILTSTONE (18%); very fine grained; very weak to weak; unweathered to slightly weathered (moderately weathered, 17.68-18.77 m); fractures close to extremely close spaced, flat to dipping, planar to undulating, smooth.
	9	19.20-20.73	100	32		
208	9	18.75-20.27	100	60	18.75-18.90	OVERBURDEN (till).
	10	20.27-21.79	100	43	18.90-21.79	SHALE, greyish red, with interbedded greenish grey SILTSTONE (13%); very fine grained; very weak to weak; unweathered to slightly weathered (moderately weathered, 18.90-18.95 m); fractures moderate to extremely close spaced, flat to near vertical, undulating to planar, smooth.

\*CR = CORE RECOVERY

\*RQD = ROCK QUALITY DESIGNATION

*Note: Depths are approximated where core recovery is less than 100%*  
 Logged by: DAW, Soils and Aggregates Section