

# Terraprobe

*Consulting Geotechnical & Environmental Engineering*

*Construction Materials Inspection & Testing*

**FOUNDATION INVESTIGATION AND DESIGN REPORT  
TEE, LYONS AND BLACK CREEKS BRIDGE STRUCTURES  
LYONS CREEK NORTH BOUND AND SOUTH BOUND  
BRIDGE REPLACEMENTS  
QUEEN ELIZABETH WAY (QEW)  
MINISTRY OF TRANSPORTATION, ONTARIO  
DB-2014-2036, SITES:34-66/1 and 34-66/2  
GEOCRETS NO. 30M3-288**

**PREPARED FOR:** MMM Group Limited  
2655 North Sheridan Way, Suite 300  
Mississauga, Ontario  
L5K 2P8

**Attention:** Mr. Brian Bridges, P.Eng.

File No. 1-15-0689  
July 15, 2016

**Terraprobe Inc.**

**Distribution:**

4 Copies- MTO Project Manager  
1 Copy - MTO Pavements and Foundations Section  
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1 Copy - MMM Group Limited, Mississauga  
1 Copy - Terraprobe Inc., Brampton

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**Terraprobe Inc.**

**Greater Toronto**  
11 Indell Lane  
**Brampton**, Ontario L6T 3Y3  
(905) 796-2650 Fax: 796-2250  
brampton@terraprobe.ca

**Hamilton – Niagara**  
903 Barton Street, Unit 22  
**Stoney Creek**, Ontario L8E 5P5  
(905) 643-7560 Fax: 643-7559  
stoneycreek@terraprobe.ca

**Central Ontario**  
220 Bayview Drive, Unit 25  
**Barrie**, Ontario L4N 4Y8  
(705) 739-8355 Fax: 739-8369  
barrie@terraprobe.ca

**Northern Ontario**  
1012 Kelly Lake Rd., Unit 1  
**Sudbury**, Ontario P3E 5P4  
(705) 670-0460 Fax: 670-0558  
sudbury@terraprobe.ca

[www.terraprobe.ca](http://www.terraprobe.ca)

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

**LYONS CREEK NORTH BOUND AND SOUTH BOUND BRIDGE REPLACEMENTS  
QUEEN ELIZABETH WAY  
REGIONAL MUNICIPALITY OF NIAGARA, ONTARIO  
CONTRACT NUMBER DB-2014-2036**



## 1.0 INTRODUCTION

Terraprobe Inc. (Terraprobe) has been retained by MMM Group Limited (MMM) on behalf of Dufferin Construction, to provide foundation engineering services in support of detailed designs for the replacement of the Lyons Creek North-Bound and South-Bound bridges.

This project is based on the Ministry of Transportation, Ontario (MTO) Design Build Minor Request for Proposals titled "*Tee Creek, Lyons and Black Creeks Bridge Structures, Central Region*", *Contract Number. DB-2014-2036*. The terms of reference and scope of work for the foundation engineering services are outlined in MTO's RFP.

This report presents the factual data on the subsurface conditions at the Lyons Creek North-Bound and South-Bound Bridges, Sites 34-66/1 and 34-66/2 on the Queen Elizabeth Way (QEW), City of Niagara Falls, Regional Municipality of Niagara, Ontario.

## 2.0 SITE DESCRIPTION

The site (with MTM coordinates of N 4,765,775; E 336,500) is located on the QEW, approximately 225 m south of the Lyons Creek Road underpass in the City of Niagara Falls, Ontario. The key plan on the Borehole Locations and Soil Strata Drawing, (Drawing 1) provides an overview of the site location.

The existing bridges are cast-in-place concrete T-beam structures that are approximately 30.3 m long and 13 m wide. Each bridge consists of a 19.7 m centre span and two 5.3 m long cantilevered end spans. Construction records indicate that the bridge foundations were formed by driving sheet piles in cruciform shaped sections, partially excavating the soils in the sheet pile surround, and filling the excavated area with concrete.

The terrain at the bridge sites and surrounding area is generally flat and the bridges span Lyons Creek which flows from west to east. The topography and contour elevations indicate that the bridges were constructed to span Lyons Creek via approach embankments consisting of  $3\pm$  m high side slopes and forward slopes that are  $4.5\pm$  m to  $5.0\pm$  m high.

## 3.0 INVESTIGATION PROCEDURES

### 3.1.1 Current Investigation

The field work for this project was carried out from November 23 to December 16, 2016 and consisted of drilling and sampling three boreholes to depths that range from 36 m to 38.2 m below ground surface. The approximate borehole locations are shown on Drawing 1.

Based on drawings provided by Terraprobe, MMM's surveyors staked out the borehole locations and supplied the borehole coordinates and geodetic elevations to Terraprobe. The actual borehole locations drilled by Terraprobe are referenced to MMM's original staked location.

The boreholes were drilled with truck and track-mounted drill rigs supplied and operated by specialist drilling contractors. Samples of the overburden soils were generally obtained at intervals of 0.75 m and 1.5 m depth using a 50 mm outer diameter (O.D.) split-spoon sampler in conjunction with the Standard

Penetration Testing (SPT) procedures as specified in ASTM Method D15861. Relatively undisturbed samples of the silty clay to clayey silt soils were collected with thin wall tube samplers (Shelby Tubes) and the undrained shear strength of the soil was determined by performing in-situ field vane tests with an MTO 'N' vane.

Ground water conditions in the open boreholes were observed during the drilling operations. The boreholes were backfilled in accordance with current MTO procedures and Ontario Regulation 903 (as amended).

The recovered soil samples were subjected to Visual Identification (VI) and select soil samples were also subjected to a laboratory testing programme consisting of natural moisture content, grain size distribution analyses, Atterberg limits determinations and one dimensional consolidation testing in accordance with MTO and/or ASTM Standards as appropriate.

### 3.1.2 Previous Investigation

In June and July 2013, subsurface investigations were carried out by Golder Associates Limited (Golder) of Mississauga, Ontario. Four boreholes (Boreholes 13-03, 13-04, 13-05 and 13-06) were drilled and the data from these investigations were used to supplement the current investigation. The boreholes were advanced to depths ranging from 35.4 m to 38.1 m below ground surface and the Record of Borehole sheets and associated laboratory test results are provided in Appendix A and B respectively. The approximate locations of these boreholes are shown on Drawing 1.

The Golder boreholes were drilled using continuous flight hollow stem auger drilling techniques. The overburden soil samples were obtained at selected intervals using a split-spoon sampler in conjunction with the Standard Penetration Test (SPT) method and the undrained shear strength of the soil was determined by performing in-situ field vane tests with an MTO 'N' vane.

### 3.1.3 Borehole Locations

The borehole locations in MTM NAD83 northing and easting coordinates, the ground surface elevations referenced to geodetic datum and depths drilled are summarized in the following table.

Borehole Data				
Borehole No.	MTM Coordinate System		Ground Surface Elevation (m)	Borehole Depth (m)
	Northing (m)	Easting (m)		
Lyons Creek North Bound Bridge				
BH1*	4 765 762.3	336 525.2	174.3	38.2
BH 13-05	4 765 768.8	336 538.3	174.3	36.9
BH2	4 765 798.9	336 508.6	174.9	37.8
BH 13-06	4 765 798.4	336 509.5	174.9	35.4
Lyons Creek South Bound Bridge				
BH1*	4 765 762.3	336 525.2	174.3	38.2
BH 13-04	4 765 750.7	336 512.4	174.5	38.1
BH3	4 765 782.8	336 485.8	174.9	36.0
BH 13-03	4 765 781.6	336 487.0	175.0	35.4

\* Borehole 1 drilled in the QEW Median between the North Bound and South Bound Bridges.

1 ASTM D1586 – Standard Test Method for Standard Penetration Tests and Split Barrel Sampling of Soils.

## **4.0 SITE GEOLOGY AND SUBSURFACE CONDITIONS**

### **4.1 Regional Geology**

The site is located between the Niagara Escarpment and Lake Erie in the physiographic region of Southern Ontario referred to as the Haldimand Clay Plain. The Haldimand Clay Plain is best described as falling into a series of parallel belts with the highest ground adjacent to the Escarpment. Generally, this region is flat and poorly drained although it includes several distinctive landforms such as dunes, cobble, clay and sand beaches, limestone pavements and back-shore wetland basins<sup>2</sup>.

The Niagara Region is underlain by a sequence of very gently south-dipping dolostones, limestones, shales and sandstones overlying Precambrian basement rock. The key elements in the bedrock geology of the region are the multiple layers of softer sedimentary limestones, shale, sandstone and dolostone.

The bedrock unit at this site is the Salina Formation of Upper Silurian Age. This unit consists essentially of grey, very finely crystalline, laminated argillaceous dolostone with grey, calcareous shale partings and gypsum veins and lenses of varying thicknesses.

### **4.2 Subsurface Conditions**

Reference is made to the Record of Borehole Sheets in Appendix A. Details of the encountered soil stratigraphy are presented in this appendix and on the "Borehole Locations and Soil Strata" drawings. An overall description of the stratigraphy is given in the following paragraphs.

The stratigraphic boundaries shown on the Record of Boreholes and on the interpreted stratigraphic sections are inferred from non-continuous soil sampling and therefore represent transitions between soil types rather than exact planes of geological change. The subsurface conditions will vary between and beyond the borehole locations.

In summary, the ground surface is underlain by a flexible pavement and fill soils consisting of very loose to compact sand and silty sand and soft to stiff silty clay. The pavement and fill material are underlain by deposits of very soft to stiff clayey organic silt, firm to very stiff silty clay to clayey silt, stiff to hard clayey silt till, very loose to dense sandy silt and silt, very loose to very dense sand to silty sand and loose to very dense layers of sand and gravel to gravelly sand. The sand and gravel deposit also contains cobble and boulder inclusions. A more detailed description of the subsurface conditions encountered in the boreholes is provided in the following sections.

#### **4.2.1 Topsoil**

A 200 mm thick topsoil layer was encountered in Borehole 1. Topsoil thickness will vary beyond the borehole location.

#### **4.2.2 Flexible Pavement**

A flexible pavement consisting of 175 mm to 380 mm thick asphalt concrete underlain by sand and gravel fill was encountered. Terraprobe Borehole 2 and Golder Borehole 13-06 also encountered a 300 mm thick

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<sup>2</sup> Chapman and Putnam, "The Physiography of South Ontario", 3rd Edition, 1984.



bridge approach slab and Golder Borehole 13-04 encountered sand and gravel fill at ground surface. The locations, thicknesses and base elevations of the sand and gravel fill are summarized in the following table.

**Sand and Gravel Fill Borehole Data**

Borehole No.	Fill Thickness (mm)	Fill Base Elevation (m)
BH2	900	173.5
BH3	600	174.0
BH 13-03	500	174.1
BH 13-04	1400	173.1
BH 13-05	1300	172.8
BH 13-06	1000	173.4

Standard Penetration tests carried out in the sand and gravel fill gave SPT N-values that range from 7 blows to 55 blows for 0.3 m of penetration indicating a loose to very dense relative density.

A grain size distribution test was carried out on a sample of the gravelly sand fill and the results are illustrated on the grain size distribution curve Figure B1, Appendix B1. The grain size distribution curves of two samples of the sand and gravel fill from the Golder study are depicted on Figure B1 in Appendix B2. These results show a grain size distribution consisting of 39% to 51% gravel, 38% to 46% sand, 11% to 13% silt and, 2% and 3% clay size soil particles. The natural water content of samples of the sand and gravel fill range from 2% to 4% by weight.

#### 4.2.3 Fill – Sand and Silty Sand

Sand and silty sand fill soils were encountered at this site. Summarized in the following table are the locations, explored depths and base elevations of the sand and silty sand fill.

**Sand and Silty Sand Fill Borehole Data**

Borehole No.	Sand & Silty Sand Fill Thickness (m)	Sand & Silty Sand Fill Depth of Deposit (m)	Sand & Silty Sand Fill Base Elevation (m)
BH1	1.9	2.1	172.2
BH3	0.4	1.3	173.6
BH 13-03	0.6	1.5	173.5
BH 13-04	0.8	2.2	172.3
BH 13-05	0.3	1.8	172.5

Standard Penetration tests carried out in the sand and silty sand fill measured SPT N-values of 4 to 12 blows per 0.3 m of penetration indicating a very loose to compact relative density.

A grain size distribution test was carried out on a sample of the silty sand to sand fill and the results are illustrated on the grain size distribution curve Figure B2, Appendix B1. These results of a gravel and sand fraction of the fill show a grain size distribution consisting of 51% gravel, 37% sand, 10% silt and, 2% clay size soil particles. The moisture content of samples of the sand and silty sand fill range from is 4% to 26% by weight.

#### 4.2.4 Fill – Silty Clay to Clay

Silty clay to clay fill material was encountered at this site. The locations, explored depths and base elevations of the silty clay fill are summarized in the following table.

**Silty Clay to Clay Fill Borehole Data**

<b>Borehole No.</b>	<b>Silty Clay to Clay Fill Thickness (m)</b>	<b>Silty Clay to Clay Fill Depth of Deposit (m)</b>	<b>Silty Clay to Clay Fill Base Elevation (m)</b>
BH1	3.2	5.3	169.0
BH2	4.5	5.9	169.0
BH3	3.9	5.2	169.7
BH 13-03	3.1	4.6	170.4
BH 13-04	0.8	3.0	171.5
BH 13-05	2.8	4.6	169.7
BH 13-06	4.0	5.5	169.4

Standard Penetration tests performed in the silty clay to clay fill measured SPT N-values that range from 3 to 12 blows for 0.3 m of penetration and field vane tests measured in-situ undrained shear strengths that range from 86 kPa to more than 100 kPa indicating a soft to stiff consistency. The natural water content of samples of the silty clay to clay fill range from 17% to 30% by weight.

The grain size distribution curves of samples of the silty clay fill are depicted on Figure B3 in Appendix B1 and the Golder grain size distribution curves of the silty clay to clay fill are shown on Figure B2, Appendix B2. These results show a grain size distribution consisting of 0% to 4% gravel, 2% to 4% sand, 33% to 45% silt and 51% to 65% clay size particles.

Samples of the silty clay fill were also subjected to Atterberg limits tests and the results are presented on Figure B4 in Appendix B1. The plasticity chart illustrating the Golder Atterberg limits results is provided as Figure B3 in Appendix B2. These results indicate that the fill is an intermediate to high plasticity (CI to CH) cohesive soil. The results from the Atterberg limits tests are summarized below:

Liquid Limit:	44% to 51%
Plastic Limit:	22% to 24%
Plasticity Index:	21% to 29%
Natural Moisture Content:	24% to 27%

#### 4.2.5 Clayey Organic Silt

Clayey organic silt was encountered at this site in the Golder study. Summarized below are the locations, thicknesses, depths and base elevations of this deposit.

**Clayey Organic Silt Borehole Data**

Borehole No.	Clayey Organic Silt Thickness (m)	Clayey Organic Silt Depth (m)	Clayey Organic Silt Base Elevation (m)
BH 13-03	0.9	5.5	169.5
BH 13-04	2.5	5.5	169.0
BH 13-05	0.9	5.5	168.8

Standard Penetration tests carried out in the clayey organic silt measured SPT N-values of 1 to 4 blows per 0.3 m of penetration and field vane tests measured in-situ undrained shear strengths that range from 81 kPa to more than 96 kPa. Based on these tests, the Golder study describes the clayey organic silt as very soft to stiff.

The grain size distribution plot of a sample of the clayey organic silt from the Golder study is illustrated in Figure B4 in Appendix B2. These results show a grain size distribution consisting of 0% gravel, 4% sand, 41% silt and 55% clay sized particles. The moisture content of samples of the clayey organic silt varies from 35% to 119.7%.

The Atterberg limits test of a sample of the clayey organic silt from the Golder study is plotted on the plasticity chart in Figure B5, Appendix B2 and the Atterberg limits test results are summarized below.

Liquid Limit:	52 %
Plastic Limit:	24%
Plasticity Index:	28%
Natural Moisture Content:	34%

#### 4.2.6 Silty Clay to Clayey Silt

Upper and lower deposits of silty clay to clayey silt soils were encountered at this site. Summarized below are the locations, thicknesses, depths and base elevations of these deposits.

**Silty Clay to Clayey Silt Borehole Data**

Borehole No.	Silty Clay to Clayey Silt Thickness (m)	Silty Clay to Clayey Silt Depth (m)	Silty Clay to Clayey Silt Base Elevation (m)
BH1	9.4	14.7	159.6
	2.6	20.4	153.9
	1.5	34.5	139.8
BH2	11.9	17.8	157.1
BH3	9.5	14.7	160.2
	6.4	22.6	152.3
BH 13-03	14.6	20.1	154.9
BH 13-04	12.8	18.3	156.2
	1.9	35.4	139.1
BH 13-05	11.0	16.5	157.8
	1.7	19.5	154.8

### Silty Clay to Clayey Silt Borehole Data

Borehole No.	Silty Clay to Clayey Silt Thickness (m)	Silty Clay to Clayey Silt Depth (m)	Silty Clay to Clayey Silt Base Elevation (m)
	0.3	33.8	140.5
BH 13-06	12.3	17.8	157.1

Standard Penetration tests carried out in the upper silty clay to clayey silt deposits measured SPT N-values of "Weight of Hammer" to 19 blows per 0.3 m of penetration. Field vane tests measured in-situ undrained shear strengths that range from 47 kPa to more than 100 kPa as depicted on the undrained shear strength versus elevation plot in Figure B5, Appendix B1. Based on these tests the upper silty clay to clayey silt is described as having a generally firm to very stiff consistency with occasional soft zones. The sensitivity of the upper silty clay to clayey silt varies from 1.0 to 3.0, indicating a low sensitivity soil class (Canadian Foundation Engineering Manual [CFEM], 2006). The lower silty clay to clayey silt deposits are described as having a hard consistency based on SPT N-values that ranged from 41 to more than 100 blows per 0.3 m of penetration.

The Terraprobe grain size distribution plots of sixteen samples of the silty clay to clayey silt soils are depicted in Figures B6 and B7 in Appendix B1. The grain size distribution plots samples of the silty clay to clayey silt from the Golder study are illustrated in Figure B6 and B16 in Appendix B2. These results show a grain size distribution consisting of 0% to 9% gravel, 0% to 55% sand, 31% to 77% silt and, 12% to 42% clay sized particles. The moisture content of samples of the silty clay to clayey silt varies from 15% to 35% by weight and the unit weight of a tested sample is 20 kN/m<sup>3</sup>.

Samples of the silty clay to clayey silt deposit from the Terraprobe study were also subjected to Atterberg limits tests and the results are presented in Figures B8 and B9 in Appendix B1. The Atterberg limits tests of samples of the silty clay to clayey silt from the Golder study are plotted on the plasticity charts in Figure B7 and B17, Appendix B2. These values indicate that the silty clay to clayey silt deposit is a low plasticity (CL) cohesive soil. The Atterberg limits test results are summarized below and the results are also plotted versus elevation in Figure B10, Appendix B1.

Liquid Limit:	23% to 36 %
Plastic Limit:	15% to 19%
Plasticity Index:	6% to 19%
Natural Moisture Content:	16% to 31%

A one-dimensional consolidation test was performed on a sample of the silty clay to clayey silt and the results are presented in Figures B11 to B13 in Appendix B1. The results of the one-dimensional consolidation test are summarized below.

### One-Dimensional Consolidation Test Results

Borehole/Sample No.	Sample Depth/Elevation (m)	$\sigma'_{vo}$ (kPa)	$\sigma'_p$ (kPa)	$C_c$	$C_r$	$e_o$
BH3, Sample TW11	9.4/165.5	106.5	185.0	0.217	0.04	0.66

Where:

- $\sigma'_{vo}$  = effective overburden pressure
- $\sigma'_p$  = Preconsolidation pressure;
- $C_c$  = Compression index;
- $C_r$  = Recompression index; and
- $e_o$  = Initial void ratio.

The preconsolidation pressure derived from the consolidation test data is slightly higher than the effective overburden pressure suggesting that the silty clay to clayey silt deposit is slightly over-consolidated.

#### 4.2.7 Clayey Silt Till

A clayey silt till deposit was encountered at this site and the locations, explored depths and base elevations of this deposit are summarized in the following table.

**Clayey Silt Till Borehole Data**

Borehole No.	Clayey Silt Till Thickness (m)	Clayey Silt Till Depth (m)	Clayey Silt Till Base Elevation (m)
BH1	3.1	17.8	156.5
BH 13-04	1.5	19.8	154.7
BH 13-05	1.3	17.8	156.5

Standard Penetration tests carried out in the clayey silt till deposit measured SPT N-values that range from 11 blows to 50 blows for less than 0.3 m of penetration indicating a stiff to hard consistency. The moisture content of samples of the clayey silt till range from 10% to 21% by weight.

The Terraprobe grain size distribution curve of a clayey silt till sample is shown in Figure B14 in Appendix B1. The grain size distribution plots of two samples of the clayey silt till from the Golder study are illustrated in Figure B8 in Appendix B2. These results show a grain size distribution consisting of 3% to 18% gravel, 17% to 32% sand, 33% to 58% silt and, 17% to 25% clay sized particles. Cobbles and boulders can also be expected to occur in till soils.

A sample of the clayey silt till deposit from the Terraprobe study was also subjected to an Atterberg limits test and the results are presented in Figures B15 in Appendix B1. The Atterberg limits tests of samples of the clayey silt till from the Golder study are plotted on the plasticity chart in Figure B9, Appendix B2. These values indicate that the clayey silt till deposit is a low plasticity (CL-ML and CL) cohesive soil. The Atterberg limits test results are summarized below.

Liquid Limit:	18% to 24%
Plastic Limit:	11% to 14%
Plasticity Index:	7% to 12%
Natural Moisture Content:	10% to 21%

#### 4.2.8 Sandy Silt and Silt

Sandy silt and silt deposits were encountered at this site and the locations, explored depths and base elevations of the deposits are summarized in the following table.

**Sandy Silt and Silt Borehole Data**

Borehole No.	Sandy Silt & Silt Thickness (m)	Sandy Silt & Silt Depth (m)	Sandy Silt & Silt Base Elevation (m)
BH1	10.3	30.7	143.6
BH3	1.5	16.2	158.7
BH 13-03	3.1	23.2	151.8

#### Sandy Silt and Silt Borehole Data

Borehole No.	Sandy Silt & Silt Thickness (m)	Sandy Silt & Silt Depth (m)	Sandy Silt & Silt Base Elevation (m)
BH 13-04	3.1	29.3	145.2
BH 13-05	9.8	29.3	145.0
BH 13-06	2.3	20.1	154.8

Standard Penetration tests carried out in this deposit measured SPT N-values that range from 3 blows to 37 blows per 0.3 m of penetration indicating a very loose to dense relative density. The moisture content of samples of the sandy silt and silt range from 18% to 25% by weight.

Terraprobe grain size distribution curves of samples of the sandy silt and silt are shown in Figure B16 in Appendix B1. The grain size distribution plots of samples of the sandy silt and silt from the Golder study are illustrated in Figures B10 and B11 in Appendix B2. These results show a grain size distribution consisting of 0% gravel, 3% to 31% sand, 65% to 89% silt and, 4% to 18% clay sized particles.

#### 4.2.9 Sand to Silty Sand

Sand to silty sand deposits were encountered at this site. Summarized in the following table are the locations, explored depths and base elevations of the sand to silty sand.

#### Sand to Silty Sand Borehole Data

Borehole No.	Sand to Silty Sand Thickness (m)	Sand to Silty Sand Depth (m)	Sand to Silty Sand Base Elevation (m)
BH2	2.6	20.4	154.5
	9.0	29.5	145.4
BH3	8.8	31.4	143.5
BH 13-03	9.1	32.3	142.7
BH 13-04	6.4	26.2	148.3
	4.2	33.5	141.0
BH 13-06	9.2	29.3	145.6

Standard Penetration tests carried out in the sand to silty sand deposits measured SPT N-values of 3 blows to 83 blows per 0.3 m of penetration indicating a very loose to very dense relative density. The moisture content of samples of the sand to silty sand range from 11% to 25% by weight.

Terraprobe grain size distribution curves of samples of the sand to silty sand are shown in Figure B17 in Appendix B1. The grain size distribution plots of samples of the sand to silty sand from the Golder study are illustrated in Figures B12 and B13 in Appendix B2. These results show a grain size distribution consisting of 0% gravel, 44% to 81% sand, 14% to 52% silt and, 2% to 8% clay sized particles.

#### 4.2.10 Sand and Gravel to Gravelly Sand

Deposits ranging in composition from sand and gravel to gravelly sand were encountered at this site. Summarized in the following table are the locations, explored depths and base elevations of this deposit.

### Sand and Gravel to Gravelly Sand Borehole Data

Borehole No.	Sand & Gravel to Gravelly Sand Thickness (m)	Sand & Gravel to Gravelly Sand Depth of Deposit (m)	Sand & Gravel to Gravelly Sand Base Elevation (m)
BH1	2.3 -	33.0 38.2*	141.3 136.1
BH2	-	37.8*	137.1
BH3	-	36.0*	138.9
BH 13-03	-	35.4*	139.6
BH 13-04	-	38.1*	136.4
BH 13-05	4.2 -	33.5 36.9*	140.8 137.4
BH 13-06	-	35.4*	139.5

\* Borehole termination depth.

Standard Penetration tests carried out in these deposits measured SPT N-values that range from 8 to more than 100 blows per 0.3 m of penetration indicating a loose to very dense relative density. The moisture contents of samples of the sand and gravel to gravelly sand range from 5% to 14% by weight.

Terraprobe grain size distribution curves of samples of the sand and gravel to gravelly sand are shown in Figure B18 in Appendix B1. The grain size distribution plots of samples of the sand and gravel and sandy gravel from the Golder study are illustrated in Figures B14 and B15 in Appendix B2. These results show a grain size distribution consisting of 0% to 59% gravel, 28% to 70% sand, 6% to 17% silt and, 3% to 6% clay sized particles. Cobbles and boulders were also encountered in the sand and gravel deposit in Terraprobe Borehole 2.

### 4.3 Ground Water Levels

The ground water conditions were observed in the boreholes during and upon completion of drilling. Based on the ground water observations, the soil moisture contents, and the creek water level; the ground water level at this site is estimated to be at an approximate elevation of 173± m. The ground water level is expected to fluctuate seasonally, will be controlled by the free water level in the creek, and is expected to rise during wet periods of the year.

## 5.0 MISCELLANEOUS

The investigation was carried out using equipment supplied and operated by DBW Drilling Services of Toronto, Ontario and Elite Drilling Services of St. Catharines, Ontario. The field operations were monitored by Ms. Sepideh D-Monfared, MEng. and Mr. Anthony Felice, who observed the drilling, sampling and in situ testing operations and logged the boreholes. The laboratory testing was carried out at Terraprobe's Brampton laboratory.

This report was prepared by Mr. Rehman Abdul, P.Eng., a Senior Geotechnical Engineer and Principal with Terraprobe. Mr. Michael Tanos, P.Eng., Terraprobe's Designated MTO Contact conducted an independent quality control review.

### Terraprobe Inc.



*Rehman Abdul*

R. Abdul, P.Eng.  
Principal, Senior Geotechnical Engineer



*Michael Tanos*

Michael Tanos, P.Eng.  
Principal, Designated MTO Contact





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

**LYONS CREEK NORTH BOUND AND SOUTH BOUND BRIDGE REPLACEMENTS  
QUEEN ELIZABETH WAY  
REGIONAL MUNICIPALITY OF NIAGARA, ONTARIO  
CONTRACT NUMBER DB-2014-2036**



## **6.0 DISCUSSION AND ENGINEERING RECOMMENDATIONS**

### **6.1 General**

This report presents interpretation of the geotechnical data in the factual report and presents geotechnical design recommendations to assist the design team to select a preferred foundation alternative for the Lyons Creek North-Bound and South-Bound Bridge replacements.

This report was prepared in the context of a design-build contract. The discussion and recommendations presented in this report are based on our understanding of the project and our interpretation of the factual data obtained from the subsurface investigations. If conditions are encountered during construction that are different than what is understood at the time this report was prepared, based on the subsurface conditions and testing described herein; Terraprobe must be consulted to update, supplement or otherwise revise these recommendations as appropriate.

The existing bridges are cast-in-place concrete T-beam structures that are approximately 30.3 m long and 13 m wide. Each bridge consists of a 19.7 m centre span and two 5.3 m long cantilevered end spans. Construction records indicate that the bridge foundations were formed by driving sheet piles to practical refusal in cruciform shaped sections, partially excavating the soils in the sheet pile surround, and filling the excavated area with concrete.

The replacement structures being considered are single span integral abutment bridges each with a span length of 22.8 m and deck widths of 14.05 m and 17.05 m for the NBL and SBL structures respectively. The bridges will be constructed on the same alignment and profile as the existing structures.

### **6.2 Foundation Alternatives**

The advantages, disadvantages, risks and consequences of foundation options for supporting a bridge are presented in Table 1. These foundation alternatives are summarized below.

- Spread footings;
- Augered Caissons (drilled shafts); and
- Driven piles.

#### **6.2.1 Spread Footings**

The firm to stiff silty clay to clayey silt deposit is unsuitable for supporting spread footings. The geotechnical resistance of this deposit is low and spread footings will also experience large time dependent consolidation settlements. There are also no advantages in founding spread footings on an engineered fill pad because the geotechnical resistance of the silty clay to clayey silt deposit remains low with increasing depth. Consequently, spread footings are not considered to be a practical foundation alternative.

## 6.2.2 Caissons (Drilled Shafts)

Caissons will have to be founded at depths in the order of 32± m to 34± m below ground surface, in the submerged and very dense gravelly sand and sand and gravel deposits and, the sand and gravel deposit also contains cobbles and boulders. It would be difficult to seal the bottom of the liner to exclude ground water because of the high permeability of the gravelly sand and sand and gravel layers and the presence of cobbles and boulders. Attempts at dewatering and maintaining a sufficiently dry excavation to permit cleaning, inspection and high quality construction, would be challenging and most likely impractical. Therefore, caisson foundations are not recommended for supporting the structure.

## 6.2.3 Driven Piles

Steel tube piles were considered but were excluded. During pile driving these “high displacement” piles will temporarily alter the pore water pressure of the silty clay to clayey silt, sand and silt, and silt deposits, causing a substantial increase in penetration resistance and heave. Since the sand and gravel layer contains cobbles and boulders, it may also be impossible to drive “high displacement” steel tube piles to the required penetration depth to achieve the desired load carrying capacity. Alternatively, H-piles are low displacement sections that have a higher probability of being installed successfully by driving to refusal in the gravelly sand and sand and gravel deposit.

### 6.2.3.1 Axial Resistance

The concentric axial factored geotechnical design resistance at ULS, the geotechnical reaction at SLS, and the estimated pile tip elevations of HP 310x110 steel piles are tabulated below. The structural resistance of the pile should also be checked by the structural designer.

**Axial Resistance of HP 310x110 Driven Piles**

Location	Reference Borehole	Estimated Pile Tip Elevation (m)	Founding Stratum	Factored Axial Resistance U.L.S (kN)	SLS (25 mm Settlement) (kN)*
Lyons Creek North-Bound Bridge					
South Abutment	BH1	139.0±	Gravelly Sand	1600	1200
North Abutment	BH2	138.0±	Sand and Gravel		
Lyons Creek South-Bound Bridge					
South Abutment	BH1	139.0±	Gravelly Sand	1600	1200
North Abutment	BH3	140.0±	Gravelly Sand		

### 6.2.3.2 Downdrag

The abutment backfill of the new bridges will be placed in the open forward slope areas below the existing bridges where excavations will extend to underside abutment elevations of elevation 170± m. Abutment backfill placed in this area will impart an additional load to the underlying silty clay to clayey silt deposit, thereby causing consolidation settlement to occur.

The construction staging requires the bridges to be constructed before the abutment backfill is placed and before consolidation settlement is complete. Therefore, downdrag loads will be imparted to the piles. An HP 310x110 pile section shall be designed for an unfactored downdrag load of 400 kN per pile.

### 6.2.3.3 Pile Tips

The tips of all piles should be fitted with a pile point from an approved manufacturer such as Titus Steel Company (Standard H-Point, HPP-S Series) or Associated Pile & Fitting Corp. (APF Hard Bite H-Pile Point). The use of a pile point is recommended for the following reasons:

- The piles will be penetrating into soil containing cobbles and boulders and these aggressive driving conditions require a higher level of tip protection; and
- A pile point will provide increased cutting ability to the pile section, reduce the probability of misalignment and increase the probability of achieving the desired penetration.

### 6.2.3.4 Pile Installation

Pile installation should be carried out in accordance with OPSS 903, November 2009. Steel H-piles will be driven to practical refusal in the gravelly sand to sand and gravel deposit. Since the sand and gravel deposit contains cobbles and boulders, piles may encounter effective refusal in this stratum without reaching the predicted pile tip elevations.

Pile driving should be controlled by the Hiley Formula and an Ultimate Pile Resistance (R) to be specified by the structural engineer in accordance with Clause 3.3.2 (b) Construction Stage of the Structural Manual. The Ultimate Pile Resistance “R” must have a minimum value of 3,200 kN and be greater than the Ultimate Geotechnical Resistance (or twice the ULS Design Load). Hiley formula calculations need not be carried out until the pile has been driven as outlined below:

- QEW North Bound Bridge Elev. 139± m at the north abutment and Elev. 140± m at the south abutment; and
- QEW South Bound Bridge Elev. 141± m at the north abutment and Elev. 140± m at the south abutment.

The pile driving hammer must be capable of installing the piles to the depths specified in the contract document. A suitable hammer capable of delivering a rated energy of at least 60 kJ/blow, but not more than 70 kJ/blow is recommended.

### 6.2.3.5 Integral Abutment Considerations

The ground conditions at this site are considered suitable for an integral abutment design. The integral abutment design requires that the piles possess flexibility in the upper 3 m of the pile length. The borehole data indicates that the upper 3 m of pile will be surrounded by soft to firm silty clay fill and the native firm silty clay deposit. Based on the consistency of these soils, lateral pile movement is not expected to be constrained.

### 6.2.3.6 Lateral Resistance

The lateral resistance of the piles may be calculated using a value for the coefficient of horizontal subgrade reaction ( $k_s$ ) and the ultimate lateral resistance ( $p_{ult}$ ) as outlined in the equations below:

$$\begin{aligned}
 k_s &= n_h z / D \text{ [cohesionless soils]} & (\text{kN/m}^3) \\
 k_s &= 67 S_u / D \text{ [cohesive soils]} & (\text{kN/m}^3) \\
 p_{ult} &= 3 \gamma z K_p \text{ [cohesionless soils]} & (\text{kPa}) \\
 p_{ult} &= 9 S_u \text{ [cohesive soils]} & (\text{kPa}) \\
 \text{where } z &= \text{depth of pile embedment} & (\text{m}) \\
 D &= \text{pile width} & (\text{m}) \\
 S_u &= \text{undrained shear strength} & (\text{kPa}) \\
 n_h &= \text{coefficient of horizontal subgrade reaction} & (\text{kN/m}^3) \\
 \gamma &= \text{unit weight} & (\text{kN/m}^3) \\
 K_p &= \text{passive earth pressure coefficient} & (\text{dimensionless})
 \end{aligned}$$

The spring constant  $K$ , for analysis of a pile segment or element of length  $L$  metres, can be obtained from the expression,  $K = k_s \times L \times D$  (kN/m). The ultimate lateral resistance  $P_{ult}$ , of a pile segment or element of length  $L$  metres, can be obtained from the expression,  $P_{ult} = p_{ult} \times L \times D$ .

The equations provided above and the soil parameters provided in the following table, may be used to analyze the interaction between a pile and the surrounding soil. The lateral pressures obtained from the analysis must not exceed the ultimate lateral resistance or the factored structural flexural resistance of the pile. A maximum horizontal passive resistance of 120 kN (ULS) is recommended for design.

**Recommended Soil Parameters**

Area Reference Borehole No	Applicable Elevation**	Soil Type	Bulk Unit Weight (kN/m <sup>3</sup> )	Angle of Internal Friction (φ) Degrees	Undrained Shear Strength (S <sub>u</sub> ) (kPa)	Recommended n <sub>h</sub> Value (kN/m <sup>3</sup> )*
<b>Lyons Creek North Bound Bridge</b>						
South Abutment BH 1 and BH 13-05	170.1 – 168.8	Fill – Silty Clay	19	0	25	–
	168.8 – 159.6	Silty Clay to Clayey Silt	20	0	60	–
	159.6 – 156.5	Clayey Silt Till	20	0	75	–
	156.5 – 153.9	Silty Clay	20	0	60	–
	153.9 – 143.6	Sandy Silt	19	32	–	4400
	143.6 – 141.3	Sand & Gravel	21	35	–	11000
	141.3 – 139.8	Silty Clay	20	0	200	–
North Abutment BH 2 and BH 13-06	139.8 – 136.1	Gravelly Sand	21	35	–	11000
	170.1 – 169.0	Fill – Silty Clay	19	0	25	–
	169.0 – 157.1	Silty Clay to Clayey Silt	20	0	60	–
	157.1 – 154.5	Silt & Sand to Silt	19	32	–	1300
	154.5 – 145.4	Sand	19	32	–	4400
	145.4 – 137.1	Sand & Gravel	21	35	–	11000



### Recommended Soil Parameters

Lyons Creek South Bound Bridge						
South Abutment BH 1 and BH 13-04	170.1 – 169.0	Fill – Silty Clay	19	0	25	–
	169.0 – 159.6	Silty Clay to Clayey Silt	20	0	60	–
	159.6 – 156.5	Clayey Silt Till	20	0	75	–
	156.5 – 153.9	Silty Clay	20	0	60	–
	153.9 – 143.6	Sandy Silt	19	32	–	4400
	143.6 – 141.3	Sand & Gravel	21	35	–	11000
	141.3 – 139.8	Silty Clay	20	0	200	–
North Abutment BH 3 and BH 13-03	139.8 – 136.1	Gravelly Sand	21	35	–	11000
	170.1 – 169.5	Fill – Silty Clay	19	0	25	–
	169.5 – 160.2	Silty Clay to Clayey Silt	20	0	60	–
	160.2 – 158.7	Silt	18	25	–	4400
	158.7 – 152.3	Silty Clay to Clayey Silt	20	0	60	–
	152.3 – 143.5	Silty Sand / Silt & Sand	19	32	–	4400
	143.5 – 138.9	Gravelly Sand	21	35	–	11000

\* Values estimated based on Table 20.3 data, Canadian Foundation Engineering Manual, 3rd edition, 1992

\*\* Based on an underside abutment elevation of 170.1 m.

Since the piles are end bearing, their vertical resistance will not be significantly affected by the pile spacing. Pile interaction should be considered with reference to the Canadian Highway Bridge Design Code, 2006 (CHBDC 2006) Clause 6.8.9.2.

For lateral soil/pile group interaction analysis, the equation for  $k_s$  quoted in this section may be used in conjunction with appropriate reduction factors. Intermediate values of the horizontal subgrade reaction reduction factor  $R$  may be obtained by interpolation. Where a pile group is oriented perpendicular to the direction of loading, group action may be considered by reducing values for  $k_s$  by a reduction factor  $R$  as follows:

Pile Spacing Perpendicular to Direction of Loading	Horizontal Subgrade Reaction Reduction Factor, $R$
4 D*	1.00
1 D*	0.50

\* D is the width of the pile, and spacing is measured centre to centre.

Where a pile group is oriented parallel to the direction of loading, group action may be considered by reducing values for  $k_s$  by a reduction factor  $R$  as follows:

Pile Spacing Parallel to Direction of Loading	Horizontal Subgrade Reaction Reduction Factor, $R$
8 D*	1.00
6 D*	0.70
4 D*	0.40
3 D*	0.25

\* D is the width of the pile, and spacing is measured centre to centre.

## 6.2.4 Recommended Foundation Scheme

From a geotechnical point of view, it is recommended that the new bridges be supported on steel H-pile foundations driven to effective refusal in the sandy gravel deposit. Based on the advantages,



disadvantages, risks and consequences, a steel H-pile foundation scheme is reliable, allows for the design of integral abutment bridges and has the highest probability of acceptable structural performance.

## 6.2.5 Design Frost Depth

Pile caps should be founded at a minimum depth of 1.2 m of earth cover below the lowest surrounding grade to provide adequate protection against frost penetration, as per OPSD 3090.101. Rock protection provides frost protection equivalent to 50% of the layer thickness and, this aspect should be considered when designing frost depths.

## 6.3 Lateral Earth Pressure

Earth pressures are generally calculated using the following expression:

$$P_h = K(\gamma h + q)$$

where  $P_h$  = horizontal pressure on the wall (kPa);

$K$  = lateral earth pressure coefficient;

$\gamma$  = unit weight of retained soil (kN/m<sup>3</sup>);

$h$  = depth below top of fill where pressure is computed (m); and

$q$  = value of any surcharge (kPa).

Earth pressures acting on the structure should be computed in accordance with Clause 6.9 of the CHBDC 2006 and, according to Clause 6.9.3 of the CHBDC 2006; a compaction surcharge should also be added. For soils with an angle of internal friction ranging from 30° to 35° the magnitude should be 12 kPa at the top of the fill decreasing linearly to 0 kPa at a depth of 1.7 m; or decreasing linearly to 0 kPa at a depth of 2.0 m for soils with an angle of internal friction that exceeds 35°.

The lateral earth pressure coefficients are dependent on the material used as backfill and typical values are provided in the following table.

**Lateral Earth Pressure Coefficients**

Wall Condition	Lateral Earth Pressure Coefficient (K)					
	OPSS Granular A or OPSS Granular B Type II $\phi = 35^\circ$ ; $\gamma = 22.8 \text{ kN/m}^3$		OPSS Granular B Type I $\phi = 32^\circ$ ; $\gamma = 21.2 \text{ kN/m}^3$		Ultra Light Weight Fill $\phi = 35^\circ$ ; $\gamma = 12.5 \text{ kN/m}^3$	
	Horizontal Surface Behind Wall	Sloping Surface Behind Wall (2H:1V)	Horizontal Surface Behind Wall	Sloping Surface Behind Wall (2H:1V)	Horizontal Surface Behind Wall	Sloping Surface Behind Wall (2H:1V)
Active (Unrestrained Wall)	0.27	0.38*	0.30	0.46*	0.27	0.38*
At rest (Restrained Wall)	0.43	-	0.47	-	0.43	-
Passive (Movement Towards Soil Mass)	3.70	-	3.30	-	3.70	-

\* For wing walls.



The lateral earth pressure coefficients provided in the table above are “ultimate” values that require certain structural movements for the respective conditions to be mobilized. The values to use in design can be estimated from Figure C6.16 in the Commentary to the CHBDC, 2006.

## 6.4 Abutment Backfill

The backfill to the abutment walls should be carried out in accordance with OPSS 902. Granular backfill should be placed to the extents shown in OPSD 3101.150 and the granular backfill shall comply with the OPSS.PROV 1010 specifications. The design of the abutment should also incorporate a subdrain as shown in OPSD 3101.150.

All granular fill should be placed in loose lifts not exceeding 150 mm thick and should be compacted to at least 95 % of the materials Standard Proctor Maximum Dry Density (SPMDD). Equal heights of backfill should be maintained on both sides of the structure during all stages of backfill placement, and backfilling operations should be carried out in accordance with OPSS 902. Compaction equipment including hand operated vibratory equipment shall comply with OPSS.PROV 501.

## 6.5 Erosion Protection

The November 2015 water level in Lyons Creek is at elevation  $171.0 \pm$  m and this water will partially submerge and erode the forward and side slopes at both bridge abutments if the slopes are not protected. Design of an erosion protection scheme will depend on hydrologic, hydraulic and/or other concerns. We recommend using rip-rap to armour the embankment slopes with which creek water is likely to be in contact. The rip-rap should be installed in accordance with OPSS 511.

Surface water can also cause erosion beneath the rip-rap and loss of fines through the rip-rap. Therefore, a properly designed filter should be installed between the rip-rap and the embankment material.

We recommend that a qualified Hydraulics Engineer be consulted to provide inputs on the design thickness and lateral extent of rip-rap protection and to estimate the scour depth.

## 6.6 Excavations

All excavations must be carried out in accordance with the guidelines outlined in the *Occupational Health and Safety Act (OHSA) and Regulations for Construction Projects*. Where workers must enter excavations extending deeper than 1.2 m, the trench walls must be suitably sloped and/or braced in accordance with the OHSA. Within the envisaged depths of temporary excavations (i.e. up to elevation  $170 \pm$  m), the OHSA soil classifications are:

- Embankment fill – Type 3 soil; and
- Clayey Organic Silt – Type 3 soil.

The side slopes of temporary excavations may be formed no steeper than 1H:1V for Type 3 soils and excavations should be carried out in accordance with OPSS 902.



## 6.7 Ground Water Control

Surface water and ground water control will be necessary to enable construction below the ground water table. We recommend temporarily diverting the flow of creek water away from the construction area. Around the perimeter of the excavation, a cofferdam and an interceptor perimeter trench should also be installed to prevent surface water from entering the excavation.

The design, installation, operation and maintenance of the dewatering system is the Contractor's responsibility. Excavations will extend through the existing embankment fill, and the clayey organic silt deposit. A suitable dewatering system that can be employed is gravity drainage and pumping from strategically placed filtered sumps.

## 6.8 Approach Embankments

### 6.8.1 Settlement

To predict the magnitude and time rate of settlement of the underlying silty clay soils, the commercially available program Settle 3D developed by Rocscience Inc. was used. The deformation parameters used for the analyses were established using data obtained from a consolidation test as well as empirical correlations of undrained shear strengths, laboratory index tests and soil moisture contents. These deformation parameters are provided in Figures C1, C2, C3 and C4, in Appendix C. The preconsolidation pressure ( $\sigma'_p$ ) derived from the consolidation test data is slightly higher than the effective overburden pressure suggesting that the silty clay to clayey silt deposit is slightly over-consolidated.

The deformation parameters used for the settlement analyses are summarized in the following table.

**Silty Clay to Clayey Silt Deformation Parameters**

Parameter	Silty Clay to Clayey Silt
Preconsolidation Pressure (kPa.)	185
Compression Index - $C_c$	0.22
Recompression Index - $C_r$	0.04
Initial Void Ratio - $e_o$	0.7
Coefficient of Consolidation - $C_v$ (m <sup>2</sup> /s)	$2.06 \times 10^{-7}$

The General Arrangement drawing shows that the bridges will be constructed on the same alignment and profile as the existing structures. However, abutment backfill for the new bridges will be placed in the open forward slope areas below the existing bridges. The new abutments construction will require excavations that extend approximately to the underside abutment elevations of the new bridges i.e. elevation 170± m.

The settlement analyses is guided by MTO's *Embankment Settlement Criteria for Design* Page 4 Table 1.2 which stipulates that 25 mm of post-construction settlement is allowable over a horizontal transition zone of 25 m measured from the bridge abutment.

It is estimated that the Granular A abutment backfill will induce approximately 85± mm of consolidation settlement in the footprint area of the new fill. About 60± mm of this settlement will be essentially complete in four months and after four months the remaining settlement in the 25 m transition zone will be 25 mm. Since it is impractical to wait four months for the 60± mm of settlement to be complete, the Design Builder can consider the following alternatives.

- Surcharge the top of abutment backfill (i.e. top of pavement design subgrade elevation) with a load equivalent to a 2 m vertical height of Granular A material. About  $60\pm$  mm of the settlement will be essentially complete in six weeks and after the surcharge period, the remaining consolidation settlement in the 25 m transition zone will be  $25\pm$  mm;
- Construct a Retained Soil System (RSS) behind the abutments and wingwalls that would allow construction of the substructure to proceed simultaneously with the settlement period. The RSS should be constructed using Granular A or free draining granular material that meets the RSS designer's performance specification. Provide a 50 mm compressible layer (such as Dow HD Styrofoam) between the RSS and concrete abutment and install a 150mm diameter subdrain near the base of the RSS. Surcharge the top of RSS with a load equivalent to a 2 m vertical height of Granular A material. About  $60\pm$  mm of the settlement will be essentially complete in six weeks and after the surcharge period, the remaining consolidation settlement in the 25 m transition zone will be  $25\pm$  mm; and
- Use lightweight cellular concrete (Cematrix) with a unit weight of  $4.9 \text{ kN/m}^3$ , a material that is listed on the Designated Materials list of the Road Authority. This lightweight fill will induce approximately 35 mm of consolidation settlement and 15 mm of this consolidation settlement will be complete in 2 weeks. Therefore, after two weeks the remaining post construction settlement in the 25 m transition zone will be  $20\pm$  mm.

Settlement monitoring is required to determine the constructing timing for paving operations. A special provision for settlement monitoring and instrumentation (including drawings) is provided as a separate document.

Embankments constructed with local earth fill or Granular A material will also settle during construction (fill compression) and, the magnitude of this settlement is expected to be about 1% and 0.5% of the fill height respectively. This settlement should be immediate in nature and essentially be complete shortly after construction is complete.

## 6.8.2 Stability

The global, internal and surficial stability of the embankment side slopes and forward slopes will depend on the slope geometry and also to a large degree on the material used to construct the embankment. For the purpose of embankment stability analyses, the commercially available slope stability program Slide 6.0 developed by Rocscience Inc. was used.

The Morgenstern-Price and Spencer methods for stability analysis were employed and a minimum target factor of safety of 1.3 was established. The soil parameters used for the slope stability analyses and the factors of safety that were obtained are provided in the following table. The slope stability models depicting the corresponding factors of safety are provided in Figure D1 in Appendix D. The analyses indicate that the factors of safety will be greater than the target factor of safety of 1.3, provided that the embankment is constructed at a minimum side slope and forward slope geometry of 2 Horizontal to 1 Vertical (2H:1V) or flatter.

### Slope Stability Design Parameters and Results

Material Type	Total Stress Analysis		Effective Stress Analysis		Unit Weight
	$\phi$ (degrees)	c (kPa)	$\phi'$ (degrees)	c' (kPa)	$\gamma$ (kN/m <sup>3</sup> )
New Embankment Fill	35	0	35	0	22.8
Clayey Organic Silt	0	12	28	0	18
Sand to Sand & Gravel Fill	30	0	30	0	20
Silty Clay Fill	28	0	28	0	19
Silty Clay to Clayey Silt	0	60	28	0	20
Silt	25	0	25	0	18
Gravelly Sand/Sand & Gravel	35	0	35	0	21
Sand to Silt and Sand	32	0	32	0	19
Clayey Silt Till	0	75	29	0	20
Design Factors of Safety	1.5 to 1.7		1.3 to 1.4		-

### 6.8.3 Embankment Construction

Materials used for embankment construction should be placed in lifts not exceeding 300 mm (before compaction), and each lift should be uniformly compacted to at least 95% of the material's SPMDD. Embankment construction should be carried out in accordance with OPSS.PROV 209, OPSS.PROV 501 and OPSS.PROV 206. Borrow material must meet the requirements of OPSS.PROV 212 and bonding between existing fill and new fill should be carried out by benching in accordance with OPSS 208.010.

Proper erosion control measures should be implemented both during construction and permanently. Temporary erosion and sediment control must be provided in accordance with OPSS 805 and embankment slopes must be reinstated with permanent erosion protection in accordance with OPSS 803 and OPSS.PROV 804.

### 6.9 Temporary Protection Systems

Temporary protection systems should be designed in accordance with OPSS.PROV 539, by a licensed Professional Engineer experienced in shoring design. The shape of the soil pressure distribution diagram behind a temporary protection system depends upon the type of soil to be supported and the amount of movement that can be permitted. The sequence of work will also alter the shape of the pressure diagram during the various construction phases.

Earth pressure computations must also take into account the ground water level. Above the ground water level, earth pressure is computed using the bulk unit weight of the retained soil. Below the ground water level, the earth pressures are computed using the submerged unit weight of the soil. A hydrostatic pressure is also applied if the retained soil is not fully drained.

Flexible shoring should be designed on the basis of the active earth pressure coefficient ( $K_a$ ). In this case, the performance level should be Level 2 – Angular Distortion 1:200 but shall not be more than 25 mm. Where limited shoring movement (Performance Level 1A or 1B) is required the design should be based on the at rest earth pressure coefficient ( $K_o$ ). For “kick out” design the lateral resistance should be computed on the basis of the passive earth pressure coefficient ( $K_p$ ). It should be noted that the lateral earth pressure

coefficients chosen for design require certain movements for the active and passive conditions to be mobilized.

The appropriate lateral earth pressure parameters for use in the design of structures subject to unbalanced earth pressures are provided in the following table. The active earth pressure coefficients are based on the assumption that the ground surface behind the temporary protection system is horizontal. Where the retained ground is sloping, the lateral earth pressure coefficients must be adjusted to account for the slope and, these earth pressure coefficients can be estimated from the equations provided on Figures C6.17 and C6.18 of the CHBDC 2006.

**Temporary Protection System Design Parameters**

Stratigraphic Unit	Friction Angle $\phi$ (degrees)	Unit Weight $\gamma$ (kN/m)	Active Earth Pressure Coefficient	At - Rest Earth Pressure Coefficient	Passive Earth Pressure Coefficient
			$K_a$	$K_o$	$K_p$
Granular A Fill	35	22.8	0.27	0.43	3.70
Existing Fill Soils	28	19	0.36	0.53	2.77
Silty Clay to Clayey Silt	28	20	0.36	0.53	2.77
Silt	25	18	0.41	0.58	2.46
Gravelly Sand/Sand & Gravel	35	21	0.27	0.43	3.70
Sand to Silt and Sand	32	19	0.31	0.47	3.25
Clayey Silt Till	29	20	0.35	0.52	2.88

## 6.10 Seismic Requirements

The site is treated as lying in Velocity Related Seismic Zone 0. Reference to Annex A3.1 of the CHBDC 2006 indicates that the following seismic parameters (Fort Erie) should be used for design:

- Velocity Related Seismic Zone 0
- Zonal Velocity Ratio 0.05
- Acceleration Related Seismic Zone 2
- Zonal Acceleration Ratio 0.10
- Peak Horizontal Ground Acceleration 0.08 g (10% in 50 years)

The soil profile type at this site has been classified as Type I and the Site Coefficient "S" (ground motion amplification factor) that should be used in seismic design as per Clause 4.4.6.1, Table 4.4 of the CHBDC is 1.0.

## 6.11 Construction Concerns

During construction, the Design Builder should employ experienced geotechnical staff to observe construction activities related to foundation construction. Potential construction concerns include, but are not necessarily limited to:

- the possibility of encountering cobbles and boulders when installing the H-piles;
- a significant portion of consolidation settlement of the silty clay to clayey silt deposit below the abutment backfill must be complete before paving operations can begin; and
- pollution, siltation or disruption of environmentally sensitive areas.

## 7.0 CLOSURE

This report was prepared by Mr. Rehman Abdul, P.Eng., a Senior Geotechnical Engineer and Principal with Terraprobe. Mr. Michael Tanos, P.Eng., Terraprobe's Designated MTO Contact conducted an independent quality control review.

### **Terraprobe Inc.**



R. Abdul, P.Eng.  
Principal, Senior Geotechnical Engineer



Michael Tanos, P.Eng.  
Principal, Designated MTO Contact



## REFERENCES

- Bowles, J.E., 1984. *Physical and Geotechnical Properties of Soils*, Second Edition. McGraw Hill Book Company, New York.
- Canadian Geotechnical Society, 2006. *Canadian Foundation Engineering Manual*, 4th Edition. The Canadian Geotechnical Society c/o BiTech Publisher Ltd, British Columbia.
- Canadian Highway Bridge Design Code (CHBDC) and Commentary on CAN/CSA S6 06. 2006.* CSA Special Publication, S6.1 06. Canadian Standard Association.
- Chapman and Putnam, "The Physiography of South Ontario", 3rd Edition, 1984.
- Ontario Division of Mines, "Quaternary Geology of The Welland Area", Preliminary Map P.796, 1972.

## Ontario Provincial Standard Specifications (OPSS)

OPSS.PROV 206	Construction Specification For Grading.
OPSS.PROV 209	Construction Specification For Embankments Over Swamps And Compressible Soils.
OPSS.PROV 212	Construction Specification For Earth Borrow.
OPSS.PROV 501	Construction Specification For Compacting.
OPSS 511	Construction Specification For Rip-Rap, Rock Protection and Granular Sheeting.
OPSS.PROV 539	Construction Specification For Temporary Protection Systems.
OPSS 803	Construction Specification For Sodding.
OPSS.PROV 804	Construction Specification For Seed and Cover.
OPSS 805	Construction Specification For Temporary Erosion And Sediment Control Measures.
OPSS 902	Construction Specification For Excavating and Backfilling – Structures.
OPSS.PROV 1010	Material Specification For Aggregates – Base, Subbase, Select Subgrade and Backfill Material.

## Ontario Provincial Standard Drawings (OPSD)

OPSD 208.010	Benching Of Earth Slopes.
OPSD 3090.101	Foundation, Frost Penetration Depths For Southern Ontario
OPSD 3101.150	Walls Abutment Backfill, Minimum Granular Requirement

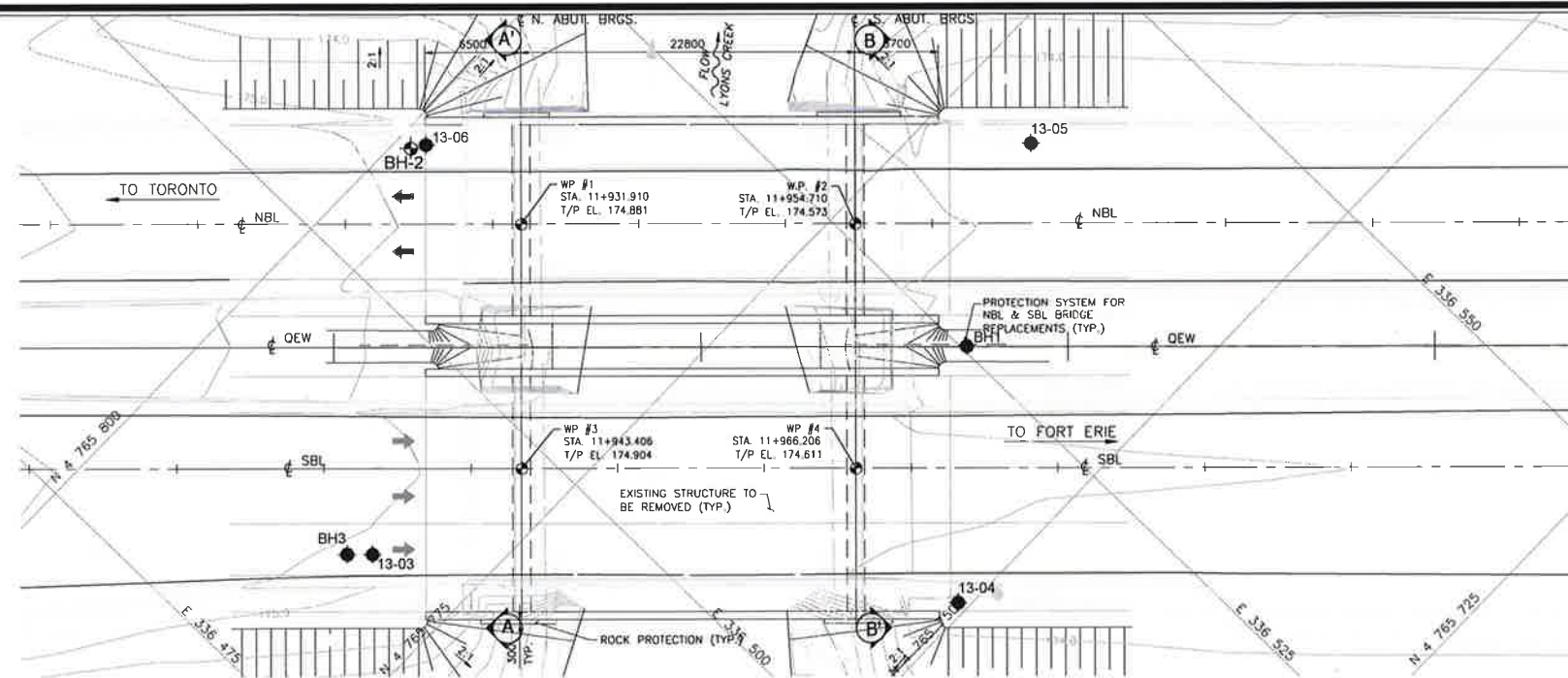


TABLE 1 COMPARISON OF FOUNDATION ALTERNATIVES		
Pile Foundations	Spread Footings	Augered Caissons
<p><b>Advantages:</b></p> <ul style="list-style-type: none"><li>Reliable performance expected.</li><li>High geotechnical resistances available by driving piles to refusal.</li><li>Allows for the design of an integral abutment.</li><li>Shallow excavation depth, reduced excavation volume and reduced dewatering requirements.</li></ul> <p><b>Disadvantages:</b></p> <ul style="list-style-type: none"><li>Construction concerns related to the possibility of piles being obstructed by boulders during driving.</li></ul>	<p><b>Advantages:</b></p> <p>None</p> <p><b>Disadvantages:</b></p> <ul style="list-style-type: none"><li>Low geotechnical resistance of surficial soils does not permit the design of economical spread footings compared to pile foundations.</li><li>Unreliable performance and high risk of performance related issues due to settlement.</li></ul>	<p><b>Advantages:</b></p> <ul style="list-style-type: none"><li>Reliable performance expected.</li><li>High geotechnical resistances available by founding caissons on competent soils.</li><li>Allows for the design of a semi integral abutment.</li></ul> <p><b>Disadvantages:</b></p> <ul style="list-style-type: none"><li>Requires a permanent liner to maintain side wall support.</li><li>Attempts at dewatering the caisson excavation and maintaining a sufficiently dry excavation to permit cleaning, inspection and high quality construction, would be challenging and most likely impractical.</li></ul>
<p><b>Risks/Consequences</b></p> <ul style="list-style-type: none"><li>Very low risk of bearing capacity failure.</li><li>Very low risk that total settlement will exceed 25 mm.</li></ul>	<p><b>Risks/Consequences</b></p> <ul style="list-style-type: none"><li>Moderate to high risk of bearing capacity failure and settlement related performance issues.</li></ul>	<p><b>Risks/Consequences</b></p> <ul style="list-style-type: none"><li>Very low risk of bearing capacity failure.</li><li>Very low risk that total settlement will exceed 25mm.</li></ul>

# DRAWINGS

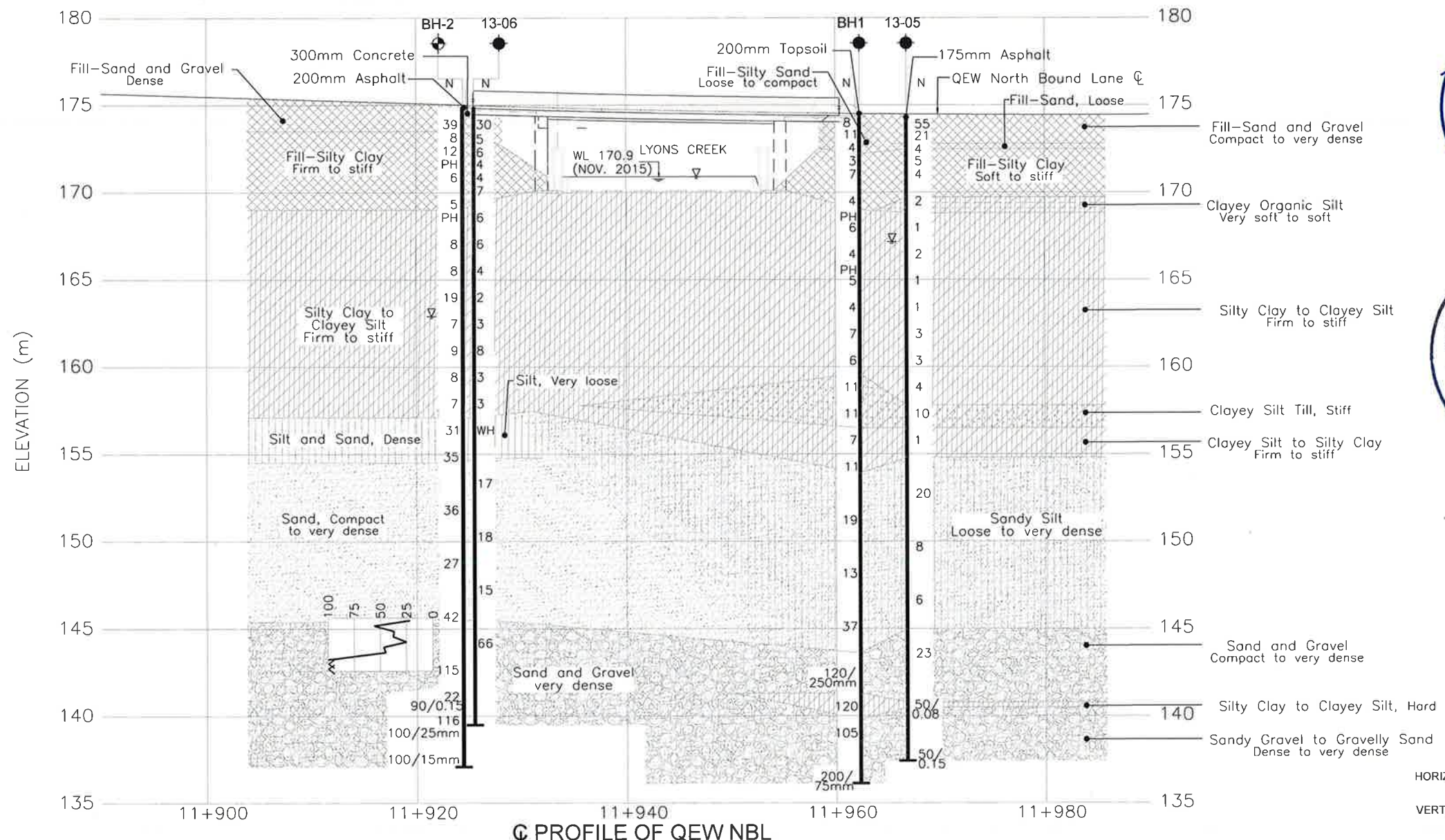






PLAN

SCALE 4 2 0 2 4 6 8m



PROFILE OF QEW NBL

HORIZ SCALE 4 2 0 2 4 6 8m  
VERT. SCALE 2.4 0 2.4 4.8m



CONT DB 2014-2036  
GWP No 2177-08-00



LYONS CREEK BRIDGE  
NORTH BOUND LANE  
BOREHOLE LOCATIONS AND SOIL STRATA







SHEET



**Terraprobe Inc.**  
Consulting Geotechnical & Environmental Engineering  
Construction Materials Engineering, Inspection & Testing  
11 Indell Lane - Brampton Ontario L6T 3Y3 (905) 786-2650



KEY PLAN

LEGEND	
	Bore Hole
	Dynamic Cone Penetration Test
	Bore Hole And Cone
'N'	Blows/0.3m (Std Pen Test, 475 J/blow)
CONE	Blows/0.3m (60° Cone, 475 J/blow)
	WL at Time of Investigation
	WL in Piezometer
	Piezometer
90%	Rock Quality Designation
A/R	Auger Refusal

No	ELEV.	COORDINATES	
		NORTHING	EASTING
1	174.3	4 765 762.3	336 525.2
2	174.9	4 765 798.9	336 508.6
3	174.9	4 765 782.8	336 485.8
13-03	175.0	4 765 781.6	336 487.0
13-04	174.5	4 765 750.7	336 512.4
13-05	174.3	4 765 768.8	336 538.3
13-06	174.9	4 765 798.4	336 509.5

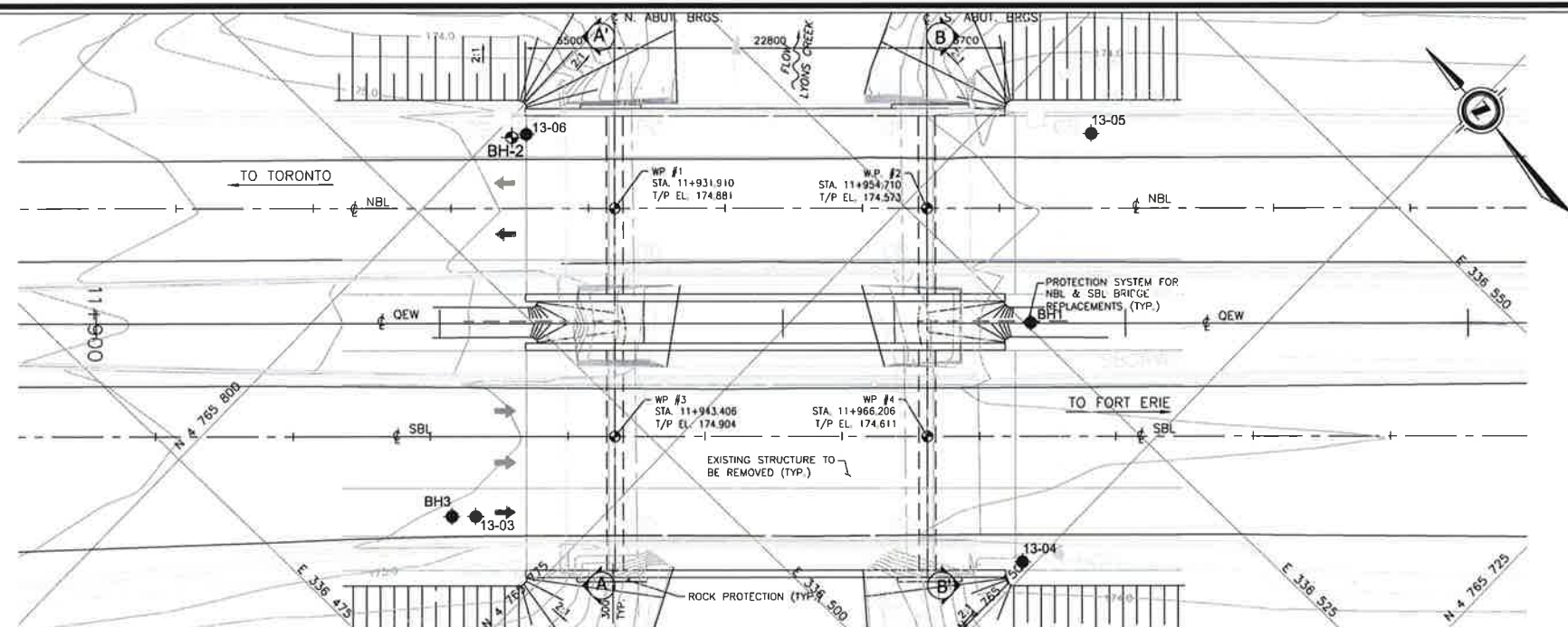
**NOTE**  
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The boundaries between soil strata have been established only at borehole locations. Between boreholes the boundaries are assumed from geological evidence.  
The complete foundation investigation and design report for this project and other related documents may be examined at the Materials Engineering and Research Office, Downsview. Information contained in this report and related documents are specifically excluded in accordance with Section GC 2.01 of OPS General Conditions

**REFERENCE**  
Drawings provided in digital format by MMM Group Limited, by email drawing file x3215095-310-001GA.dwg, 3215095-310-001XG.dwg, H3215095XB01.dwg, H3215095XB02.dwg received January 12, 2016.

REVISIONS		
DATE	BY	DESCRIPTION

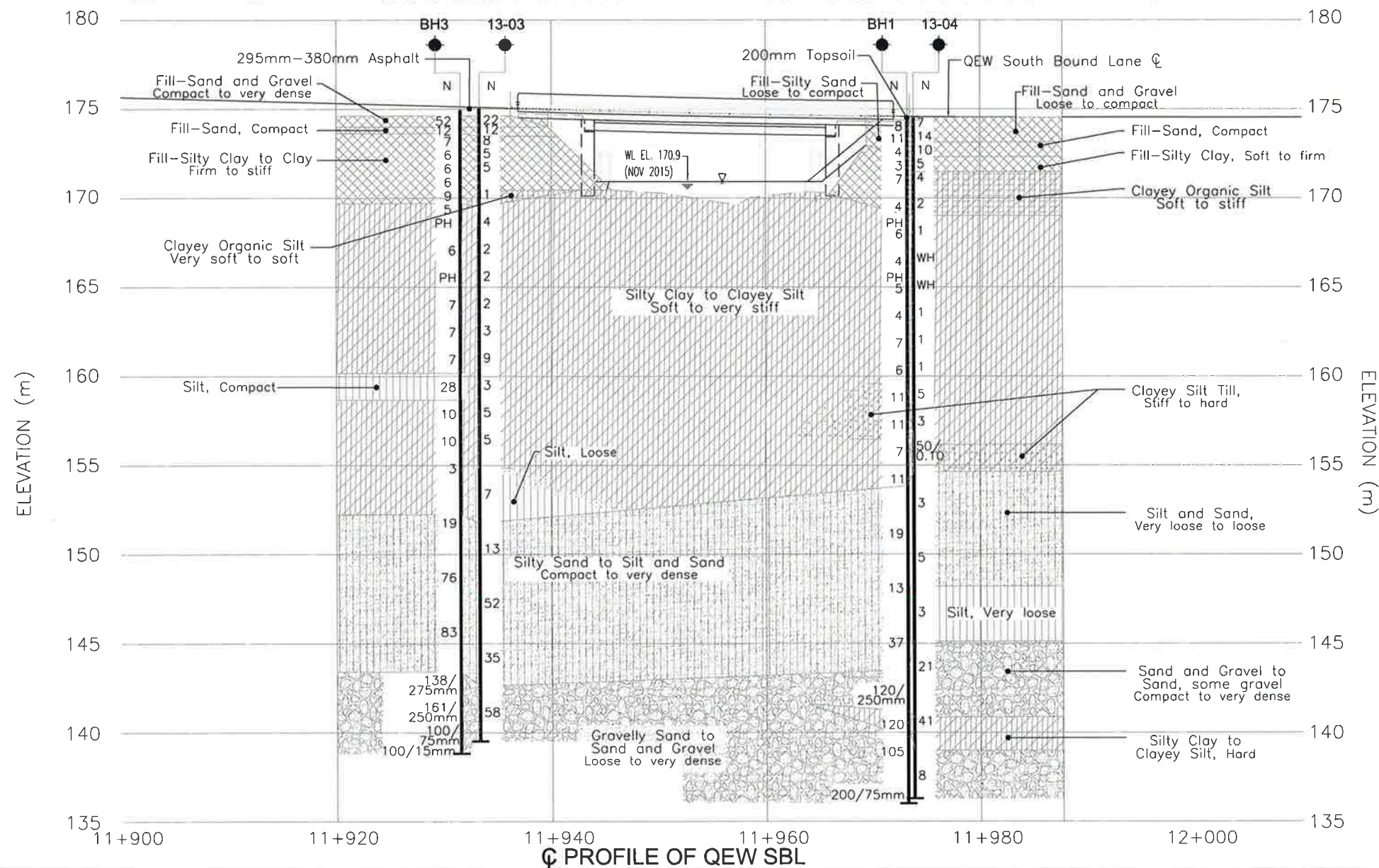
HWY. 401/404 PROJECT No. 1-15-0689/GEOCR No. 30M3-288  
SUBM'D RA CHKD. RA DATE: July, 2016 SITE: 34-66/1  
DRAWN: KC CHKD. APPD: MT DWG. 1





PLAN

SCALE 4 2 0 2 4 6 8m



ELEVATION (m)

HORIZ. SCALE 4 2 0 2 4 6 8m  
VERT. SCALE 2.4 0 2.4 4.8m

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

CONT DB 2014-2036

GWP No 2177-08-00

LYONS CREEK BRIDGE  
SOUTH BOUND LANE

BOREHOLE LOCATIONS AND SOIL STRATA

WSP | MMM GROUP

**Terraprobe Inc.**  
Consulting Geotechnical & Environmental Engineering  
Construction Materials Engineering, Inspection & Testing  
11 Indell Lane - Brampton Ontario L6T 3Y3 (905) 796-2650



KEY PLAN

LEGEND			
●	Bore Hole		
⊕	Dynamic Cone Penetration Test		
⊙	Bore Hole And Cone		
'N'	Blows/0.3m (Std Pen Test, 475 J/blow)		
CONE	Blows/0.3m (60' Cone, 475 J/blow)		
WL	WL at Time of Investigation		
WL	WL in Piezometer		
90%	Rock Quality Designation		
A/R	Auger Refusal		

No	ELEV.	COORDINATES	
		NORTHING	EASTING
1	174.3	4 765 762.3	336 525.2
2	174.9	4 765 798.9	336 508.6
3	174.9	4 765 782.8	336 485.8
13-03	175.0	4 765 781.6	336 487.0
13-04	174.5	4 765 750.7	336 512.4
13-05	174.3	4 765 768.8	336 538.3
13-06	174.9	4 765 798.4	336 509.5

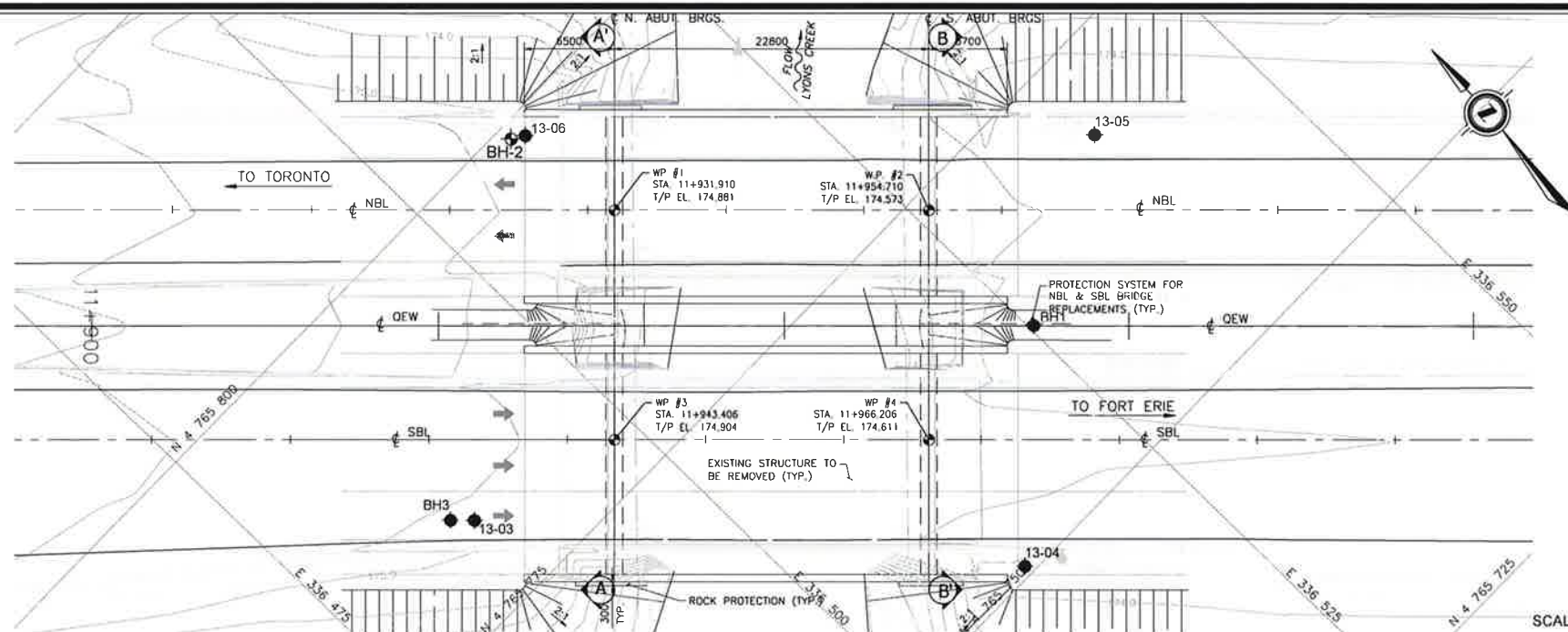
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**REFERENCE**  
Drawings provided in digital format by MMM Group Limited, by email drawing file x3215095-310-001GA.dwg, 3215095-310-001XG.dwg, H3215095XB01.dwg, H3215095XB02.dwg received January 12, 2016.

REVISIONS	DATE	BY	DESCRIPTION

HWY: QEW	PROJECT No. 1-15-0689	GEORES No. JOM3-288
SUBM'D RA	CHKD. RA	DATE: July, 2016 SITE: 34-66/2
DRAWN: KC	CHKD. APPD: MT	DWG. 2



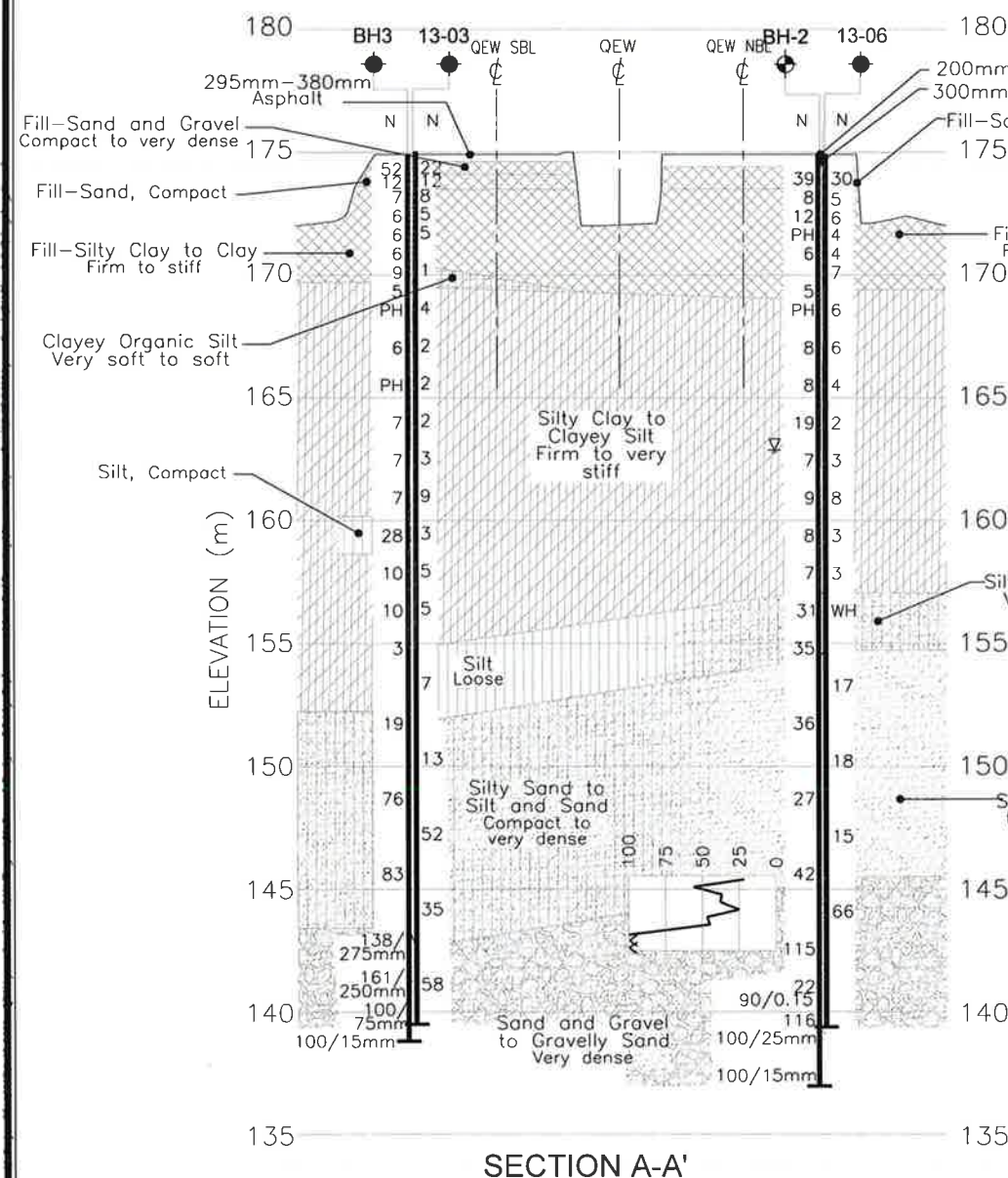


METRIC  
DIMENSIONS ARE IN METRES  
AND/OR MILLIMETERS UNLESS  
OTHERWISE SHOWN

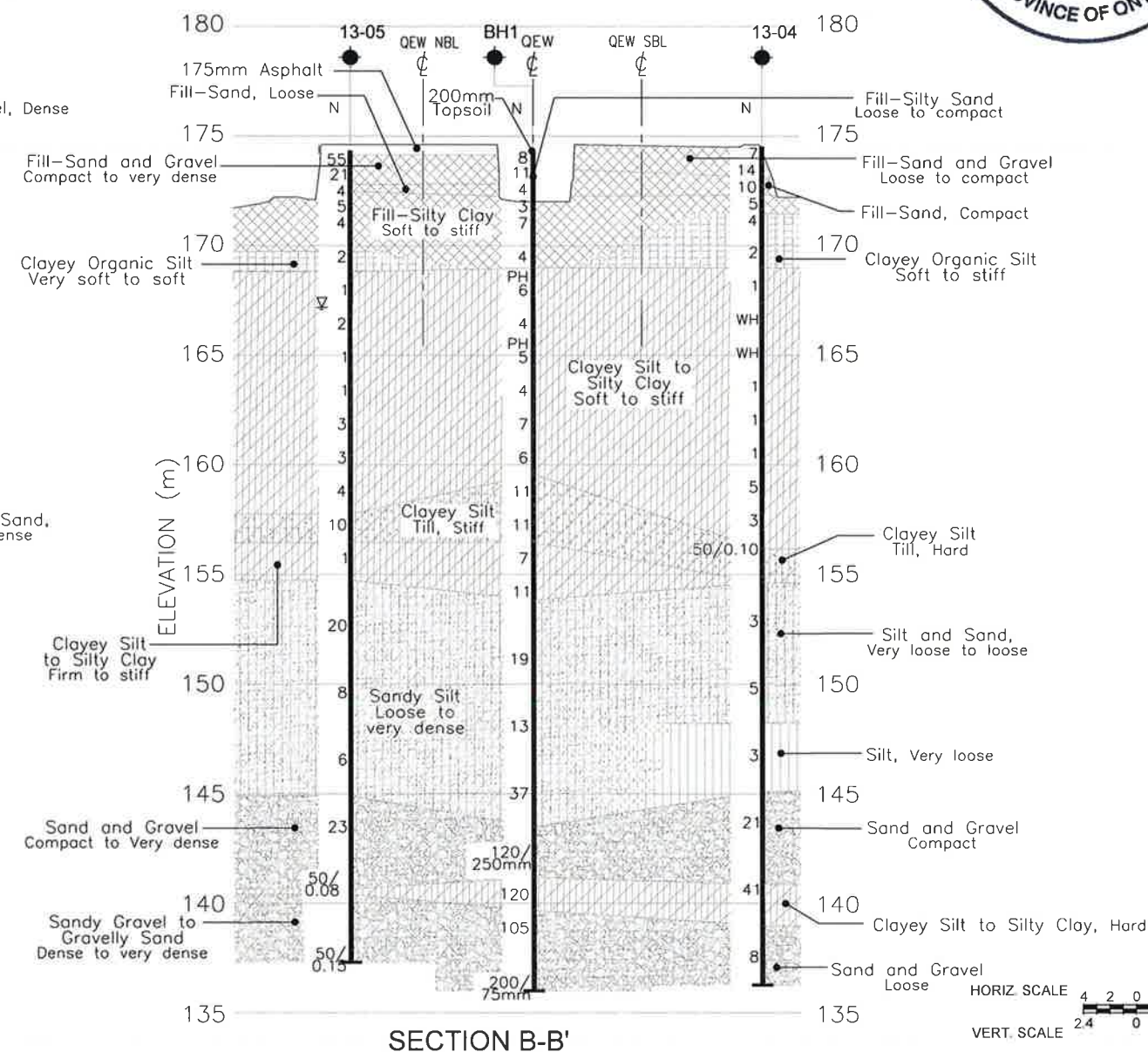


PLAN

SCALE 4 2 0 2 4 6 8m



SECTION A-A'



SECTION B-B'

HORIZ SCALE 4 2 0 2 4 6 8m  
VERT. SCALE 2.4 0 2.4 4.8m

CONT DB 2014-2036  
GWP No 2177-08-00



LYONS CREEK BRIDGE  
SECTIONS  
BOREHOLE LOCATIONS AND SOIL STRATA

SHEET  
---



**Terraprobe Inc.**  
Consulting Geotechnical & Environmental Engineering  
Construction Materials Engineering, Inspection & Testing  
11 Indell Lane - Brampton Ontario L6T 3Y3 (905) 796-2650



KEY PLAN

LEGEND	
	Bore Hole
	Dynamic Cone Penetration Test
	Bore Hole And Cone
	Blows/0.3m (Std Pen Test, 475 J/blow)
	Blows/0.3m (60° Cone, 475 J/blow)
	WL at Time of Investigation
	WL in Piezometer
	Piezometer
	Rock Quality Designation
	Auger Refusal

No	ELEV.	COORDINATES	
		NORTHING	EASTING
1	174.3	4 765 782.3	336 525.2
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REVISIONS		
DATE	BY	DESCRIPTION

HWY. QEW PROJECT No. 1-15-0689 GEOS No. 30M3-288  
SUBM'D.RA CHKD. RA DATE: July, 2016 SITE: 34-66  
DRAWN: KC CHKD. APPD. MT DWG. 3

**APPENDIX A1**  
**Record of Borehole Sheets**  
**Terraprobe Inc.**



## **LIMITATIONS AND RISK**

### **Procedures**

The soil conditions were confirmed at the borehole locations only and conditions may vary between and beyond the boreholes. The boundaries between the various strata as shown on the logs are based on non-continuous sampling. These boundaries represent an inferred transition between the various strata, rather than a precise plane of stratigraphic change.

This investigation has been carried out using investigation techniques and engineering analysis methods consistent with those ordinarily exercised by Terraprobe and other engineering practitioners, working under similar conditions and subject to the time, financial and physical constraints applicable to this project. The discussions and recommendations that have been presented are based on the factual data obtained.

It must be recognized that there are special risks whenever engineering or related disciplines are applied to identify subsurface conditions. Even a comprehensive sampling and testing programme implemented in accordance with the most stringent level of care may fail to detect certain conditions. Terraprobe has assumed for the purposes of providing design parameters and advice, that the conditions that exist between sampling points are similar to those found at the sample locations. The conditions that Terraprobe has interpreted to exist between sampling points can differ from those that actually exist.

It may not be possible to drill a sufficient number of boreholes or sample and report them in a way that would provide all the subsurface information that could affect construction costs, techniques, equipment and scheduling. Contractors bidding on or undertaking work on the project should be directed to draw their own conclusions as to how the subsurface conditions may affect them, based on their own investigations and their own interpretations of the factual investigation results, cognizant of the risks implicit in the subsurface investigation activities.

### **Changes In Site And Scope**

It must be recognized that the passage of time, natural occurrences, and direct or indirect human intervention at or near the site have the potential to alter subsurface conditions. Groundwater levels are particularly susceptible to seasonal fluctuations.

The design advice is based on the factual data obtained from this investigation made at the site by Terraprobe and are intended for use by the owner and its retained designers in the design phase of the project. If there are changes to the project scope and development features, or there is any additional information relevant to the interpretations made of the subsurface information, the geotechnical design parameters and comments relating to constructibility issues and quality control may not be relevant or complete for the revised project. Terraprobe should be retained to review the implications of such changes with respect to the contents of this report.

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## 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  $\bar{u}$ .

DYNAMIC CONE PENETRATION TEST: CONTINUOUS PENETRATION OF A CONICAL STEEL POINT (51mm O.D. 60° CONE ANGLE) DRIVEN BY 475J 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

SS	SPLIT SPOON	TP	THINWALL PISTON
WS	WASH SAMPLE	OS	OSTERBERG SAMPLE
ST	SLOTTED TUBE SAMPLE	RC	ROCK CORE
BS	BLOCK SAMPLE	PH	TW ADVANCED HYDRAULICALLY
CS	CHUNK SAMPLE	PM	TW ADVANCED MANUALLY
TW	THINWALL OPEN	FS	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
$S_r$	1	SENSITIVITY = $c_u / \tau_r$

## PHYSICAL PROPERTIES OF SOIL

$\rho_s$	kg/m <sup>3</sup>	DENSITY OF SOLID PARTICLES	e	1.0%	VOID RATIO	$e_{min}$	1.0%	VOID RATIO IN DENSEST STATE
$\gamma_s$	kN/m <sup>3</sup>	UNIT WEIGHT OF SOLID PARTICLES	n	1.0%	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	1.0%	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>2</sup> /s	RATE OF DISCHARGE
$\gamma_d$	kN/m <sup>3</sup>	UNIT WEIGHT OF DRY SOIL	$I_p$	%	PLASTICITY INDEX = $(w_L - w_p)$	v	m/s	DISCHARGE VELOCITY
$\rho_{sat}$	kg/m <sup>3</sup>	DENSITY OF SATURATED SOIL	$I_L$	1	LIQUIDITY INDEX = $(w - w_p)/I_p$	i	1	HYDRAULIC GRADIENT
$\gamma_{sat}$	kN/m <sup>3</sup>	UNIT WEIGHT OF SATURATED SOIL	$I_C$	1	CONSISTENCY INDEX = $(w_L - w)/I_p$	k	m/s	HYDRAULIC CONDUCTIVITY
$\rho'$	kg/m <sup>3</sup>	DENSITY OF SUBMERGED SOIL	$e_{max}$	1.0%	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 3

METRIC

G.W.P. \_\_\_\_\_ LOCATION \_\_\_\_\_ Coords: E:336525.2 N:4765762.3 ORIGINATED BY AF  
 DIST \_\_\_\_\_ HWY QEW \_\_\_\_\_ BOREHOLE TYPE HOLLOW STEM AUGERS/CASING AND WASH BORING COMPILED BY SD  
 DATUM GEODETIC DATE 2015-12-14 - 2015-12-16 CHECKED BY RA

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT   NATURAL MOISTURE CONTENT   LIQUID LIMIT			UNIT WEIGHT  γ	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH (m)	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	SPT 'N' VALUE			SHEAR STRENGTH (kPa)					WATER CONTENT (%)				
								20	40	60	80	100	W <sub>P</sub>	W	W <sub>L</sub>		
174.3	GROUND SURFACE																
174.1	200mm TOPSOIL																
0.2	FILL, silty sand to sand, trace gravel, loose, brown, dry		1	SS	8		174										
	gravel and sand, compact		2	SS	11		173									51 37 10 2	
			3	SS	4												
172.2							172										
2.1	FILL, silty clay, trace sand, trace organics, soft to firm, grey, moist		4	SS	3												
			5	SS	7		171										
							170										
	containing organics, black		6	SS	4		169										
169.0																	
5.3	SILTY CLAY to CLAYEY SILT, trace sand, trace gravel, firm to stiff, grey, wet		7	TW	PH		168									0 0 77 23	
			8	SS	6												
							167										
			9	SS	4		166									0 6 52 42	
			10	TW	PH												
			11	SS	5		165									0 7 51 42	
							164										
			12	SS	4		163									Dec. 14, 2015 Dec. 15, 2015	
							162									0 6 52 42	
			13	SS	7		161										
							160										
159.6																	
14.7																	

Continued Next Page

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

# RECORD OF BOREHOLE No 1

2 of 3

METRIC

G.W.P. \_\_\_\_\_ LOCATION \_\_\_\_\_ Coords: E:336525.2 N:4765762.3 ORIGINATED BY AF  
 DIST \_\_\_\_\_ HWY QEW \_\_\_\_\_ BOREHOLE TYPE HOLLOW STEM AUGERS/CASING AND WASH BORING COMPILED BY SD  
 DATUM GEODETIC DATE 2015-12-14 - 2015-12-16 CHECKED BY RA

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC NATURAL LIQUID LIMIT MOISTURE LIMIT CONTENT			UNIT WEIGHT $\gamma$ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH (m)	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	SPT 'N' VALUE			20 40 60 80 100	20 40 60 80 100	W <sub>p</sub> W W <sub>L</sub>	WATER CONTENT (%)			
	(continued)													
	CLAYEY SILT, trace to some sand, trace gravel, stiff, grey, wet (GLACIAL TILL)		15	SS	11		159							3 16 58 23
			16	SS	11		158							
							157							
156.5														
17.8	SILTY CLAY, trace sand, trace gravel, firm to stiff, grey, wet		17	SS	7		156							
							155							
			18	SS	11		154							0 2 56 42
153.9							153							
20.4	SANDY SILT, compact to very dense, brown, wet		19	SS	19		151							0 31 65 4
							150							
							149							
			20	SS	13		148							
							147							
							146							
			21	SS	37		145							

Continued Next Page

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



# RECORD OF BOREHOLE No 1

3 of 3

METRIC

G.W.P. \_\_\_\_\_ LOCATION \_\_\_\_\_ Coords: E:336525.2 N:4765762.3 ORIGINATED BY AF  
 DIST \_\_\_\_\_ HWY QEW \_\_\_\_\_ BOREHOLE TYPE HOLLOW STEM AUGERS/CASING AND WASH BORING COMPILED BY SD  
 DATUM GEODETIC DATE 2015-12-14 - 2015-12-16 CHECKED BY RA

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT	NATURAL MOISTURE CONTENT	LIQUID LIMIT	UNIT WEIGHT  γ	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH (m)	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	SPT 'N' VALUE			SHEAR STRENGTH (kPa)					WATER CONTENT (%)				
								20	40	60	80	100	W <sub>p</sub>	W	W <sub>L</sub>		
	(continued)																
143.6	SANDY SILT, compact to very dense, brown, wet						144										
30.7	SAND AND GRAVEL, trace to some silt, very dense, brown, wet							143									
			22	SS	120 / 250mm		142										
141.3	SILTY CLAY, trace sand, hard, brown, moist						141										
33.0				23	SS	120		140									
139.8	GRAVELLY SAND, trace silt, trace clay, very dense, brown, wet						139										
34.5			24	SS	105		138										
							137										
136.1			25	SS	200 / 75mm												
38.2																	

## END OF BOREHOLE

Borehole filled with drill water upon completion of drilling.

# RECORD OF BOREHOLE No 2

1 of 3

METRIC

G.W.P. \_\_\_\_\_ LOCATION \_\_\_\_\_ Coords: E:336508.6 N:4765798.9 ORIGINATED BY AF  
DIST \_\_\_\_\_ HWY QEW \_\_\_\_\_ BOREHOLE TYPE HOLLOW STEM AUGERS/CASING AND WASH BORING COMPILED BY SD  
DATUM GEODETIC DATE 2015-11-23 - 2015-11-27 CHECKED BY RA

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT	NATURAL MOISTURE CONTENT	LIQUID LIMIT	UNIT WEIGHT  <b>γ</b>	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH (m)	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	SPT 'N' VALUE			SHEAR STRENGTH (kPa)					WATER CONTENT (%)				
								20	40	60	80	100	W <sub>P</sub>	W	W <sub>L</sub>		
174.9	GROUND SURFACE															kN/m <sup>3</sup>	GR SA SI CL
174.7	200mm ASPHALTIC CONCRETE																
174.4	300mm CONCRETE																
174.0	FILL, sand and gravel, trace silt, trace clay, dense, brown, dry		1	SS	39												39 46 13 2
173.5	FILL, silty clay, trace sand, trace organics, firm to stiff, brown, moist		2	SS	8												
173.0			3	SS	12												sampler wet at 2.3m 0 4 45 51
172.5			4	TW	PH												
172.0			5	SS	6												
171.5																	
171.0																	
170.5																	
170.0																	
169.5	containing organics grey to black		6	SS	5												
169.0	SILTY CLAY, trace sand, trace gravel, firm to stiff, brown, wet		7	TW	PH												
168.5																	
168.0																	
167.5			8	SS	8												2 8 48 42
167.0																	
166.5																	
166.0			9	SS	8												
165.5																	
165.0																	
164.5																	
164.0			10	SS	19												0 9 50 41
163.5																	
163.0																	
162.5																	
162.0																	
161.5																	
161.0			12	SS	9												0 10 52 38
160.5																	
160.0																	

Continued Next Page

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

## METRIC

[illegible]

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

# RECORD OF BOREHOLE No 2

3 of 3

METRIC

G.W.P. \_\_\_\_\_ LOCATION \_\_\_\_\_ Coords: E:336508.6 N:4765798.9 ORIGINATED BY AF  
 DIST \_\_\_\_\_ HWY QEW \_\_\_\_\_ BOREHOLE TYPE HOLLOW STEM AUGERS/CASING AND WASH BORING COMPILED BY SD  
 DATUM GEODETIC DATE 2015-11-23 - 2015-11-27 CHECKED BY RA

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 (m)	DESCRIPTION	STRAT PLOT	NUMBER	TYPE			SPT 'N' VALUE	SHEAR STRENGTH (kPa)						WATER CONTENT (%)		
							○ UNCONFINED ● QUICK TRIAXIAL	+ FIELD VANE × LAB VANE								
	(continued)						20 40 60 80 100	20 40 60 80 100	10 20 30							
137.1 37.8	SAND AND GRAVEL, trace to some silt, trace clay, containing cobbles and boulders, very dense, grey, wet												Nov. 24, 2015 Nov. 25, 2015  Nov. 25, 2015 Nov. 26, 2015  0 84 13 3  Nov. 26, 2015 Nov. 27, 2015			
			20	SS	115											
			21	SS	22											
			22	SS	116											
			23	RC												
			24 25	RC SS	100 / 25mm											
			26	SS	100 / 15mm											

## END OF BOREHOLE

Wet cave at 19.8m upon completion of drilling.

Dynamic cone penetration test (DCPT) performed from 29.0m to 32.0m

# RECORD OF BOREHOLE No 3

1 of 3

METRIC

G.W.P. \_\_\_\_\_ LOCATION \_\_\_\_\_ Coords: E:336485.8 N:4765782.8 ORIGINATED BY AF  
 DIST \_\_\_\_\_ HWY QEW \_\_\_\_\_ BOREHOLE TYPE HOLLOW STEM AUGERS COMPILED BY SD  
 DATUM GEODETIC DATE 2015-12-7 - 2015-12-9 CHECKED BY RA

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT	NATURAL MOISTURE CONTENT	LIQUID LIMIT	UNIT WEIGHT  γ	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH (m)	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	SPT 'N' VALUE			SHEAR STRENGTH (kPa)					WATER CONTENT (%)				
								20	40	60	80	100	W <sub>P</sub>	W	W <sub>L</sub>		
174.9	GROUND SURFACE															kN/m <sup>3</sup>	GR SA SI CL
174.6	295mm ASPHALTIC CONCRETE																
0.3	FILL, sand and gravel, trace silt, very dense, brown, dry		1	SS	52												
174.0	FILL, sand, trace gravel, compact, reddish brown, moist		2	SS	12												
0.9																	
173.6	FILL, silty clay, trace sand, trace gravel, trace organics, firm to stiff, brown, moist		3	SS	7												
1.3																	
			4	SS	6												
			5	SS	6												
			6	SS	6												
			7	SS	9												
169.7	containing organics, black																
5.2	SILTY CLAY, trace sand, trace gravel, firm to very stiff, brown, moist		8	SS	5												
			9	TW	PH												
			10	SS	6												
			11	TW	PH												
			12	SS	7												

Continued Next Page

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

# RECORD OF BOREHOLE No 3

2 of 3

METRIC

G.W.P. \_\_\_\_\_ LOCATION \_\_\_\_\_ Coords: E:336485.8 N:4765782.8 ORIGINATED BY AF  
 DIST \_\_\_\_\_ HWY QEW \_\_\_\_\_ BOREHOLE TYPE HOLLOW STEM AUGERS COMPILED BY SD  
 DATUM GEODETIC DATE 2015-12-7 - 2015-12-9 CHECKED BY RA

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT	NATURAL MOISTURE CONTENT	LIQUID LIMIT	UNIT WEIGHT  <b>γ</b>  kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)	
ELEV DEPTH (m)	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	SPT 'N' VALUE			SHEAR STRENGTH (kPa)					WATER CONTENT (%)					
	(continued)							20	40	60	80	100	W <sub>P</sub>	W	W <sub>L</sub>		GR SA SI CL	
	<b>SILT</b> , trace clay, trace sand, compact, grey, wet		15	SS	28		159								○		0 3 89 8	
158.7	<b>SILTY CLAY</b> , trace to some sand, trace sand, trace gravel, stiff to very stiff, brown to grey, wet						158											
16.2			16	SS	10		157											
							156											
				17	SS	10		155										4 14 49 33
							154											
				18	SS	3		153										
							152											
							151											
							150											
152.3	<b>SILTY SAND</b> , trace clay, compact to very dense, brown, wet		19	SS	19		149											
22.6							148											
							147											
							146											
							145											

Continued Next Page

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

# RECORD OF BOREHOLE No 3

3 of 3

METRIC

G.W.P. \_\_\_\_\_ LOCATION \_\_\_\_\_ Coords: E:336485.8 N:4765782.8 ORIGINATED BY AF  
 DIST \_\_\_\_\_ HWY QEW \_\_\_\_\_ BOREHOLE TYPE HOLLOW STEM AUGERS COMPILED BY SD  
 DATUM GEODETIC DATE 2015-12-7 - 2015-12-9 CHECKED BY RA

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 (%)			
ELEV DEPTH (m)	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	SPT 'N' VALUE			SHEAR STRENGTH (kPa)										WATER CONTENT (%)		
								20	40	60	80	100						10	20	30

○ UNCONFINED  
● QUICK TRIAXIAL

+ FIELD VANE  
× LAB VANE

20 40 60 80 100

10 20 30

143.5  
31.4

138.9  
36.0

(continued)

SILTY SAND, trace clay, compact to very dense, brown, wet

GRAVELLY SAND, trace clay, some silt, very dense, grey, wet

22 SS 138 / 275mm

23 SS 161 / 250mm

24 SS 100 / 75mm

25 SS 100 / 15mm

144

143

142

141

140

139

29 49 17 5

Dec. 08, 2015

Dec. 09, 2015

## END OF BOREHOLE

Borehole filled with drill water upon completion of drilling.

Borehole extended with a Tricone bit below 29.0m.

Consolidation test performed on TW11

29 49 17 5  
 Dec. 08, 2015  
 Dec. 09, 2015

# **APPENDIX A2**

## **Record of Borehole Sheets**

### **Golder**







# **APPENDIX A**

## **Record of Borehole Sheets**



## LIST OF SYMBOLS

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

### I. GENERAL

$\pi$	3.1416
$\ln x$ ,	natural logarithm of x
$\log_{10}$	x or log x, logarithm of x to base 10
g	acceleration due to gravity
t	time
FoS	factor of safety

### II. STRESS AND STRAIN

$\gamma$	shear strain
$\Delta$	change in, e.g. in stress: $\Delta \sigma$
$\varepsilon$	linear strain
$\varepsilon_v$	volumetric strain
$\eta$	coefficient of viscosity
$\nu$	Poisson's ratio
$\sigma$	total stress
$\sigma'$	effective stress ( $\sigma' = \sigma - u$ )
$\sigma'_{vo}$	initial effective overburden stress
$\sigma_1, \sigma_2, \sigma_3$	principal stress (major, intermediate, minor)
$\sigma_{oct}$	mean stress or octahedral stress $= (\sigma_1 + \sigma_2 + \sigma_3)/3$
$\tau$	shear stress
u	porewater pressure
E	modulus of deformation
G	shear modulus of deformation
K	bulk modulus of compressibility

### III. SOIL PROPERTIES

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

### (a) Index Properties (continued)

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

### (b) Hydraulic Properties

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

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

$C_c$	compression index (normally consolidated range)
$C_r$	recompression index (over-consolidated range)
$C_s$	swelling index
$C_\alpha$	secondary compression index
$m_v$	coefficient of volume change
$C_v$	coefficient of consolidation (vertical direction)
$C_h$	coefficient of consolidation (horizontal direction)
$T_v$	time factor (vertical direction)
U	degree of consolidation
$\sigma'_p$	pre-consolidation stress
OCR	over-consolidation ratio = $\sigma'_p / \sigma'_{vo}$

### (d) Shear Strength

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

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

Notes: 1  
2

$$\tau = c' + \sigma' \tan \phi'$$
$$\text{shear strength} = (\text{compressive strength})/2$$



## LIST OF ABBREVIATIONS

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

### I. SAMPLE TYPE

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

### II. PENETRATION RESISTANCE

#### Standard Penetration Resistance (SPT), N:

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

#### Dynamic Cone Penetration Resistance; $N_d$ :

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

**PH:** Sampler advanced by hydraulic pressure

**PM:** Sampler advanced by manual pressure

**WH:** Sampler advanced by static weight of hammer

**WR:** Sampler advanced by weight of sampler and rod

#### Piezo-Cone Penetration Test (CPT)

A electronic cone penetrometer with a 60° conical tip and a project end area of 10 cm<sup>2</sup> pushed through ground at a penetration rate of 2 cm/s. Measurements of tip resistance ( $Q_t$ ), porewater pressure (PWP) and friction along a sleeve are recorded electronically at 25 mm penetration intervals.

### III. SOIL DESCRIPTION

#### (a) Non-Cohesive (Cohesionless) Soils

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

#### (b) Cohesive Soils Consistency

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

### IV. SOIL TESTS

w	water content
w <sub>p</sub>	plastic limit
w <sub>l</sub>	liquid limit
C	consolidation (oedometer) test
CHEM	chemical analysis (refer to text)
CID	consolidated isotropically drained triaxial test <sup>1</sup>
CIU	consolidated isotropically undrained triaxial test with porewater pressure measurement <sup>1</sup>
D <sub>R</sub>	relative density (specific gravity, $G_s$ )
DS	direct shear test
M	sieve analysis for particle size
MH	combined sieve and hydrometer (H) analysis
MPC	Modified Proctor compaction test
SPC	Standard Proctor compaction test
OC	organic content test
SO <sub>4</sub>	concentration of water-soluble sulphates
UC	unconfined compression test
UU	unconsolidated undrained triaxial test
V	field vane (LV-laboratory vane test)
$\gamma$	unit weight

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

### V. MINOR SOIL CONSTITUENTS

Per cent by Weight	Modifier	Example
0 to 5	Trace	Trace sand
5 to 12	Trace to Some (or Little)	Trace to some sand
12 to 20	Some	Some sand
20 to 30	(ey) or (y)	Sandy
over 30	And (non-cohesive (cohesionless)) or With (cohesive)	Sand and Gravel Silty Clay with sand / Clayey Silt with sand



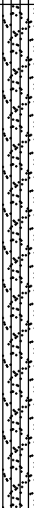
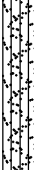

PROJECT <u>12-1111-0088</u>		<b>RECORD OF BOREHOLE No 13-03</b>		SHEET 1 OF 3		<b>METRIC</b>	
W.P. <u>2177-08-00</u>		LOCATION <u>N 4765781.6; E 336487.0</u>		ORIGINATED BY <u>SB</u>			
DIST <u>Central</u> HWY <u>QEW</u>		BOREHOLE TYPE <u>108 mm I.D. Continuous Flight Hollow Stem Augers</u>		COMPILED BY <u>AV</u>			
DATUM <u>Geodetic</u>		DATE <u>July 7 to 9, 2013</u>		CHECKED BY <u>MM</u>			

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT w <sub>p</sub>	NATURAL MOISTURE CONTENT w	LIQUID LIMIT w <sub>L</sub>	UNIT WEIGHT γ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL				
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa							WATER CONTENT (%)			
								○ UNCONFINED	+ FIELD VANE							● QUICK TRIAXIAL	× REMOULDED	
175.0	GROUND SURFACE						20	40	60	80	100	20	40	60				
0.0	ASPHALT (380 mm)																	
174.6																		
0.4	Sand and gravel, trace fines (FILL)		1	SS	22													
174.1	Compact Brown Moist		2	SS	12													
0.9	Sand (FILL)																	
173.5	Compact Reddish brown Moist		3	SS	8													
1.5	Silty clay to clay, trace sand (FILL)																	
	Stiff Mottled brown and grey Wet		4	SS	5													
			5	SS	5													
170.4	Clayey ORGANIC SILT		6	SS	1													
4.6	Very soft to soft Dark grey to black Wet																	
169.5	CLAYEY SILT, trace to some sand		7	SS	4													
5.5	Stiff Grey Wet																	
			8	SS	2													
			9	SS	2													
			10	SS	2													
			11	SS	3													
			12	SS	9													

Continued Next Page

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

GTA-MTO 001 T:\PROJECTS\2012\12-1111-0088 (URS, VARIOUS STRUCTURE REPLACEMENT, QEW)\LOG\12-1111-0088.GPJ GAL-GTA GDT 1/8/15

PROJECT 12-1111-0088		RECORD OF BOREHOLE No 13-03		SHEET 2 OF 3		METRIC													
W.P. 2177-08-00		LOCATION N 4765781.6; E 336487.0		ORIGINATED BY SB															
DIST Central HWY QEW		BOREHOLE TYPE 108 mm I.D. Continuous Flight Hollow Stem Augers		COMPILED BY AV															
DATUM Geodetic		DATE July 7 to 9, 2013		CHECKED BY MM															
SOIL PROFILE			SAMPLES			DYNAMIC CONE PENETRATION RESISTANCE PLOT			PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT			REMARKS & GRAIN SIZE DISTRIBUTION (%)				
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × REMOULDED			WATER CONTENT (%) W <sub>p</sub> — W — W <sub>L</sub>			γ kN/m <sup>3</sup>			GR SA SI CL		
--- CONTINUED FROM PREVIOUS PAGE ---																			
154.9 20.1	CLAYEY SILT, trace to some sand Stiff Grey Wet		13	SS	3		159												
			14	SS	5		158												
			15	SS	5		157												
151.8 23.2	SILT, trace to some clay, trace sand Loose Brown Wet						156												
			16	SS	7		155												
	SILT and SAND, trace clay Compact to very dense Brown Wet						154												
			17	SS	13		153												
							152												
			18	SS	52		151												
							150												
						149													
						148													
						147													
						146													

Continued Next Page

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

GTA-MTO 001 T:\PROJECTS\2012\12-1111-0088 [URS, VARIOUS STRUCTURE REPLACEMENT, QEW]\LOG\12-1111-0088.GPJ GAL-GTA.GDT 1/8/15

PROJECT		2177-08-00		LOCATION		N 4765781.6; E 336487.0		ORIGINATED BY		SB							
DIST		Central HWY QEW		BOREHOLE TYPE		108 mm I.D. Continuous Flight Hollow Stem Augers		COMPILED BY		AV							
DATUM		Geodetic		DATE		July 7 to 9, 2013		CHECKED BY		MM							
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 $\gamma$ 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									
	--- CONTINUED FROM PREVIOUS PAGE ---																
142.7	SILT and SAND, trace clay Compact to very dense Brown Wet		19	SS	35		144										
							143										
32.3	SAND and GRAVEL, trace to some silt, trace clay Very dense Brown Moist						142										
			20	SS	58		141										47 37 12 4
139.6	END OF BOREHOLE AUGER REFUSAL						140										
35.4	NOTE:  1. Depth to groundwater level was not measured upon completion of drilling.																

GTA-MTO 001 T:\PROJECTS\2012\12-1111-0088 [URS, VARIOUS STRUCTURE REPLACEMENT, QEW]\LOG\12-1111-0088.GPJ GAL-GTA.GDT 1/8/15



PROJECT	12-1111-0088	RECORD OF BOREHOLE No 13-04		SHEET 1 OF 3	METRIC
W.P.	2177-08-00	LOCATION	N 4767570.7 ;E 336512.4	ORIGINATED BY SB	
DIST	Central	HWY	QEW	BOREHOLE TYPE	108 mm I.D. Continuous Flight Hollow Stem Augers
DATUM	Geodetic	DATE	July 9 to 11, 2013	COMPILED BY	AV
				CHECKED BY	MM

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

○ 3% STRAIN AT FAILURE

GTA-MTO 001 T:\PROJECTS\2012\12-1111-0088 (URS, VARIOUS STRUCTURE REPLACEMENT, QEW)\LOG\12-1111-0088.GPJ GAL-GTA.GDT 1/8/15

PROJECT		12-1111-0088		RECORD OF BOREHOLE No 13-04		SHEET 2 OF 3		METRIC						
W.P.		2177-08-00		LOCATION		N 4765750.7 ; E 336512.4		ORIGINATED BY						
DIST		Central HWY QEW		BOREHOLE TYPE		108 mm I.D. Continuous Flight Hollow Stem Augers		COMPILED BY						
DATUM		Geodetic		DATE		July 9 to 11, 2013		CHECKED BY						
								MM						
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 (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa						
	--- CONTINUED FROM PREVIOUS PAGE ---							20 40 60 80 100						
	CLAYEY SILT, trace sand, trace gravel Soft to stiff Grey Wet		13	SS	5		159							
	Trace silt seams below a depth of 16.8 m.		14	SS	3		158							
156.2							157							
18.3	Sandy CLAYEY SILT, some gravel (TILL) Hard Grey Wet		15	SS	50/0.10		156							13 21 41 25
154.7							155							
19.8	SILT and SAND, trace clay Very loose to loose Brown Wet						154							
			16	SS	3		153							0 45 52 3
							152							
							151							
			17	SS	5		150							
							149							
148.3							148							
26.2	Silt, some clay, trace sand Very loose Brown Wet						147							0 3 79 18
			18	SS	3		146							
							145							
145.2														
29.3	SAND, some gravel Compact Grey Wet													

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

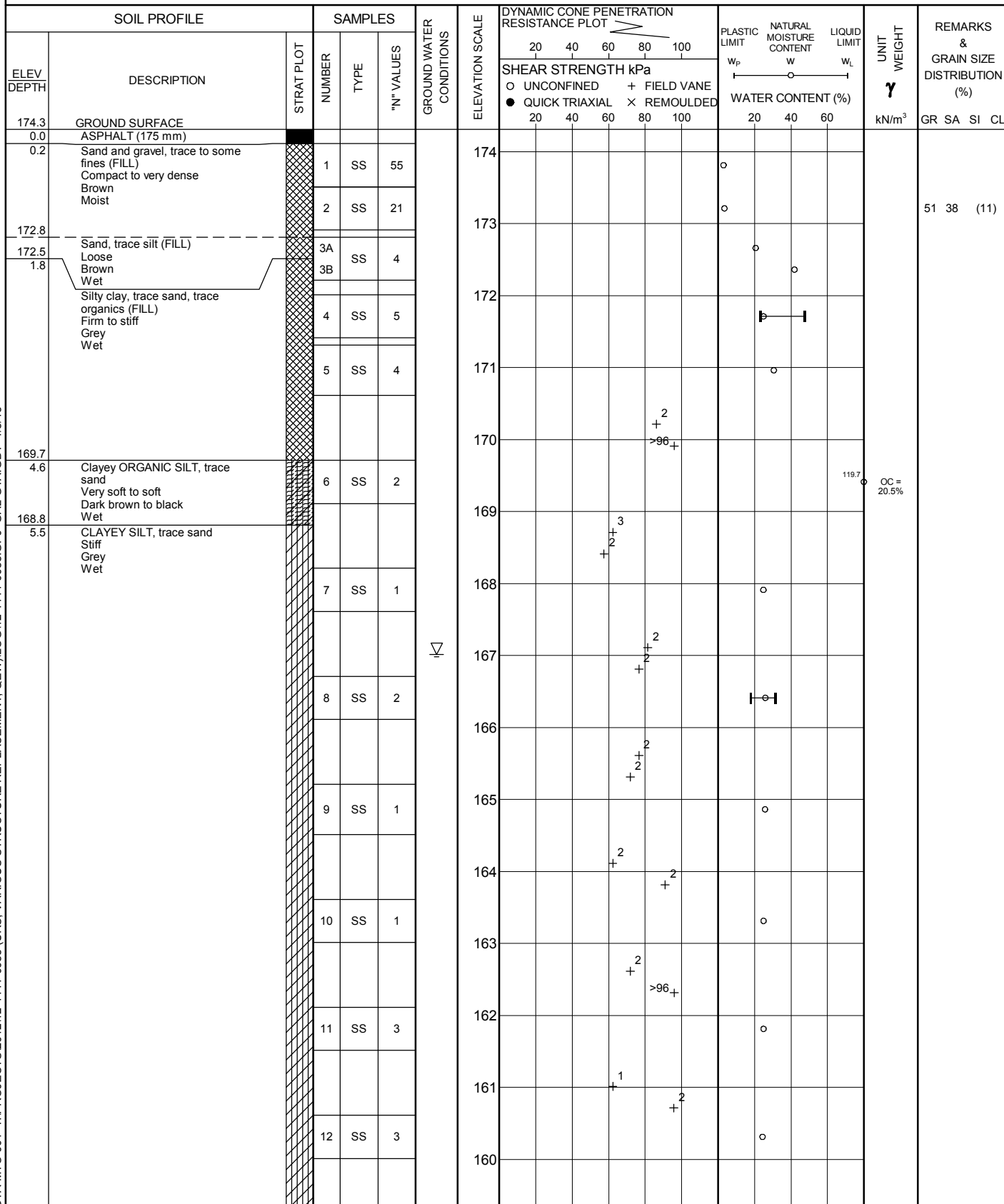
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PROJECT 12-1111-0088		RECORD OF BOREHOLE No 13-04		SHEET 3 OF 3		METRIC											
W.P. 2177-08-00		LOCATION N 4765750.7 ; E 336512.4		ORIGINATED BY SB													
DIST Central HWY QEW		BOREHOLE TYPE 108 mm I.D. Continuous Flight Hollow Stem Augers		COMPILED BY AV													
DATUM Geodetic		DATE July 9 to 11, 2013		CHECKED BY MM													
SOIL PROFILE			SAMPLES			DYNAMIC CONE PENETRATION RESISTANCE PLOT			PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT			REMARKS & GRAIN SIZE DISTRIBUTION (%)		
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	SHEAR STRENGTH kPa					WATER CONTENT (%)			γ kN/m³	GR SA SI CL
							20 40 60 80 100	20 40 60 80 100	20 40 60	20 40 60	20 40 60	20 40 60	20 40 60				
	--- CONTINUED FROM PREVIOUS PAGE ---																
141.0	SAND, some gravel Compact Grey Wet		19	SS	21		144										
							143										
							142										
141.0 33.5	CLAYEY SILT, trace to some sand Hard Grey Wet		20	SS	41		141										0 8 53 39
							140										
139.1 35.4	SAND and GRAVEL, trace to some silt, trace clay Loose Brown Wet		21	SS	8		139										
							138										34 57 6 3
							137										
136.4 38.1	END OF BOREHOLE AUGER REFUSAL  NOTE:  1. Depth to groundwater level was not measured upon completion of drilling.																

GTA-MTO 001 T:\PROJECTS\2012\12-1111-0088 [URS, VARIOUS STRUCTURE REPLACEMENT, QEW]\LOG\12-1111-0088.GPJ GAL-GTA.GDT 1/8/15

PROJECT <u>12-1111-0088</u>		<b>RECORD OF BOREHOLE No 13-05</b>		SHEET 1 OF 3		<b>METRIC</b>	
W.P. <u>2177-08-00</u>		LOCATION <u>N 4765768.8 ; E 336538.3</u>		ORIGINATED BY <u>SB</u>			
DIST <u>Central</u> HWY <u>QEW</u>		BOREHOLE TYPE <u>108 mm I.D. Continuous Flight Hollow Stem Augers</u>		COMPILED BY <u>AV</u>			
DATUM <u>Geodetic</u>		DATE <u>June 19 and 20, 2013</u>		CHECKED BY <u>MM</u>			



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

GTA-MTO 001 T:\PROJECTS\2012\12-1111-0088 (URS, VARIOUS STRUCTURE REPLACEMENT, QEW)\LOG\12-1111-0088.GPJ GAL-GTA GDT 1/8/15



PROJECT <u>12-1111-0088</u>		<b>RECORD OF BOREHOLE No 13-05</b>		SHEET 2 OF 3		<b>METRIC</b>	
W.P. <u>2177-08-00</u>		LOCATION <u>N 4765768.8 ;E 336538.3</u>		ORIGINATED BY <u>SB</u>			
DIST <u>Central</u> HWY <u>QEW</u>		BOREHOLE TYPE <u>108 mm I.D. Continuous Flight Hollow Stem Augers</u>		COMPILED BY <u>AV</u>			
DATUM <u>Geodetic</u>		DATE <u>June 19 and 20, 2013</u>		CHECKED BY <u>MM</u>			

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GTA-MTO 001 T:\PROJECTS\2012\12-1111-0088 (URS, VARIOUS STRUCTURE REPLACEMENT, QEW)\LOG\12-1111-0088.GPJ GAL-GTA.GDT 1/8/15

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

PROJECT 12-1111-0088		RECORD OF BOREHOLE No 13-05		SHEET 3 OF 3		METRIC								
W.P. 2177-08-00		LOCATION N 4765768.8 ; E 336538.3		ORIGINATED BY SB										
DIST Central HWY QEW		BOREHOLE TYPE 108 mm I.D. Continuous Flight Hollow Stem Augers		COMPILED BY AV										
DATUM Geodetic		DATE June 19 and 20, 2013		CHECKED BY MM										
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	SHEAR STRENGTH kPa						
	--- CONTINUED FROM PREVIOUS PAGE ---													
	SAND and GRAVEL, trace to some fines Compact Brown Wet		19	SS	23									48 44 (8)
140.8														
140.5	CLAYEY SILT with SAND, trace gravel Hard Brown Wet		20A	SS	50/0.08									2 55 31 12
140.5			20B											
33.8	Sandy GRAVEL, trace to some fines Dense Brown Wet													
137.4	END OF BOREHOLE		21	SS	50/0.15									59 28 (13)
36.9	NOTE: 1. Water level inside auger at a depth of 7.3 m below ground surface (Elev. 167.0 m) upon completion of drilling.													

GTA-MTO 001 T:\PROJECTS\2012\12-1111-0088 [URS, VARIOUS STRUCTURE REPLACEMENT, QEW]\LOG\12-1111-0088.GPJ GAL-GTA.GDT 1/8/15

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

○ 3% STRAIN AT FAILURE

GTA-MTO 001 T:\PROJECTS\2012\12-1111-0088 (URS, VARIOUS STRUCTURE REPLACEMENT, QEW)\LOG\12-1111-0088.GPJ GAL-GTA.GDT 1/8/15

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

PROJECT 12-1111-0088		RECORD OF BOREHOLE No 13-06		SHEET 3 OF 3		METRIC											
W.P. 2177-08-00		LOCATION N 4765798.4 ;E 336509.5		ORIGINATED BY SB													
DIST Central HWY QEW		BOREHOLE TYPE 108 mm I.D. Continuous Flight Hollow Stem Augers		COMPILED BY AV													
DATUM Geodetic		DATE June 18 and 19, 2013		CHECKED BY MM													
SOIL PROFILE			SAMPLES			DYNAMIC CONE PENETRATION RESISTANCE PLOT			PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT			REMARKS & GRAIN SIZE DISTRIBUTION (%)		
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	SHEAR STRENGTH kPa					WATER CONTENT (%)			γ	GR SA SI CL
							20 40 60 80 100	20 40 60 80 100	W <sub>p</sub>	W	W <sub>L</sub>	20 40 60	kN/m <sup>3</sup>				
	--- CONTINUED FROM PREVIOUS PAGE ---																
	SAND and GRAVEL, some silt, trace to some clay Very dense Brown Wet		19	SS	66		144										
							143										
							142										
	Split-spoon sampler bouncing.		20	SS	90/0.15		141									42 37 15 6	
139.5 35.4	AUGER REFUSAL END OF BOREHOLE						140										
NOTES:																	
1. Sand blown up inside auger to a depth of 12.2 m (Elev. 162.7 m) during drilling at a depth of 18.9 m (Elev. 156.0 m).																	
2. Water level inside auger at a depth of 9.1 m below ground surface (Elev. 165.8 m) during drilling.																	

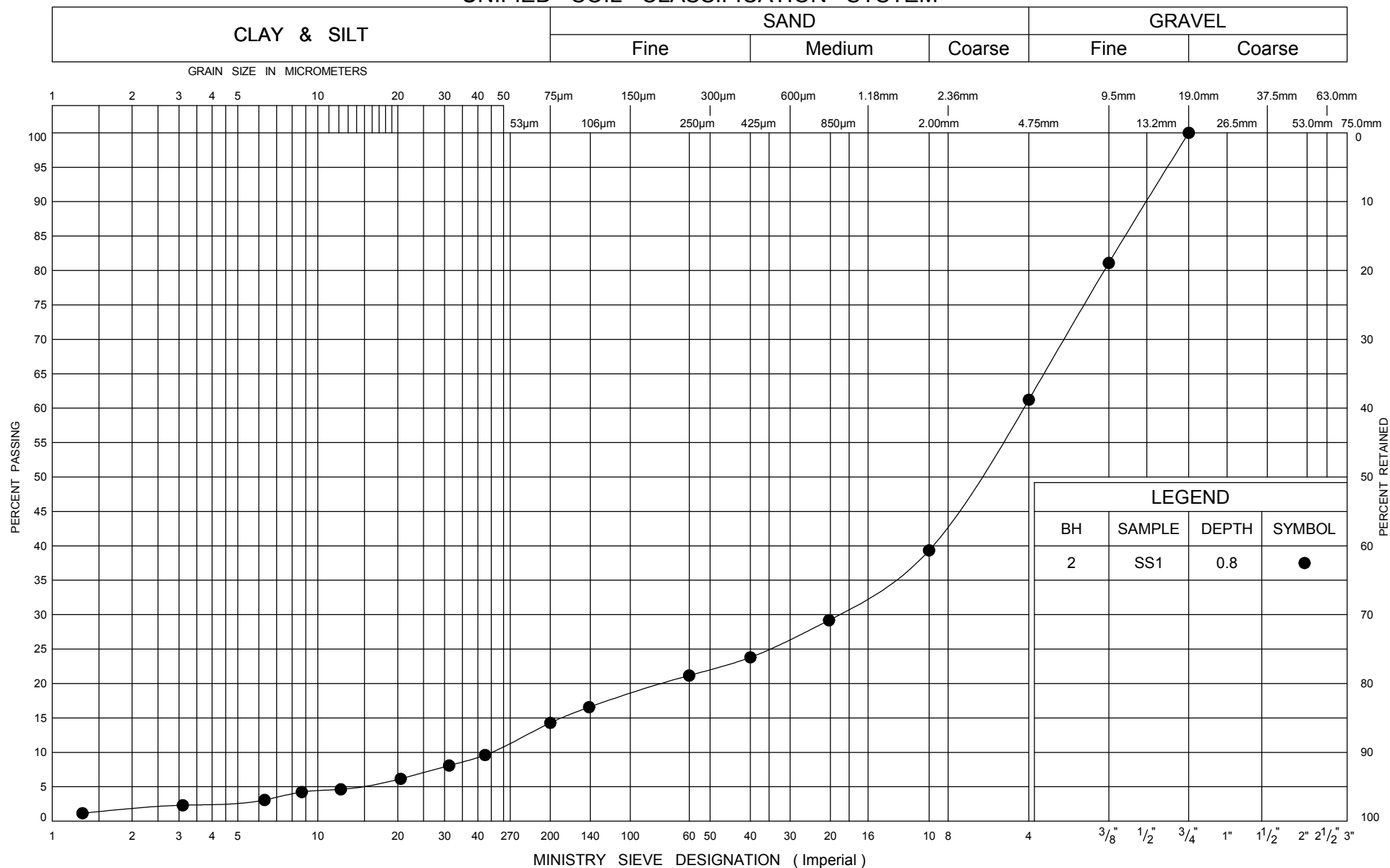
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**APPENDIX B1**  
**Laboratory Test Results**  
**Terraprobe Inc.**

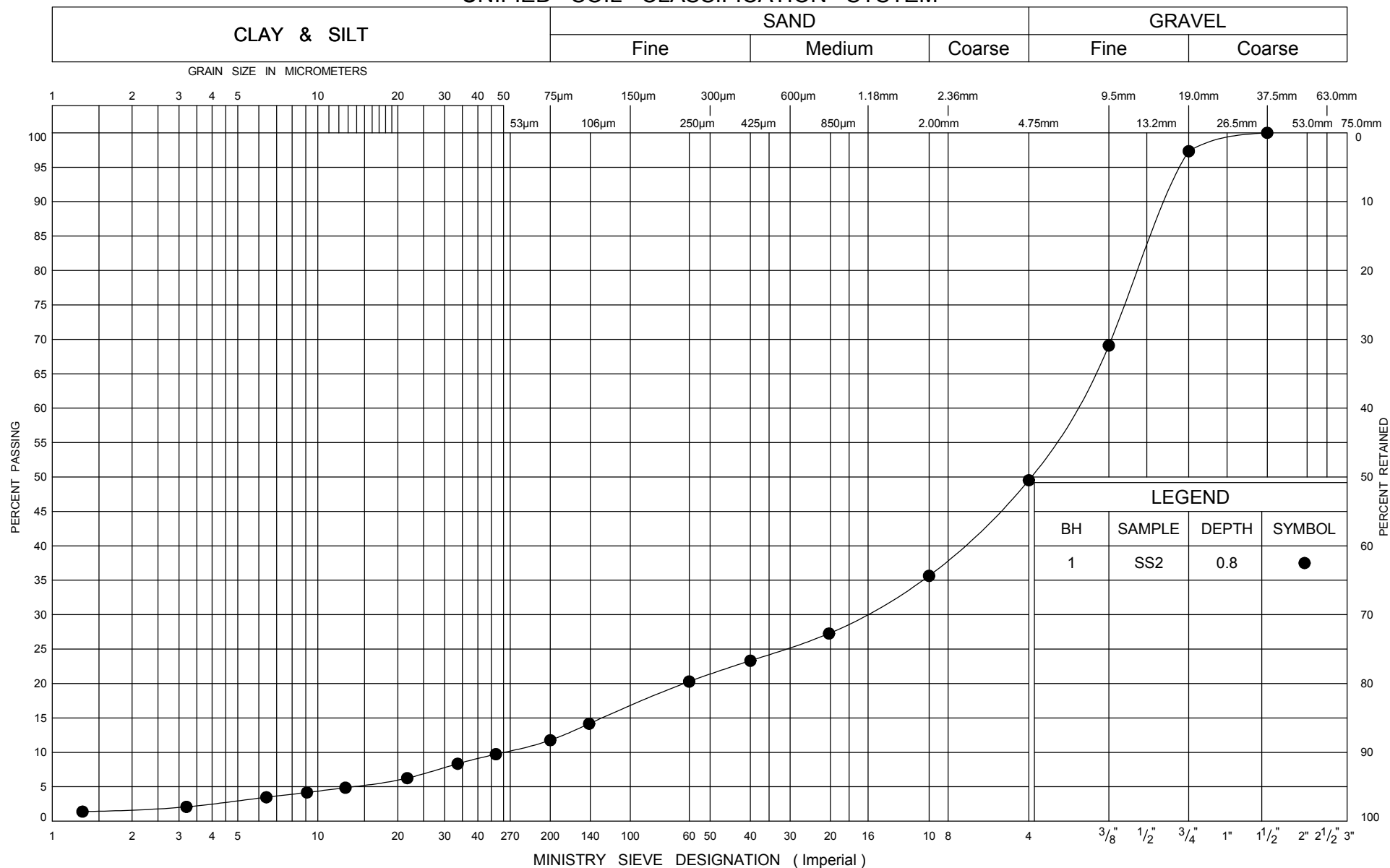




# UNIFIED SOIL CLASSIFICATION SYSTEM



# UNIFIED SOIL CLASSIFICATION SYSTEM



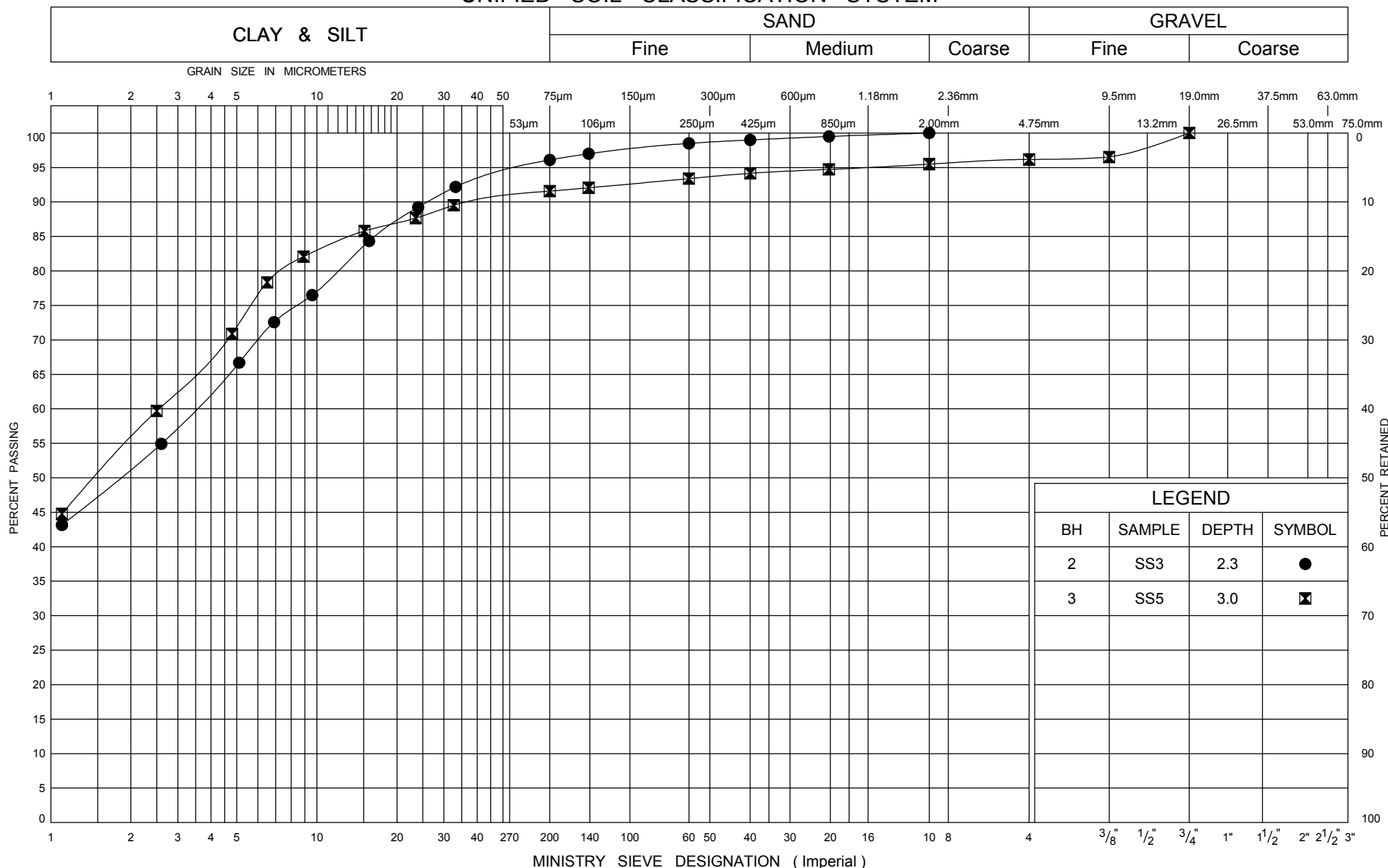
Ministry of  
Transportation

## GRAIN SIZE DISTRIBUTION FILL-SILTY SAND TO SAND

FIG No B2

DB 2014-2036

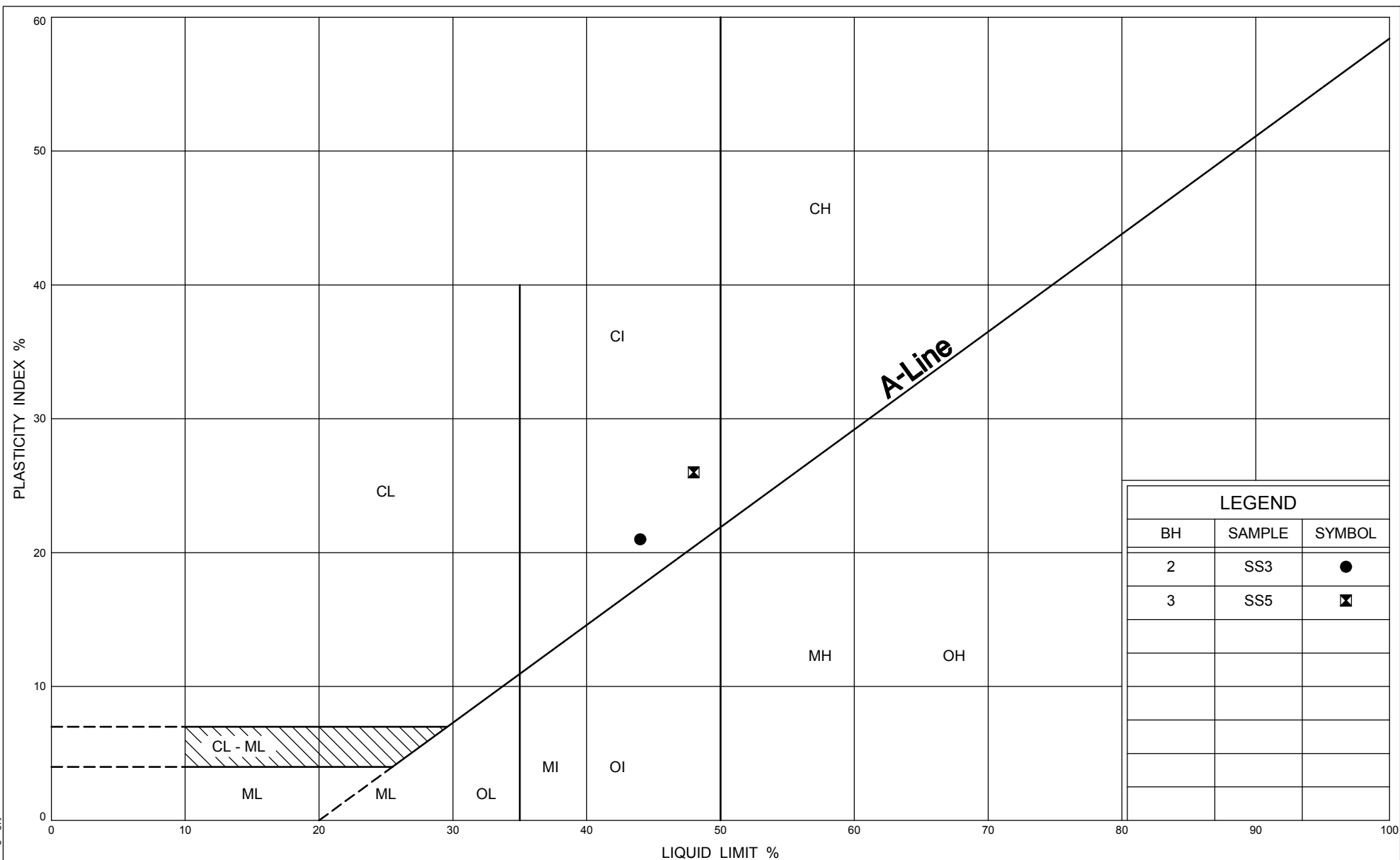
# UNIFIED SOIL CLASSIFICATION SYSTEM



## GRAIN SIZE DISTRIBUTION FILL-SILTY CLAY

FIG No B3

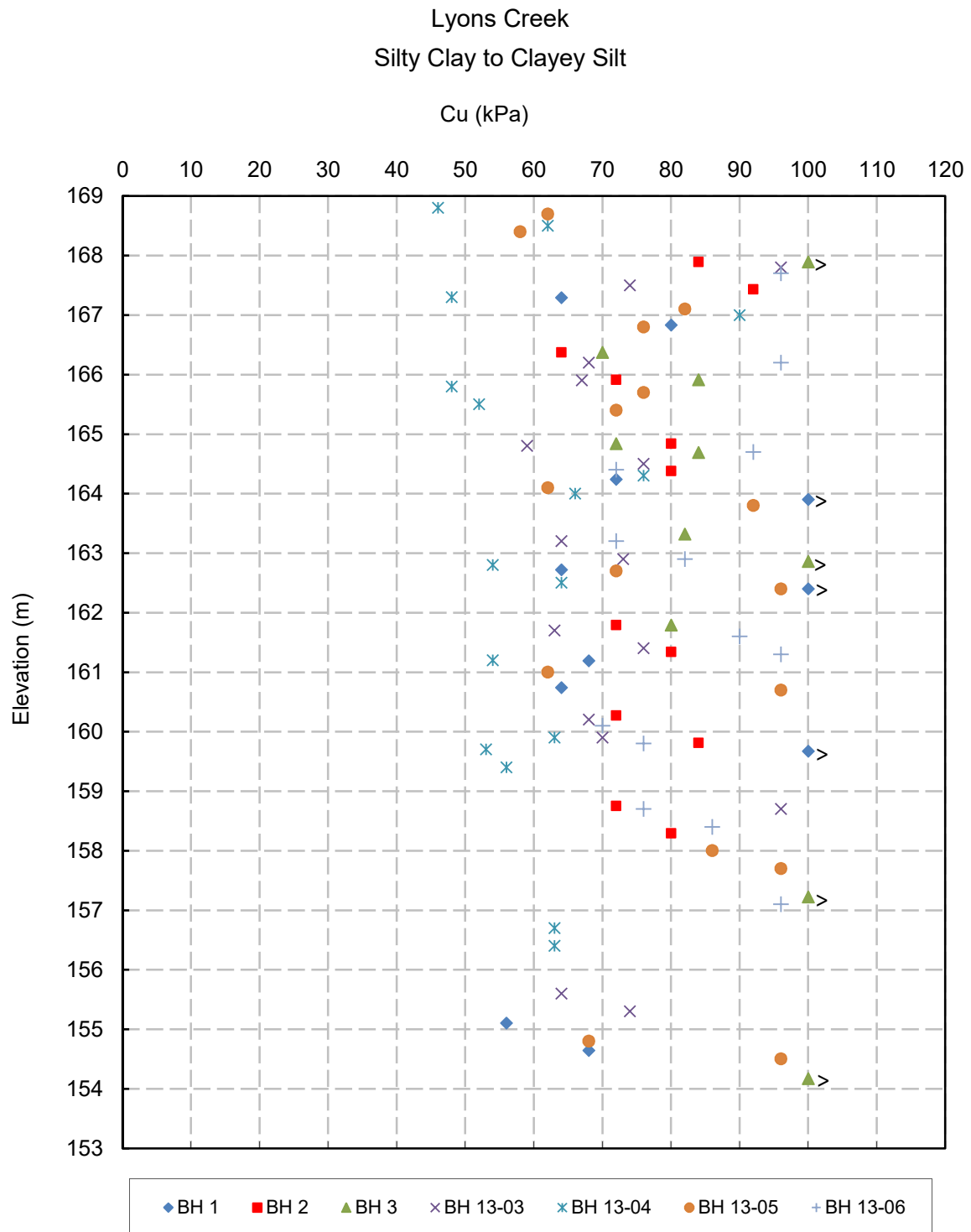
DB 2014-2036



file: 1-15-0689 jyon creek rd - bh logs .gpg

# UNDRAINED SHEAR STRENGTH

FIGURE B5



Project No. : 1-15-0689

Date : March, 2016

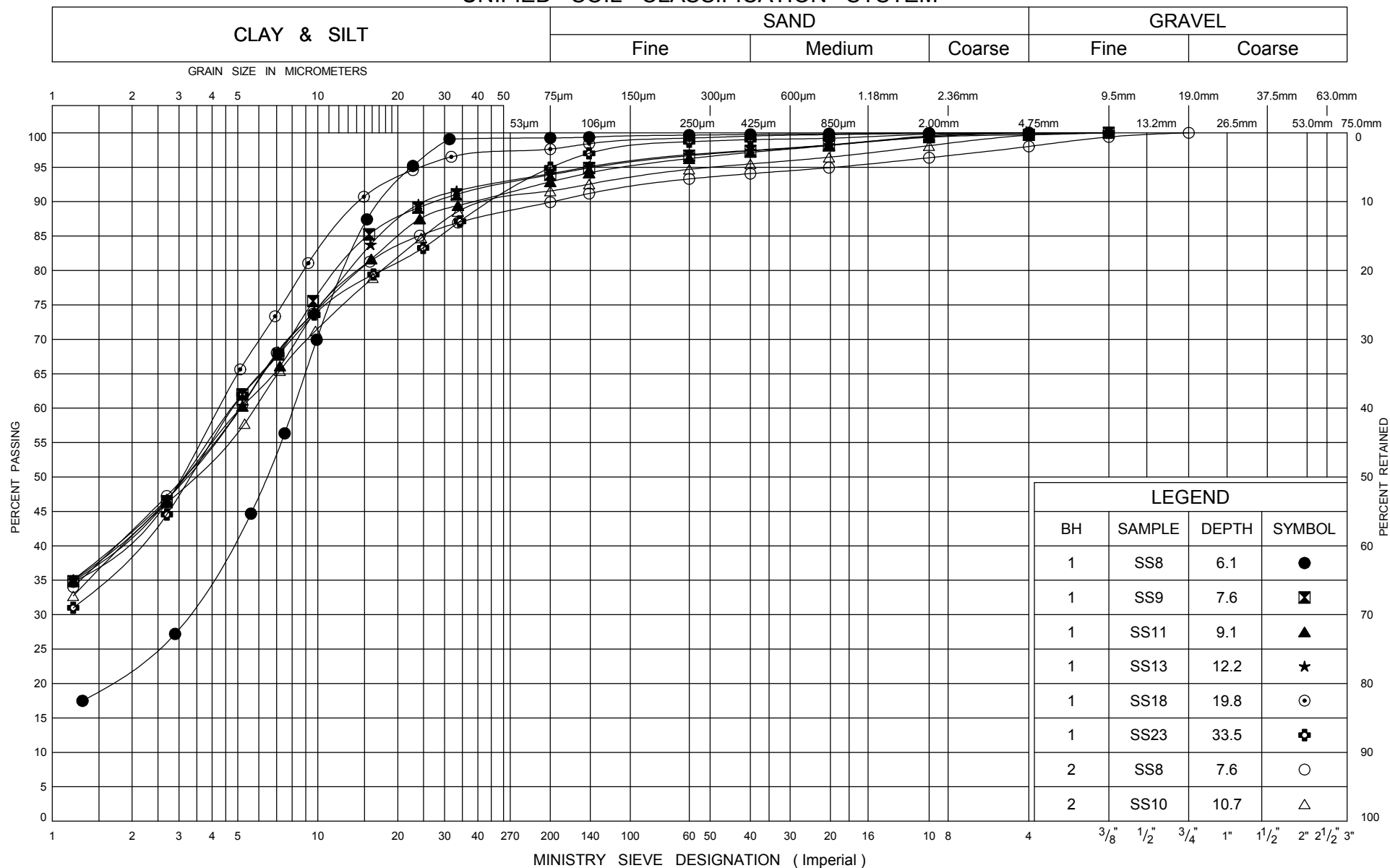


**Terraprobe Inc.**

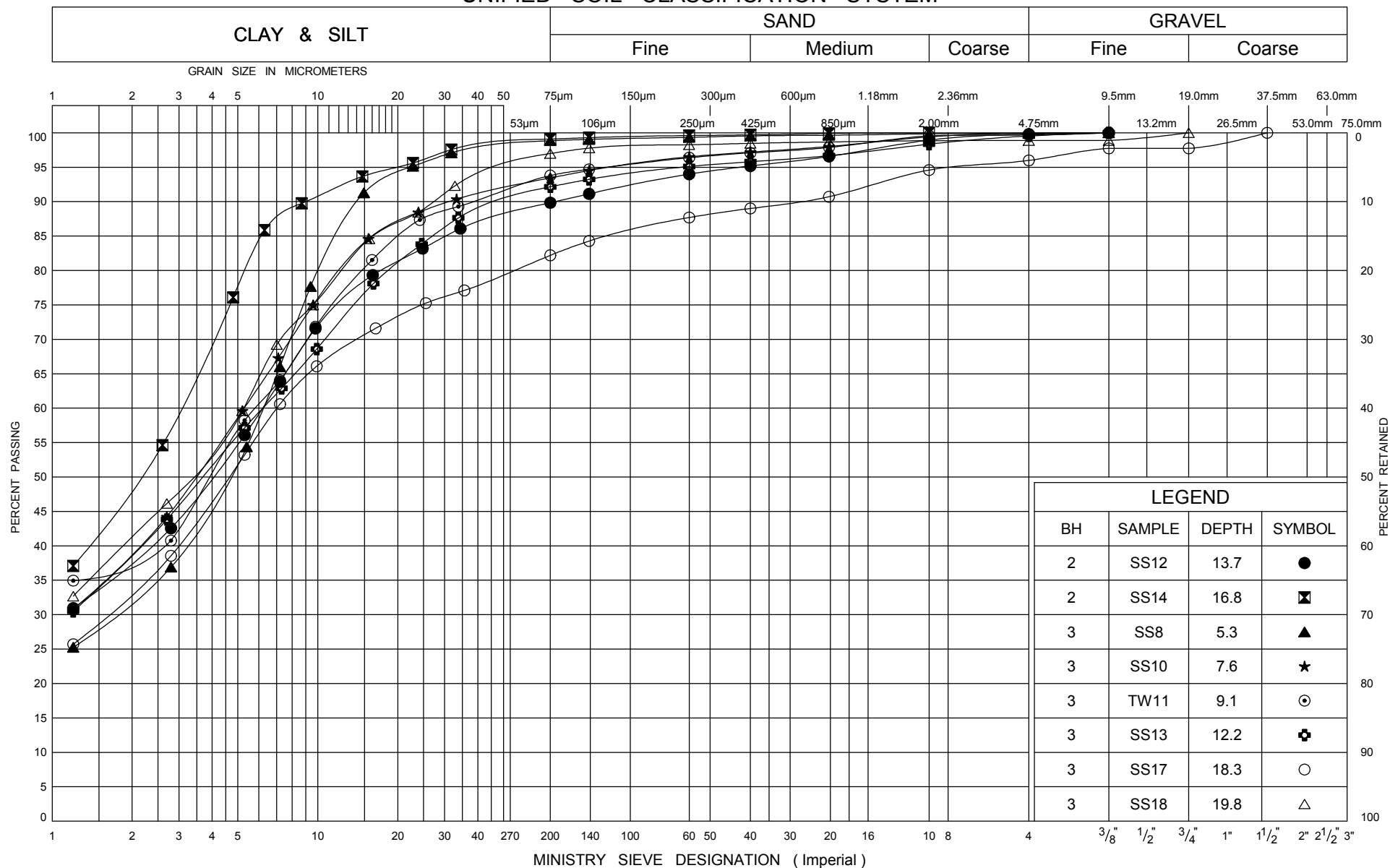
Prepared by : SD

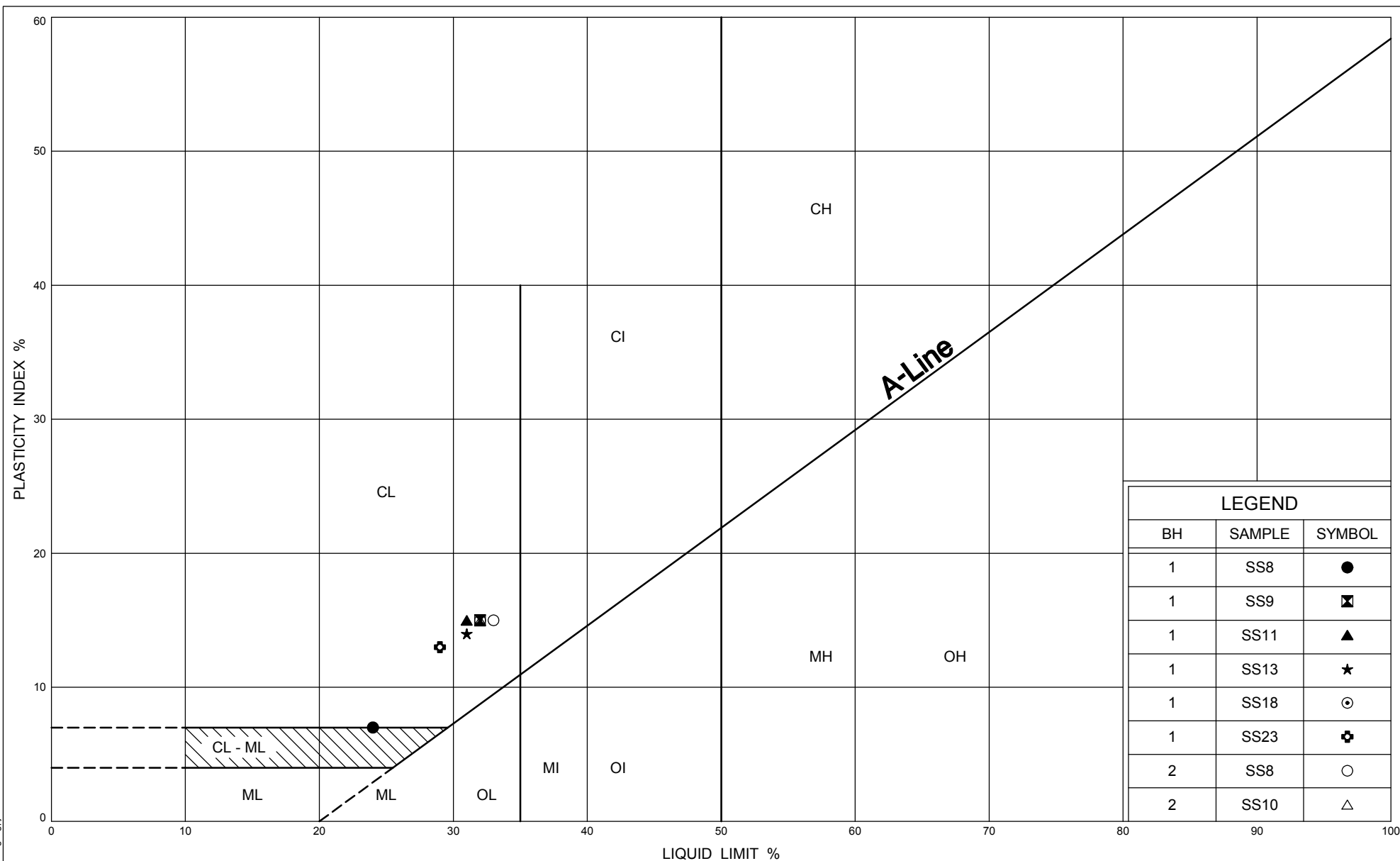
Checked by : RA

# UNIFIED SOIL CLASSIFICATION SYSTEM



# UNIFIED SOIL CLASSIFICATION SYSTEM





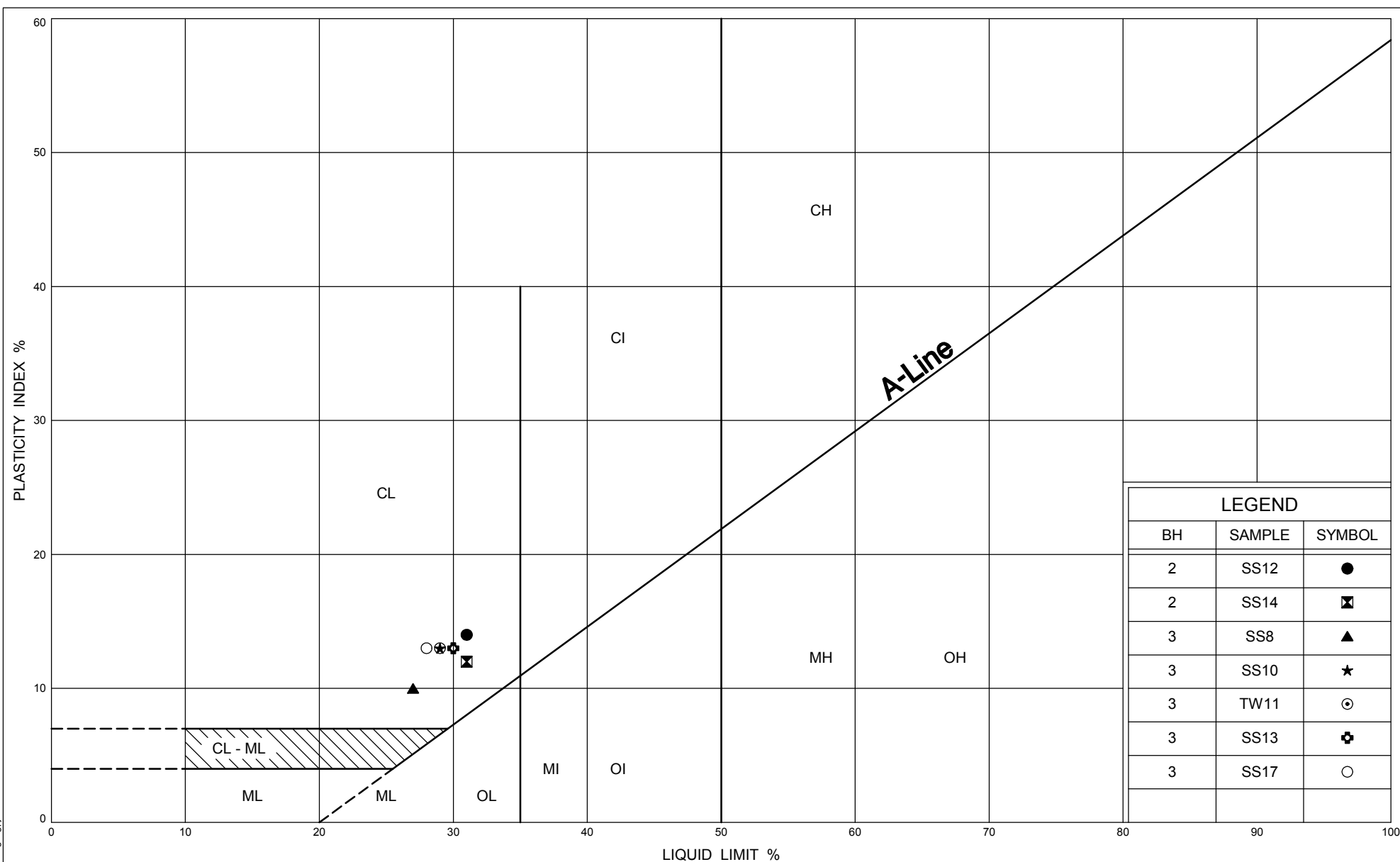
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Transportation

# PLASTICITY CHART SILTY CLAY TO CLAYEY SILT

FIG No B8

DB 2014-2036





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Transportation

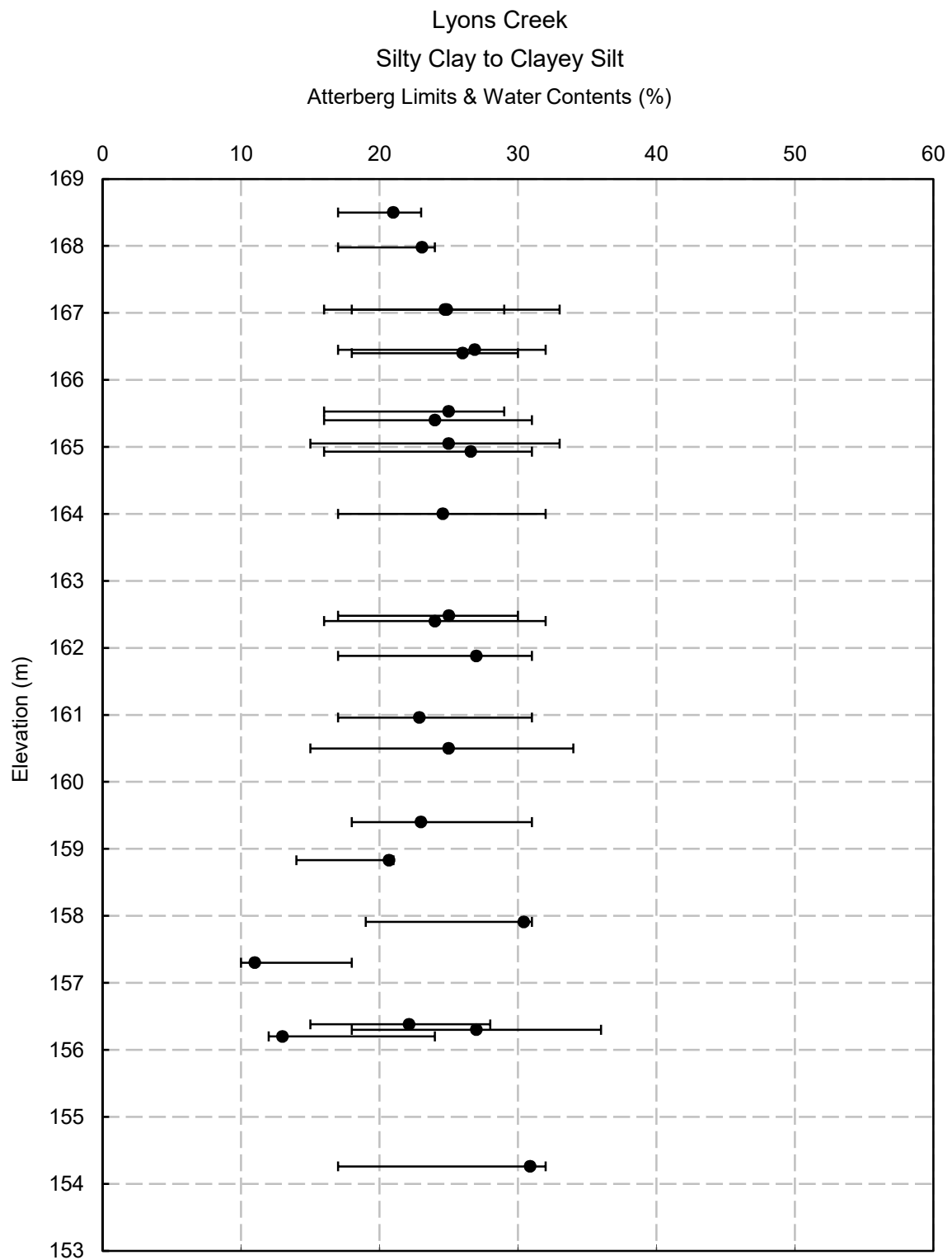
# PLASTICITY CHART SILTY CLAY TO CLAYEY SILT

FIG No B9

DB 2014-2036

# ATTERBERG LIMITS AND WATER CONTENTS

FIGURE B10



C:\Users\bradull\Documents\Reviewed Reports\Tee Lyons Black Creek\Lyons Creek FID\Reb-Pc-Cc-Cr-Cu - Lyons Creek.xlsx

Project No. : 1-15-0689

Date : March, 2016



Prepared by : SD

Checked by : RA

CONSOLIDATION TEST SUMMARY				FIGURE B11			
<b>SAMPLE IDENTIFICATION</b>							
Borehole No. :		3		Sample No. :		TW11	
				Sample Depth (m) :		9.1 - 9.6	
<b>TEST CONDITIONS</b>							
Test Type :		Laboratory Standard		Date Started :		15-Dec-15	
Load Duration (hr) :		24		Date Completed :		24-Dec-15	
<b>SAMPLE DIMENSIONS AND PROPERTIES _ INITIAL</b>							
Sample Height (mm) :		25.27		Unit Weight (kN/m <sup>3</sup> ) :		20.10	
Sample Diameter (mm) :		63.35		Dry Unit Weight (kN/m <sup>3</sup> ) :		16.13	
Area (cm <sup>2</sup> ) :		31.52		Specific Gravity :		2.74	
Volume (cm <sup>3</sup> ) :		79.65		Solid Height (mm) :		15.2	
Water Content (%) :		24.6%		Volume of Solids (cm <sup>3</sup> ) :		47.74	
Wet Mass (g) :		163.23		Volume of Voids (cm <sup>3</sup> ) :		31.91	
Dry Mass (g) :		131.00		Degree of Saturation (%) :		101.00	
<b>TEST COMPUTATIONS</b>							
Stress (kPa)	Initial Height (mm)	Final Height (mm)	Void Ratio	t <sub>90</sub> (min)	C <sub>v</sub> (cm <sup>2</sup> /s)	m <sub>v</sub> (m <sup>2</sup> /kN)	k (cm/s)
1.2214	25.27	25.27	0.662				
35.582	25.27	24.97	0.642	9.00	2.45E-03	3.50E-04	8.43E-08
69.942	24.97	24.79	0.631	10.56	2.06E-03	2.07E-04	4.19E-08
138.66	24.79	24.55	0.615	9.00	2.37E-03	1.42E-04	3.30E-08
276.1	24.55	23.95	0.575	9.00	2.26E-03	1.77E-04	3.93E-08
550.98	23.95	23.25	0.530	12.25	1.57E-03	1.06E-04	1.63E-08
1100.7	23.25	22.35	0.470	10.56	1.68E-03	7.09E-05	1.17E-08
2200.3	22.35	21.53	0.416	9.00	1.83E-03	3.31E-05	5.96E-09
551.0	21.53	21.73	0.430				
138.66	21.73	22.11	0.455				
35.582	22.11	22.51	0.481				
<b>SAMPLE DIMENSIONS AND PROPERTIES _ FINAL</b>							
Sample Height (mm) :		22.51		Unit Weight (kN/m <sup>3</sup> ) :		21.45	
Sample Diameter (mm) :		63.35		Dry Unit Weight (kN/m <sup>3</sup> ) :		17.80	
Area (cm <sup>2</sup> ) :		31.52		Specific Gravity :		2.74	
Volume (cm <sup>3</sup> ) :		70.95		Solid Height (mm) :		15.2	
Water Content (%) :		20.5%		Volume of Solids (cm <sup>3</sup> ) :		46.94	
Wet Mass (g) :		155.19		Volume of Voids (cm <sup>3</sup> ) :		24.01	
Dry Mass (g) :		128.80					
Project No. : 1-15-0689				Prepared By : SD			
Date : February 2016				Checked By : RA			

C:\Users\labdul\Documents\Reviewed Reports\Tee Lyons Black Creek\Lyons Creek FIDR\Consolidation Results - LYONS Creek.xlsx



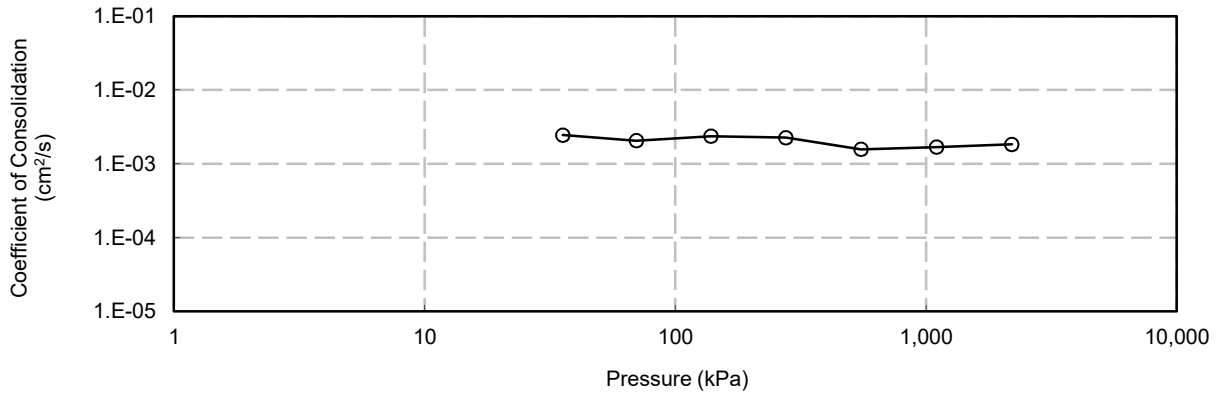
**Terraprobe Inc.**

# CONSOLIDATION TEST

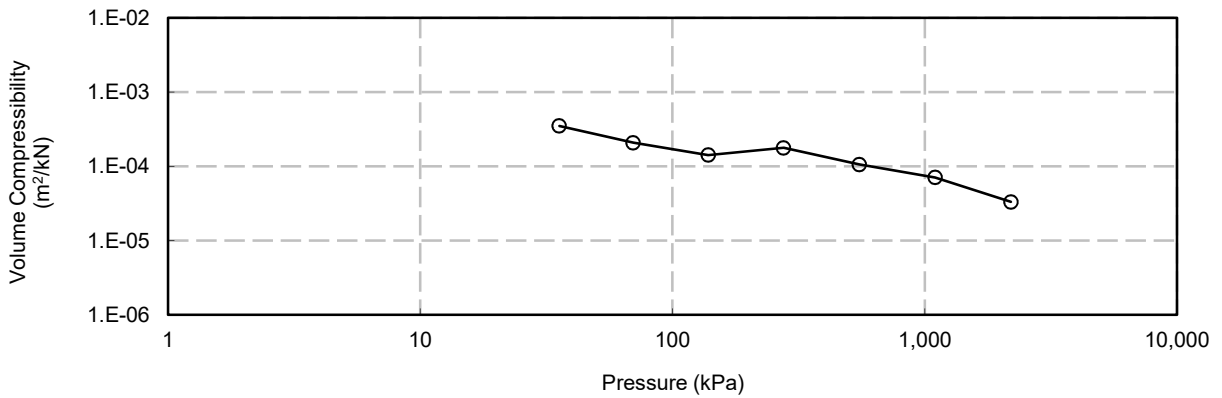
FIGURE B12

Site: Lyons Creek  
Sample #: BH3 TW11

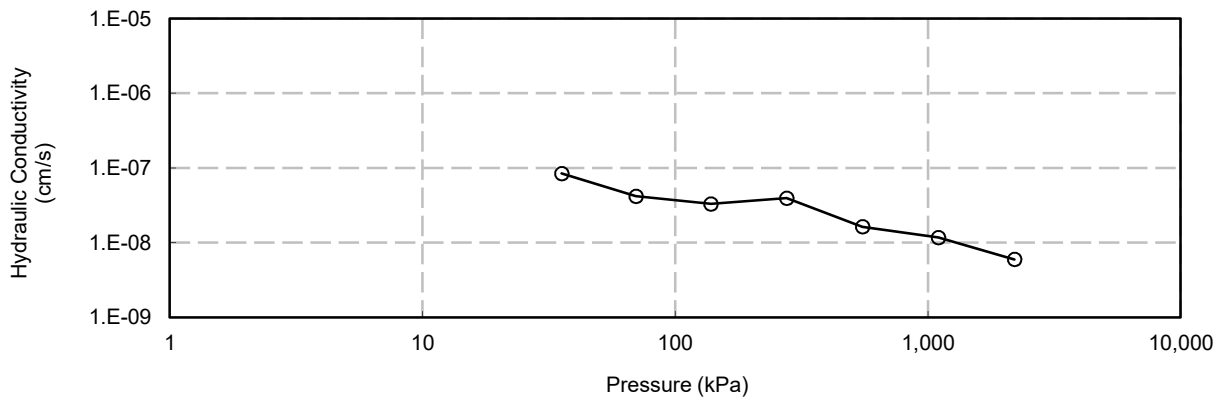
$C_v$  vs Pressure



$m_v$  vs Pressure



$k$  vs Pressure



Project No.: 1-15-0689  
Date: February 2016



Prepared By: SD  
Checked By: RA

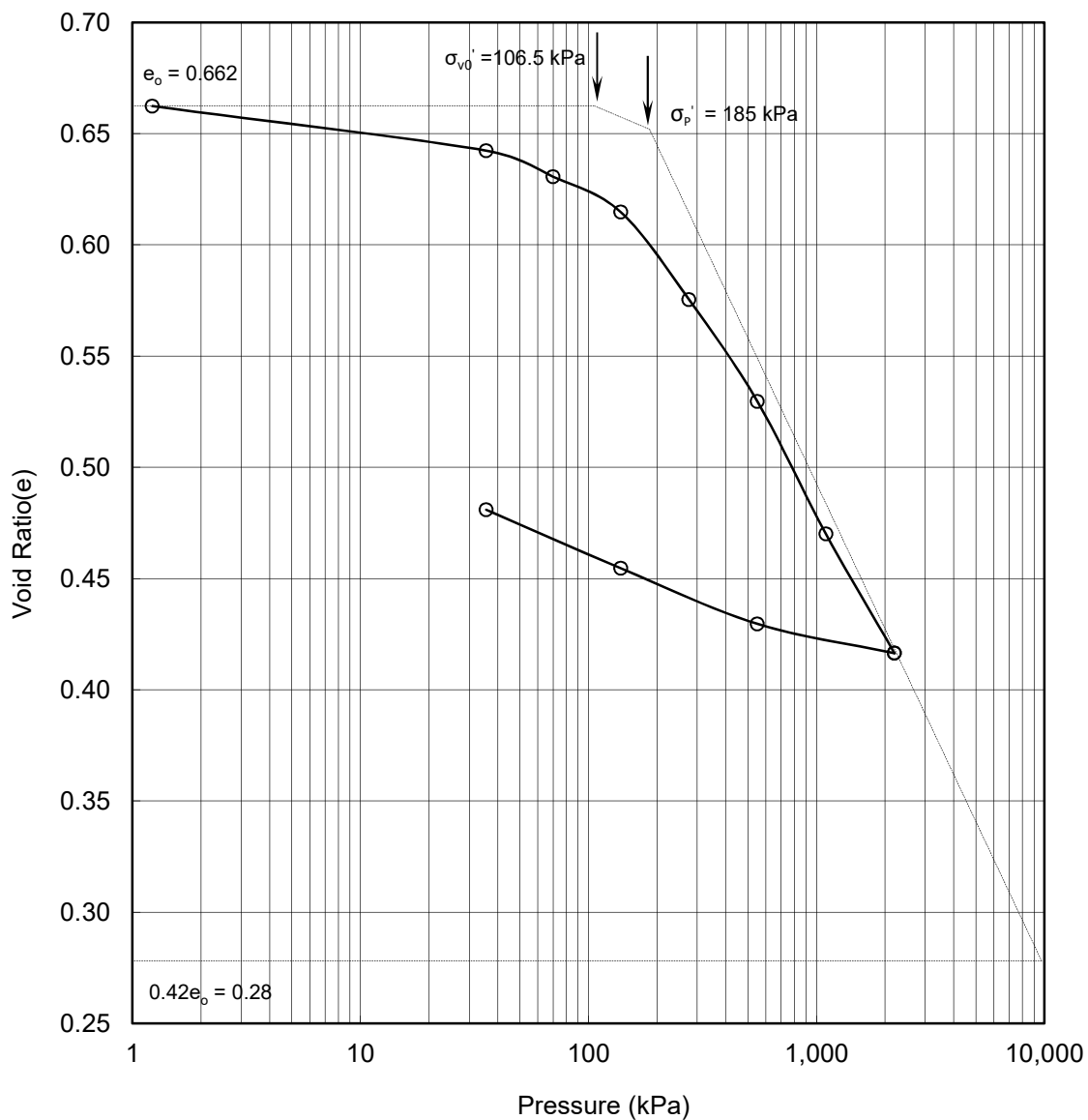
# CONSOLIDATION TEST

FIGURE B13

Site: Lyons Creek

Sample # : BH3 TW11

## Void Ratio vs Pressure



Soil Type : Silty Clay to Clay

$e_o =$	0.66	$\omega_L =$	29%	$\sigma_{v0}' =$	106.5 kPa
$\omega =$	25%	$\omega_p =$	16%	$\sigma_p' =$	185.0 kPa
$\gamma =$	20.1 kN/m <sup>3</sup>	PI =	13%	$C_c =$	0.217
$G_s =$	2.74			$C_r =$	0.043

Project No. : 1-15-0689

Date : February 2016

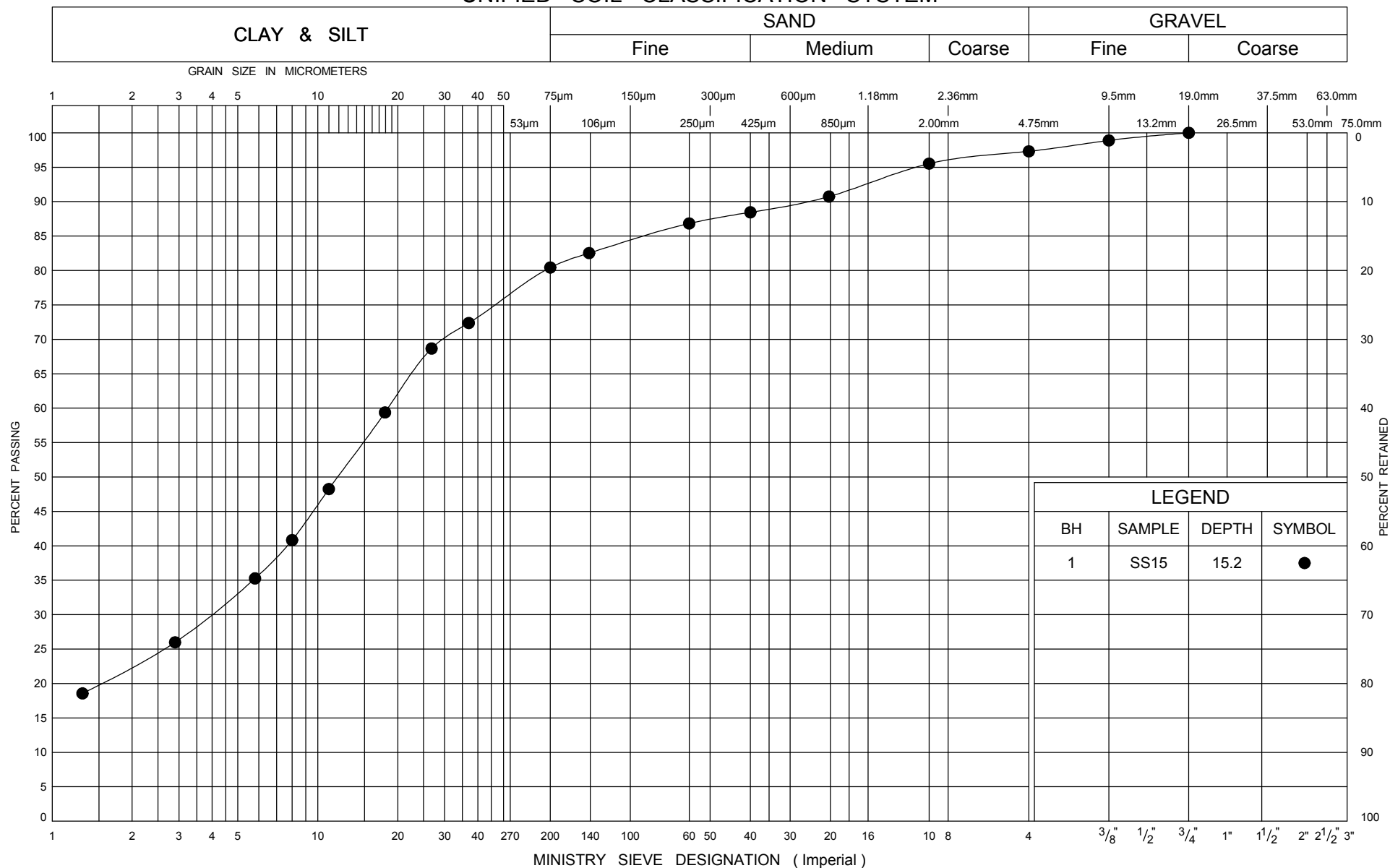


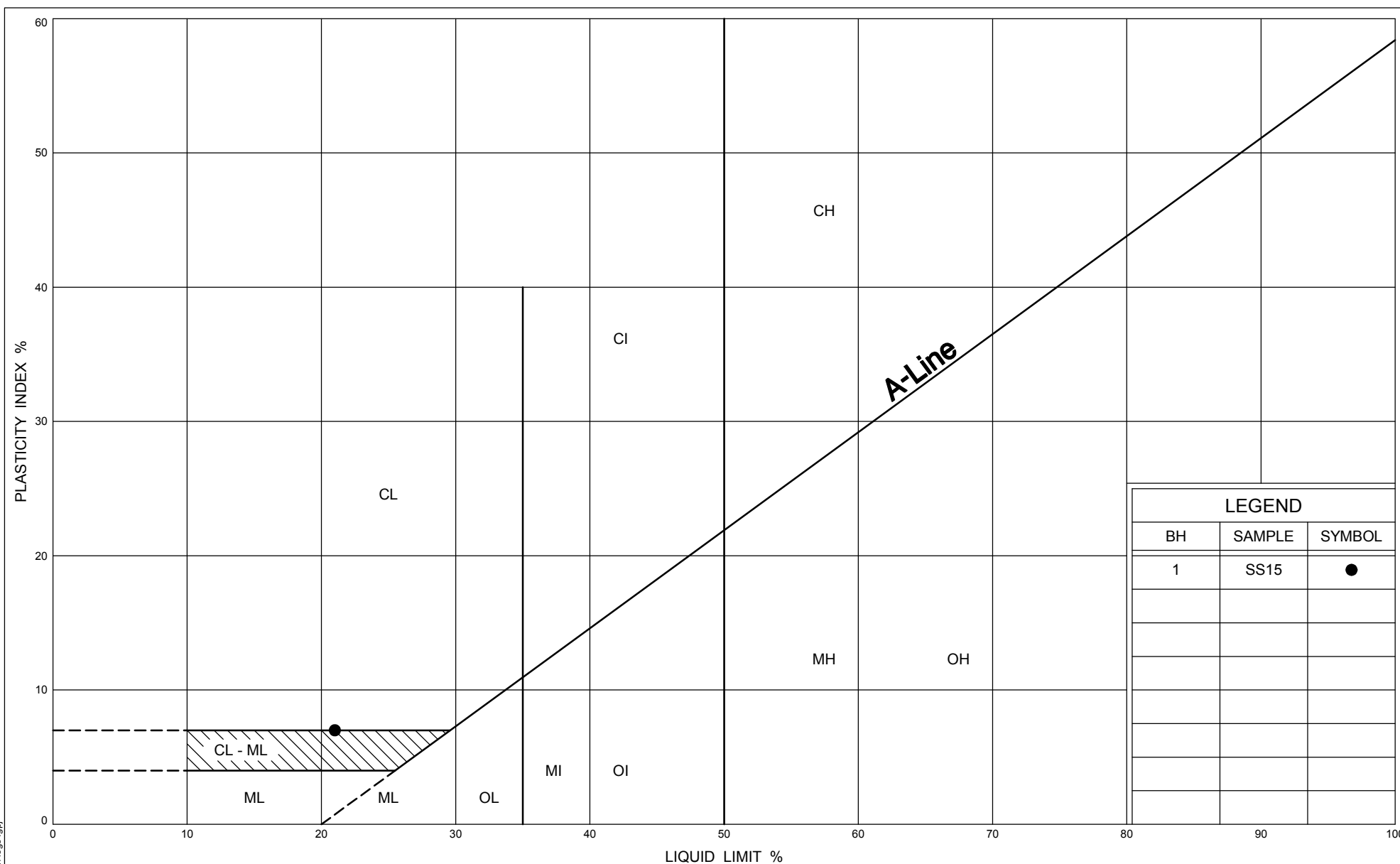
**Terraprobe Inc.**

Prepared By : SD

Checked By : RA

# UNIFIED SOIL CLASSIFICATION SYSTEM





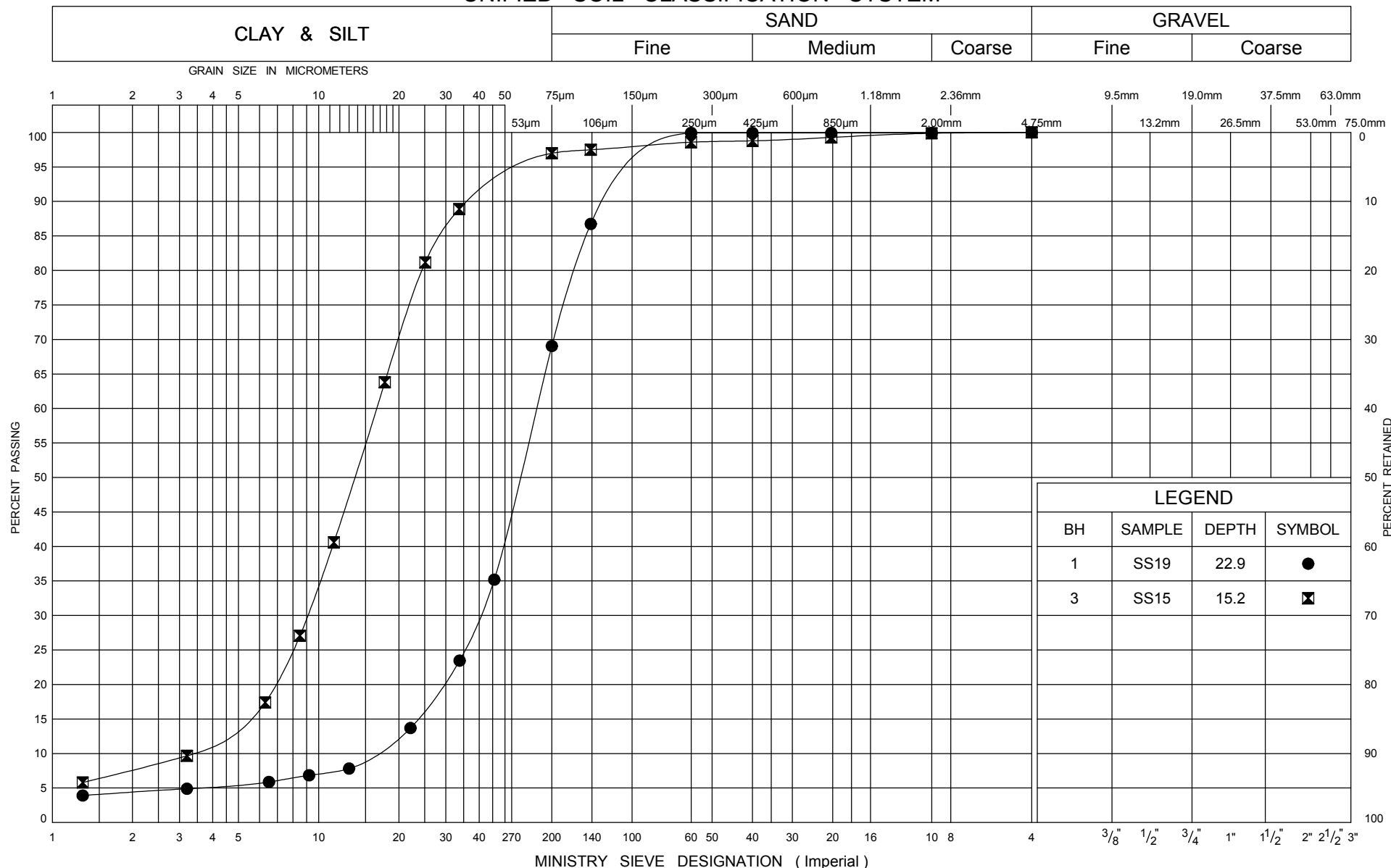
LEGEND		
BH	SAMPLE	SYMBOL
1	SS15	●

# PLASTICITY CHART CLAYEY SILT TILL

FIG No B15

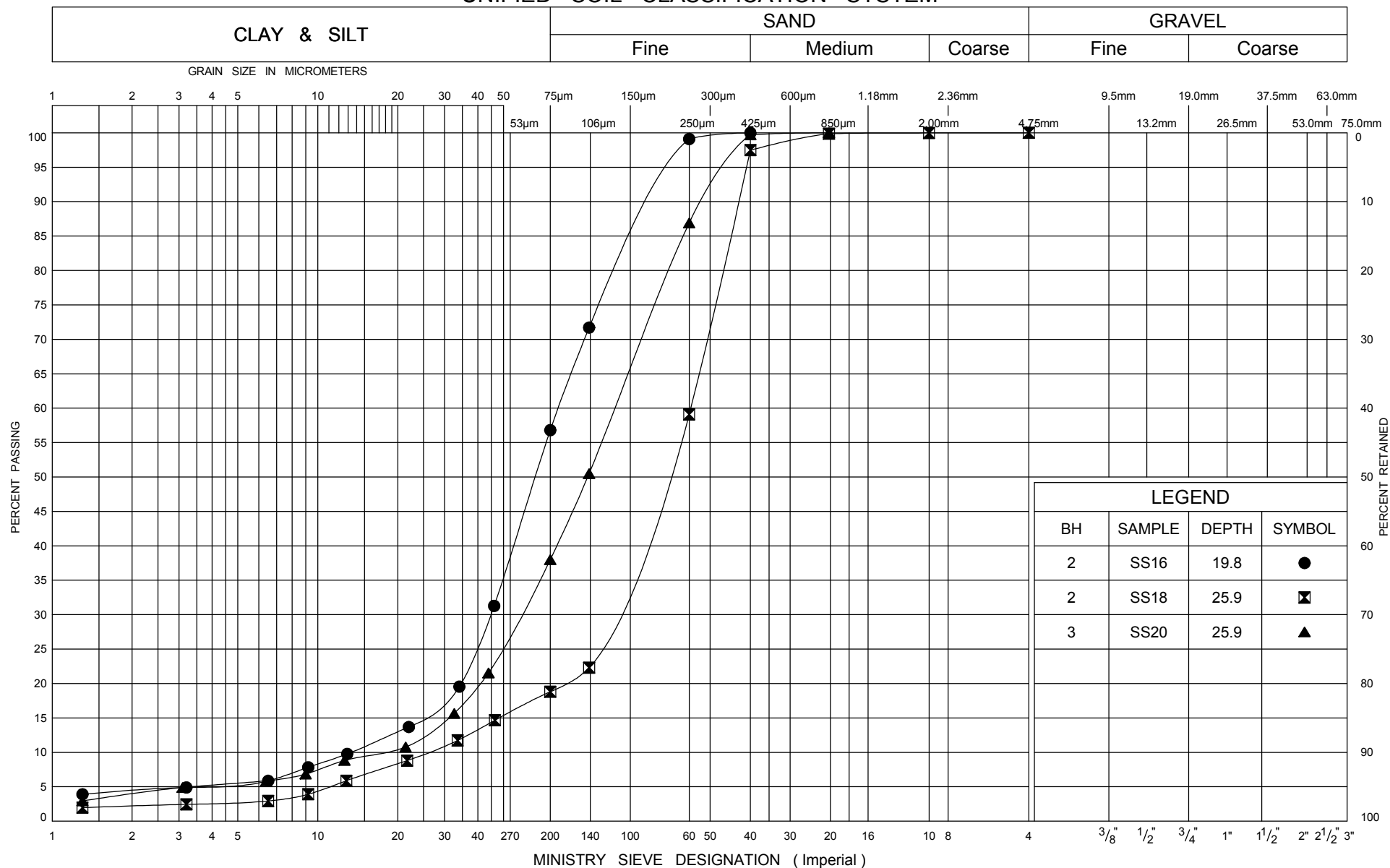
DB 2014-2036

# UNIFIED SOIL CLASSIFICATION SYSTEM





# UNIFIED SOIL CLASSIFICATION SYSTEM



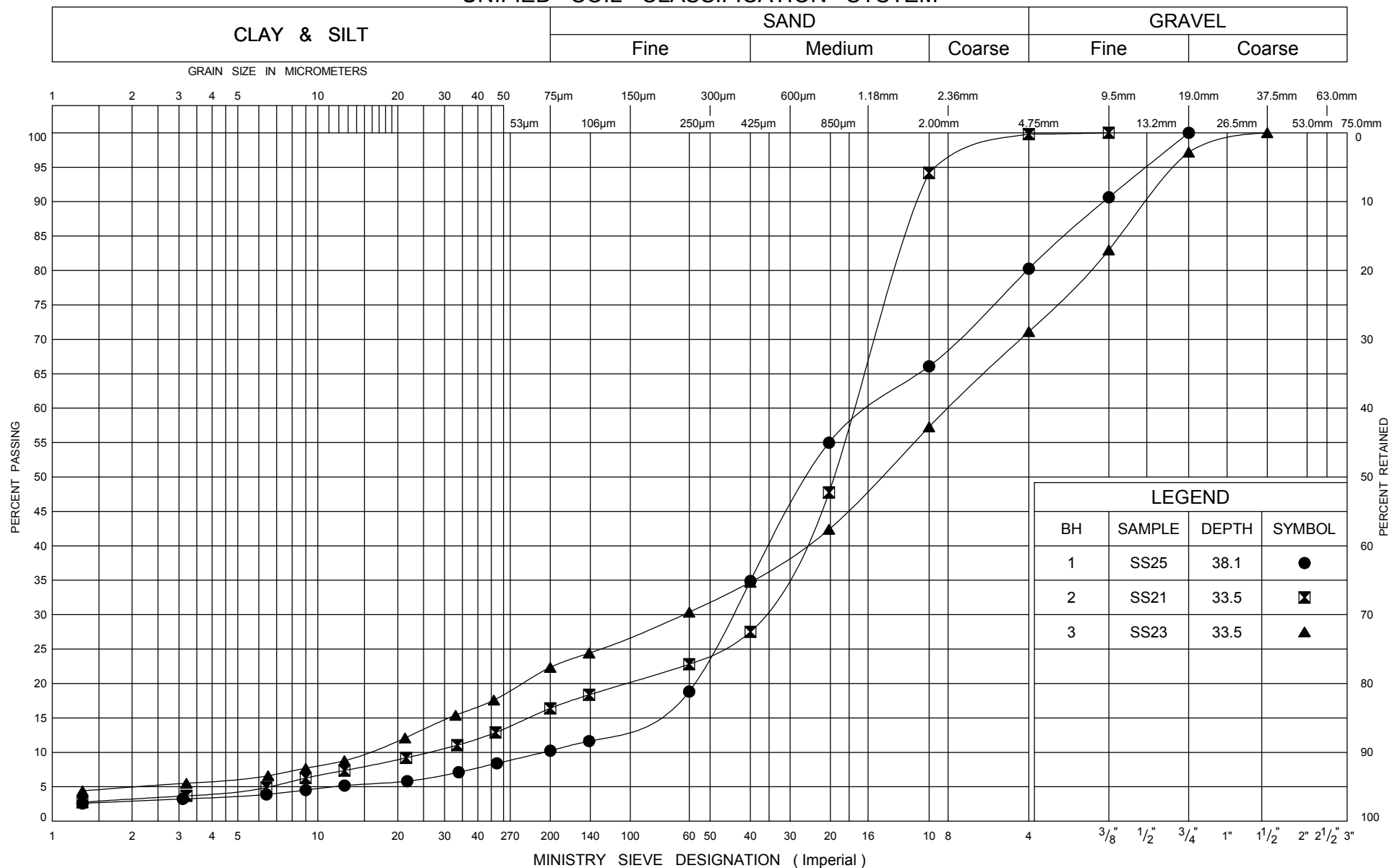
Ministry of  
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## GRAIN SIZE DISTRIBUTION SAND TO SILTY SAND

FIG No B17

DB 2014-2036

# UNIFIED SOIL CLASSIFICATION SYSTEM


Ministry of  
Transportation

## GRAIN SIZE DISTRIBUTION SAND AND GRAVEL TO GRAVELLY SAND

FIG No B18

DB 2014-2036

# **APPENDIX B2**

## **Laboratory Test Results**

### **Golder**





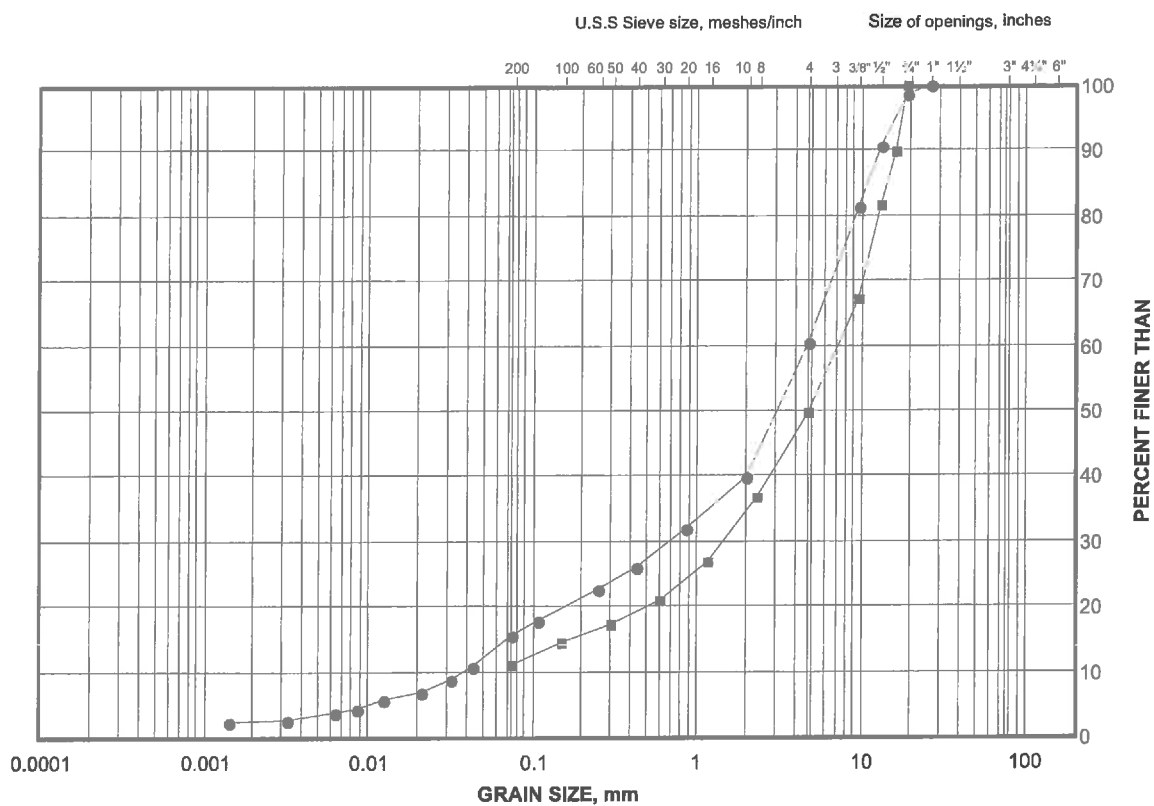
# **APPENDIX B**

## **Laboratory Test Results**

# GRAIN SIZE DISTRIBUTION

Sand and Gravel Fill

FIGURE B1



SILT AND CLAY SIZES	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED	SAND SIZE			GRAVEL SIZE		SIZE

## LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	13-04	2	173.4
■	13-05	2	173.2

Project Number: 12-1111-0088

Checked By: 

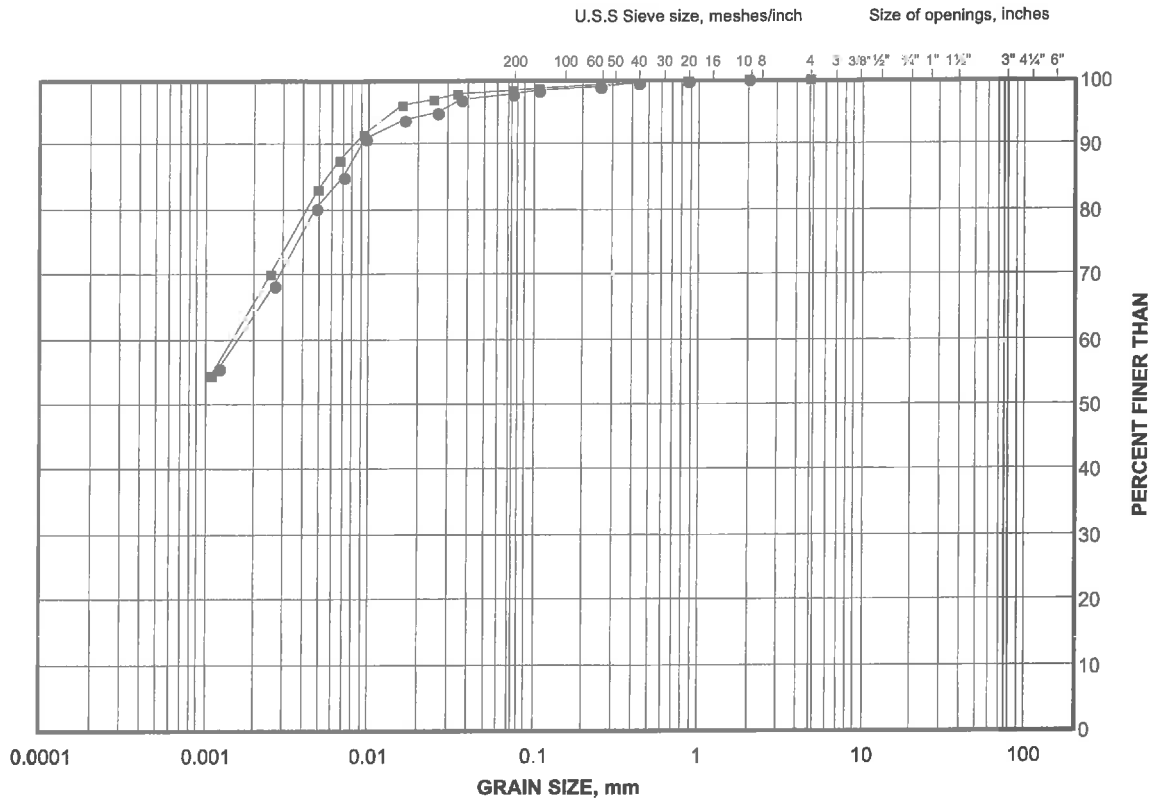
Golder Associates

Date: 22-Oct-13

# GRAIN SIZE DISTRIBUTION

Silty Clay to Clay Fill

FIGURE B2



SILT AND CLAY SIZES		FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED		SAND SIZE			GRAVEL SIZE		SIZE

## LEGEND

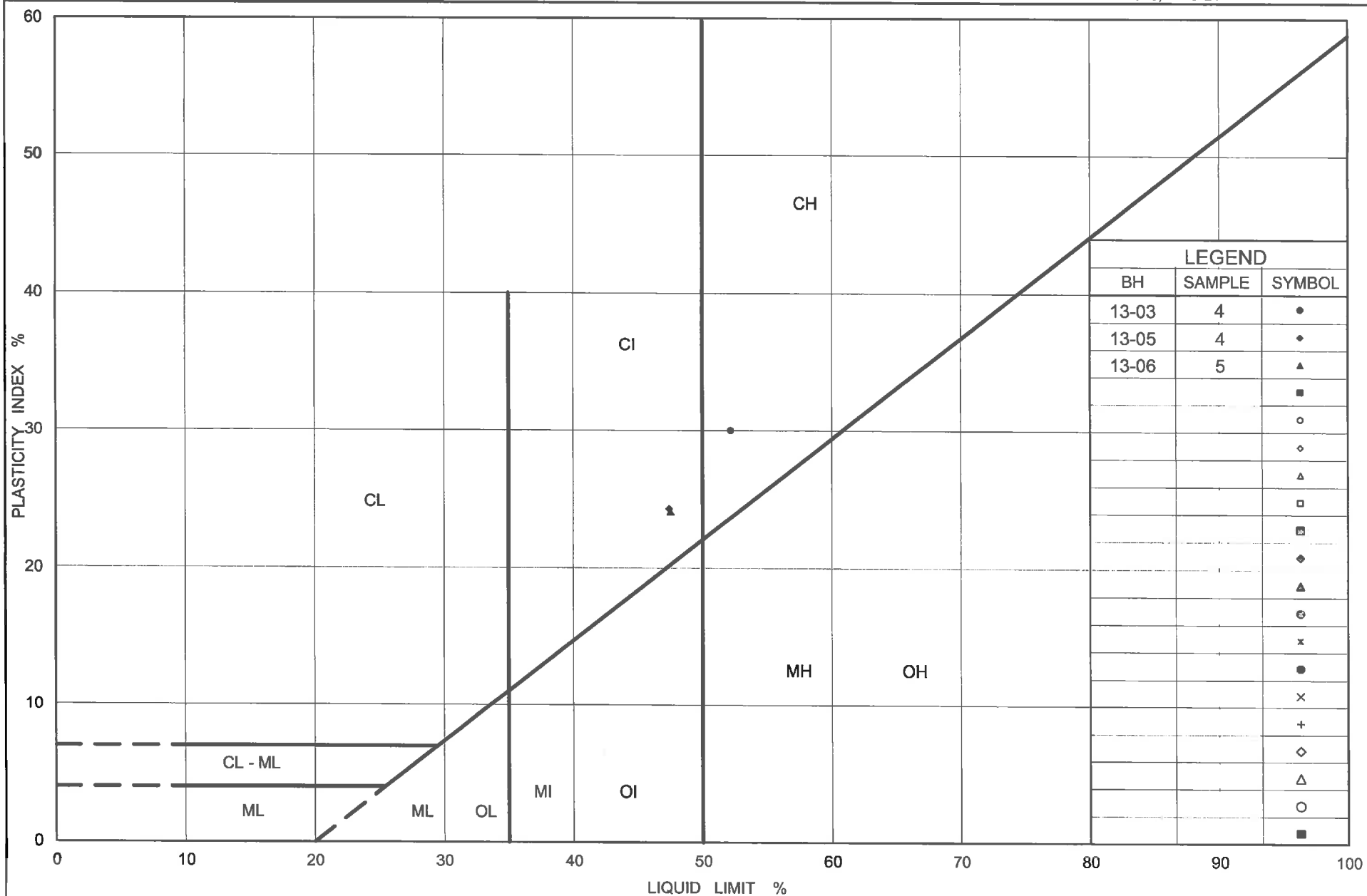
SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	13-03	4	172.4
■	13-06	5	170.8

Project Number: 12-1111-0088

Checked By: 

Golder Associates

Date: 22-Oct-13



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## PLASTICITY CHART

Silty Clay to Clay Fill

Figure No. B3

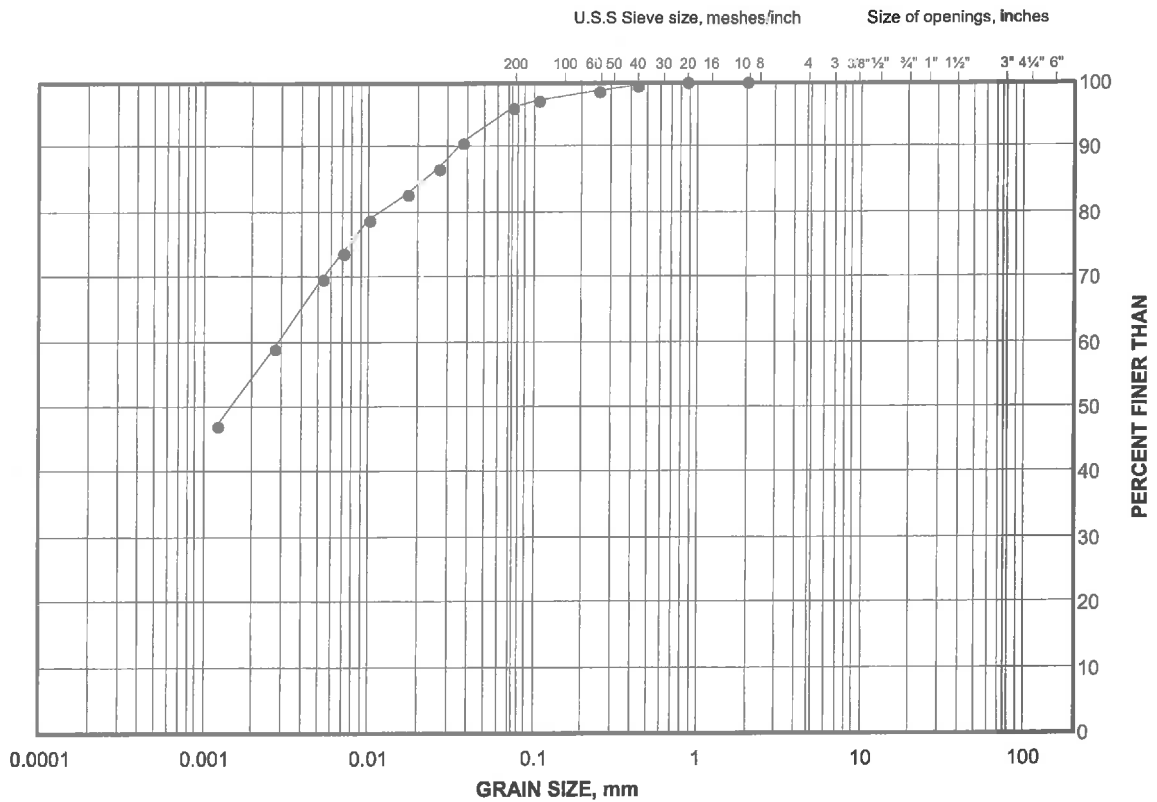
Project No. 12-1111-0088

Checked By: *[Signature]*

# GRAIN SIZE DISTRIBUTION

Clayey Organic Silt

FIGURE B4



SILT AND CLAY SIZES		FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED		SAND SIZE			GRAVEL SIZE		SIZE

## LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
•	13-04	5	171.1

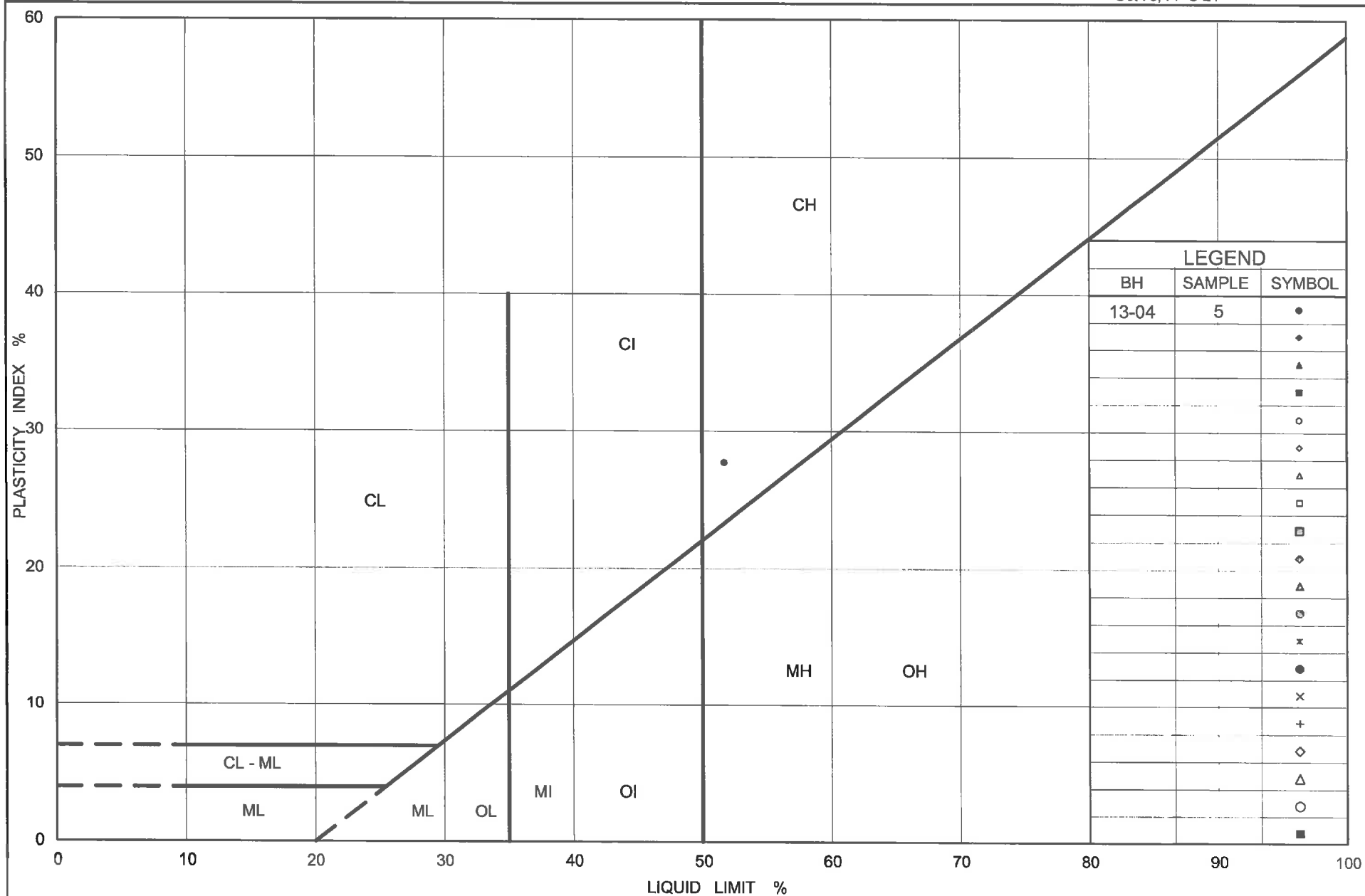
Project Number: 12-1111-0088

Checked By: 

Golder Associates

Date: 22-Oct-13





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## PLASTICITY CHART

Clayey Organic Silt

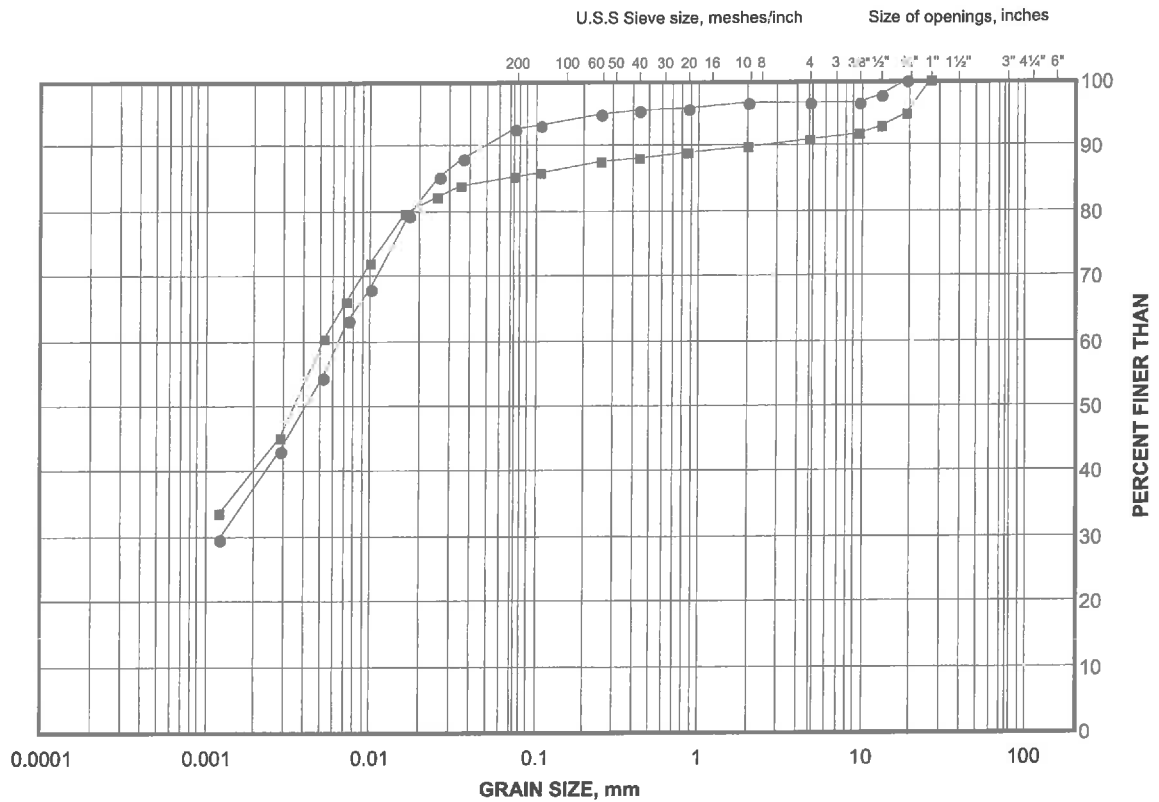
Figure No. B5

Project No. 12-1111-0088

Checked By: *[Signature]*

# GRAIN SIZE DISTRIBUTION CLAYEY SILT

FIGURE B6



SILT AND CLAY SIZES	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED	SAND SIZE			GRAVEL SIZE		SIZE

## LEGEND

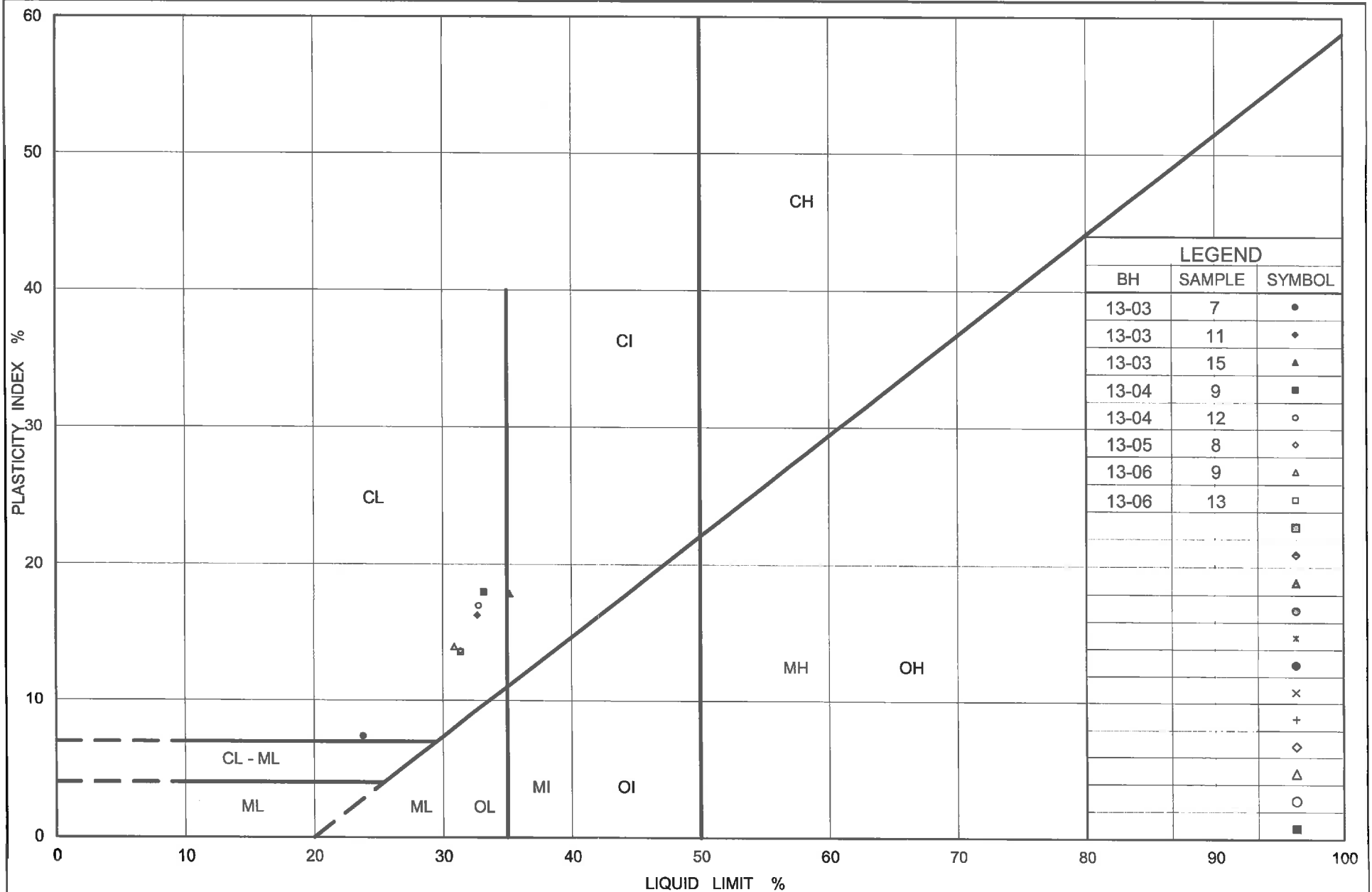
SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	13-04	12	160.5
■	13-06	13	159.4

Project Number: 12-1111-0088

Checked By: *[Signature]*

**Golder Associates**

Date: 22-Oct-13



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## PLASTICITY CHART CLAYEY SILT

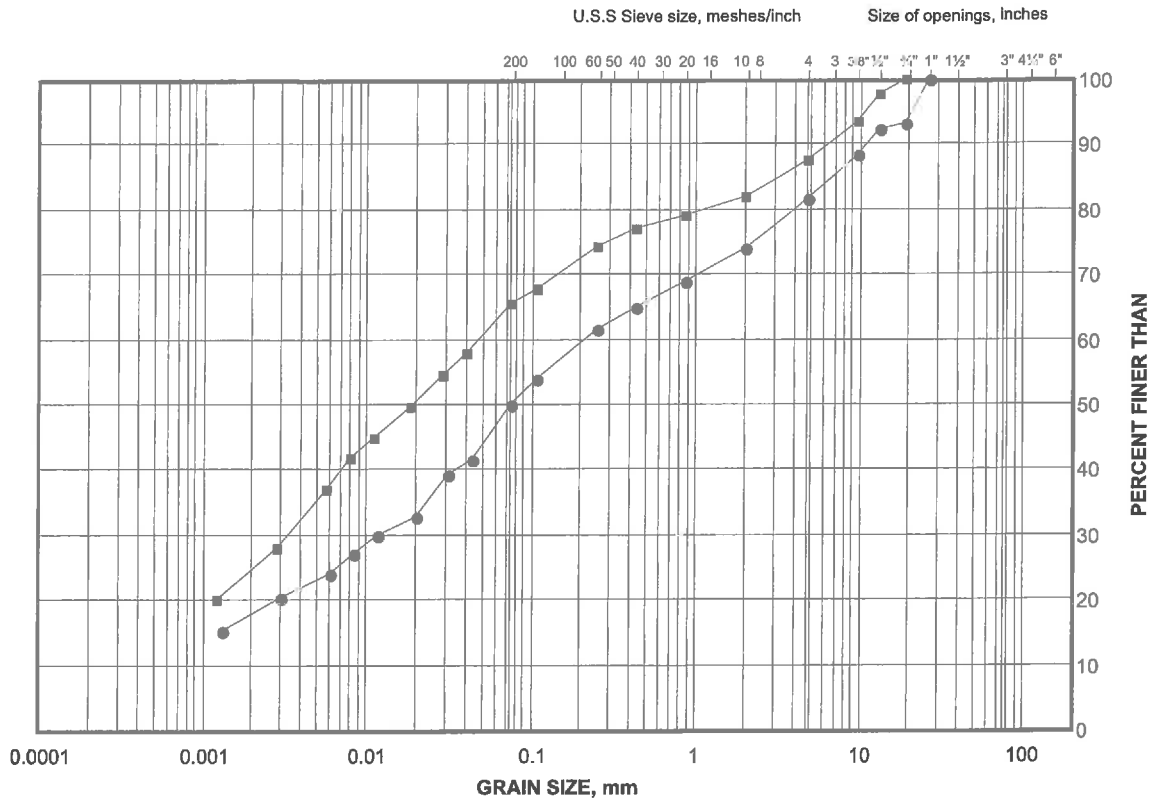
Figure No. B7

Project No. 12-1111-0088

Checked By: *[Signature]*

# GRAIN SIZE DISTRIBUTION CLAYEY SILT TILL

FIGURE B8



SILT AND CLAY SIZES	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED	SAND SIZE			GRAVEL SIZE		SIZE

## LEGEND

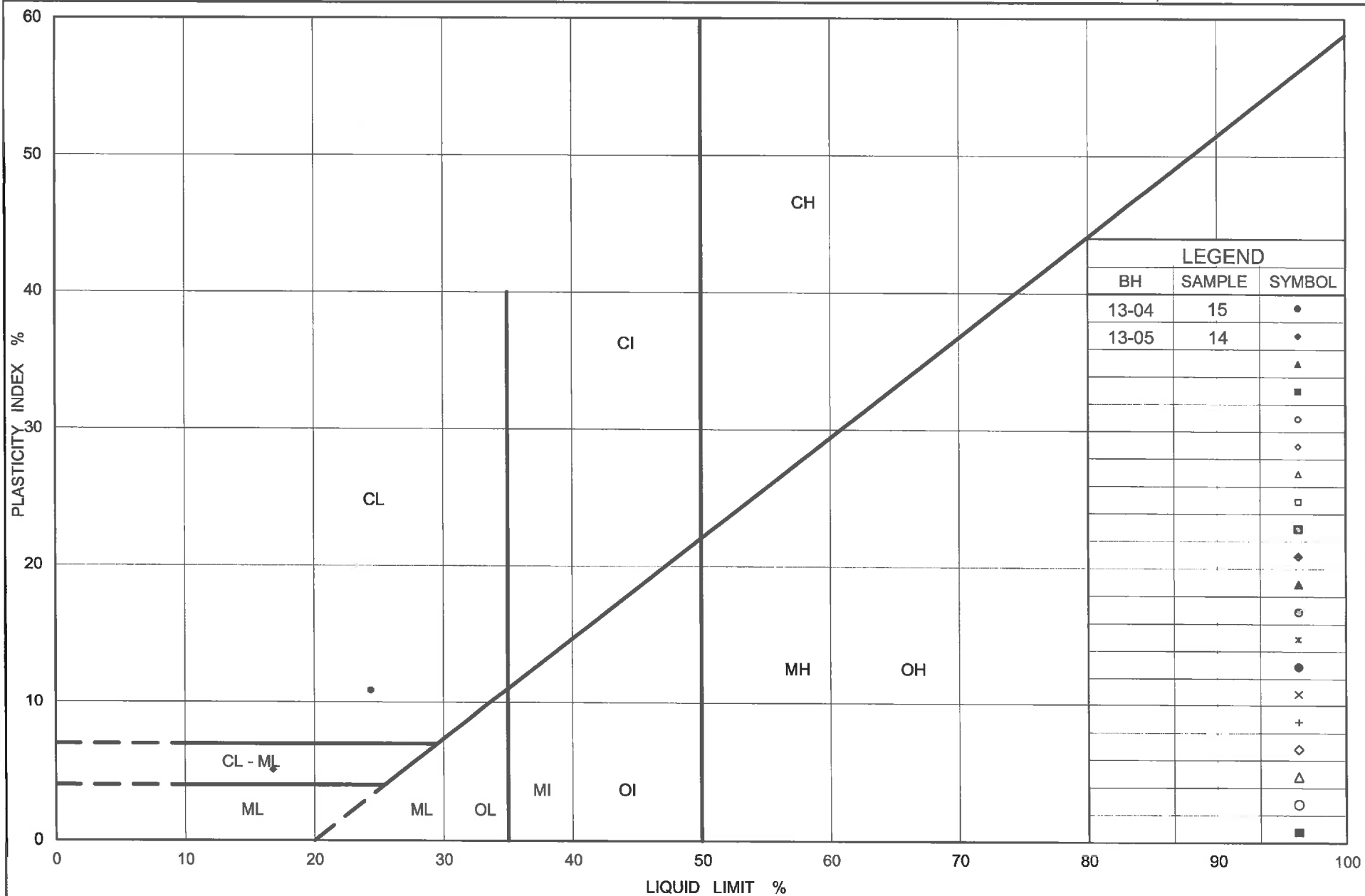
SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	13-05	14	157.2
■	13-04	15	155.9

Project Number: 12-1111-0088

Checked By: *[Signature]*

**Golder Associates**

Date: 22-Oct-13



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## PLASTICITY CHART CLAYEY SILT TILL

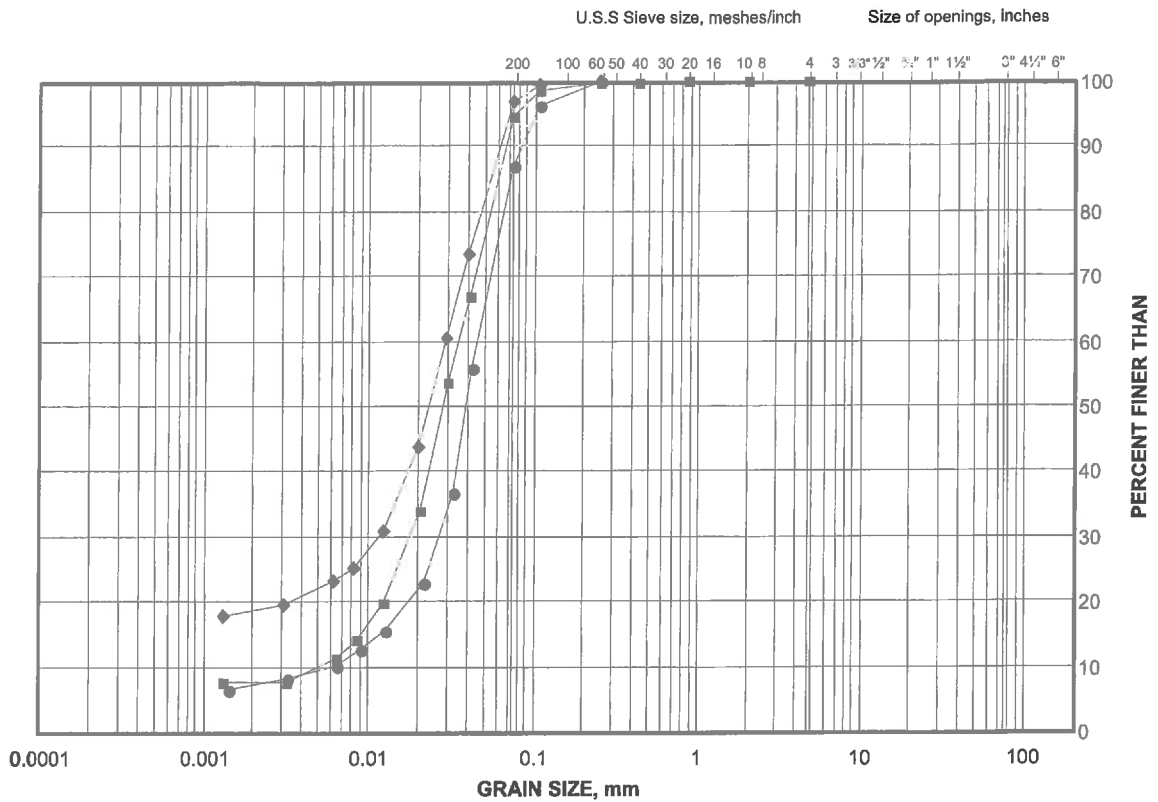
Figure No. B9

Project No. 12-1111-0088

Checked By: *h.*

# GRAIN SIZE DISTRIBUTION SILT

FIGURE B10



SILT AND CLAY SIZES	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED	SAND SIZE			GRAVEL SIZE		SIZE

## LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	13-06	15	156.3
■	13-03	16	153.4
◆	13-04	18	146.8

Project Number: 12-1111-0088

Checked By: 

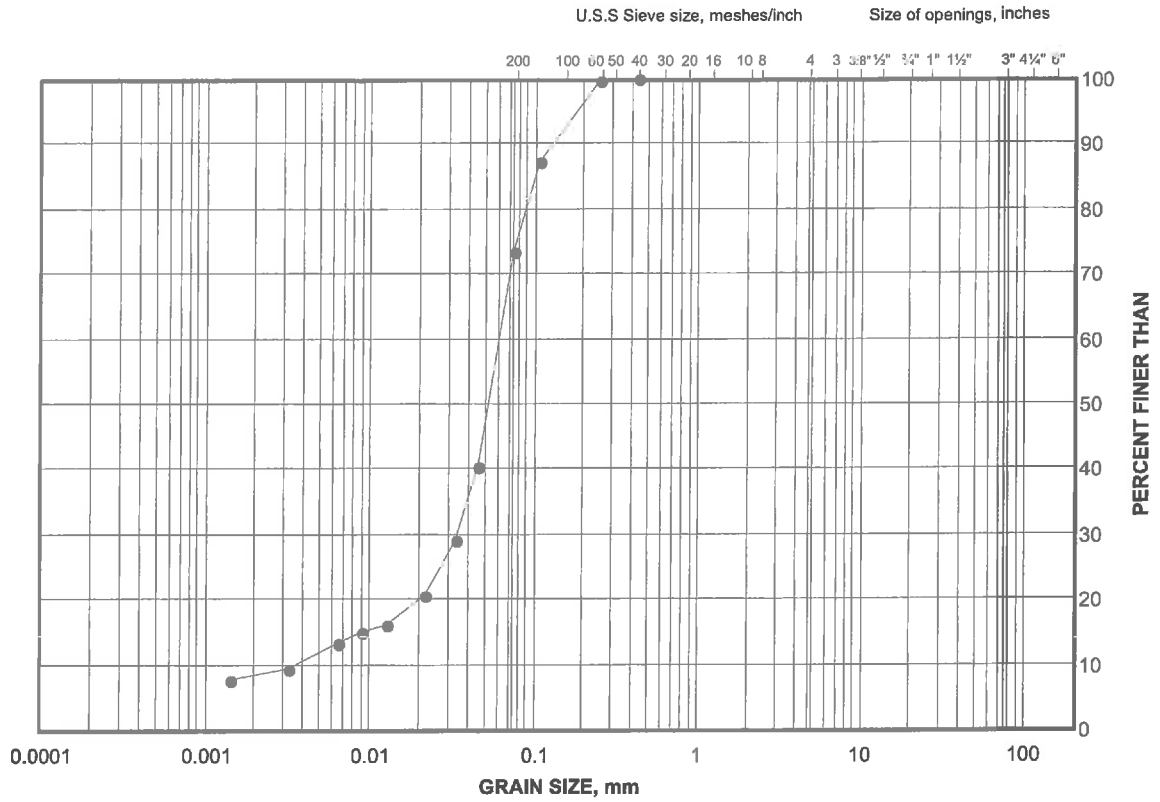
**Golder Associates**

Date: 22-Oct-13

# GRAIN SIZE DISTRIBUTION

Sandy SILT

FIGURE B11



SILT AND CLAY SIZES	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED	SAND SIZE			GRAVEL SIZE		SIZE

## LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
•	13-05	17	149.6

Project Number: 12-1111-0088

Checked By: *[Signature]*

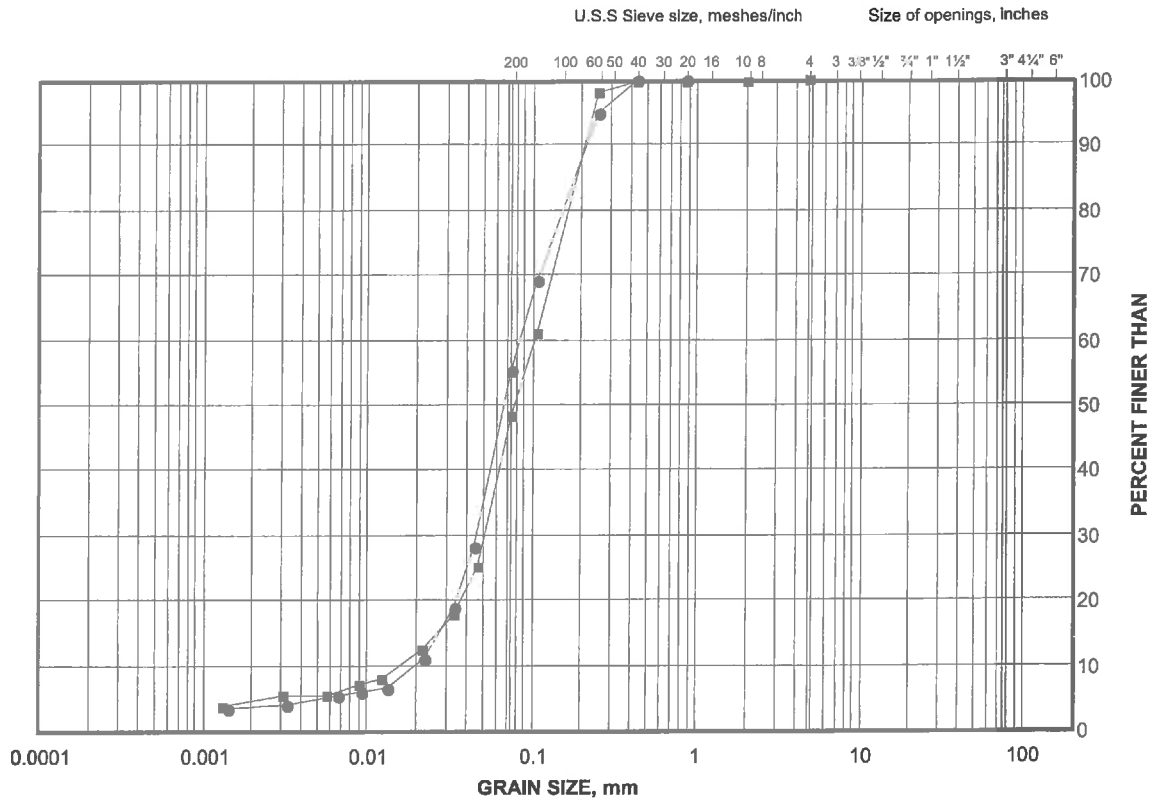
**Golder Associates**

Date: 22-Oct-13

# GRAIN SIZE DISTRIBUTION

## SILT and SAND

FIGURE B12



SILT AND CLAY SIZES	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED	SAND SIZE			GRAVEL SIZE		SIZE

### LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	13-04	16	152.9
■	13-03	18	147.3

Project Number: 12-1111-0088

Checked By: *[Signature]*

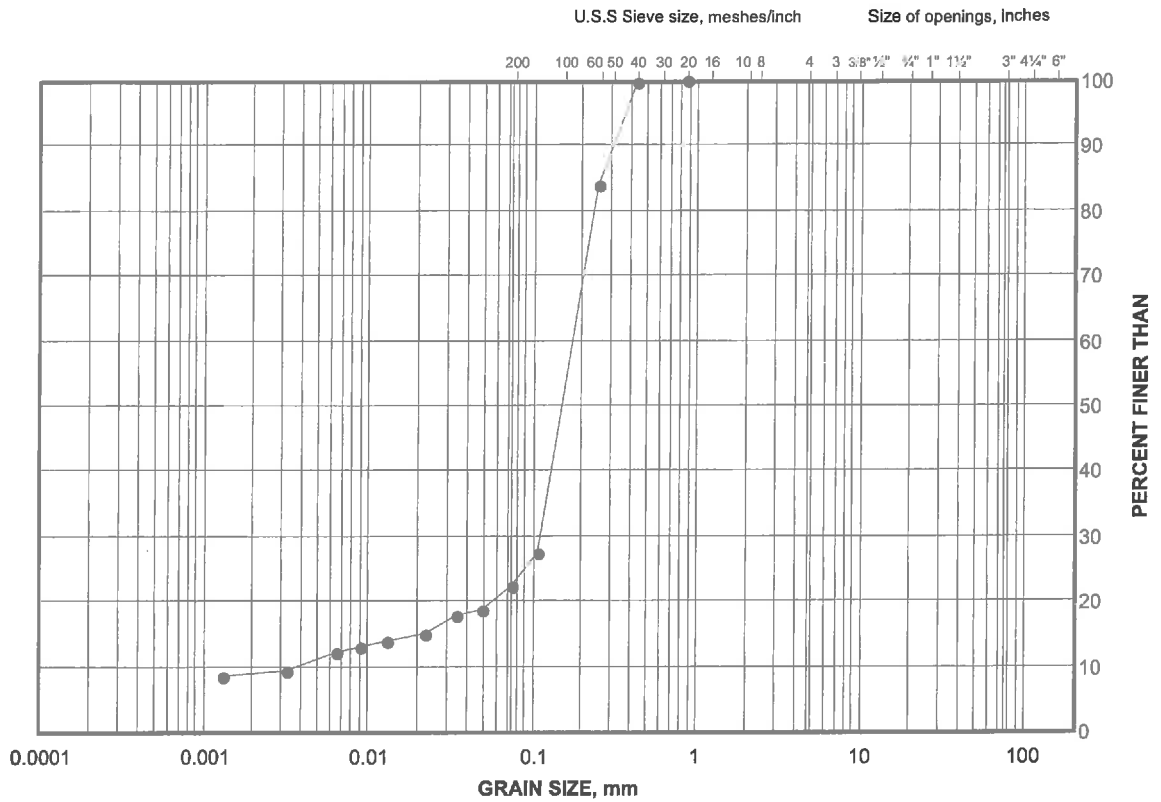
**Golder Associates**

Date: 22-Oct-13



# GRAIN SIZE DISTRIBUTION SAND

FIGURE B13



SILT AND CLAY SIZES	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED	SAND SIZE			GRAVEL SIZE		SIZE

## LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
•	13-06	17	150.2

Project Number: 12-1111-0088

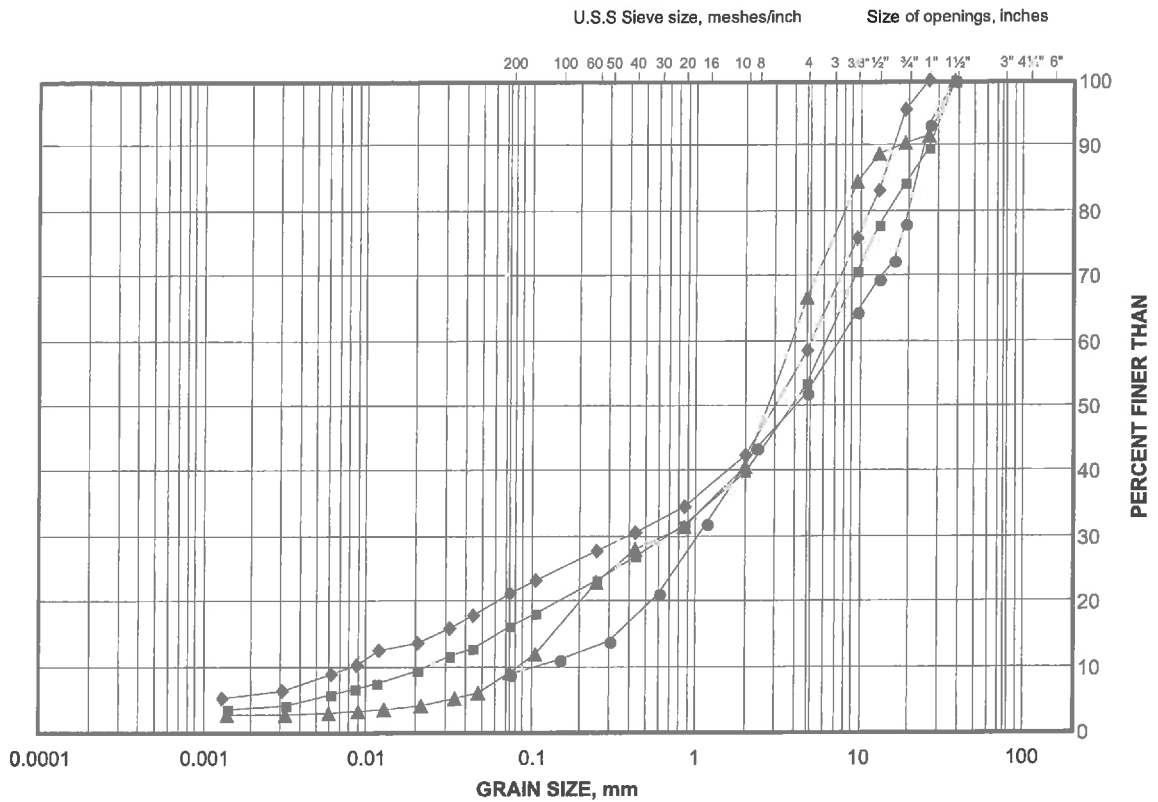
Checked By: *[Signature]*

**Golder Associates**

Date: 22-Oct-13

# GRAIN SIZE DISTRIBUTION SAND and GRAVEL

FIGURE B14



SILT AND CLAY SIZES	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED	SAND SIZE			GRAVEL SIZE		SIZE

## LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	13-05	19	143.5
■	13-03	20	141.2
◆	13-06	20	141.3
▲	13-04	21	137.6

Project Number: 12-1111-0088

Checked By: 

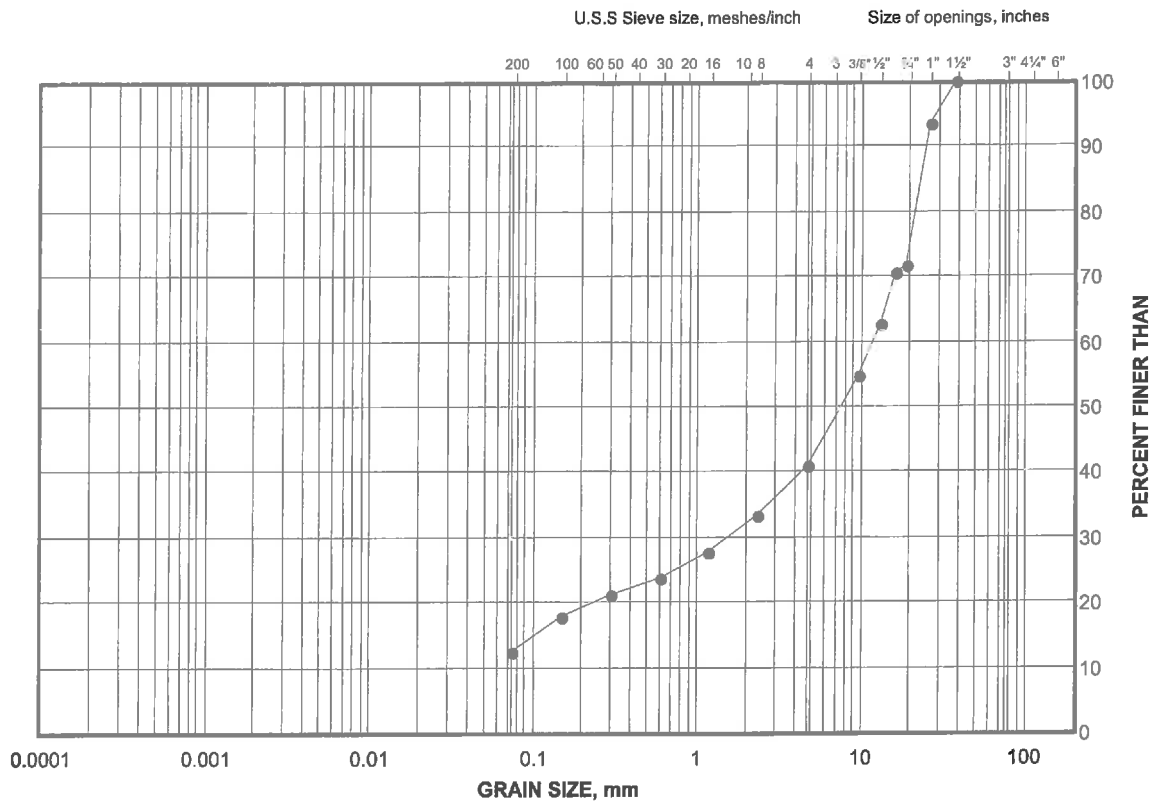
Golder Associates

Date: 22-Oct-13

# GRAIN SIZE DISTRIBUTION

Sandy GRAVEL

FIGURE B15



SILT AND CLAY SIZES	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED	SAND SIZE			GRAVEL SIZE		SIZE

## LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
•	13-05	21	137.6

Project Number: 12-111-0088

Checked By: 

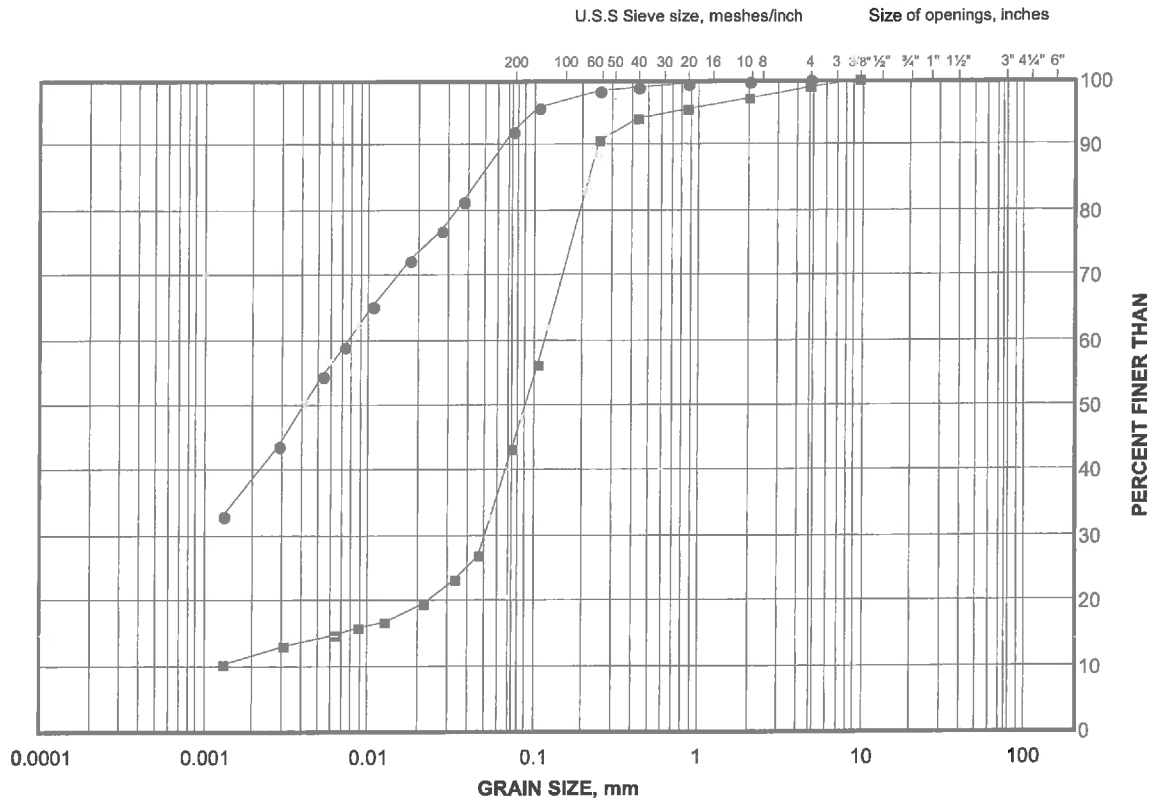
Golder Associates

Date: 22-Oct-13

# GRAIN SIZE DISTRIBUTION

## CLAYEY SILT to CLAYEY SILT with SAND

FIGURE B16



SILT AND CLAY SIZES	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED	SAND SIZE			GRAVEL SIZE		SIZE

### LEGEND

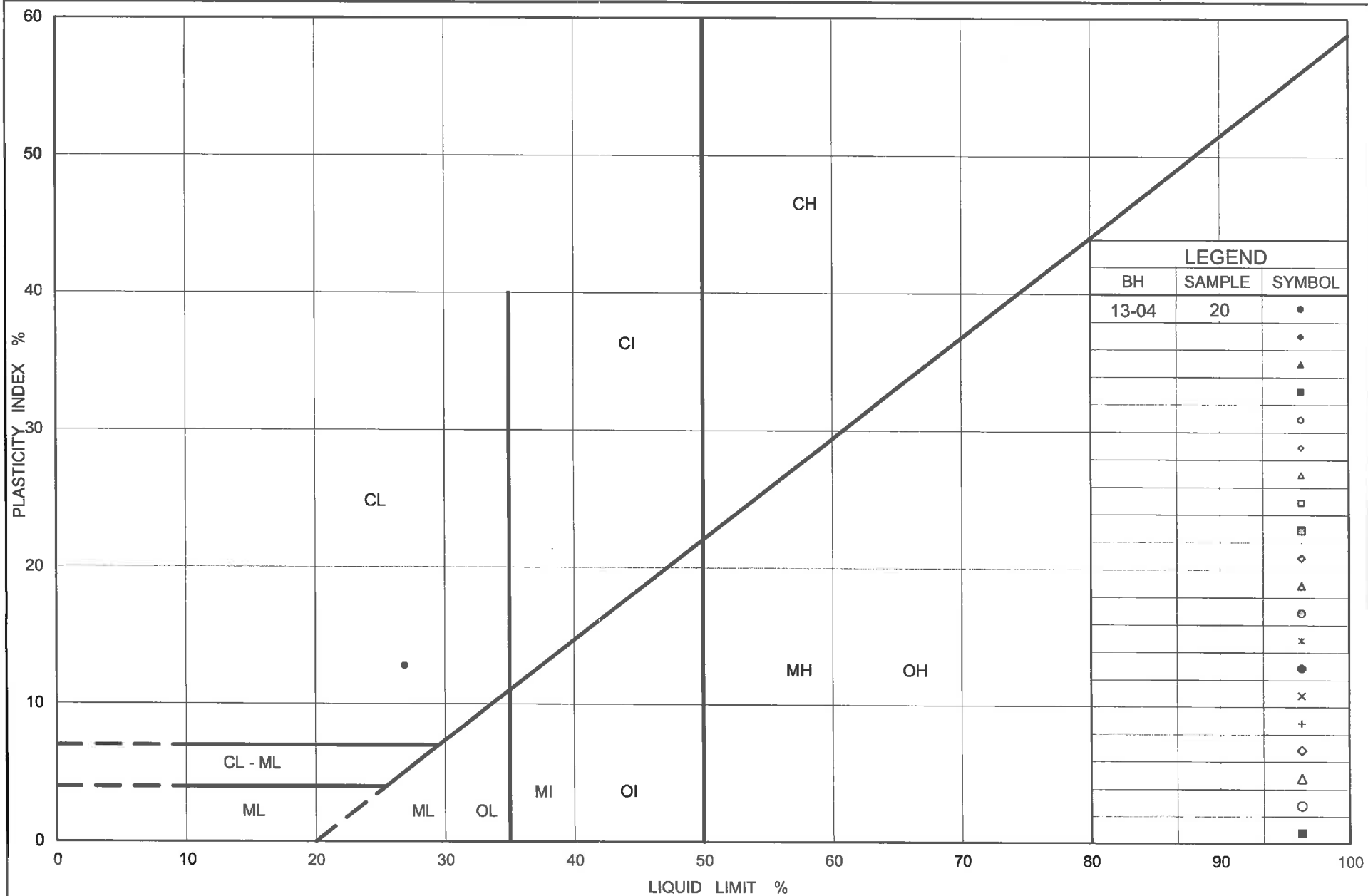
SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	13-04	20	140.7
■	13-05	20B	140.6

Project Number: 12-1111-0088

Checked By: *[Signature]*

**Golder Associates**

Date: 22-Oct-13



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# PLASTICITY CHART CLAYEY SILT to CLAYEY SILT with SAND

Figure No. B17

Project No. 12-1111-0088

Checked By:

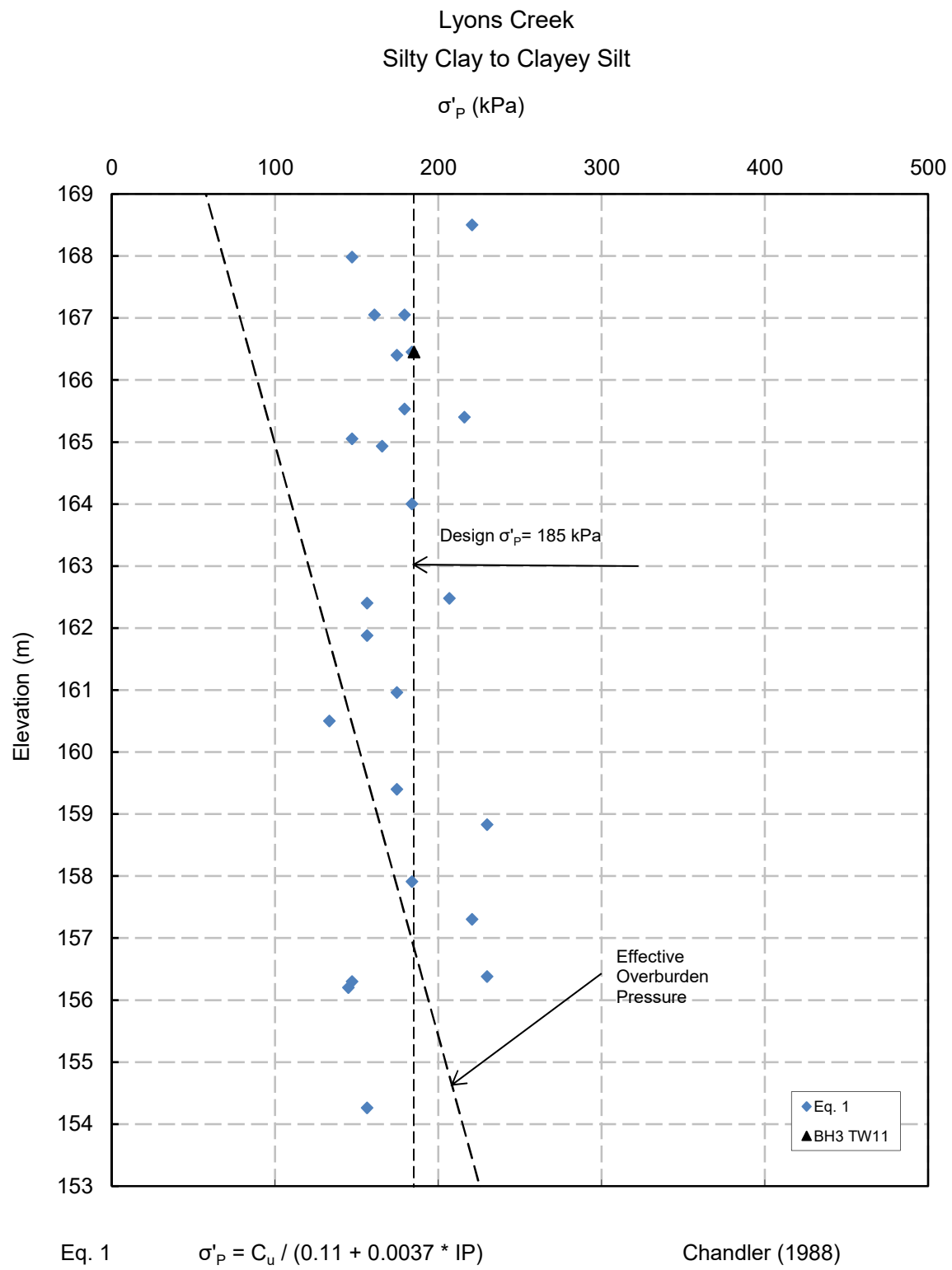
## **APPENDIX C**

### **Soil Design Parameters**



# PREDICTED AND MEASURED PRECONSOLIDATION STRESSES

FIGURE C1



Project No. : 1-15-0689

Date : February, 2016



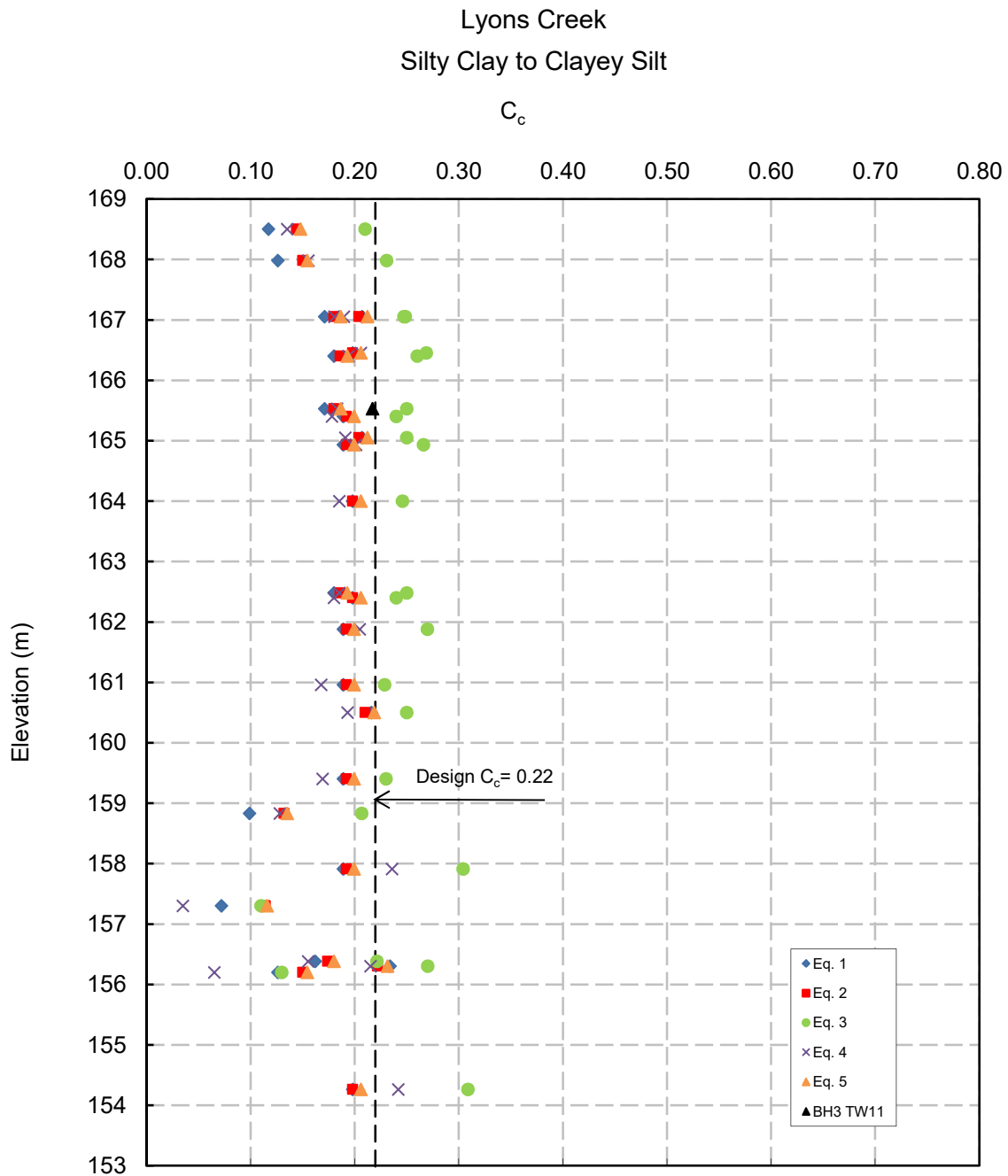
**Terraprobe Inc.**

Prepared by : SD

Checked by : RA

# PREDICTED AND MEASURED COMPRESSION INDICES

FIGURE C2



Eq. 1  $C_c = 0.009 * (LL - 10)$

Terzaghi & Peck (1967)

Eq. 2  $C_c = 0.006 * (LL + 1)$

Lav & Ansal (2001)

Eq. 3  $C_c = 0.01 * \omega$

Osterberg (1972)

Eq. 4  $C_c = 0.009 * \omega + 0.002 * LL - 0.1$

Azzouz et al. (1976)

Eq. 5  $C_c = 0.002343 * LL * G_s$

Nagaraj & Murty (1985)

Project No. : 1-15-0689

Date : February, 2016



**Terraprobe Inc.**

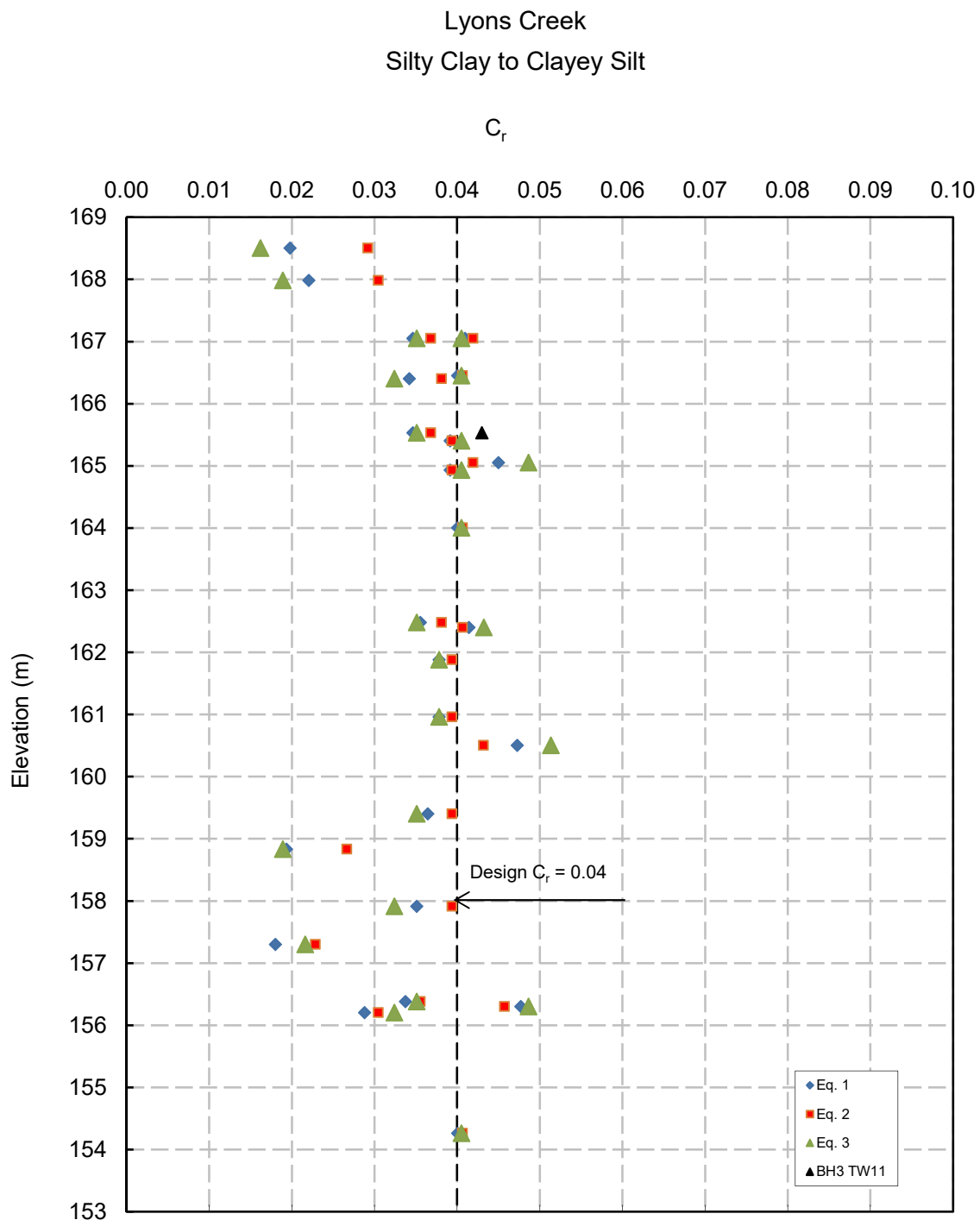
Prepared by : SD

Checked by : RA



# PREDICTED AND MEASURED RECOMPRESSION INDICES

FIGURE C3



Eq. 1  $C_r = C_c / 5 \sim C_c / 10$

Das (1993)

Eq. 2  $C_r = 0.000463 * LL * G_s$

Nagaraj & Murty (1985)

Eq. 3  $C_r = I_p / 370$

Kulhawy & Mayne (1990)

Project No. : 1-15-0689

Date : February, 2016

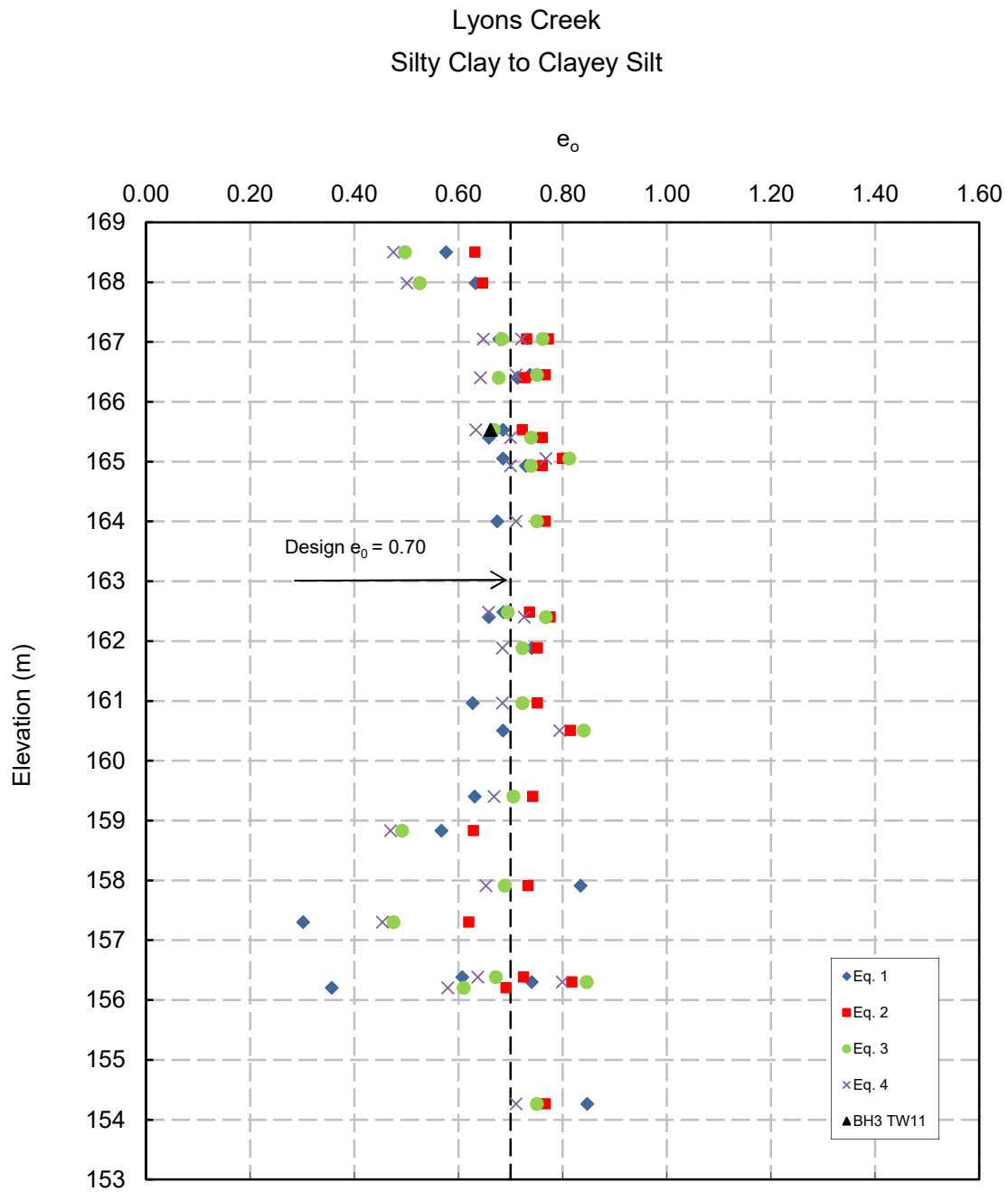


Prepared by : SD

Checked by : RA

# PREDICTED AND MEASURED VOID RATIOS

FIGURE C4



Eq. 1  $e_o = w * G_s$

when saturated

Eq. 2  $e_o = C_c / 0.75 + 0.50$

derived from Sowers (1970)

Eq. 3  $e_o = (C_c + 0.10) / 0.40$

derived from Lav & Ansal (2001)

Eq. 4  $e_o = (C_c - 0.256) / 0.43 + 0.84$

derived from Cozzolino (1961)

Project No. : 1-15-0689

Date : February, 2016

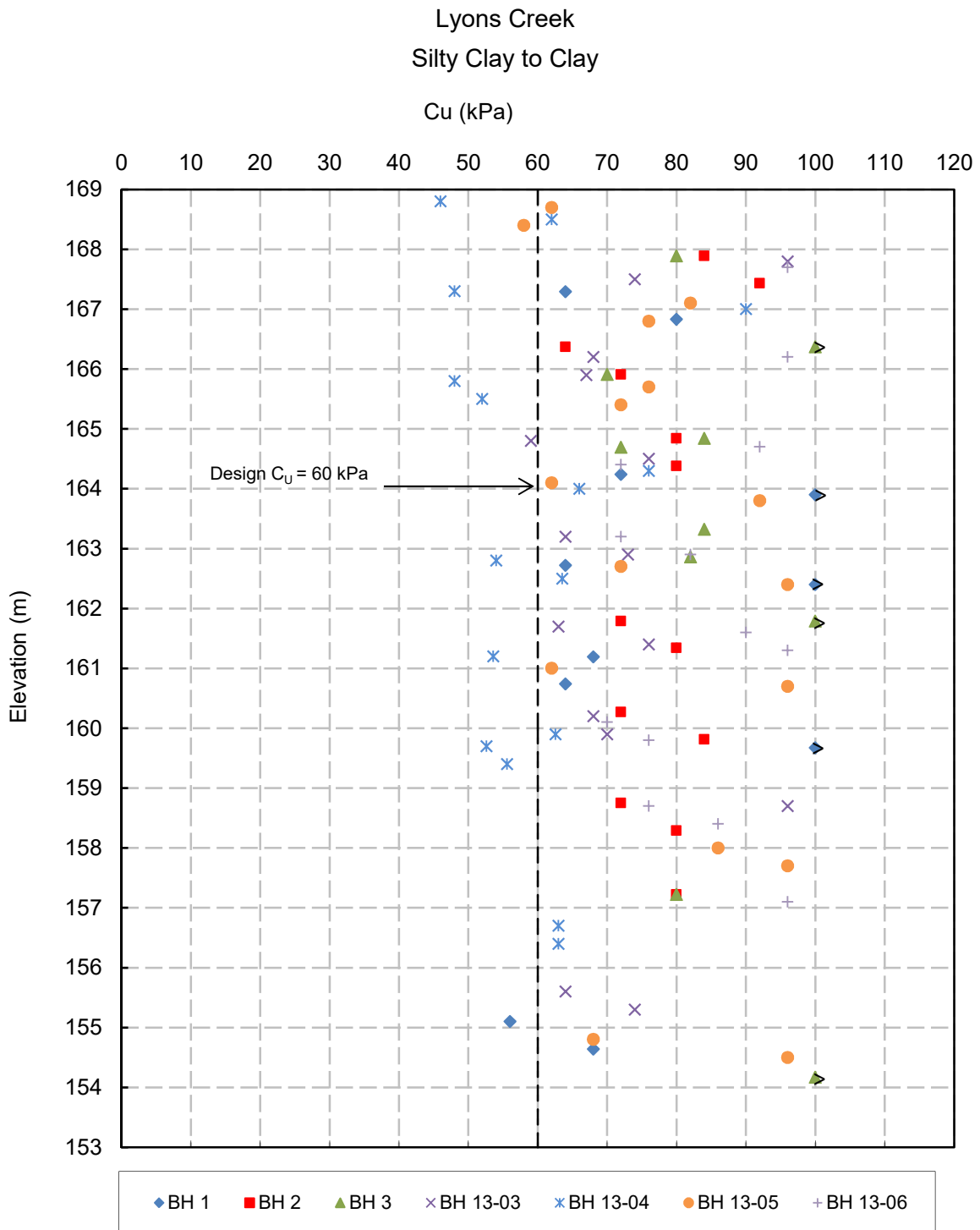


Prepared by : SD

Checked by : RA

# DESIGN UNDRAINED SHEAR STRENGTH

FIGURE C5



Field vane shear strengths were corrected based on Bjerrum, (1972) for  $I_p > 20$

Project No. : 1-15-0689

Date : March, 2016



**Terraprobe Inc.**

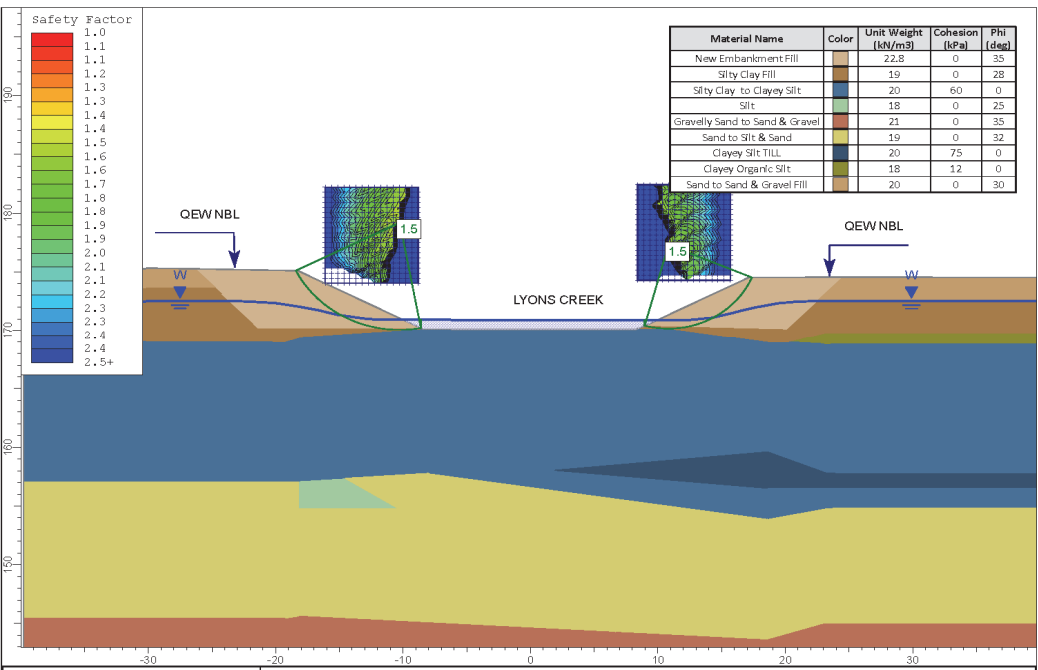
Prepared by : SD

Checked by : RA

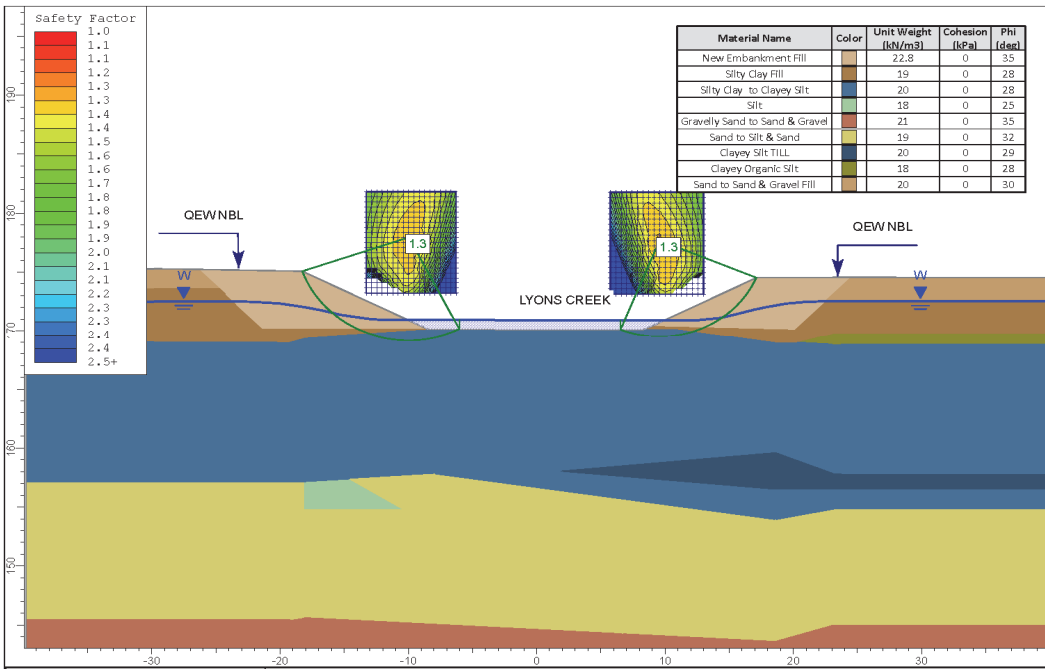
## **APPENDIX D**

### **Slope Stability Models and Results**

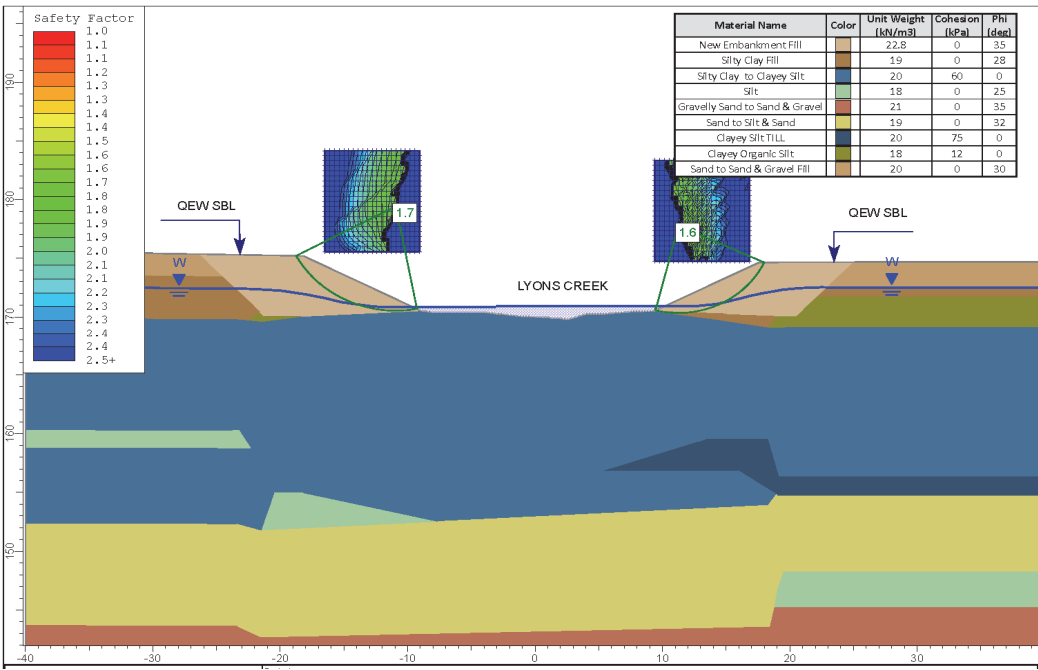




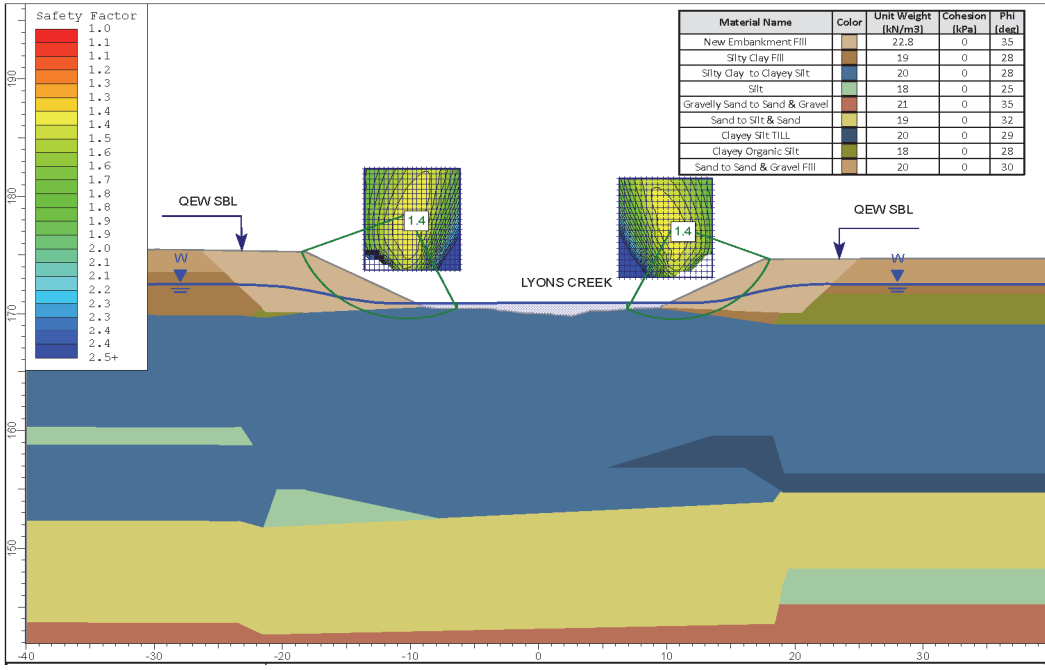
Lyons Creek North-Bound Structure  
Forward Slope Stability (Total Stress Analysis)



Lyons Creek North-Bound Structure  
Forward Slope Stability (Effective Stress Analysis)



Lyons Creek South-Bound Structure  
Forward Slope Stability (Total Stress Analysis)



Lyons Creek South-Bound Structure  
Forward Slope Stability (Effective Stress Analysis)