Terraprobe

Consulting Geotechnical & Environmental Engineering

Construction Materials Inspection & Testing

DRAFT
PRELIMINARY
FOUNDATION INVESTIGATION REPORT
SMITH CREEK BRIDGE REPLACEMENT
HIGHWAY 668
ASSIGNMENT No. 5013-E-0018
MINISTRY OF TRANSPORTATION, ONTARIO
G.W.P. No. 5267-11-00, SITE 39E-014
GEOCRES NO.

PREPARED FOR: MMM Group Limited
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Attention: Mr. Trevor Small, M.Sc., P.Eng.

File No. 1-15-0509
July 19, 2016

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SMITH CREEK BRIDGE REPLACEMENT, SITE 39E-014
HIGHWAY 668
TOWNSHIP OF CLUTE, DISTRICT OF COCHRANE, ONTARIO
ASSIGNMENT No. 5013-E-0018, G.W.P. 5267-11-00

1.0 INTRODUCTION

Terraprobe Inc. (Terraprobe) has been retained by MMM Group Limited (MMM) on behalf of the Ministry of Transportation, Ontario (MTO) to provide foundation engineering services in support of preliminary designs for the rehabilitation of structures identified in MTO's Request for Proposal (RFP) titled *"Preliminary Design, Rehabilitation/Replacement of Twelve Structures on Highway 11, 101, 577, 579, 634 & 668, in New Liskeard Area", Contract Number. 5013-E-0018*.

The terms of reference and scope of work for the foundation engineering services are outlined in MTO's RFP, and in Section 5.7 of MMM's *Technical Proposal* for this assignment. This report presents the factual data on subsurface conditions at the Smith Creek Bridge, Site 39E-014 on Highway 668, Township of Clute, District of Cochrane, Ontario.

2.0 SITE DESCRIPTION

The site is located on Highway 668 (Latitude 49.157°, Longitude – 81.272°), approximately 11 km north of the highway's south junction with Trans-Canada Highway 11 in the Township of Clute, Ontario. Cochrane is located south-east of the site and Kennedy Lake is situated on the east side of Hwy. 668 approximately 3 km south of the site. The key plan on the Borehole Locations and Soil Strata Drawing, (Drawing 1) provides an overview of the site location.

The existing structure is a three-span timber bridge that is 17± m long and 10± m wide, supported on timber piles. This bridge carries Highway 668 north bound and south bound traffic over Smith Creek. Smith Creek flows from west to east meandering within a well-defined flood plain.

The terrain at the bridge site and surrounding area is generally gently rolling. Vegetation within the flood plain area consists primarily of grass and shrubs. Beyond the flood plain, the area is vegetated with mature stands of deciduous and coniferous trees.

3.0 INVESTIGATION PROCEDURES

The field work for this project was carried out between August 31 and September 03, 2015 and consisted of drilling and sampling two boreholes to depths of 22.6 m and 22.4 m below ground surface. The approximate borehole locations are shown on Drawing 1.

Based on borehole locations plans provided by Terraprobe, MTO Geomatics staked out the boreholes in the field. Terraprobe's staff surveyed the boreholes for coordinates and geodetic elevations by referring to Control Point HCP 104. This data is summarized in the following table.

Borehole No.	MTM NAD 83 Coordinates		Ground Surface Elevation (m)	Borehole Depth (m)
	Northing (m)	Easting (m)		
BH1	5 446 605.2	284 950.4	260.6	22.6
BH2	5 446 629.9	284 943.9	260.6	22.4

The boreholes were drilled with a truck-mounted CME 55 drill rig supplied and operated by a specialist drilling contractor. 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 D 1586[1]. Relatively undisturbed samples of the clay soils were also collected with thin-walled Shelby Tube samplers. In the clay deposits an MTO 'N' vane was used to perform in-situ field vane tests, in order to determine the undrained shear strength of the soil. Terraprobe's staff observed the drilling, sampling and in situ testing operations and logged the boreholes on a full-time basis.

Ground water conditions in the open boreholes were observed during the drilling operations and a standpipe piezometer was installed in Borehole 1 to permit longer term ground water level monitoring. The boreholes were backfilled in accordance with current MTO procedures and Ontario Regulation 903 (as amended).

The recovered soil and rock 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. The bedrock core samples were subjected to point load index tests.

4.0 SITE GEOLOGY AND SUBSURFACE CONDITIONS

4.1 Regional Geology

The study area is located north of the Great Lakes-Hudson Bay drainage divide. All surface drainage flows northwards into James Bay. The major river system located close to the site is the Abitibi river. Surficial geology of the study area indicates the presence of clays, silts, organic deposits and glaciofluvial ice-contact deposits such as gravels, sands and minor till.

The study area lies within the Abitibi Greenstone Belt of the Superior structural province of the Canadian Shield. The Abitibi Greenstone Belt consists of both volcanic and sedimentary rocks though typically dominated by mafic metavolcanic rocks. Several felsic and alkaline intrusions occur throughout the area.

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 section 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 highway pavement is generally underlain by fill material consisting of compact sand and gravel and sand, very loose to compact sand and firm to stiff silty clay. The fill material is further underlain by deposits of peat, firm to stiff silty clay to clay, loose silt and compact to very dense cobbles and boulders. The overburden soils are further underlain by greywacke bedrock. A more detailed description of the subsurface conditions is provided in the following sections.

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

4.2.1 Flexible Pavement

Both boreholes encountered a flexible pavement consisting of 25 mm and 75 mm thick asphaltic concrete, underlain by granular fill varying in composition from sand and gravel to sand. The locations, thicknesses and base elevations of the granular base fill are summarized in the following table.

Borehole No.	Fill Thickness (mm)	Fill Base Elevation (m)
BH1	355	260.2
BH2	285	260.2

Standard Penetration tests carried out in the sand and gravel and sand fill measured SPT N-values of 12 and 21 blows for 0.3 m of penetration indicating a compact relative density. The natural water content of a sample of the sand and gravel fill is 2% by weight.

The grain size distribution curve of a sample of the sand and gravel fill is presented in Figure B1 in Appendix B. The results show a grain size distribution consisting of 35% gravel, 59% sand and, 6% silt and clay size particles.

4.2.2 Fill – Sand

A layer of sand fill was encountered below the flexible pavement in both boreholes. The locations, thicknesses and base elevations of the sand fill are summarized in the following table.

Borehole No.	Fill Thickness (m)	Fill Depth (m)	Fill Base Elevation (m)
BH1	1.5	1.9	258.7
BH2	1.7	2.1	258.5

Standard Penetration tests carried out in this sand fill measured SPT N-values ranging from 4 to 21 blows for 0.3 m of penetration suggesting a very loose to compact relative density. The moisture contents (by weight) of two samples of the sand fill are 3% and 5%.

The grain size distribution curve of a sample of the sand fill is illustrated in Figure B2 in Appendix B. The results show a grain size distribution consisting of 2% gravel, 86% sand and, 12% silt and clay size particles.

4.2.3 Fill – Silty Clay

Both boreholes encountered a layer of silty clay fill material. The locations, thicknesses, depths and base elevations of the silty clay fill are summarized in the following table.

Borehole No.	Fill Thickness (m)	Fill Depth (m)	Fill Base Elevation (m)
BH1	1.8	3.7	256.9
BH2	1.6	3.7	256.9

Standard Penetration tests performed in the silty clay fill measured SPT N-values ranging from 5 to 11 blows for 0.3 m of penetration indicating a firm to stiff consistency. The moisture contents (by weight) of two samples of the silty clay fill are 17% and 20%.

The grain size distribution plot of a sample of the silty clay fill is depicted in Figure B3 in Appendix B. The results show a grain size distribution consisting of 1% gravel, 11% sand, 51% silt and, 37% clay size particles.

An Atterberg limits test was also carried out on a sample of the silty clay fill and the results are presented in Figure B4 in Appendix B. These values indicate that the fill is a cohesive soil (CL) with low plasticity. The Atterberg limits test results are summarized below:

Liquid Limit:	29 %
Plastic Limit:	14 %
Plasticity Index:	15 %
Natural Moisture Content:	17 %

4.2.4 Peat

A layer of amorphous peat was encountered below the silty clay fill in both boreholes, extending to depths of 5.2 m below ground surface or to elevation 255.4 m. The N-values of Standard Penetration tests carried out in the peat deposit range from 4 blows to 12 blows per 0.3 m of penetration and the moisture contents (by weight) of two samples of the peat are 48% and 59%.

4.2.5 Silty Clay to Clay

The site is underlain by a silty clay to clay deposit that contains occasional clayey silt zones. The locations, thicknesses, depths and base elevations of the silty clay to clay deposit are summarized in the following table.

Borehole No.	Silty Clay to Clay Thickness (m)	Silty Clay to Clay Depth (m)	Silty Clay to Clay Base Elevation (m)
BH1	8.4	13.6	247.0
	1.4	15.7	244.9
BH2	11.6	16.8	243.8

The N-values of Standard Penetration tests carried out in the silty clay to clay deposit range from 0 blows (weight of rods) to 11 blows per 0.3 m of penetration. Field vane tests generally measured in-situ undrained shear strengths ranging from 40 kPa to 84 kPa and a laboratory vane test carried out on a Shelby Tube sample, measured an undrained shear strength of 36 kPa. A plot of undrained shear strength versus elevation is shown in Figure B5 in Appendix B. Based on the undrained shear strength values, the consistency of the silty clay to clay is described as firm to stiff. The sensitivity of the silty clay to clay generally ranges from about 1.3 to 8.8, indicating a low to extra-sensitive soil class (Canadian Foundation Engineering Manual [CFEM], 2006).

Samples of the silty clay to clay soils were subjected to grain size distribution tests and the grain size distribution curves are illustrated in Figure B6 in Appendix B. The test results show a grain size distribution consisting of 0% to 1% gravel, 0% to 11% sand, 12% to 57% silt and, 32% to 87% clay size particles.

Atterberg limits tests were carried out on five samples of the silty clay to clay and the results are plotted on the plasticity chart, Figure B7 in Appendix B. The results indicate a cohesive deposit with low to high plasticity (CL, CI and CH). The Atterberg limits test results are summarized below.

Liquid Limit:	24% to 62 %
Plastic Limit:	13% to 25 %
Plasticity Index:	10% to 32 %
Natural Moisture Content:	17% to 57 %

The Atterberg Limits test results of the silty clay to clay deposit are also plotted against elevation in Figure B8. The moisture content of samples of the silty clay to clay varies between 17% and 57% and the unit weight of a tested sample is 17.0 kN/m^3.

A one-dimensional consolidation test was performed on a sample of the silty clay to clay and the results are presented in Figures B9 to B11 in Appendix B. The results of the one-dimensional consolidation test are summarized below.

Borehole/Sample No.	Sample Depth/Elevation (m)	σ'_{vo} (kPa)	σ'_P (kPa)	C_c	C_r	e_o
BH2, TW11	10.2 / 250.4	85	150	0.63	0.08	1.46

Where: σ'_{vo} = effective overburden pressure;
σ'_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 higher than the effective overburden pressure suggesting that the silty clay to clay deposit is overconsolidated.

Clayey silt zones were encountered within the silty clay to clay matrix, below a depth of 10.5 m± (elevation 250.1 m±) below ground surface. A grain size distribution test was carried out on a sample of the clayey silt and the results are shown on the grain size distribution curve in Figure B12 in Appendix B. The grain size distribution of the clayey silt consists of 0% gravel, 0% sand, 81% silt and, 19% clay size particles.

An Atterberg limits test was also carried out on a sample of the clayey silt and the results are plotted on the plasticity chart, Figure B13 in Appendix B. The results indicate a low plasticity (CL-ML) clayey silt. The Atterberg limits test results are summarized below.

Liquid Limit:	23 %
Plastic Limit:	18 %
Plasticity Index:	5 %
Natural Moisture Content:	27 %

4.2.6 Silt

In Borehole 1 the silty clay to clay deposit is divided by a 0.7 m thick layer of silt, encountered at a depth of 13.6 m (Elevation 247.0 m) below ground surface. A Standard Penetration test performed in the silt deposit measured a SPT N-value of 5 blows for 0.3 m of penetration indicating a loose relative density. The moisture content (by weight) of a sample of the silt is 27%.

The grain size distribution plot of a sample of the silt is depicted in Figure B14 in Appendix B. The results show a grain size distribution consisting of 0% gravel, 0% sand, 86% silt and, 14% clay size particles.

4.2.7 Cobbles and Boulders

A layer of cobbles and boulders with a sand matrix was encountered in both boreholes. Summarized below are the explored depths and base elevations of the cobbles and boulders deposit.

Borehole No.	Cobbles and Boulders Thickness (m)	Cobbles and Boulders Depth of Deposit (m)	Cobbles and Boulders Base Elevation (m)
BH1	3.4	19.1	241.5
BH2	2.4	19.2	241.4

Standard Penetration tests carried out in the cobbles and boulders deposit measured SPT N-values that range from 28 to more than 100 blows per 0.3 m of penetration, indicating a compact to very dense relative density. The natural water content (by weight) of a sample of the sand matrix is 26%.

A grain size distribution test was carried out on the sand matrix and the results are illustrated in Figure B15, Appendix B. The results show a grain size distribution consisting of 0% gravel, 83% sand and 17% silt size particles. The cobbles and boulders were also cored using NQ size coring techniques, and the recovered core samples are illustrated in the photographs provided in Figure B16 in Appendix B.

4.2.8 Bedrock

The overburden soils are underlain by greywacke bedrock. Summarized below are the depths to bedrock and the bedrock surface elevations.

Borehole No.	Depth to Bedrock (m)	Top of Bedrock Elevation (m)
BH1	19.1	241.5
BH2	19.2	241.4

The greywacke bedrock is described as unweathered to slightly weathered, thickly bedded and its colour is light grey to grey. Photographs of the bedrock core samples are provided in Figures B17 and B18 in Appendix B. Summarized below are the Rock Quality Designation, Rock Mass Quality, Total Core Recovery and Solid Core Recovery.

Borehole No.	Rock Quality Designation (RQD)	Rock Mass Quality[2]	Total Core Recovery (TCR)	Solid Core Recovery (SCR)
BH1	48% to 96%	Poor to Excellent	90% to 100%	62% to 100%
BH2	69% to 100%	Fair to Excellent	100%	84% to 100%

Point Load Index Tests were carried out on the bedrock core samples and the interpreted unconfined compressive strength (UCS) results range from 108 MPa to 249 MPa. These UCS results classify the tested portions of the bedrock as very strong (R5 grade, 100 MPa to 250 MPa) according to the rock strength classification in Table 3.5 of the *Canadian Foundation Engineering Manual 2006*.

2 Deere et al., 1967.

4.3 Ground Water Levels

The ground water conditions were observed in the boreholes during and upon completion of drilling and a standpipe piezometer was installed in Borehole 1. The ground water levels measured in the piezometer are summarized in the following table.

Borehole No.	Date	Water Levels	
		Depth (m)	Elevation (m)
BH1	October 1, 2015	1.3	259.3
	October 7, 2015	1.4	259.4

The ground water level at this site is estimated to be at approximately Elevation 259.4 m, based on the soil moisture conditions, measured ground water levels and creek water levels. The ground water level is expected to fluctuate seasonally, will rise during wet periods of the year, and will also be controlled by the free water level in the creek.

5.0 MISCELLANEOUS

The investigation was carried out using drilling equipment supplied and operated by Landcore Drilling of Chelmsford, Ontario. The field operations were supervised by Ms. Sepideh D-Monfared, MESc. and the routine laboratory and one-dimensional consolidation testing was carried out at Terraprobe's Brampton laboratory.

This report was prepared by Ms. Sepideh D-Monfared, MESc. and reviewed 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.

Sepideh D-Monfared, MESc.

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

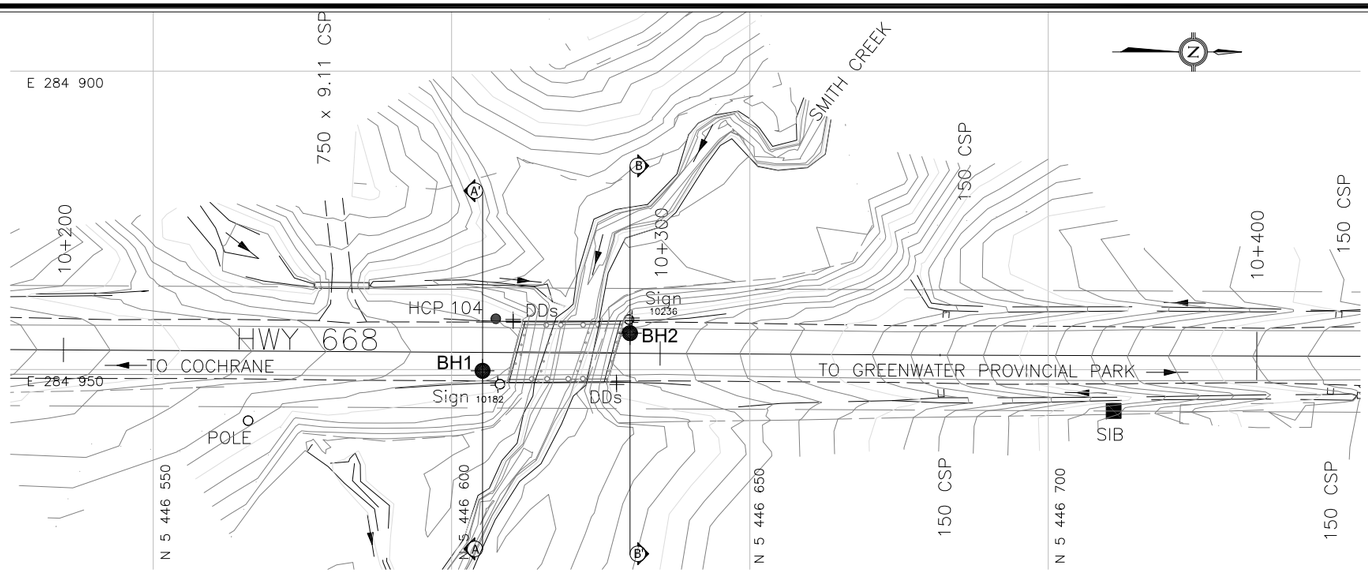
Michael Tanos, P.Eng.
Designated MTO Contact

REFERENCES

Canadian Geotechnical Society, 2006. *Canadian Foundation Engineering Manual*, 4th Edition. The Canadian Geotechnical Society c/o BiTech Publisher Ltd, British Columbia.

Deere et al., 1967. *Design of Surface and Near Surface Construction in Rock*. Society of Mining Engineers of AIME, New York.

DRAWINGS



PLAN

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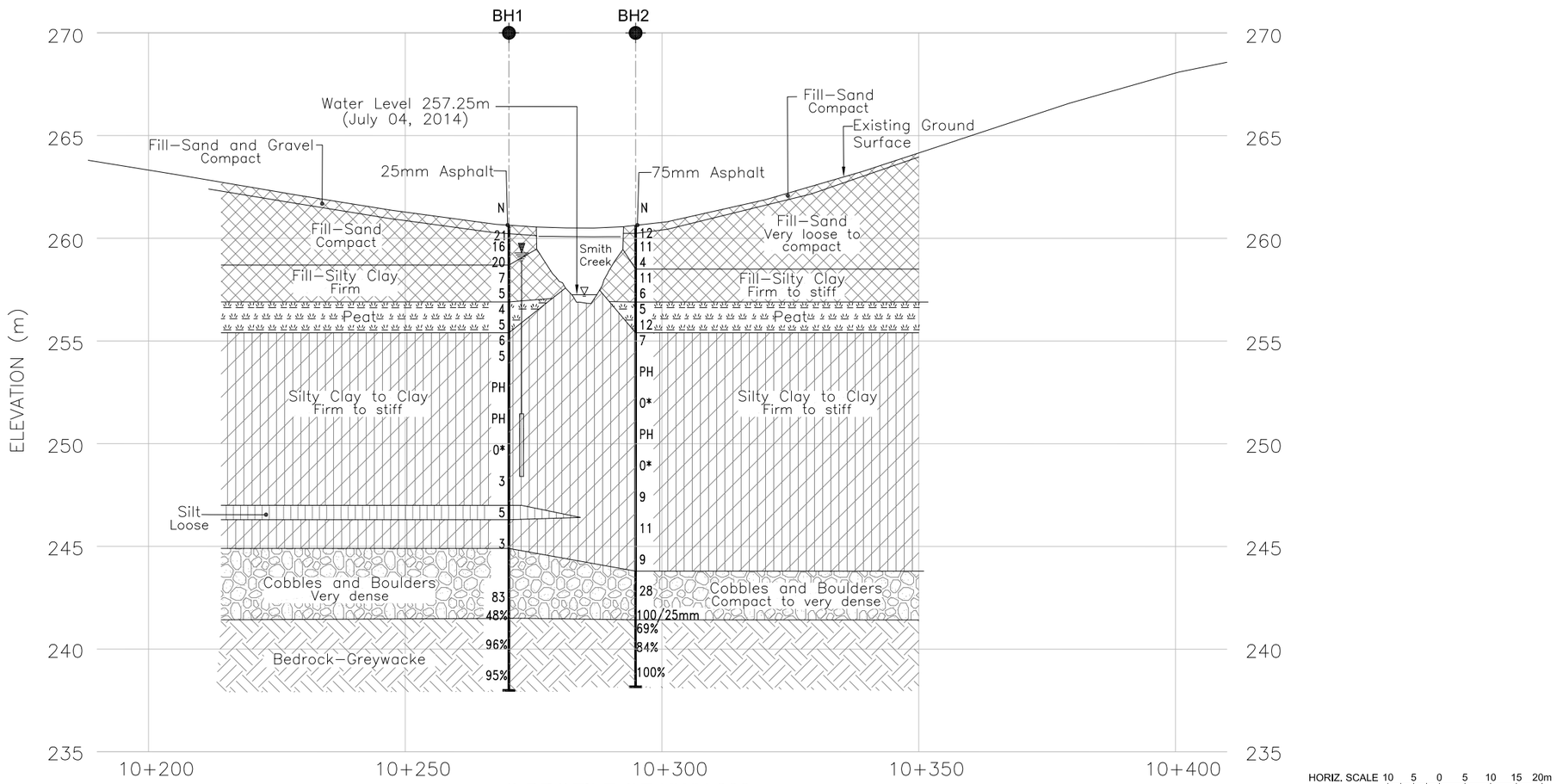

CL PROFILE OF HWY 668

HORIZ. SCALE 10 5 0 5 10 15 20m
VERT. SCALE 2.5 0 2.5 5m

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

GWP No 5267–11–00

HWY 668
SMITH CREEK BRIDGE
BOREHOLE LOCATIONS AND SOIL STRATA

SHEET 1 of 2

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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	260.6	5 446 605.2	284 950.4
2	260.6	5 446 629.9	284 943.9

NOTE

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

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 Ltd. by CD (Assignment 5013–E–0018 Preliminary Design for Rehab/Replacement of 12 Structures on Highways in New Liskeard Area) drawing files BS280668002, DTM5280668002, received September 11, 2014

REVISIONS			
	DATE	BY	DESCRIPTION

HWY. QEW	PROJECT No. 1–15–0509		DIST.
SUBM'D. RA	CHKD. RA	DATE: JULY. 2016	SITE: 39E–014
DRAWN: KC	CHKD. RA	APPD: MT	DWG. 1

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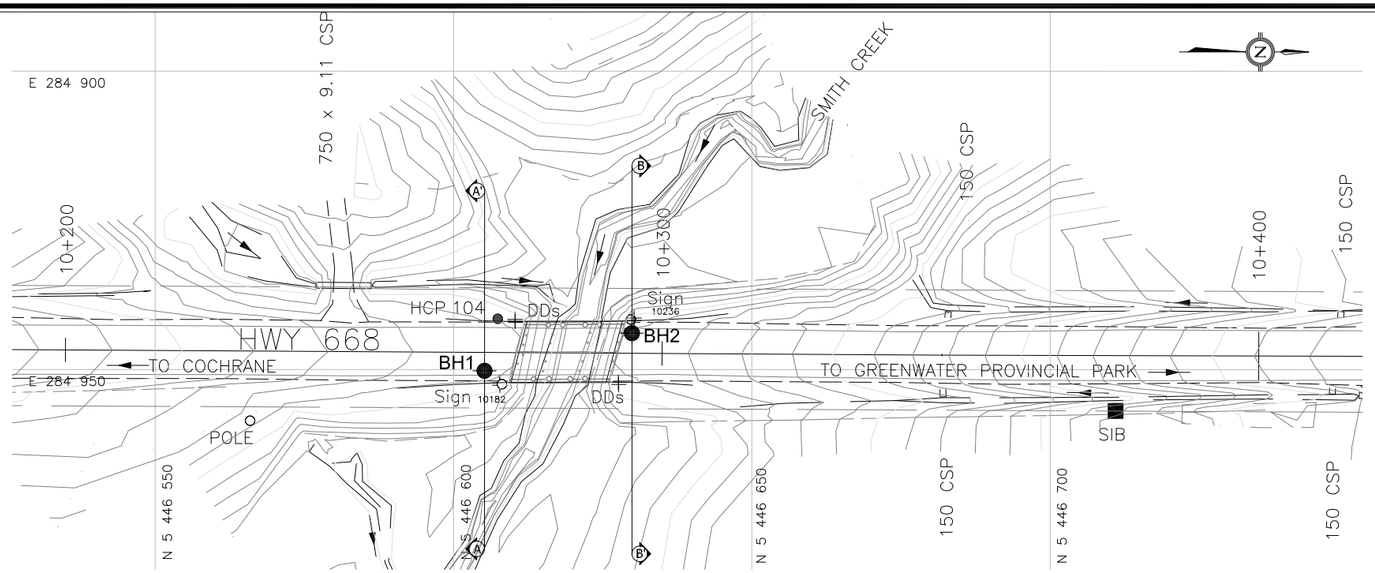

PLAN

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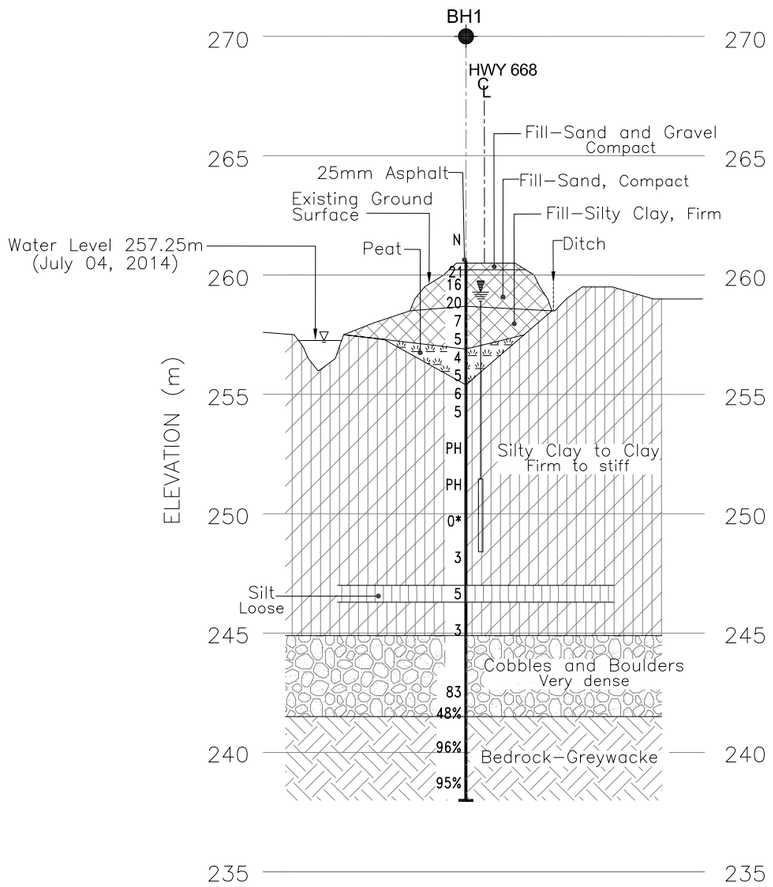

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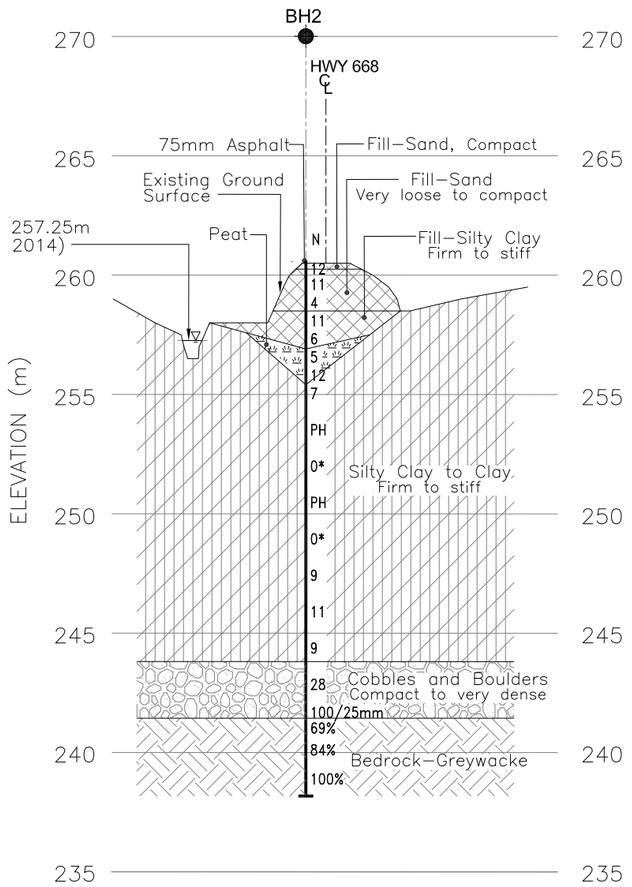

SECTION B-B'

HORIZ. SCALE 10 5 0 5 10 15 20m
VERT. SCALE 2.5 0 2.5 5m

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GWP No 5267–11–00

HWY 668
SMITH CREEK BRIDGE
BOREHOLE LOCATIONS AND SOIL STRATA

SHEET 2 of 2

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KEY PLAN

	LEGEND
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REVISIONS			
	DATE	BY	DESCRIPTION

HWY. QEW	PROJECT No. 1–15–0509		DIST.
SUBM'D.RA	CHK'D. RA	DATE: JULY. 2016	SITE: 39E–014
DRAWN: KC	CHK'D. RA	APP'D: MT	DWG. 2

Z:\1-Project Files\2015\1-15-0509 -New Liskeard Area, MTO Northern Region\01-Preliminary FID\1 Smith Creek Bridge\A Dwgs, Logs\AutoCAD\1-15-0509 Smith Creek Bridge BH Plan & Profile--dwg, Kamal

APPENDIX A
Record of Borehole Sheets

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 ú.

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
σ	kPa	TOTAL NORMAL STRESS
σ'	kPa	EFFECTIVE NORMAL STRESS
τ	kPa	SHEAR STRESS
$\sigma_1, \sigma_2, \sigma_3$	kPa	PRINCIPAL STRESSES
ε	%	LINEAR STRAIN
$\varepsilon_1, \varepsilon_2, \varepsilon_3$	%	PRINCIPAL STRAINS
E	kPa	MODULUS OF LINEAR DEFORMATION
G	kPa	MODULUS OF SHEAR DEFORMATION
μ	1	COEFFICIENT OF FRICTION

MECHANICAL PROPERTIES OF SOIL

m_v	kPa^{-1}	COEFFICIENT OF VOLUME CHANGE
C_C	1	COMPRESSION INDEX
C_S	1	SWELLING INDEX
C_α	1	RATE OF SECONDARY CONSOLIDATION
C_v	m^2/s	COEFFICIENT OF CONSOLIDATION
H	m	DRAINAGE PATH
T_v	1	TIME FACTOR
U	%	DEGREE OF CONSOLIDATION
σ'_{vo}	kPa	EFFECTIVE OVERBURDEN PRESSURE
σ'_p	kPa	PRECONSOLIDATION PRESSURE
τ_f	kPa	SHEAR STRENGTH
c'	kPa	EFFECTIVE COHESION INTERCEPT
ϕ'	- °	EFFECTIVE ANGLE OF INTERNAL FRICTION
c_u	kPa	APPARENT COHESION INTERCEPT
ϕ_u	- °	APPARENT ANGLE OF INTERNAL FRICTION
τ_R	kPa	RESIDUAL SHEAR STRENGTH
τ_r	kPa	REMOULDED SHEAR STRENGTH
S_t	1	SENSITIVITY = c_u / τ_r

PHYSICAL PROPERTIES OF SOIL

r_s	kg/m^3	DENSITY OF SOLID PARTICLES	e	1,%	VOID RATIO	e_{min}	1,%	VOID RATIO IN DENSEST STATE
γ_s	kN/m^3	UNIT WEIGHT OF SOLID PARTICLES	n	1,%	POROSITY	I_D	1	DENSITY INDEX = $\frac{e_{max} - e}{e_{max} - e_{min}}$
r_w	kg/m^3	DENSITY OF WATER						
γ_w	kN/m^3	UNIT WEIGHT OF WATER	w	1,%	WATER CONTENT	D	mm	GRAIN DIAMETER
r	kg/m^3	DENSITY OF SOIL	S_r	%	DEGREE OF SATURATION	D_n	mm	n PERCENT - DIAMETER
γ	kN/m^3	UNIT WEIGHT OF SOIL	w_L	%	LIQUID LIMIT	C_u	1	UNIFORMITY COEFFICIENT
r_d	kg/m^3	DENSITY OF DRY SOIL	w_P	%	PLASTIC LIMIT	h	m	HYDRAULIC HEAD OR POTENTIAL
γ_d	kN/m^3	UNIT WEIGHT OF DRY SOIL	w_S	%	SHRINKAGE LIMIT	q	m^3/s	RATE OF DISCHARGE
r_{sat}	kg/m^3	DENSITY OF SATURATED SOIL	I_P	%	PLASTICITY INDEX = $(w_L - w_P)$	v	m/s	DISCHARGE VELOCITY
γ_{sat}	kN/m^3	UNIT WEIGHT OF SATURATED SOIL	I_L	1	LIQUIDITY INDEX = $(w - w_P)/I_P$	i	1	HYDRAULIC GRADIENT
r'	kg/m^3	DENSITY OF SUBMERGED SOIL	I_C	1	CONSISTENCY INDEX = $(w_L - w)/I_P$	k	m/s	HYDRAULIC CONDUCTIVITY
γ'	kN/m^3	UNIT WEIGHT OF SUBMERGED SOIL	e_{max}	1,%	VOID RATIO IN LOOSEST STATE	j	kN/m^3	SEEPAGE FORCE

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RECORD OF BOREHOLE No 1

1 of 2

METRIC

G.W.P. 5267-11-00 | LOCATION Coords: E:284950.4 N:5446605.2 | ORIGINATED BY SD

DIST _____ | HWY 668 | BOREHOLE TYPE SOLID STEM AUGERS / NW CASING AND WASH BORING / NQ CORING | COMPILED BY SD

DATUM GEODETIC | DATE 2015-9-2 - 2015-9-3 | CHECKED BY RA

ELEV / DEPTH (m)	DESCRIPTION	NUMBER	TYPE	SPT 'N' VALUE	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
260.6	**GROUND SURFACE**				
260.2	25mm **ASPHALTIC CONCRETE**	1	AS		35 59 *(6)*
0.4	355mm **FILL - SAND AND GRAVEL**, trace silt, compact, brown, dry	2	SS	21	
	FILL, sand, trace to some silt, trace gravel, compact, brown, dry	3	SS	16	
258.7		4	SS	20	
1.9	**FILL**, silty clay, trace to some sand, trace gravel, firm, brown to 2.9m, grey below, moist	5	SS	7	1 11 51 37
		6	SS	5	
256.9					commence NW casing and wash boring
3.7	**PEAT**, amorphous, some silt and wood pieces, black	7	SS	4	
		8	SS	5	
255.4					
5.2	**SILTY CLAY to CLAY**, trace to some sand, firm to stiff, grey, wet	9	SS	6	
		10	SS	5	0 11 55 34
		11	TW	PH	
		12	TW	PH	
		13	SS	0*	0 0 21 79
		14	SS	3	
247.0					
13.6	**SILT**, some clay, loose, grey, wet	15	SS	5	0 0 86 14
246.3					
14.3	**SILTY CLAY**, frequent clayey silt seams, firm to stiff, grey, wet				

ELEVATION SCALE: 260, 259, 258, 257, 256, 255, 254, 253, 252, 251, 250, 249, 248, 247, 246

DYNAMIC CONE PENETRATION RESISTANCE PLOT — 20 40 60 80 100

SHEAR STRENGTH (kPa) — ○ UNCONFINED ● QUICK TRIAXIAL + FIELD VANE × LAB VANE — 20 40 60 80 100

PLASTIC LIMIT w_P | NATURAL MOISTURE CONTENT w | LIQUID LIMIT w_L

WATER CONTENT (%) — 10 20 30

UNIT WEIGHT γ kN/m^3

+1.3, +2.2, +2.4, +1.8, +5.0, +5.5, +5.3, +4.9, +3.8, +2.8, +3.4

48, 46 LL=43

Continued Next Page

+^{3}, ×^{3}: Numbers refer to Sensitivity ○$^{3\%}$ STRAIN AT FAILURE

file: 1-15-0509-01 smith creek bh logs.gpj

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RECORD OF BOREHOLE No 1

2 of 2

METRIC

G.W.P. 5267-11-00 | LOCATION Coords: E:284950.4 N:5446605.2 | ORIGINATED BY SD

DIST | HWY 668 | BOREHOLE TYPE SOLID STEM AUGERS / NW CASING AND WASH BORING / NQ CORING | COMPILED BY SD

DATUM GEODETIC | DATE 2015-9-2 - 2015-9-3 | CHECKED BY RA

ELEV / DEPTH (m)	DESCRIPTION (continued)	STRAT PLOT	SAMPLES NUMBER	TYPE	SPT 'N' VALUE	GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT (20 40 60 80 100) / SHEAR STRENGTH (kPa) (20 40 60 80 100) O UNCONFINED ● QUICK TRIAXIAL + FIELD VANE × LAB VANE	PLASTIC LIMIT w_P / NATURAL MOISTURE CONTENT w / LIQUID LIMIT w_L WATER CONTENT (%) (10 20 30)	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
244.9 / 15.7	**SILTY CLAY**, frequent clayey silt seams, firm to stiff, grey, wet		16	SS	3		245			
	COBBLES and BOULDERS, and sand, trace to some silt, very dense, grey, wet		17	RC			244			
			18	RC			243			
			19	SS	83					0 83 *(17)*
241.5 / 19.1			1	RUN	NQ		242			Run #1 TCR: 90% SCR: 62% RQD: 48% UCS**= 133 - 238 (MPa)
	BEDROCK - GREYWACKE containing quartz veins, slightly weathered to 19.7m, unweathered below, thickly bedded, light grey to grey, very strong		2	RUN	NQ		241			Run #2 TCR: 100% SCR: 96% RQD: 96% UCS**= 192 - 249 (MPa)
			3	RUN	NQ		240			Run #3 TCR: 100% SCR: 100% RQD: 95% UCS**= 108 - 187 (MPa)
238.0 / 22.6	**END OF BOREHOLE**						239			
							238			

WATER LEVEL READINGS

Date	Water Depth (m)	Elevation (m)
Oct 1, 2015	1.3	259.3
Oct 7, 2015	1.4	259.2

* Sampler sinking under weight of rods.

Piezometer installation consists of a 50mm diameter PVC pipe with a 3.0m slotted screen. Piezometer installed 0.6m west of this borehole.

Excess hydrostatic pressure encountered in cobble and boulder deposit at a depth of 18.3m. Borehole grouted and sealed with bentonite slurry after drilling was completed.

Atterberg Limits test attempted on SS15. Sample is non-plastic.

SS19 - Grain Size Distribution test carried out on sand fraction of deposit.

**Uniaxial Compressive Strength determined from Point Load Strength Index values.

$+^3, \times^3$: Numbers refer to Sensitivity

$\circ^{3\%}$ STRAIN AT FAILURE

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RECORD OF BOREHOLE No 2

1 of 2

METRIC

G.W.P. 5267-11-00 | LOCATION Coords: E:284943.9 N:5446629.9 | ORIGINATED BY SD

DIST _____ HWY 668 | BOREHOLE TYPE SOLID STEM AUGERS / NW CASING AND WASH BORING / NQ CORING | COMPILED BY SD

DATUM GEODETIC | DATE 2015-8-31 - 2015-9-1 | CHECKED BY RA

ELEV / DEPTH (m)	DESCRIPTION	STRAT PLOT	SAMPLES: NUMBER	TYPE	SPT 'N' VALUE	GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT (20 40 60 80 100) / SHEAR STRENGTH (kPa) (20 40 60 80 100): ○ UNCONFINED ● QUICK TRIAXIAL + FIELD VANE × LAB VANE	PLASTIC LIMIT w_P / NATURAL MOISTURE CONTENT w / LIQUID LIMIT w_L — WATER CONTENT (%) (10 20 30)	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
260.6	**GROUND SURFACE**										
260.2	75mm **ASPHALTIC CONCRETE**										
0.4	285mm **FILL - SAND**, some gravel, trace silt, compact, brown, dry										
	FILL, sand, trace to some silt, trace gravel, very loose to compact, brown, moist		1	SS	12		260				
			2	SS	11				○		2 86 *(12)*
			3	SS	4		259				sampler wet at 1.8m
258.5											
2.1	**FILL**, silty clay, trace sand, trace gravel, firm to stiff, brown to 2.9m, dark brown below, trace organics below 2.9m		4	SS	11		258		○		
			5	SS	6						
256.9							257				
3.7	**PEAT**, amorphous, some silt and wood pieces, black		6	SS	5				59 ○		commence NW casing and wash boring
			7	SS	12		256				
255.4											
5.2	**SILTY CLAY to CLAY**, trace to some sand, trace gravel, firm to stiff, grey, wet		8	SS	7		255	2.0 +	○		0 11 57 32
							254	2.2 +			
			9	TW	PH						
							253	3.2 +			
								2.3 +			
			10	SS	0*		252		48 ○ *LL=51*		1 2 19 78
								6.0 +			
	occasional clayey silt seams						251	4.0 +			
			11	TW	PH			×	57 ○ *LL=62*	17.0	0 1 12 87
							250	8.8 +			
								3.5 +			
			12	SS	0*		249		43 ○		
								6.5 +			
							248	3.8 +			
			13	SS	9						
							247				
			14	SS	11		246		○		0 0 81 19

Continued Next Page

+ ^{3}, × ^{3}: Numbers refer to Sensitivity ○ $^{3\%}$ STRAIN AT FAILURE

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RECORD OF BOREHOLE No 2

2 of 2

METRIC

G.W.P. 5267-11-00 | LOCATION Coords: E:284943.9 N:5446629.9 | ORIGINATED BY SD

DIST | HWY 668 | BOREHOLE TYPE SOLID STEM AUGERS / NW CASING AND WASH BORING / NQ CORING | COMPILED BY SD

DATUM GEODETIC | DATE 2015-8-31 - 2015-9-1 | CHECKED BY RA

ELEV / DEPTH (m)	DESCRIPTION (continued)	STRAT PLOT	SAMPLES: NUMBER	SAMPLES: TYPE	SAMPLES: SPT 'N' VALUE	GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT (20 40 60 80 100) / SHEAR STRENGTH (kPa) (20 40 60 80 100): ○ UNCONFINED ● QUICK TRIAXIAL + FIELD VANE × LAB VANE	PLASTIC LIMIT w_P / NATURAL MOISTURE CONTENT w / LIQUID LIMIT w_L — WATER CONTENT (%) (10 20 30)	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
	SILTY CLAY to CLAY, trace to some sand, trace gravel, firm to stiff, grey, wet						245				
			15	SS	9				○		
243.8							244				
16.8	**COBBLES and BOULDERS**, some sand, trace to some silt, trace gravel, compact to very dense, grey, wet										
			16	SS	28		243				
			17	RC							
241.4							242				
19.2			18	SS	100 / 125mm						
	BEDROCK - GREYWACKE containing quartz veins, slightly weathered to 20.3m, unweathered below, medium bedded to 21.3m, thickly bedded below, light grey to grey, very strong		1	RUN	NQ		241				Run #1 TCR: 100% SCR: 84% RQD: 69% UCS**= 145 - 218 (MPa)
			2	RUN	NQ		240				Run #2 TCR: 100% SCR: 98% RQD: 84% UCS**= 129 - 164 (MPa)
			3	RUN	NQ		239				Run #3 TCR: 100% SCR: 100% RQD: 100% UCS**= 139 - 228 (MPa)
238.2											
22.4	**END OF BOREHOLE**										

* Sampler sinking under weight of rods.

Excess hydrostatic pressure encountered in cobble and boulder deposit at a depth of 18.3m. Borehole grouted and sealed with bentonite slurry after drilling was completed.

Consolidation test performed on TW11.

**Uniaxial Compressive Strength determined from Point Load Strength Index values.

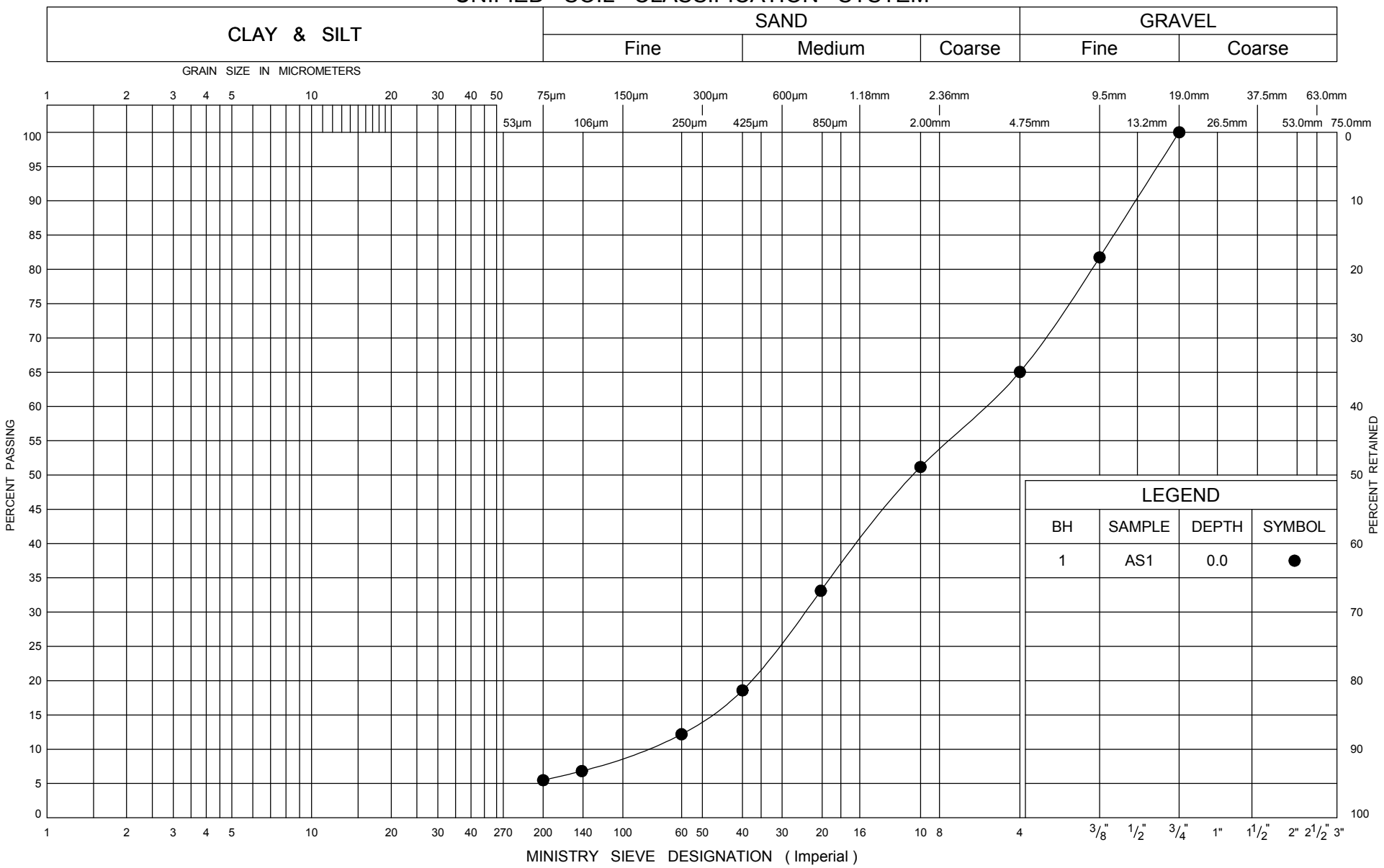
+ ^{3}, × ^{3}: Numbers refer to Sensitivity ○ $^{3\%}$ STRAIN AT FAILURE

file: 1-15-0509-01 smith creek bh logs.gpj

APPENDIX B
Field & Laboratory Test Results
&
Photographs

Terraprobe

UNIFIED SOIL CLASSIFICATION SYSTEM



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GRAIN SIZE DISTRIBUTION
FILL-SAND AND GRAVEL

FIG No B1

G W P 5267-11-00

New Liskeard Area

file: 1-15-0509-01 smith creek bh logs.gpj

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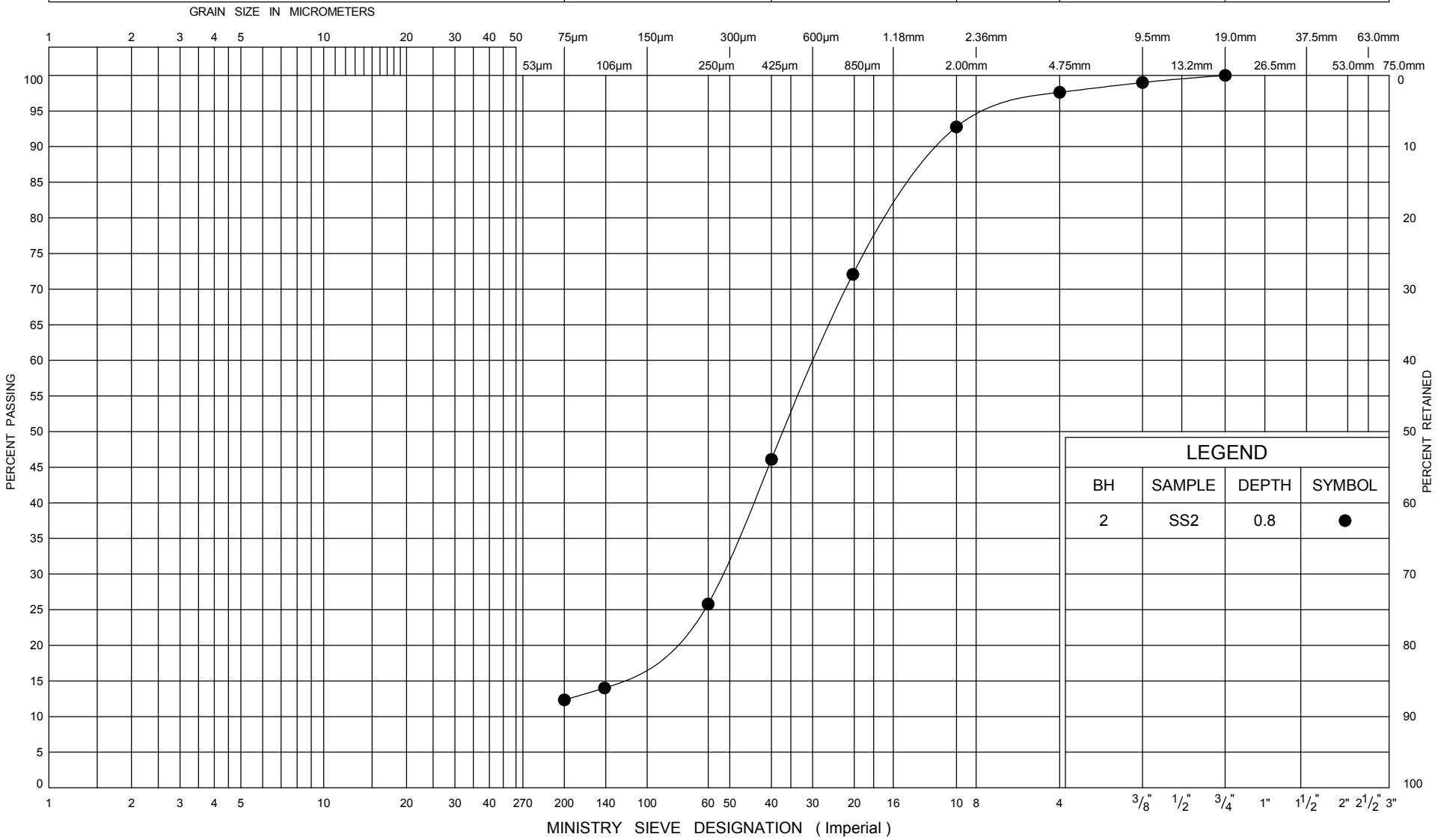
UNIFIED SOIL CLASSIFICATION SYSTEM



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GRAIN SIZE DISTRIBUTION
FILL-SAND

FIG No B2

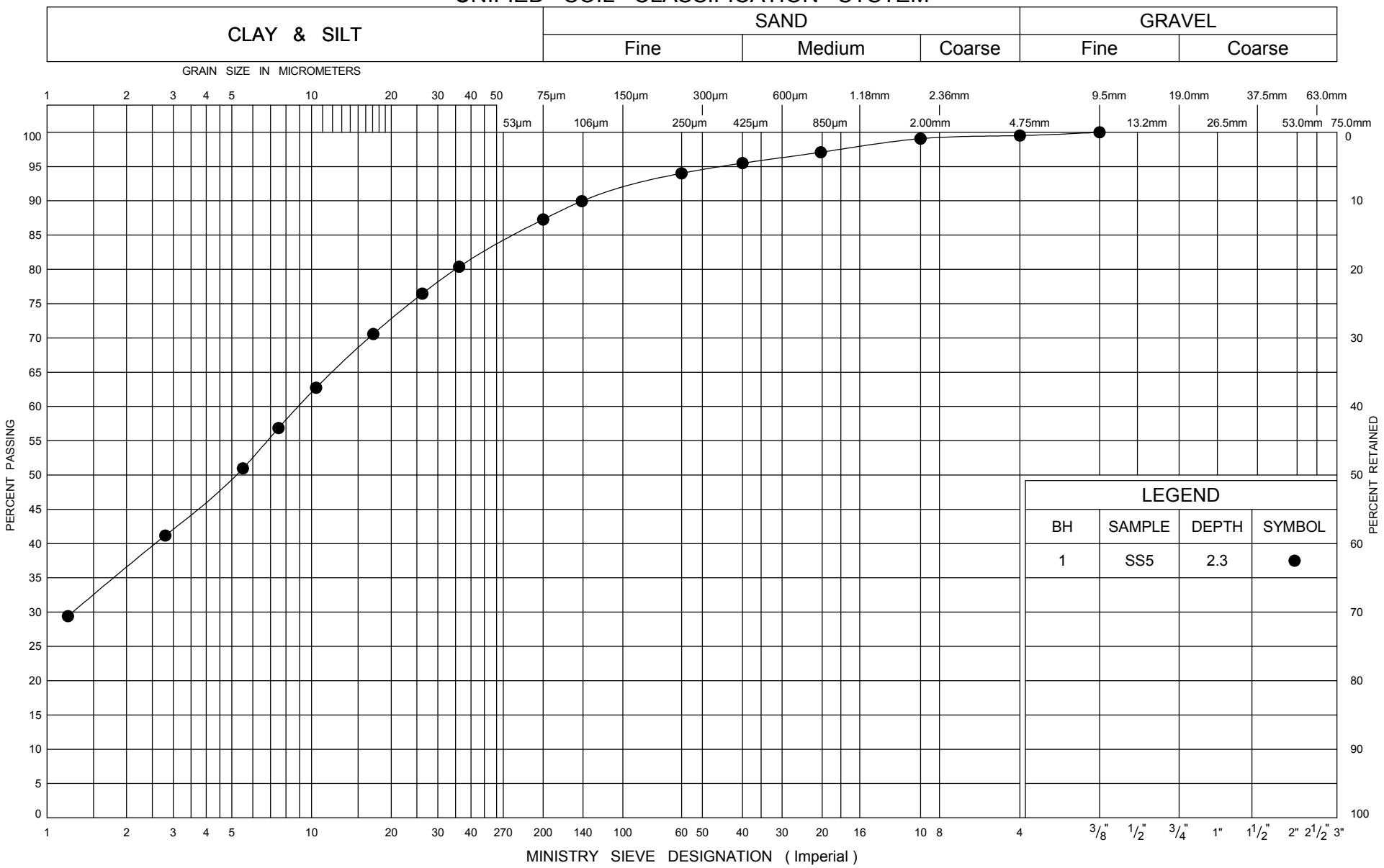
G W P 5267-11-00

New Liskeard Area

file: 1-15-0509-01 smith creek bh logs.gpj

Terraprobe

UNIFIED SOIL CLASSIFICATION SYSTEM



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GRAIN SIZE DISTRIBUTION
FILL-SILTY CLAY

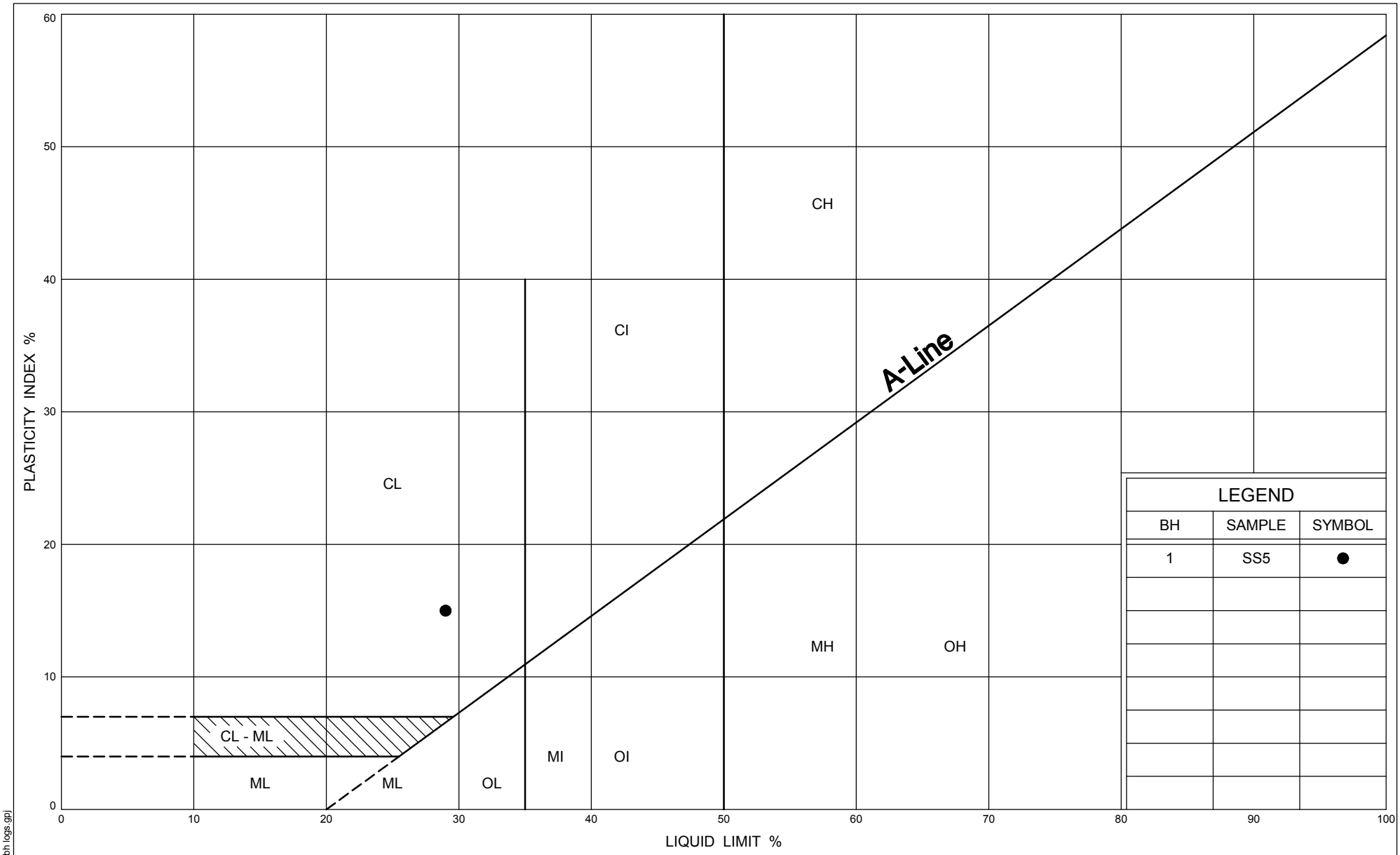
FIG No B3

G W P 5267-11-00

New Liskeard Area

file: 1-15-0509-01 smith creek bh logs.gpj

Terraprobe



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PLASTICITY CHART

FILL-SILTY CLAY

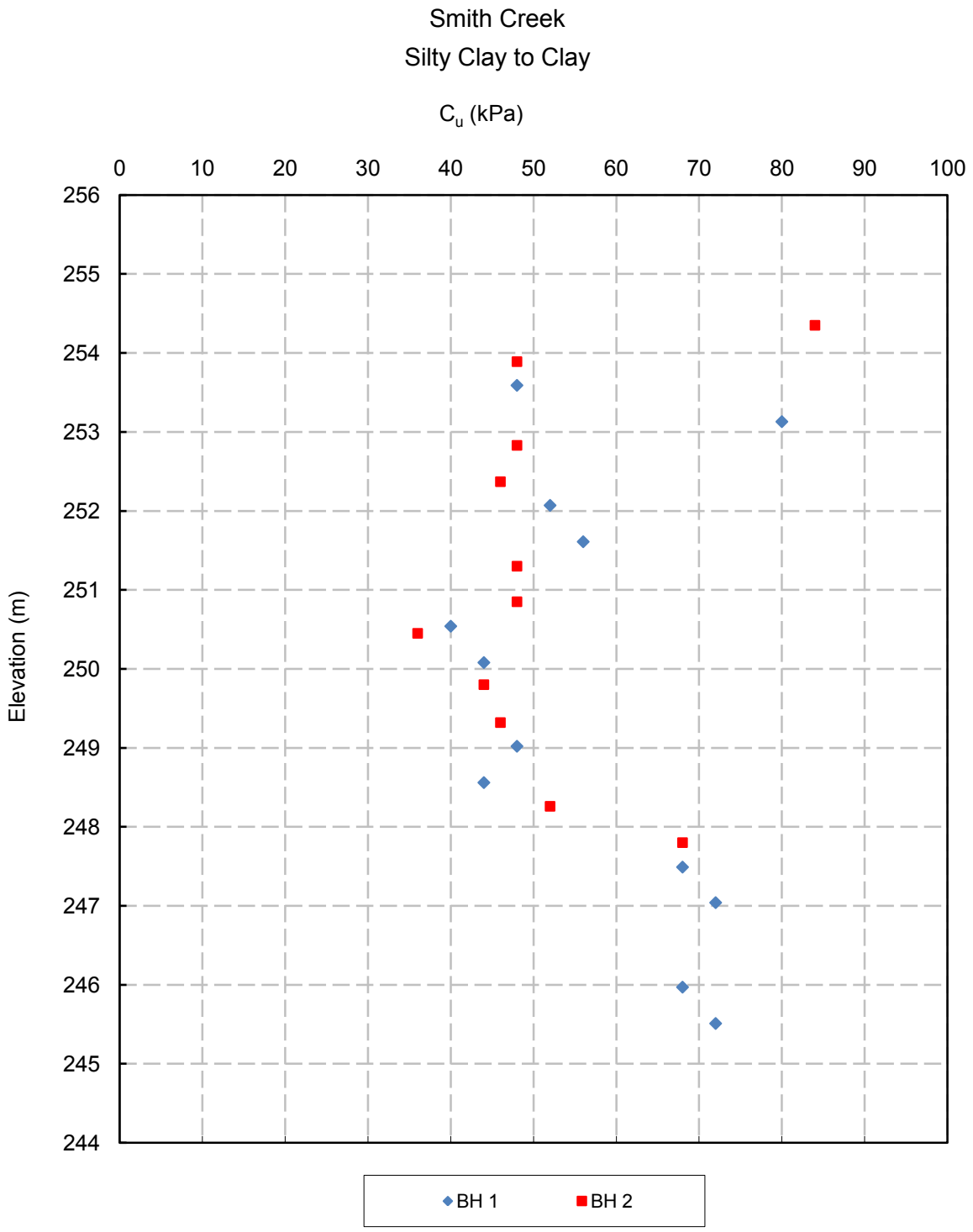
FIG No B4

G W P 5267-11-00

New Liskeard Area

file: 1-15-0509-01 smith creek bh logs.gpj

UNDRAINED SHEAR STRENGTH	FIGURE B5



Project No. : 1-15-0509
Date : July, 2016

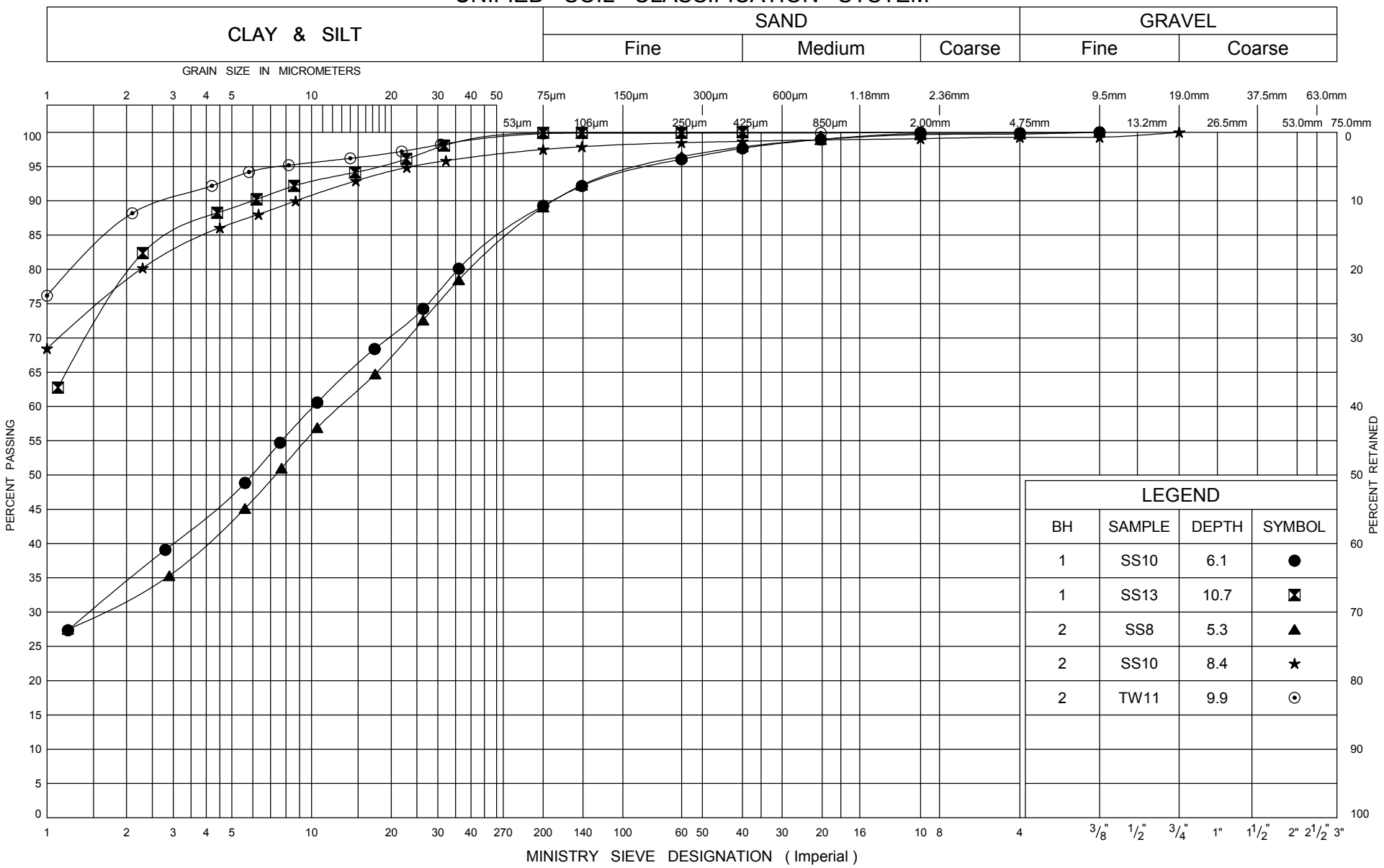
Terraprobe Inc.

Prepared by : SD
Checked by : RA

F:\Project\Smith Creek\e0-P'c-Cc-Cr-Cu.xlsx

Terraprobe

UNIFIED SOIL CLASSIFICATION SYSTEM



LEGEND			
BH	SAMPLE	DEPTH	SYMBOL
1	SS10	6.1	●
1	SS13	10.7	⊠
2	SS8	5.3	▲
2	SS10	8.4	★
2	TW11	9.9	⊙

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GRAIN SIZE DISTRIBUTION
SILTY CLAY TO CLAY

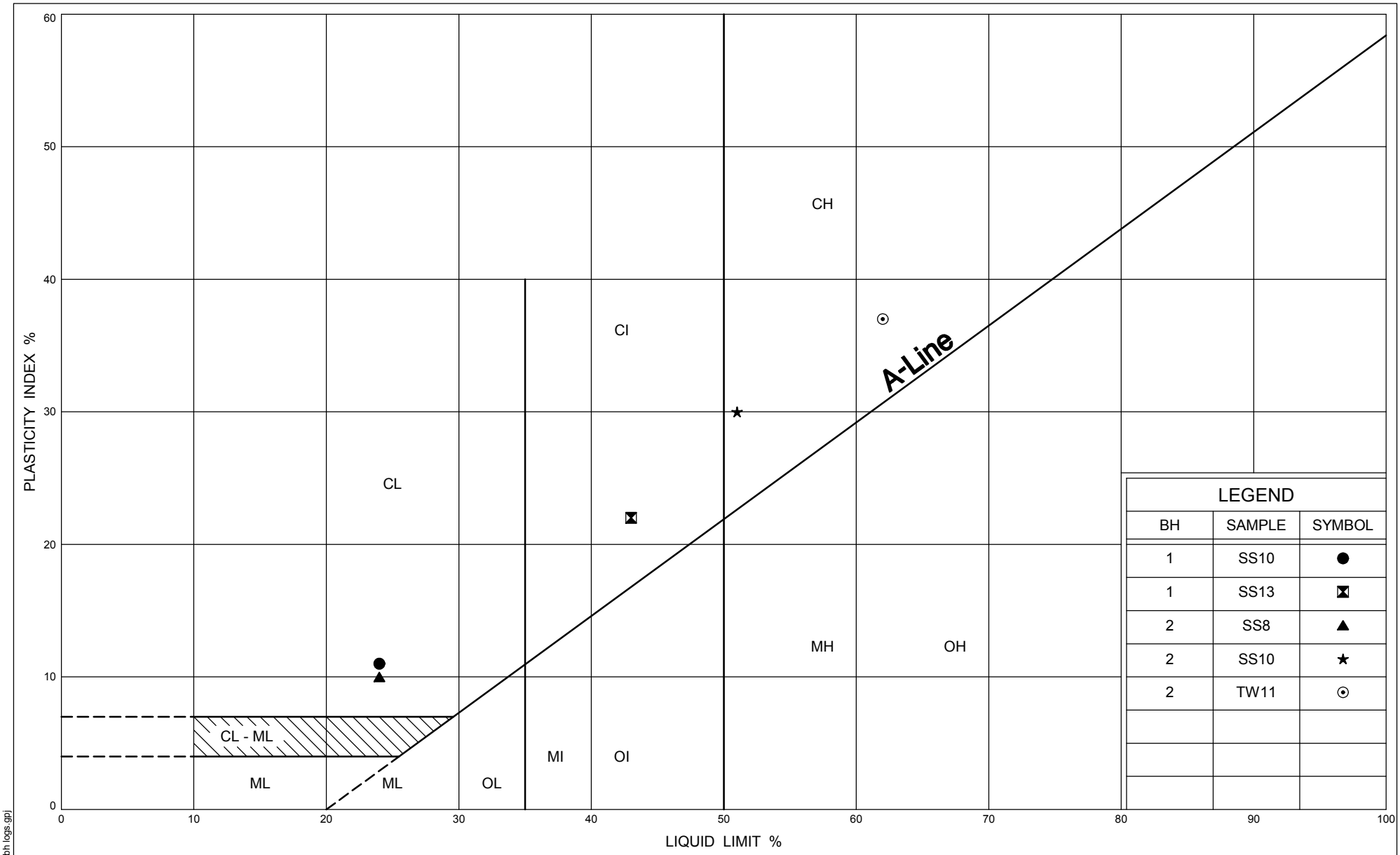
FIG No B6

G W P 5267-11-00

New Liskeard Area

file: 1-15-0509-01 smith creek bh logs.gpj

Terraprobe



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PLASTICITY CHART

SILTY CLAY TO CLAY

FIG No B7

G W P 5267-11-00

New Liskeard Area

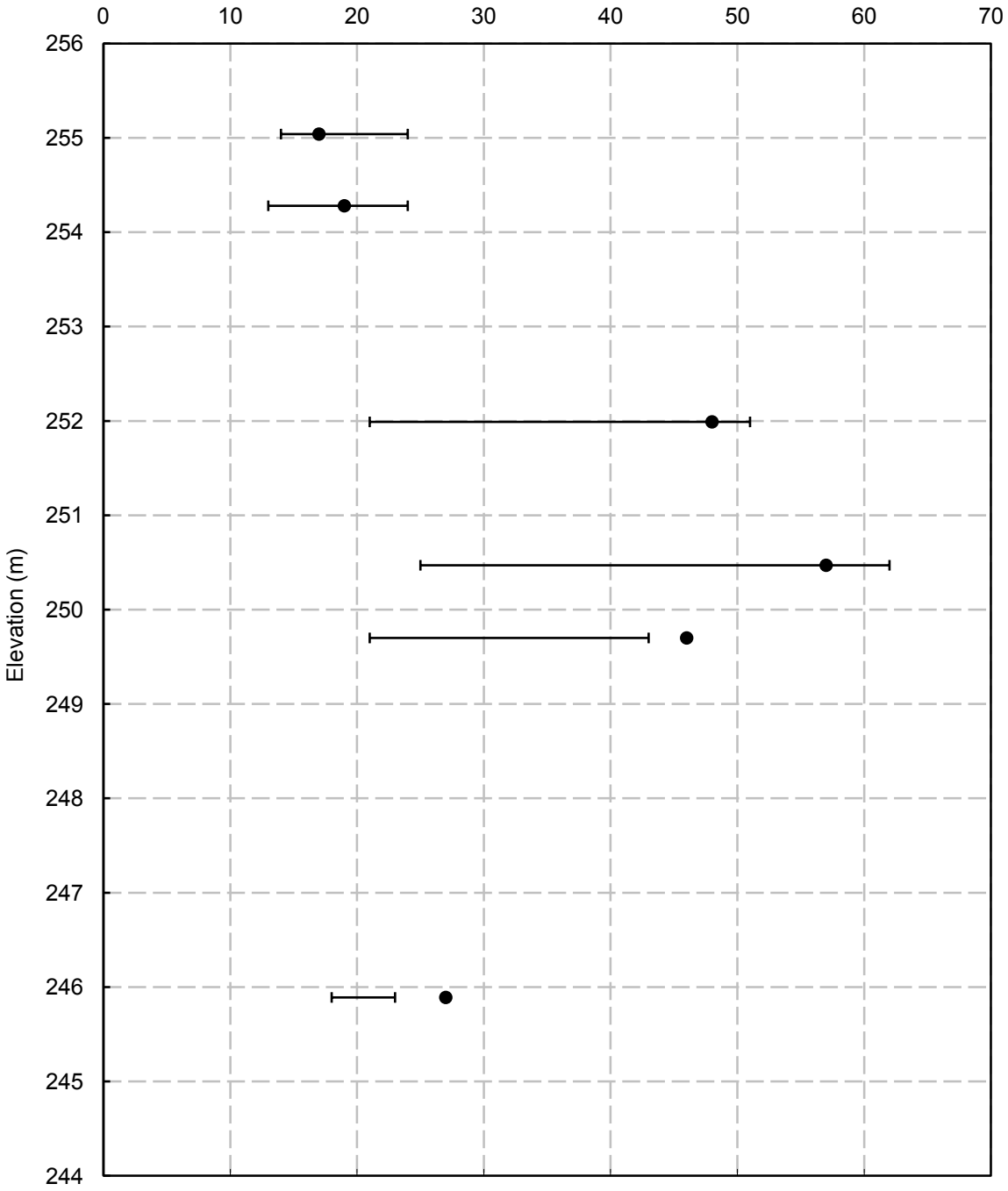
file: 1-15-0509-01 smith creek bh logs.gpj

ATTERBERG LIMITS AND WATER CONTENTS	FIGURE B8

Smith Creek

Silty Clay to Clay

Atterberg Limits & Water Content (%)



Project No. : 1-15-0509

Date : July, 2016

Terraprobe Inc.

Prepared by : SD

Checked by : RA

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CONSOLIDATION TEST SUMMARY

FIGURE B9

SAMPLE IDENTIFICATION

Borehole No. :	2	Sample No. :	TW11
		Sample Depth (m) :	9.9 - 10.4

TEST CONDITIONS

Test Type :	Laboratory Standard	Date Started :	27-Sep-15
Load Duration (hr) :	24	Date Completed :	13-Oct-15

SAMPLE DIMENSIONS AND PROPERTIES _ INITIAL

Sample Height (mm) :	19.04	Unit Weight (kN/m^3) :	16.43
Sample Diameter (mm) :	63.44	Dry Unit Weight (kN/m^3) :	10.67
Area (cm^2) :	31.61	Specific Gravity :	2.68
Volume (cm^3) :	60.18	Solid Height (mm) :	7.73
Water Content (%) :	53.9%	Volume of Solids (cm^3) :	24.43
Wet Mass (g) :	100.81	Volume of Voids (cm^3) :	35.75
Dry Mass (g) :	65.50	Degree of Saturation (%) :	98.76

TEST COMPUTATIONS

Stress (kPa)	Initial Height (mm)	Final Height (mm)	Void Ratio	t_{90} (min)	C_v (cm^2/s)	m_v (m^2/kN)	k (cm/s)
1.566	19.04	19.04	1.463				
18.7	19.04	18.96	1.452	9.00	1.41E-03	2.58E-04	3.57E-08
35.83	18.96	18.82	1.435	7.56	1.66E-03	4.06E-04	6.61E-08
70.09	18.82	18.61	1.407	14.06	8.72E-04	3.35E-04	2.86E-08
138.6	18.61	18.20	1.354	14.06	8.36E-04	3.22E-04	2.64E-08
275.7	18.20	17.09	1.211	27.56	3.79E-04	4.43E-04	1.65E-08
549.8	17.09	15.45	0.999	42.25	2.04E-04	3.50E-04	7.01E-09
1098.0	15.45	14.26	0.844	22.56	3.24E-04	1.41E-04	4.47E-09
2194.4	14.26	13.25	0.713	12.25	5.14E-04	6.49E-05	3.27E-09
275.7	13.25	13.62	0.762				
70.09	13.62	14.16	0.832				
18.7	14.16	14.80	0.914				

SAMPLE DIMENSIONS AND PROPERTIES _ FINAL

Sample Height (mm) :	14.80	Unit Weight (kN/m^3) :	18.46
Sample Diameter (mm) :	63.44	Dry Unit Weight (kN/m^3) :	13.46
Area (cm^2) :	31.61	Specific Gravity :	2.68
Volume (cm^3) :	46.78	Solid Height (mm) :	7.73
Water Content (%) :	37.70	Volume of Solids (cm^3) :	23.95
Wet Mass (g) :	88.04	Volume of Voids (cm^3) :	22.83
Dry Mass (g) :	64.21		

Project No. : 1-15-0509
Date : July 2016

Terraprobe Inc.

Prepared By : SD
Checked By : RA

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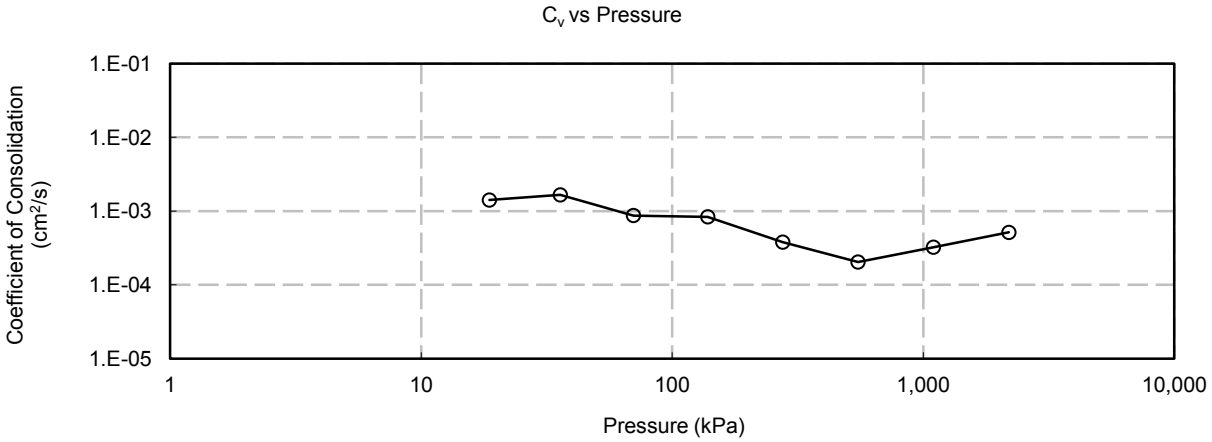
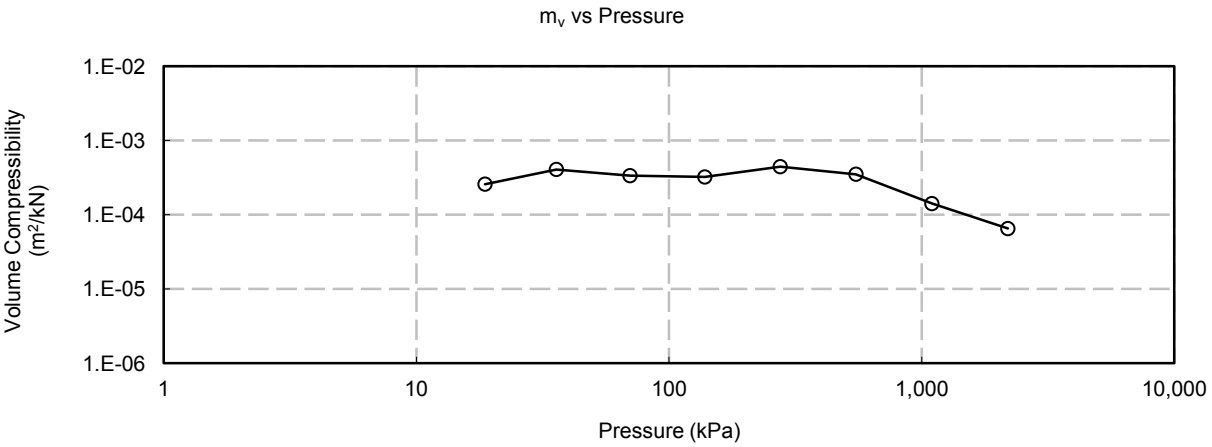
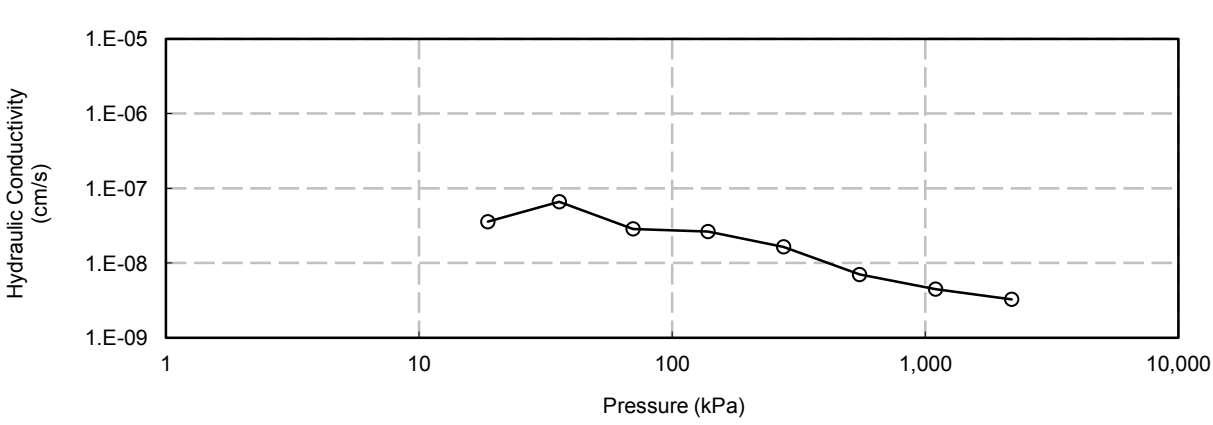
CONSOLIDATION TEST	FIGURE B10

Site: Smith Creek
Sample # : BH2 TW11







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Project No. : 1-15-0509
Date : July 2016

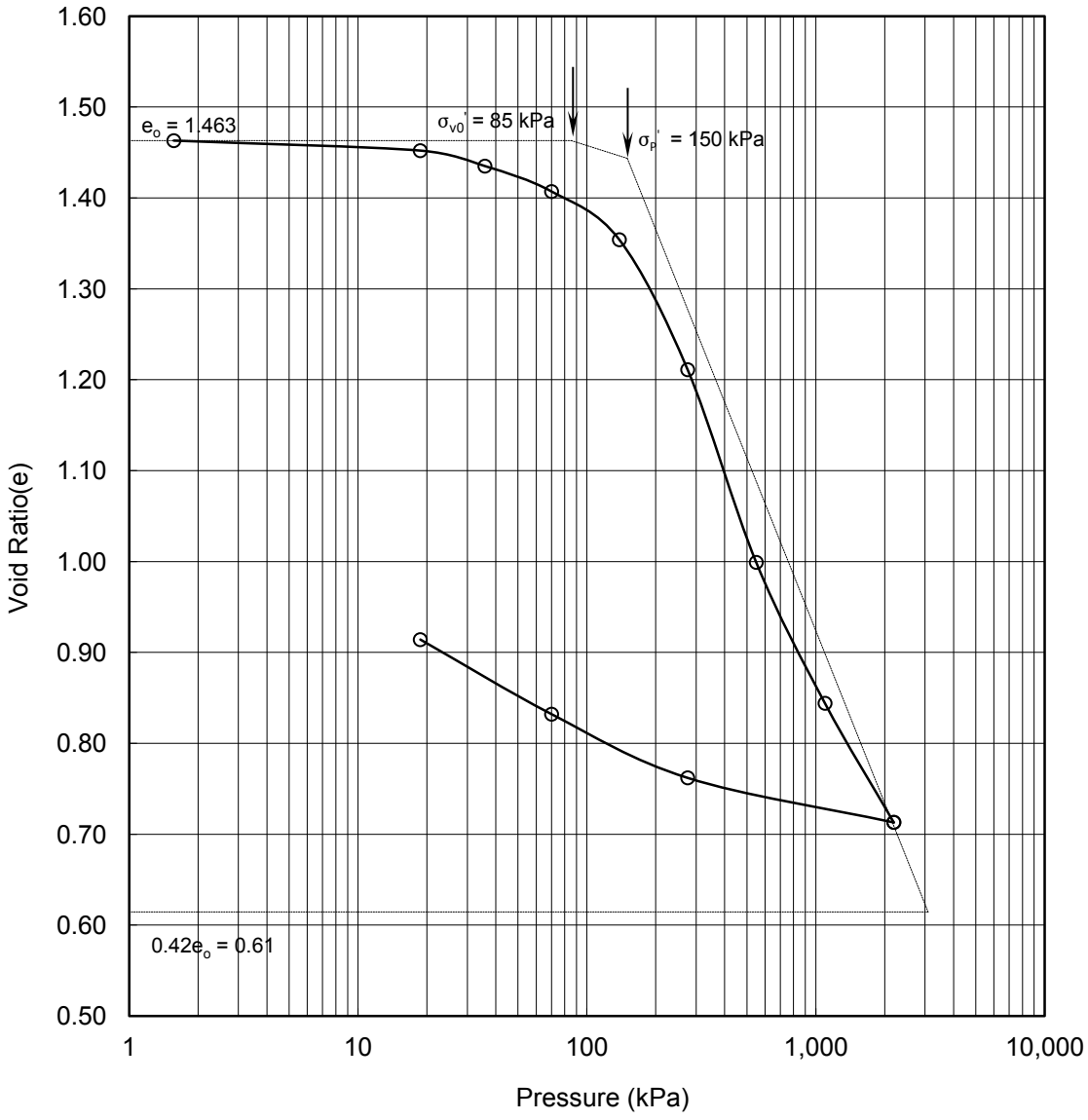
Terraprobe Inc.

Prepared By : SD
Checked By : RA

CONSOLIDATION TEST	FIGURE B11

Site: Smith Creek
Sample # : BH2 TW11

Void Ratio vs Pressure



Soil Type :	Silty Clay to Clay				
e_o =	1.46	ω_L =	62%	σ_{v0}' =	85 kPa
ω =	54%	ω_P =	25%	σ_P' =	150 kPa
γ =	16.4 kN/m^3	PI =	37%	C_c =	0.63
Gs =	2.68			C_r =	0.08

Project No. : 1-15-0509
Date : July 2016

Terraprobe Inc.

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Checked By : RA

F:\Project\Smith Creek\Consolidation Results Smith Creek.xlsx

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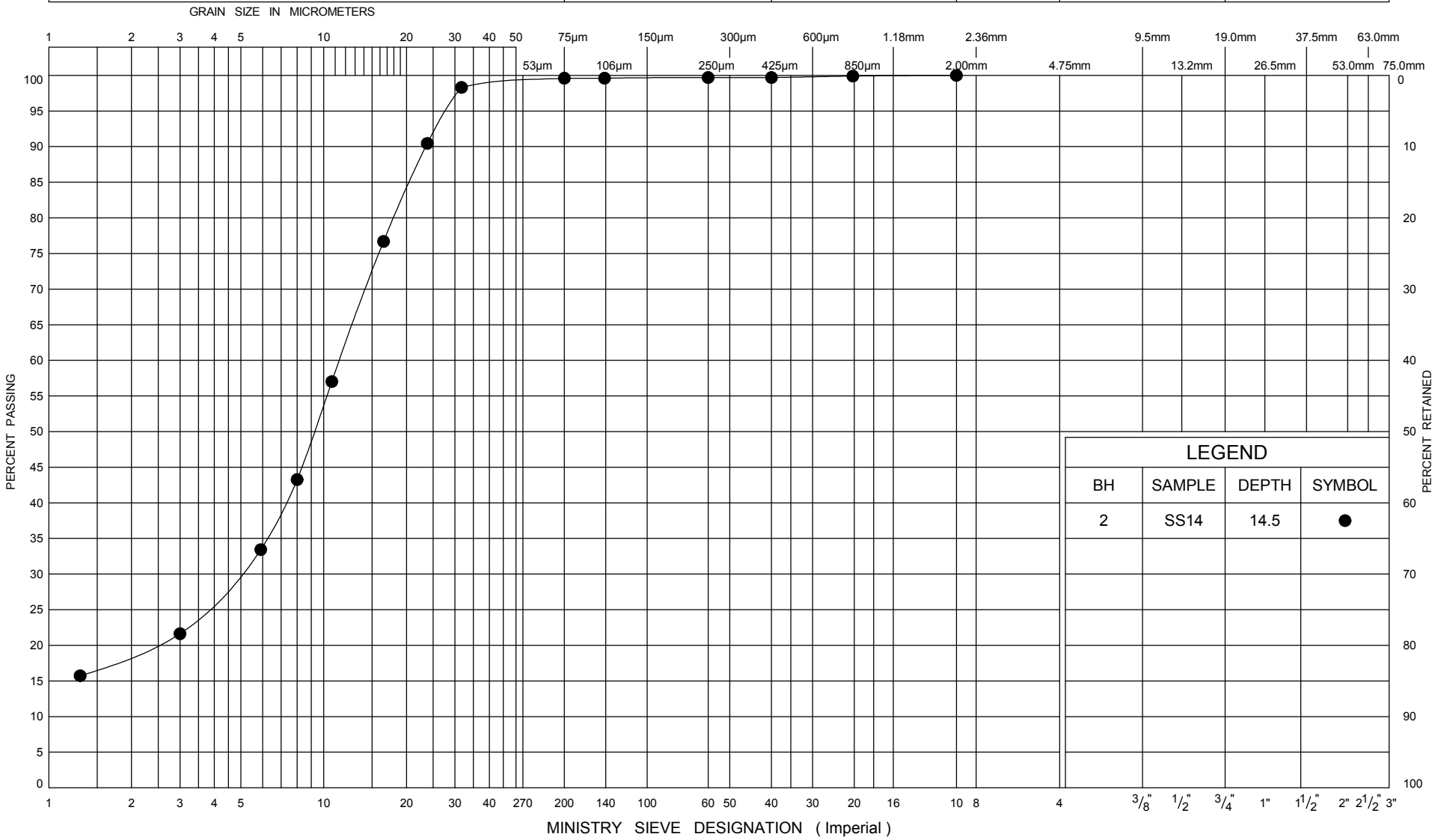
UNIFIED SOIL CLASSIFICATION SYSTEM



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GRAIN SIZE DISTRIBUTION
CLAYEY SILT

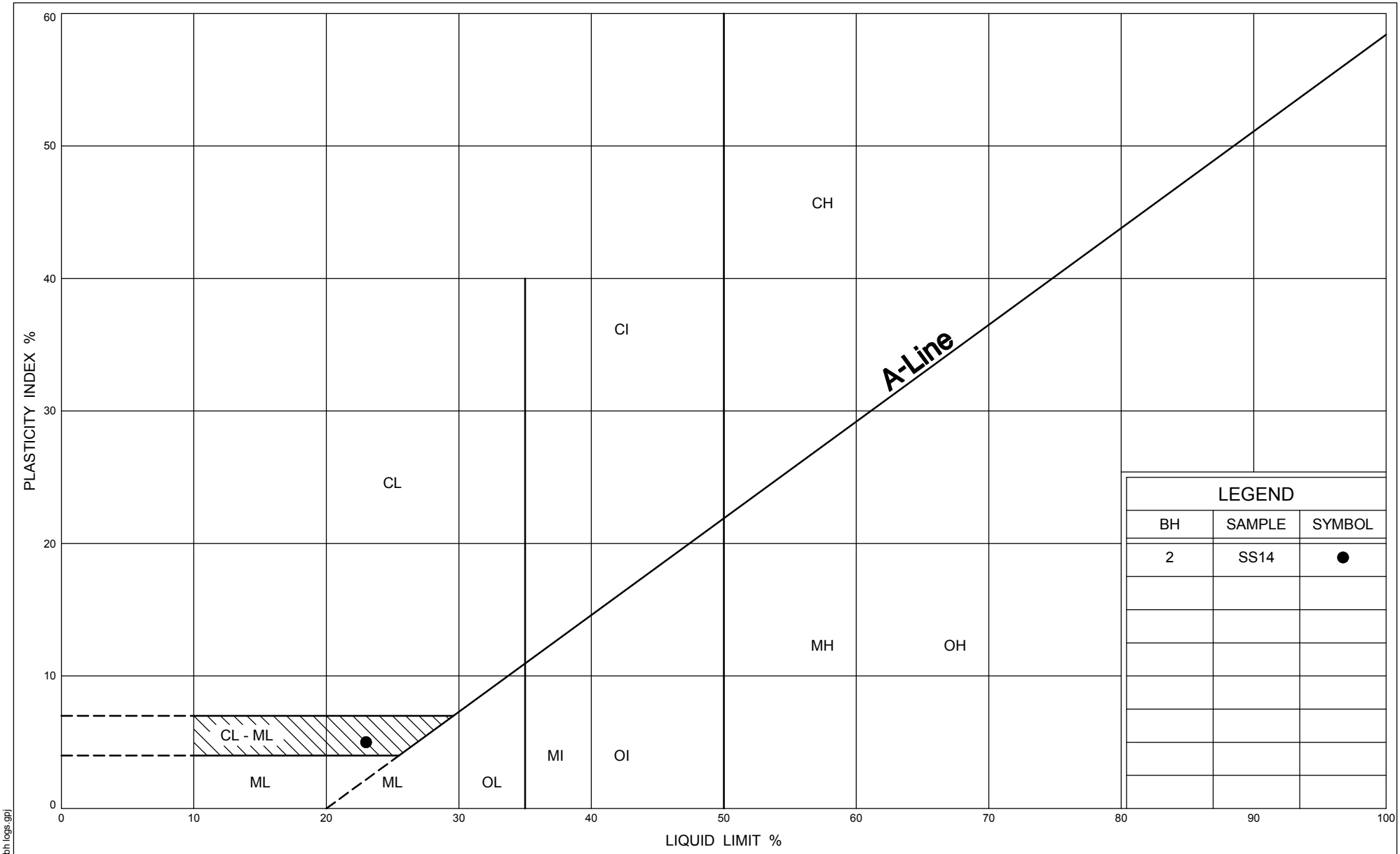
FIG No B12

G W P 5267-11-00

New Liskeard Area

file: 1-15-0509-01 smith creek bh logs.gpj

Terraprobe



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PLASTICITY CHART

CLAYEY SILT

FIG No B13

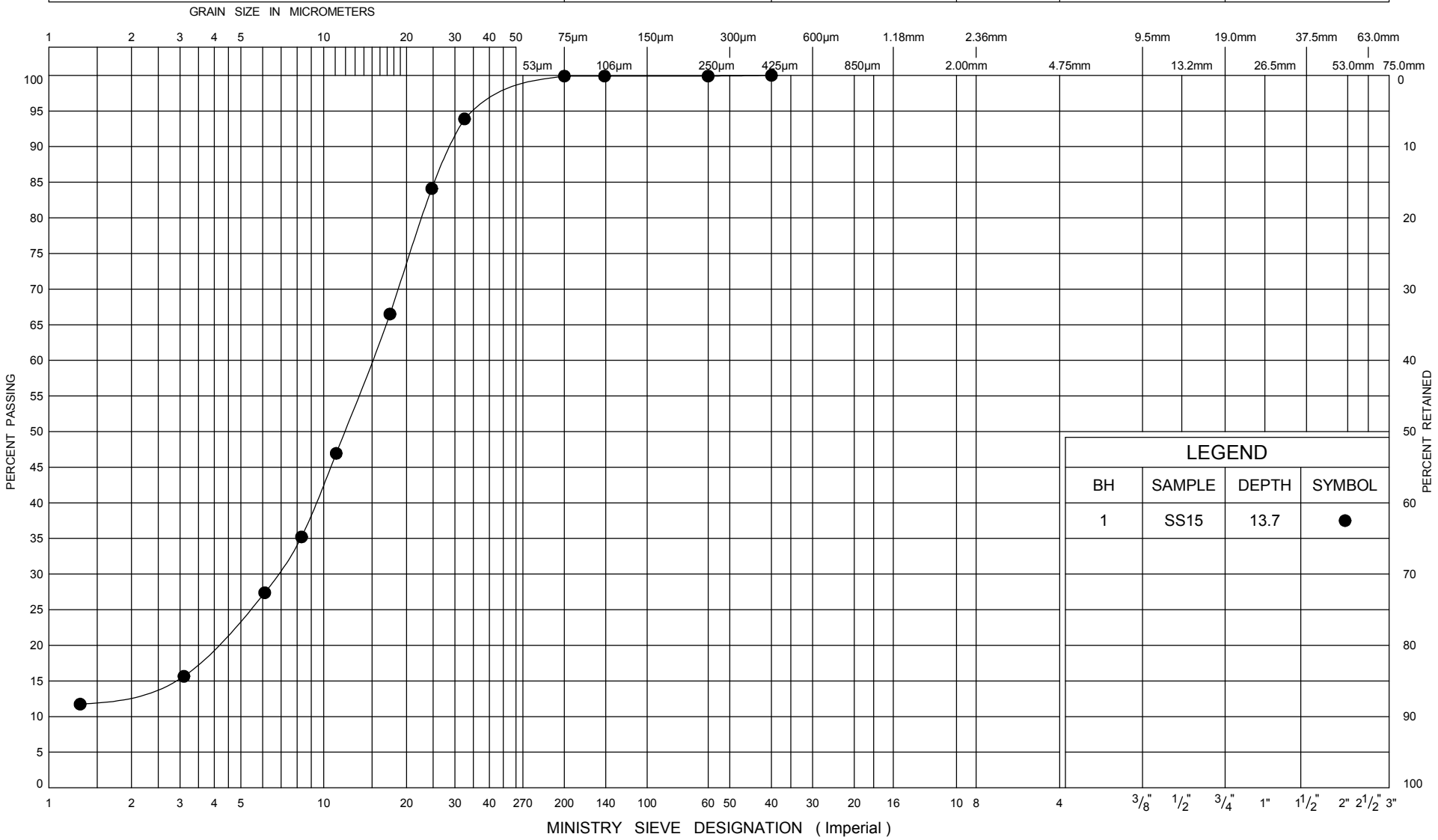
G W P 5267-11-00

New Liskeard Area

file: 1-15-0509-01 smith creek bh logs.gpj

Terraprobe

UNIFIED SOIL CLASSIFICATION SYSTEM



LEGEND

BH	SAMPLE	DEPTH	SYMBOL
1	SS15	13.7	●

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GRAIN SIZE DISTRIBUTION

SILT

FIG No B14

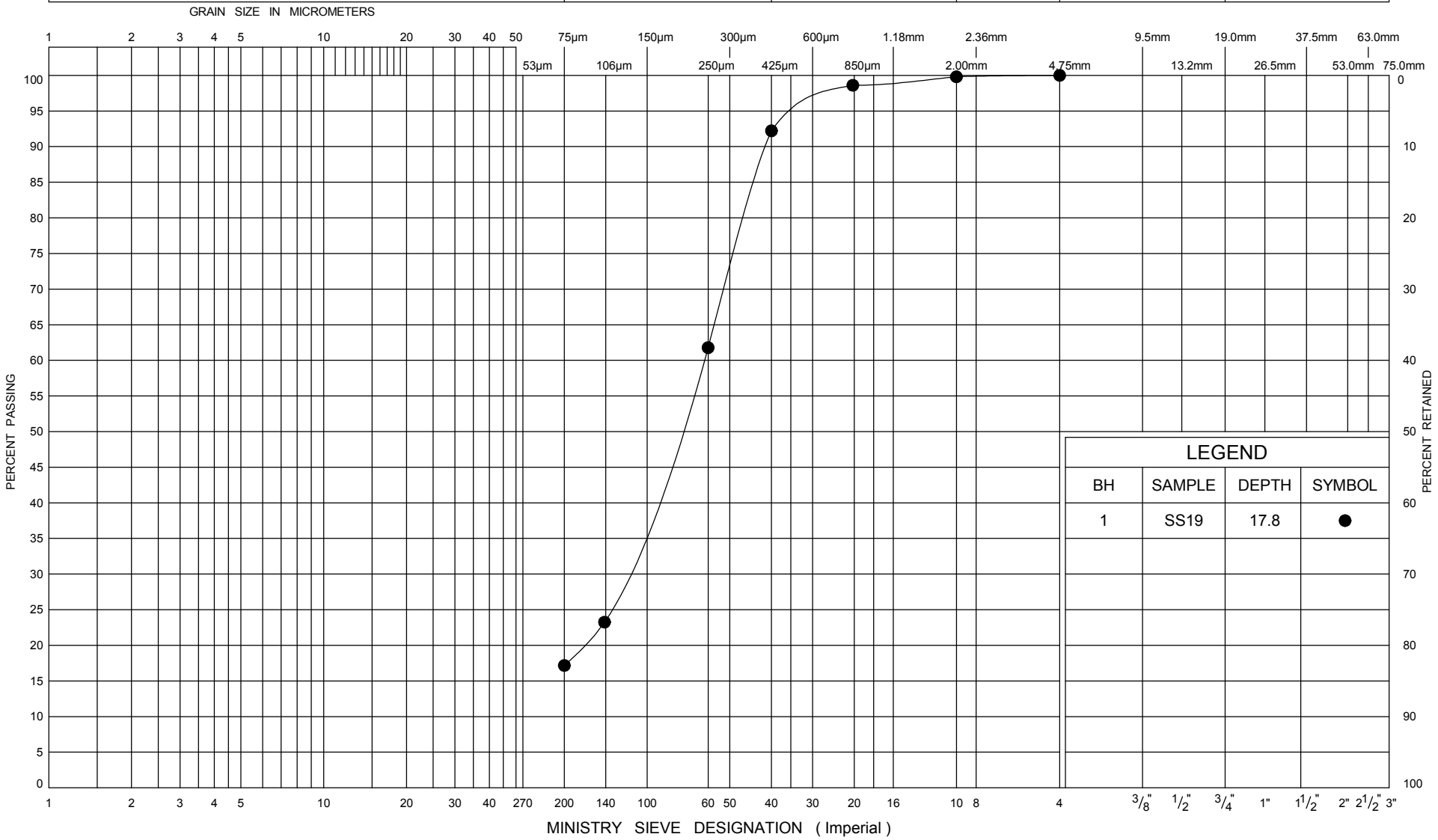
G W P 5267-11-00

New Liskeard Area

file: 1-15-0509-01 smith creek bh logs.gpj

Terraprobe

UNIFIED SOIL CLASSIFICATION SYSTEM



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GRAIN SIZE DISTRIBUTION
SAND MATRIX (COBBLES AND BOULDERS)

FIG No B15

G W P 5267-11-00

New Liskeard Area

file: 1-15-0509-01 smith creek bh logs.gpj

PHOTOGRAPHS OF COBBLES AND BOULDERS	FIGURE B16

NEW LISKEARD AREA

Smith Creek Bridge

Borehole No.1

Borehole No.2

Project No. : 1-15-0509

Date : July, 2016

Terraprobe Inc.

Prepared by : SD

Checked by : RA

PHOTOGRAPHS OF BEDROCK CORE SAMPLES	FIGURE B17

NEW LISKEARD AREA

Smith Creek Bridge

Borehole No.1

Borehole No.1

Project No. : 1-15-0509

Date : July, 2016

Terraprobe Inc.

Prepared by : SD

Checked by : RA

PHOTOGRAPHS OF BEDROCK CORE SAMPLES	FIGURE B18

NEW LISKEARD AREA

Smith Creek Bridge

Borehole No.2

Borehole No.2

Project No. : 1-15-0509

Date : July, 2016

Terraprobe Inc.

Prepared by : SD

Checked by : RA

Z:\1-Project Files\2015\1-15-0509 -New Liskeard Area, MTO Northern Region\01-Preliminary FID\1 Smith Creek Bridge\B. Photos\1-15-0509-01 Sept-09-2015 (Rock photos)\Rock Photos.xls