



**FINAL REPORT**

# Foundation Investigation Report

*Slope Stability Assessment*

*Langstaff Road Underpass Southeast Embankment*

*Highway 400 Widening, Langstaff Road to Major Mackenzie Drive*

*Vaughan, Ontario*

*MTO GWP 2836-02-00*

Submitted to:

**Parsons Inc.**

625 Cochrane Drive, Suite 300  
Markham, Ontario L3R 9R9

Submitted by:

**WSP Golder**

21490972-R-Rev0-LS

November 17, 2023

**GEOCRES NO.: 30M13-306**

**Latitude:** 43.809377°

**Longitude:** -79.542854°



## Distribution List

- 1 Electronic Copy - MTO Central Region
- 1 Electronic Copy - MTO Foundations Section
- 1 Electronic Copy - Parsons Inc.
- 1 Electronic Copy - WSP Golder

# Table of Contents

<b>1.0 INTRODUCTION .....</b>	<b>1</b>
<b>2.0 SITE DESCRIPTION .....</b>	<b>1</b>
<b>3.0 INVESTIGATION PROCEDURES .....</b>	<b>2</b>
<b>4.0 SITE GEOLOGY AND SUBSURFACE CONDITIONS.....</b>	<b>3</b>
4.1 Regional Geology.....	3
4.2 Subsurface Conditions .....	3
4.2.1 Asphalt .....	3
4.2.2 Topsoil.....	4
4.2.3 Granular Fill (Pavement Structure) .....	4
4.2.4 CLAYEY SILT (CL) to SILTY CLAY (CI) (FILL) – Embankment Fill .....	4
4.2.5 CLAYEY SILT (CL) .....	4
4.2.6 SILT (ML) to Sandy CLAYEY SILT-SILT (CL-ML) (TILL) .....	5
4.3 Groundwater Conditions .....	5
<b>5.0 CLOSURE .....</b>	<b>6</b>

## REFERENCES

## DRAWINGS

Drawing 1 Borehole Locations and Soil Strata

## PHOTOGRAPHS

Photographs 1 to 3

## APPENDICES

### APPENDIX A – Borehole Records

List of Symbols and Abbreviations

Records of Boreholes LS-1, LS-2 and LS-3

### APPENDIX B – Geotechnical Laboratory Test Results

Figure B1 Grain Size Distribution – CLAYEY SILT (CL) to SILTY CLAY (CI) (FILL)

Figure B2 Plasticity Chart – CLAYEY SILT (CL) to SILTY CLAY (CI) (FILL)

Figure B3 Grain Size Distribution – CLAYEY SILT (CL)

Figure B4 Plasticity Chart – CLAYEY SILT (CL)

Figure B5 Grain Size Distribution – SILT (ML) to CLAYEY SILT-SILT (CL-ML)

Figure B6 Plasticity Chart – SILT (ML) to CLAYEY SILT-SILT (CL-ML)

## 1.0 INTRODUCTION

WSP Golder (formerly Golder Associates Ltd., now a member of WSP Canada Inc.) has been retained by Parsons Inc. (Parsons) on behalf of the Ministry of Transportation, Ontario (MTO) to provide foundation engineering services for the detail design of the Highway 400 widening and rehabilitation, extending from 1.3 km south of the Langstaff Road interchange to 1.5 km north of Major Mackenzie Drive (a length of approximately 7.3 km) in the City of Vaughan, Ontario. As part of the Highway widening and rehabilitation program, embankment slope remediation work will be undertaken in the southeast quadrant of the Highway 400/Langstaff Road interchange.

This report summarizes the factual results of field and laboratory work (including field investigation procedures, borehole stratigraphy, and geotechnical laboratory test results) and provides a description of interpreted soil and groundwater conditions in the vicinity of the approach embankment in the southeast quadrant of the Langstaff Road Underpass site.

## 2.0 SITE DESCRIPTION

The orientation (i.e., north, south, east, and west) stated in the text of this report is referenced to project north and therefore may differ from magnetic north shown on Drawing 1. For the purpose of this report, Langstaff Road is described as oriented in a west-east direction on a slight skew to Highway 400, which generally runs in a north-south direction.

In general, the topography surrounding the Langstaff Road interchange is relatively flat. The existing Langstaff Road embankment side slope and ground surface beyond the toe in the southeast quadrant of the Highway 400/Langstaff Road interchange is landscaped with grass cover and a few limited zones of tree cover. Land use surrounding the area is primarily commercial. There is an existing dry pond located just south of the embankment. A concrete box culvert runs through the embankment (i.e., perpendicular to Langstaff Road) to facilitate drainage along Black Creek. The inlet and outlet locations of the box culvert are near the toe of the slope on both sides of the north and south sides of the Langstaff Road embankment and retaining walls consisting of rows of gabions are present on each side of the culvert. There is also a culvert that runs beneath Highway 400 and connects to Black Creek immediately south of the embankment toe.

The Langstaff Road grade east of the underpass is at about Elevation 213 m to 214 m and the toe of the embankment in the southeast quadrant of the interchange is at about Elevation 205 m to 206 m (i.e., embankment height on the order of about 8 m). The southeast embankment has a side slope inclination of about 2 horizontal to 1 vertical (2H:1V).

The guardrail along the south side of Langstaff Road in this quadrant is located immediately adjacent to the crest of the embankment slope, and some of the guardrail posts are leaning southward (i.e., downslope). Some limited settlement of the south edge of the sidewalk was also observed. There was no other visual evidence of slope instability, gabion wall instability or loss of ground behind the gabion wall in this quadrant at the time of field investigation. The ground surface conditions in the vicinity of the southeast embankment are shown on Photographs 1 to 3 following the text of this report.

### 3.0 INVESTIGATION PROCEDURES

The field work for this subsurface exploration program consisted of three boreholes (designated LS-1, LS-2, and LS-3) advanced in the vicinity of the southeast embankment of the Langstaff Road Underpass. These boreholes were advanced between March 30, 2023, and July 17, 2023, at the approximate locations shown on Drawing 1.

Boreholes LS-1 and LS-2 were advanced through the existing embankment of Langstaff Road on the south side of the roadway (i.e., through the crest of the southeast embankment), and Borehole LS-3 was advanced at the toe of the southeast embankment near Highway 400 grade. The boreholes were advanced using a truck-mounted CME 75 drill rig supplied and operated by 3D Drilling of Whitchurch-Stouffville, Ontario. The boreholes were advanced through the overburden using 159 mm outside diameter hollow stem augers. Soil samples were obtained at 0.75 m and 1.5 m intervals of depth, using a 50 mm outside diameter split spoon sampler driven by an automatic hammer in accordance with Standard Penetration Test (SPT) procedures (ATM D1586)<sup>1</sup>. The split-spoon samplers used in the investigation limits the maximum particle size that can be sampled and tested to about 35 mm. Therefore, particles or objects that may exist within the soils that are larger than this dimension would not be sampled or represented in the grain size distributions.

The groundwater conditions were noted in the boreholes during and upon completion of drilling and were backfilled in accordance with Ontario Regulation 903 (Wells, as amended), and the asphalt surface at the locations of Boreholes LS-1 and LS-2 was capped with tamped cold patch asphalt. At the location of Borehole LS-3, a standpipe piezometer was installed to allow monitoring of the groundwater level. The installed piezometer consists of a 50 mm diameter PVC pipe, with a 3.0 m long slotted screen within a filtered sand pack. The borehole and annulus surrounding the piezometer pipe above the filter sand pack was backfilled to near ground surface with bentonite pellets. The standpipe piezometer was left sticking up out of the ground and protected with a monument cover.

The field work was observed by members of WSP Golder's engineering and technical staff, who located the boreholes, arranged for the clearance of underground services, observed the drilling, sampling and in situ testing operations, and logged the boreholes. The samples were identified in the field, placed in appropriate containers, labelled, and transported to WSP Golder's Mississauga laboratory where the samples underwent further visual examination. Geotechnical laboratory testing (water content, grain size distribution, and Atterberg limits) was carried out on select soil samples, in accordance with MTO and / or ASTM Standards, as appropriate. In addition, select soil samples were submitted to Bureau Veritas Laboratories of Mississauga, Ontario for analysis of select parameters to assess for the potential corrosion of buried steel and deterioration of concrete.

The as-drilled borehole locations and elevations were surveyed by WSP Golder using a Trimble Geo 7x GPS unit. The locations are referenced to NAD 83(CSRS)v6 MTM Zone 10 coordinates and the ground surface elevations are referenced to CGVD28 Geodetic datum benchmark. The borehole locations, including geographic coordinates, ground surface elevations, and borehole depths are summarized below.

---

<sup>1</sup> ASTM D1586 Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils



Borehole No.	MTM NAD83 Northing (Latitude, °)	MTM NAD83 Easting (Longitude, °)	Ground Surface Elevation (m)	Borehole Depth (m)
LS-1	4,852,156.4 (43.809364)	301,336.7 (-79.543046)	213.9	12.8
LS-2	4,852,165.5 (43.809446)	301,368.7 (-79.542649)	213.3	9.8
LS-3	4,852,106.6 (43.808916)	301,348.8 (-79.542896)	205.4	8.2

## 4.0 SITE GEOLOGY AND SUBSURFACE CONDITIONS

### 4.1 Regional Geology

As delineated in The Physiography of Southern Ontario (Chapman and Putnam, 1984)<sup>2</sup>, this section of Highway 400 lies within the region known as the Peel Plain and consists of level to undulating tracts of clayey glacial till soils, which are presumed to have been derived from moraines, interspersed with non-cohesive silts and sands from interstadial stages of Wisconsinan glaciation.

Based on geological mapping by the Ministry of Northern Development and Mines (MNDM)<sup>3</sup>, the site is underlain by bedrock from the Upper Ordovician era consisting of shale, limestone, dolostone, and siltstone.

### 4.2 Subsurface Conditions

The detailed subsurface soil and groundwater conditions encountered in the boreholes and the results of in situ and laboratory testing from the investigation are shown on the borehole records presented in Appendix A. The detailed results of the geotechnical laboratory testing are presented in Appendix B. The results of the in situ field tests (i.e., SPT “N”-values) as presented on the borehole records and in Section 4.2 are uncorrected.

The stratigraphic boundaries shown in the borehole records are inferred from non-continuous sampling and, therefore, these boundaries represent transitions between soil types rather than exact planes of geological change. The subsurface conditions will vary between and beyond the borehole locations.

In general, the subsurface conditions at the southeast embankment of the Langstaff Road Underpass consist of the existing Langstaff Road pavement structure underlain by cohesive embankment fill comprised of sandy clayey silt to silty clay having a stiff to hard consistency. The embankment fill is underlain by till or “till-like” soils comprised of clayey silt, sandy clayey silt-silt, silt and sand, and silt having a stiff to hard (but generally very stiff to hard) consistency. A more detailed description of the major stratigraphic units encountered in the boreholes is described in the sections below.

#### 4.2.1 Asphalt

A layer of asphalt approximately 205 mm thick was encountered at ground surface in Boreholes LS-1 and LS-2, which were drilled through the Langstaff Road pavement.

<sup>2</sup> Chapman, L.J. and Putnam, D.F., 1984, The Physiography of Southern Ontario, Ontario Geological Society, Special Volume 2, Third Edition. Accompanied by Map p. 2715, Scale 1:600,000.)

<sup>3</sup> Ministry of Northern Development of Mines. Bedrock Geology of Ontario – Southern Sheet, Ontario Geological Survey - Map 2544.

#### 4.2.2 Topsoil

A layer of topsoil approximately 150 mm thick was encountered at the ground surface in Borehole LS-3, which was drilled at the toe of the embankment slope.

#### 4.2.3 Granular Fill (Pavement Structure)

A layer of granular fill consisting of poorly graded gravelly sand was encountered underlying the asphalt in Boreholes LS-1 and LS-2, which were advanced through the crest of the Langstaff Road embankment on the south side of the roadway. The granular fill was encountered at a depth of approximately 0.2 m below ground surface (approximately Elevations 213.7 and 213.1 m) and was about 0.6 m to 1.3 m thick, extending to depths of 0.8 m to 1.5 m below ground surface (to approximately Elevation 212.4 m).

The SPT “N”-values measured within the granular fill range from 23 to 45 blows per 0.3 m penetration, indicating a compact to dense state of compactness. In one instance in the granular fill, the split-spoon sampler did not penetrate the entire SPT depth due to refusal conditions (100 blows for less than 0.3 m of penetration).

The water content measured on samples of the granular fill ranges from about 2% to 5%.

#### 4.2.4 CLAYEY SILT (CL) to SILTY CLAY (CI) (FILL) – Embankment Fill

Cohesive embankment fill was encountered underlying the pavement structure in Boreholes LS-1 and LS-2 and underlying the topsoil in Borehole LS-3. The embankment fill was encountered at depths ranging from 0.8 m to 1.4 m below ground surface (approximately Elevations 212.4 m to 205.3 m) and extended to the termination depth of 9.8 m (approximately Elevation 203.5 m) in Borehole LS-2. In Boreholes LS-1 and LS-3, the embankment fill was about 2.2 m to 8.8 m thick, extending to Elevations 203.6 m to 203.2 m.

The SPT “N”-values measured within the cohesive fill range from 11 to 31 blows per 0.3 m of penetration, indicating a stiff to hard consistency. In one instance in the embankment fill, the split-spoon sampler did not penetrate the entire SPT depth due to refusal conditions (100 blows for less than 0.3 m of penetration).

Grain size distribution testing was carried out on five samples of the cohesive fill and the results are presented on Figure B1 in Appendix B. Atterberg limit testing was carried out on five samples of the cohesive fill and the results are presented on a plasticity chart in Figure B2 in Appendix B. The Atterberg limits tests measured liquid limits ranging from about 24% to 46%, plastic limits ranging from about 13% to 19%, and plasticity indices ranging from about 11% to 27%. The Atterberg limits tests generally indicate a clayey silt to silty clay of low to medium plasticity. The water content measured on samples of the cohesive fill ranges from about 11% to 22%, generally near the plastic limit of the material.

#### 4.2.5 CLAYEY SILT (CL)

A cohesive deposit of clayey silt was encountered underlying the cohesive embankment fill in Borehole LS-3, which was advanced near the original ground surface at the toe of the Langstaff Road southeast embankment. The cohesive deposit was encountered at a depth of 2.2 m below ground surface (at approximately Elevation 203.2 m) and was about 1.5 m thick, extending to a depth of 3.7 m (approximately Elevation 201.7 m).

The SPT “N”-values measured within the cohesive deposit ranges from 12 to 24 blows per 0.3 m of penetration, indicating a stiff to very stiff consistency.

Grain size distribution testing was carried out on a sample of the cohesive deposit and the results are presented on Figure B3 in Appendix B. Atterberg limit testing was carried out on a sample of the cohesive deposit and the results

are presented on Figure B4 in Appendix B. The Atterberg limits test measured a liquid limit of about 22%, a plastic limit of about 13% and a corresponding plasticity index of about 9%. The Atterberg limits test generally indicates a clayey silt of low plasticity.

#### 4.2.6 SILT (ML) to Sandy CLAYEY SILT-SILT (CL-ML) (TILL)

A glacial till deposit varying in composition from silt to sandy clayey silt-silt was encountered underlying the cohesive embankment fill in Borehole LS-1 and underlying the clayey silt deposit in Borehole LS-3. The glacial till material was encountered at depths ranging from 3.7 m to 10.2 m below ground surface (approximately Elevations 203.6 m to 201.7 m); both Boreholes LS-1 and LS-3 were terminated in the till after penetrating 2.6 m to 4.5 m into the deposit (to Elevations 201.2 m to 197.2 m).

The SPT “N”-values measured within the till deposit ranges from 11 to 65 blows per 0.3 m of penetration, indicating a stiff to hard consistency.

Grain size distribution testing was carried out on three samples of the glacial till and the results are presented on Figure B5 in Appendix B. Atterberg limit testing was carried out on three samples of the glacial till and the results are presented on a plasticity chart in Figure B6 in Appendix B. The Atterberg limits tests measured liquid limits ranging from about 14% to 22%, plastic limits ranging from about 11% to 18%, and plasticity indices ranging from about 3% to 4%. The Atterberg limits tests generally indicate a silt to clayey silt-silt of slight to low plasticity. The water content measured on samples of the till ranges from about 7% to 13%, slightly below the plastic limit of the material.

### 4.3 Groundwater Conditions

The groundwater levels measured in the open boreholes at the time of the investigation are not considered representative of the stabilized hydrostatic groundwater levels at the site. All water levels recorded as part of this subsurface exploration program were taken shortly after drilling operations and therefore represent an unstabilized groundwater level.

A standpipe piezometer was installed in Borehole LS-3 to allow monitoring of the stabilized groundwater level at this site. The groundwater levels recorded during drilling (i.e., the unstabilized groundwater levels) and the groundwater level recorded in the standpipe piezometer (i.e., the stabilized groundwater level) are shown on the borehole records in Appendix A and are summarized below.

Borehole No.	Ground Surface Elevation (m)	Depth (Elevation) of Screen Interval / Sand Pack (m)	Depth to Water Level (m)	Groundwater Elevation (m)	Date	Comments
LS-1	213.9	N/A	10.7	203.2	Mar. 30, 2023	Open borehole / inside hollow stem augers
LS-2	213.3		Dry	-	Mar. 30, 2023	Open borehole / inside hollow stem augers
LS-3	206.4		8.1	197.3	Jul. 17, 2023	Open borehole / inside hollow stem augers
		5.2 m to 8.2 m (El. 194.2 to 197.2 m)	2.1	203.3	Oct. 31, 2023	Standpipe Piezometer



Groundwater levels are subject to seasonal fluctuations and precipitation events and should be expected to be higher during wet periods of the year.

## **5.0 CLOSURE**

This Foundation Investigation Report was prepared by Ms. Sunduss Asghar, EIT, and Mr. Mark Henderson, P.Eng., a Geotechnical Engineer with WSP Golder. Ms. Lisa Coyne, P.Eng., a Geotechnical Engineering Fellow and MTO Principal Foundations Contact for WSP Golder, conducted an independent technical and quality control review of this report.

## Signature Page

### WSP Golder



Sunduss Asghar  
Geotechnical EIT



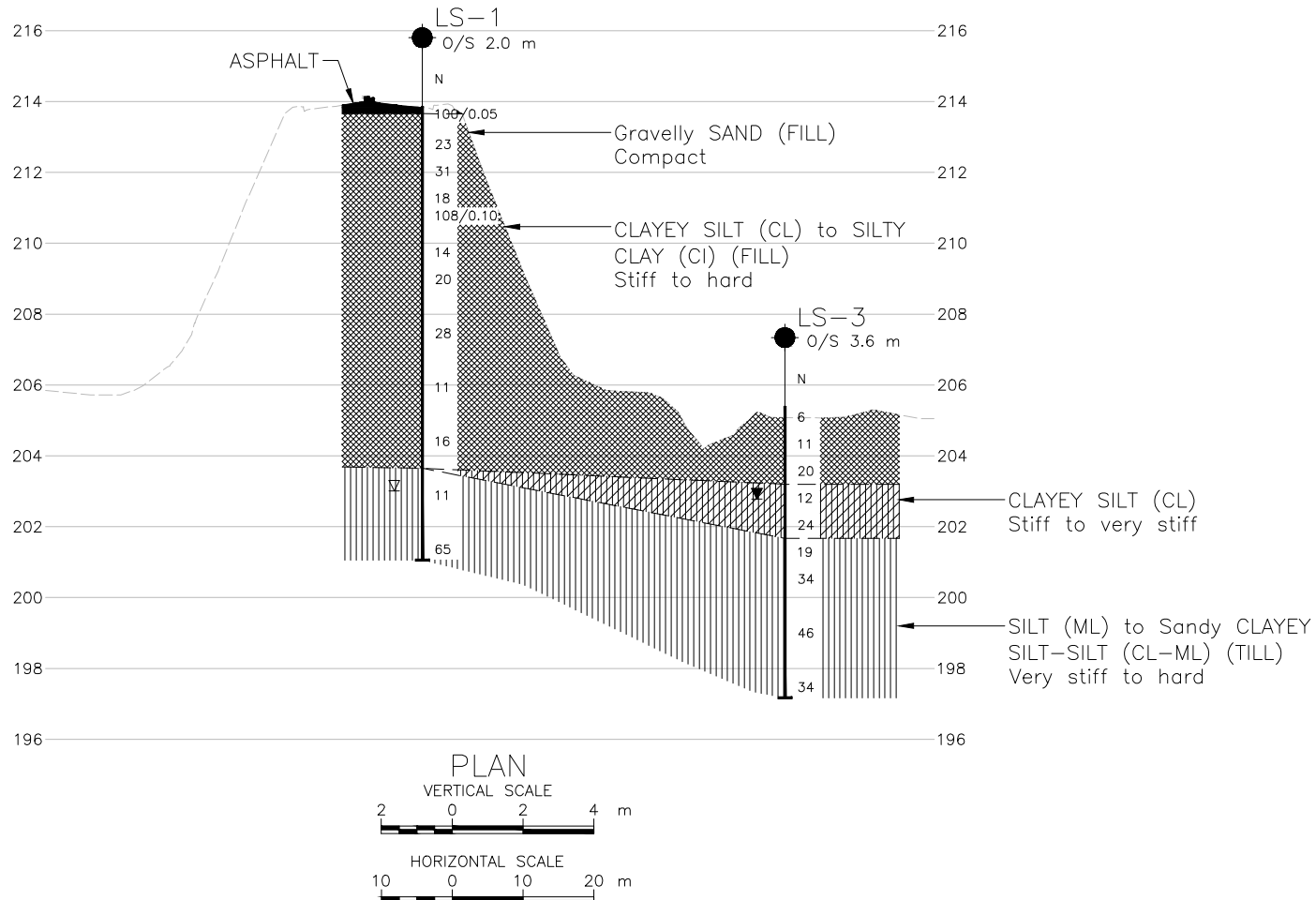
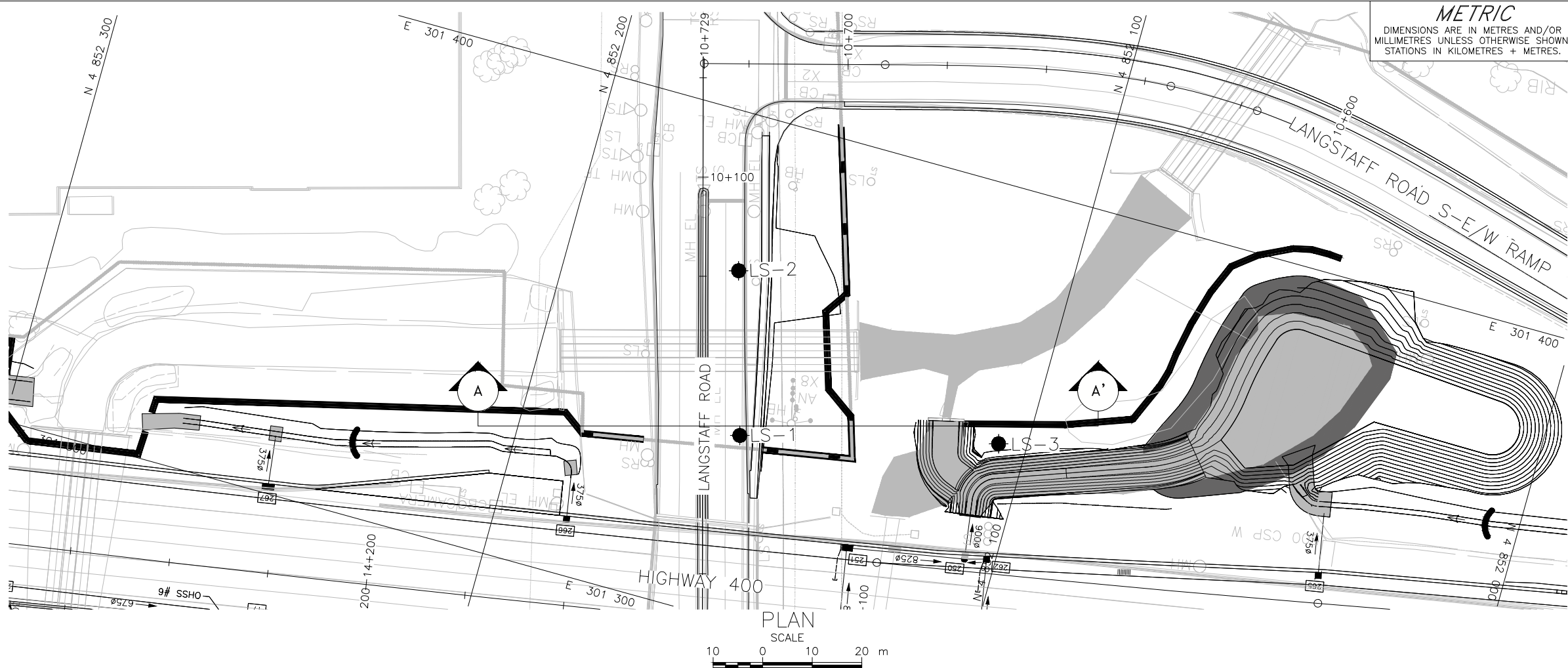
Mark Henderson, P.Eng.  
*Geotechnical Engineer*



Lisa Coyne, P.Eng.  
*Fellow, MTO Principal Foundations Contact*

MH/LCC/al

[https://golderassociates.sharepoint.com/sites/152126/project files/6 deliverables/3. foundations/2. reports/02. langstaff embankment stability/final/21490972-r-rev0\\_fir\\_ls\\_17nov2023.docx](https://golderassociates.sharepoint.com/sites/152126/project%20files/6%20deliverables/3.%20foundations/2.%20reports/02.%20langstaff%20embankment%20stability/final/21490972-r-rev0_fir_ls_17nov2023.docx)

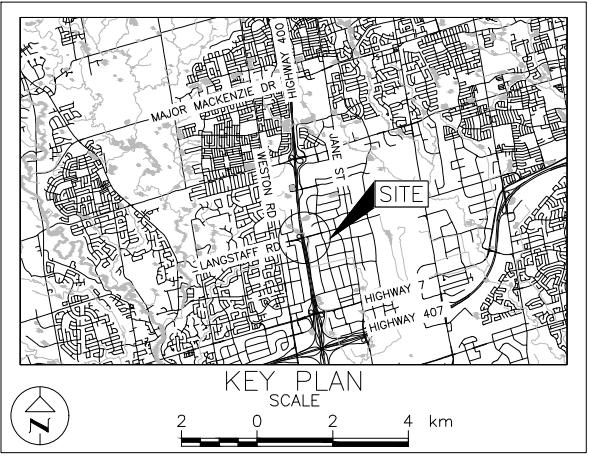


**METRIC**  
DIMENSIONS ARE IN METRES AND/OR  
MILLIMETRES UNLESS OTHERWISE SHOWN.  
STATIONS IN KILOMETRES + METRES.

CONT No.  
GWP No.2836-02-00

SLOPE STABILITY ASSESSMENT  
LANGSTAFF ROAD SOUTHEAST EMBANKMENT  
BOREHOLE LOCATIONS AND SOIL  
STRATA

SHEET



LEGEND

- Borehole - Current Investigation
- N Standard Penetration Test Value
- 16 Blows/0.3m unless otherwise stated (Std. Pen. Test, 475 j/blow)
- WL in piezometer
- WL upon completion of drilling

BOREHOLE CO-ORDINATES NAD 83 MTM ZONE 10			
No.	ELEVATION	NORTHING	EASTING
LS-1	213.9	4852156.4	301336.7
LS-2	213.3	4852165.5	301368.7
LS-3	205.4	4852105.7	301349.1



NOTES

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

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

REFERENCE

Base plans provided in digital format by Parsons, drawing file nos. Hwy400\_Exsting Survey-Topo.dwg, H400-ROD-PLN.dwg, 73-400.xml, received June 1, 2022.  
Design plan provided by Parsons, file no. H400-478918-ROD-PLN-S\_Binded 2023-10-18.dwg, received October 18, 2023.  
Horizontal alignment provided in digital format by Parsons, drawing file no. Hwy 400 Alignments.xml, received October 24, 2023.

NO.	DATE	BY	REVISION
Geocres No. 30M13-306			
HWY. 400	PROJECT NO. 21490972		DIST. .
SUBM'D. MH	CHKD. MH	DATE: 11/15/2023	SITE: .
DRAWN: DD	CHKD. MH	APPD. LCC	DWG. 1



**Photograph 1: Looking northwest at existing southeast embankment side slope;  
note the section of leaning guardrail in the background**



**Photograph 2: Looking west at sidewalk along the crest of the southeast  
embankment; note the section of leaning guardrail in the background**





**Photograph 3: Looking east towards gabion walls at Black Creek Triple Cell Culvert outlet (photograph taken at the toe of the southeast embankment)**



**APPENDIX A**

# Borehole Records

# ABBREVIATIONS AND TERMS USED ON RECORDS OF BOREHOLES AND TEST PITS

## MINISTRY OF TRANSPORTATION, ONTARIO

### PARTICLE SIZES OF CONSTITUENTS

Soil Constituent	Particle Size Description	Millimetres	Inches (US Std. Sieve Size)
BOULDERS	Not Applicable	>200	>8
COBBLES	Not Applicable	75 to 200	3 to 8
GRAVEL	Coarse	19 to 75	0.75 to 3
	Fine	4.75 to 19	(4) to 0.75
		2.00 to 4.75	(10) to (4)
SAND	Coarse	0.425 to 2.00	(40) to (10)
	Medium	0.075 to 0.425	(200) to (40)
	Fine		
FINES	Classified by plasticity	<0.075	< (200)

### MODIFIERS FOR SECONDARY COMPONENTS<sup>1,2</sup>

Percentage by Mass	Modifier
> 35	Use 'and' to combine primary and secondary component ( <i>i.e.</i> , SAND and gravel)
> 20 to 35	Primary soil name prefixed with "gravelly, sandy" as applicable
> 10 to 20	some ( <i>i.e.</i> , some sand)
≤ 10	trace ( <i>i.e.</i> , trace fines)

1. Only applicable to components not described by Primary Group Name.

2. Classification of Primary Group Name based on Unified Soil Classification System (ASTM D2487) for coarse-grained soils; fine-grained soils described per current MTO Soil Classification System.

### PENETRATION RESISTANCE

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

The number of blows by a 63.5 kg (140 lb) hammer dropped 760 mm (30 in.) required to drive a 50 mm (2 in.) split-spoon sampler for a distance of 300 mm (12 in.). Values reported are as recorded in the field and are uncorrected.

#### Cone Penetration Test (CPT)

An 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 ( $u$ ) and sleeve friction ( $f_s$ ) are recorded electronically at 25 mm penetration intervals.

#### Dynamic Cone Penetration Resistance (DCPT); $N_d$ :

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

### SAMPLES

AS	Auger sample
BS	Block sample
CS	Chunk sample
DD	Diamond Drilling
DO or DP	Seamless open ended, driven or pushed tube sampler – note size
DS	Denison type sample
GS	Grab Sample
MC	Modified California Samples
MS	Modified Shelby (for frozen soil)
RC / SC	Rock core / Soil core
SS	Split spoon sampler – note size
ST	Slotted tube
TO	Thin-walled, open – note size (Shelby tube)
TP	Thin-walled, piston – note size (Shelby tube)
WS	Wash sample
OD / ID	Outer Diameter / Inner Diameter
HSA / SSA	Hollow-Stem Augers / Solid-Stem Augers

### SOIL TESTS

w	water content
PL, $w_p$	plastic limit
LL, $w_L$	liquid limit
C	consolidation (oedometer) test
CHEM	chemical analysis (refer to text)
CID	consolidated isotropically drained triaxial test <sup>1</sup>
CIU	consolidated isotropically undrained triaxial test with porewater pressure measurement <sup>1</sup>
$D_R$	relative density (specific gravity, $G_s$ )
DS	direct shear test
GS	specific gravity
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 (FV)	field vane (LV-laboratory vane test)
Y	unit weight

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

### COARSE-GRAINED SOILS

#### Compactness<sup>1</sup>

Term	SPT 'N' (blows/0.3m) <sup>2</sup>
Very Loose	0 to 4
Loose	4 to 10
Compact	10 to 30
Dense	30 to 50
Very Dense	> 50

1. Definition of compactness terms are based on SPT 'N' ranges as provided in Terzaghi, Peck and Mesri (1996). Many factors affect the recorded SPT 'N' value, including hammer efficiency (which may be greater than 60% in automatic trip hammers), overburden pressure, groundwater conditions, and grain size. As such, the recorded SPT 'N' value(s) should be considered only an approximate guide to the soil compactness. These factors need to be considered when evaluating the results, and the stated compactness terms should not be relied upon for design or construction.

2. SPT 'N' in accordance with ASTM D1586, uncorrected for the effects of overburden pressure.

### FINE-GRAINED SOILS

#### Consistency

Term	Undrained Shear Strength (kPa)	SPT 'N' <sup>1,2</sup> (blows/0.3m)
Very Soft	< 12	0 to 2
Soft	12 to 25	2 to 4
Firm	25 to 50	4 to 8
Stiff	50 to 100	8 to 15
Very Stiff	100 to 200	15 to 30
Hard	> 200	> 30

1. SPT 'N' in accordance with ASTM D1586, uncorrected for overburden pressure effects; approximate only.

2. SPT 'N' values should be considered ONLY an approximate guide to consistency; for sensitive clays (e.g., Champlain Sea clays), the N-value approximation for consistency terms does NOT apply. Rely on direct measurement of undrained shear strength or other manual observations.

### Field Moisture Condition

Term	Description
Dry	Soil flows freely through fingers.
Moist	Soils are darker than in the dry condition and may feel cool.
Wet	As moist, but with free water forming on hands when handled.

# LIST OF SYMBOLS

## MINISTRY OF TRANSPORTATION, ONTARIO

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

#### (a) Index Properties

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

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

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

#### (b) Hydraulic Properties

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

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

$C_c$	compression index (normally consolidated range)
$C_r$	recompression index (over-consolidated range)
$C_s$	swelling index
$C_{a(e)}$	secondary compression index
$C_a$	rate of secondary compression
$C_{a(e)}$	modified 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
$c'$	effective cohesion
$\phi'$	effective angle of internal friction
$\delta$	angle of interface friction
$\mu$	coefficient of friction = $\tan \delta$
$c_u, s_u$	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 or $q'$	$(\sigma_1 - \sigma_3)/2$ 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  $\gamma = \rho \cdot g$  (i.e., mass density multiplied by  
acceleration due to gravity)

Notes: 1  
2

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


PROJECT 21490972		<b>RECORD OF BOREHOLE No. LS-1</b>		Sheet 1 of 2		<b>METRIC</b>	
G.W.P. 2836-02-00		LOCATION N 4852156.4; E 301336.7 NAD83 / MTM Zone 10 (LAT. 43.809364; LONG. -79.543046)		ORIGINATED BY		M.L.	
DIST CENTRAL HWY 400		BOREHOLE TYPE Power Auger; 159 mm O.D. Hollow Stem Augers		COMPILED BY		M.L.	
DATUM Geodetic Surface Elevation:213.9 m		DATE Mar 30, 2023		CHECKED BY		M.H.	

SOIL PROFILE			SAMPLES			GROUNDWATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					WATER CONTENT (%)			UNIT WEIGHT  Y  kN/m³	GR	SA	SI	CL	REMARKS
ELEV. ----- DEPTH	DESCRIPTION	STRATA PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH (kPa)					PL	NMC	LL						
								Field Vane					W <sub>p</sub>	W	W <sub>L</sub>						
								Remoulded					NP Nonplastic								
0.0	ASPHALT (205 mm)																				
0.2	Gravelly SAND (SP), some silt (FILL) Compact Brown Moist		1	SS	100/0.05																
213.7																					
			2	SS	23																
212.4	Sandy CLAYEY SILT (CL), trace gravel (FILL) contains organics Stiff to hard Brown; becoming grey at about 4.6 m depth (Elev. 201.3 m) Moist  - 3.1 to 3.4 m: Gravel pocket with black colouration (Elev. 210.7 m to Elev. 210.5 m)          - 5.6 to 7.2 m: Silty sand layer (Elev. 208.2 m to Elev. 206.7 m)																				
1.4																					
			3	SS	31																
			4	SS	18																
			5	SS	108/0.10																
			6	SS	14																
			7	SS	20																
				</																	

Continued on Next Page

+³, x³ : Numbers refer to Sensitivity    o³% STRAIN AT FAILURE

PROJECT	21490972		RECORD OF BOREHOLE		No. LS-1	Sheet 2 of 2	METRIC	
G.W.P.	2836-02-00		LOCATION	N 4852156.4; E 301336.7 NAD83 / MTM Zone 10 (LAT. 43.809364; LONG. -79.543046)			ORIGINATED BY	M.L.
DIST	CENTRAL	HWY 400	BOREHOLE TYPE	Power Auger; 159 mm O.D. Hollow Stem Augers			COMPILED BY	M.L.
DATUM	Geodetic Surface Elevation:213.9 m		DATE	Mar 30, 2023			CHECKED BY	M.H.

SOIL PROFILE			SAMPLES			GROUNDWATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					WATER CONTENT (%)			UNIT WEIGHT					REMARKS
ELEV. DEPTH	DESCRIPTION	STRATA PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH (kPa)					PL W <sub>p</sub>	NMC W	LL W <sub>L</sub>		GR	SA	SI	CL	
								Field Vane	Remoulded	Pocket Pen	Quick Triaxial	Unconfined	NP Nonplastic			Y					
								20	40	60	80	100	20	40	60	kN/m <sup>3</sup>					
203.6 10.2	SILTY CLAY (CI), some sand (FILL) Very stiff Grey Moist																				
	SILT (ML) and sand to Sandy CLAYEY SILT - SILT (CL- ML), trace gravel (TILL) Stiff to hard Grey Moist		11	SS	11		203										5	38	48	9	
	-Wet from 10.7 m to 11.3 m below ground surface (Elev. 203.2 m to 202.6 m)						202														
201.1 12.8	End of Borehole		12	SS	65												2	28	56	14	
	NOTES:  1. Borehole open upon completion of drilling.  2. Water encountered at a depth of 10.7 m below ground surface (Elevation. 203.2 m) during drilling.																				
							194														



PROJECT	21490972		RECORD OF BOREHOLE		No. LS-2	Sheet 1 of 1	METRIC	
G.W.P.	2836-02-00		LOCATION	N 4852165.5; E 301368.7 NAD83 / MTM Zone 10 (LAT. 43.809446; LONG. -79.542649)			ORIGINATED BY	M.L.
DIST	CENTRAL	HWY 400	BOREHOLE TYPE	Power Auger; 159 mm O.D. Hollow Stem Augers			COMPILED BY	M.L.
DATUM	Geodetic Surface Elevation:213.3 m		DATE	Mar 30, 2023			CHECKED BY	M.H.

SOIL PROFILE			SAMPLES			GROUNDWATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					WATER CONTENT (%)			UNIT WEIGHT  Y  kN/m³	GR	SA	SI	CL	REMARKS
ELEV. ----- DEPTH	DESCRIPTION	STRATA PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH (kPa)					PL	NMC	LL						
								Field Vane	Remoulded	Pocket Pen	Quick Triaxial	Unconfined	W <sub>p</sub>	W	W <sub>i</sub>						
							20	40	60	80	100	20	40	60							
0.0	ASPHALT (205 mm)																				
0.2	Gravelly SAND (SP), some silt (FILL) Dense Brown Moist		1	SS	45		213														
213.1																					
212.4	CLAYEY SILT (CL) and sand to sandy, trace gravel (FILL) Stiff to hard Brown; becoming grey at about 7.2 m depth (Elev. 206.1 m). Moist		2	SS	31		212														
0.8			3	SS	17		211										3	37	42	18	
			4	SS	18		210														
			5	SS	12		209														
			6	SS	25		208														
			7	SS	13		207														
			8	SS	14		206														
			9	SS	11		205														
204.6	SILTY CLAY (CI), some sand (FILL) Stiff Brown Moist		10	SS	14		204														
8.7																					
203.5	End of Borehole 1. Borehole open and dry upon completion of drilling.																				
9.8																					

+<sup>3</sup>, x<sup>3</sup> : Numbers refer to Sensitivity o<sup>30</sup>% STRAIN AT FAILURE

METRIC

T.T.

P.T.

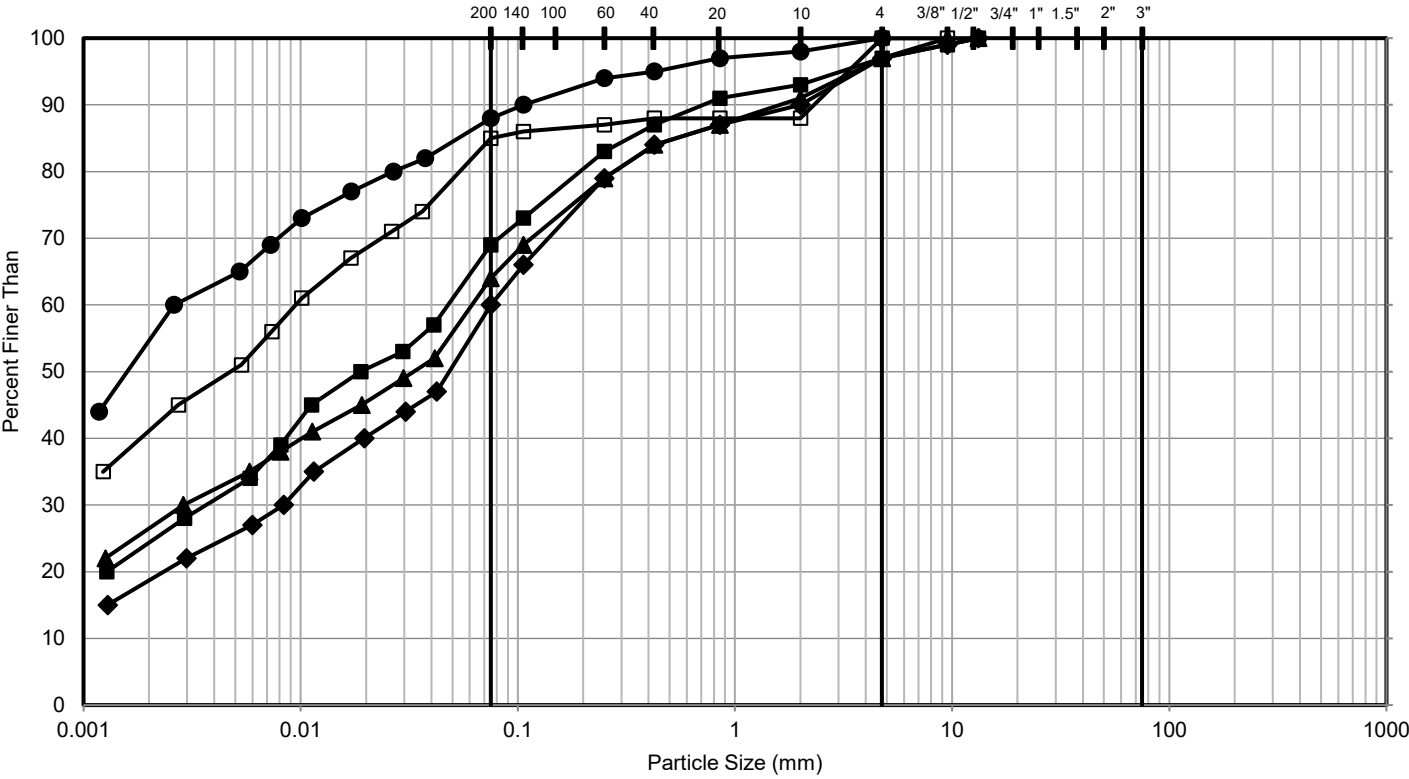
M.H.

+<sup>3</sup>, x<sup>3</sup> : Numbers refer to Sensitivity    o<sup>30</sup>% STRAIN AT FAILURE

**APPENDIX B**

# Geotechnical Laboratory Test Results

# GRAIN SIZE DISTRIBUTION



FINES (Silt, Clay)	SAND			GRAVEL		COBBLES	BOULDERS
	Fine	Medium	Coarse	Fine	Coarse		

Symbol	Sample Location	Sample Number	Depth (m)	Elevation (m)
■	LS-1	4	2.3 - 2.9	211.6 to 211.0
◆	LS-2	3	1.5 - 2.1	211.7 to 211.1
▲	LS-2	8	6.1 - 6.7	207.2 to 206.6
●	LS-2	10	9.1 - 9.8	204.1 to 203.5
□	LS-3	2	0.8 - 1.4	204.6 to 204.0

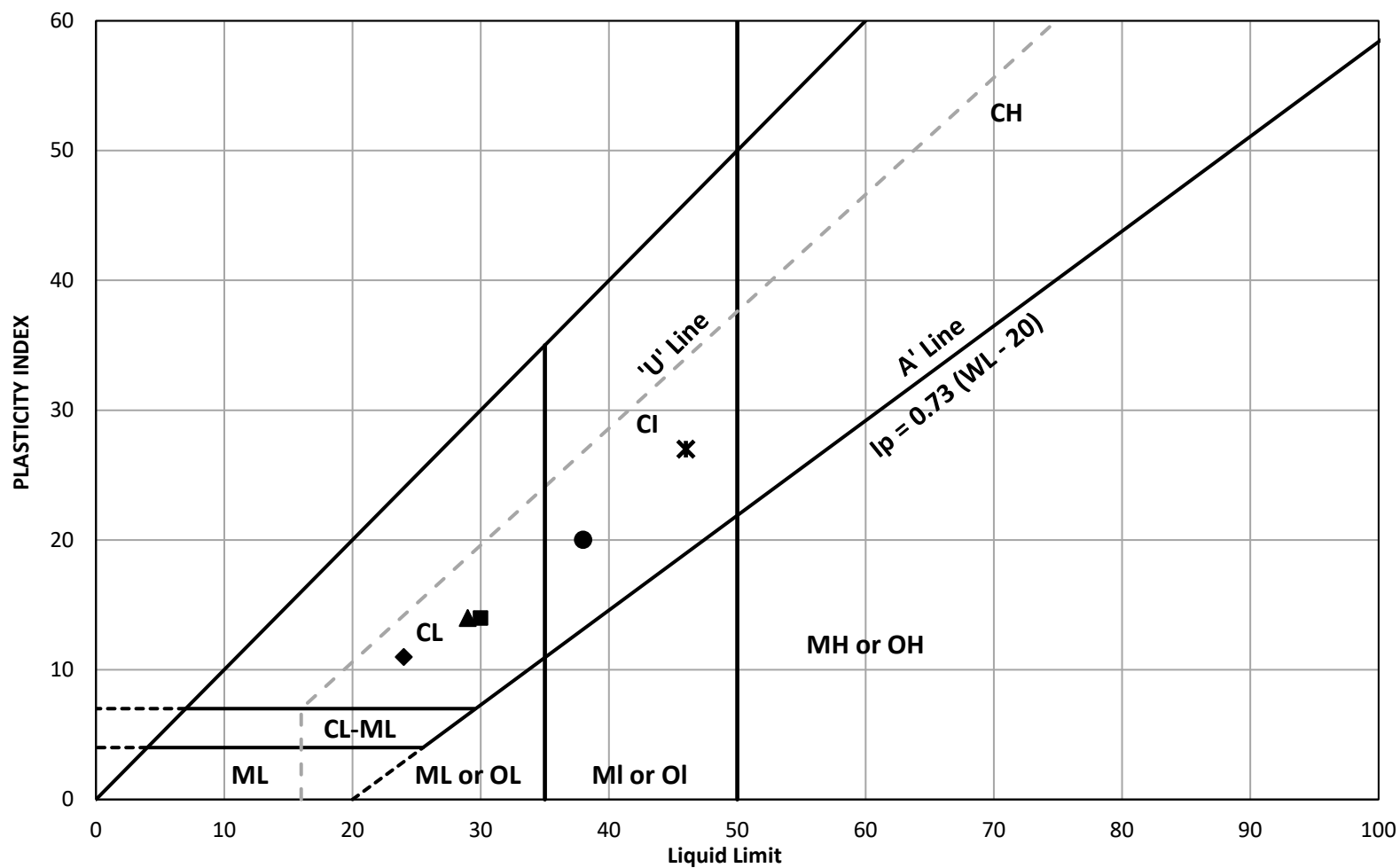
CLIENT	
PARSONS / MTO	
CONSULTANT	YYYY-MM-DD 2023-08-11
	DESIGNED TT
	PREPARED TT
	REVIEWED MH
	APPROVED LCC




PROJECT			
LANGSTAFF ROAR UNDERPASS SOUTHEAST EMBANKMENT			
HIGHWAY 400 WIDENING			
GWP 2836-02-00			
TITLE			
GRAIN SIZE DISTRIBUTION			
CLAYEY SILT (CL) to SILTY CLAY (CI) (FILL)			
PROJECT NO.	CONTROL	REV.	FIGURE
21490972	0	0	B1

PATH: https://wsponline-my.sharepoint.com/personal/mark\_henderson\_wsp\_com/\_f/IDR/21490972 | FILE NAME: LS\_Embankment Atterberg Working File.xlsm

PLASTICITY CHART



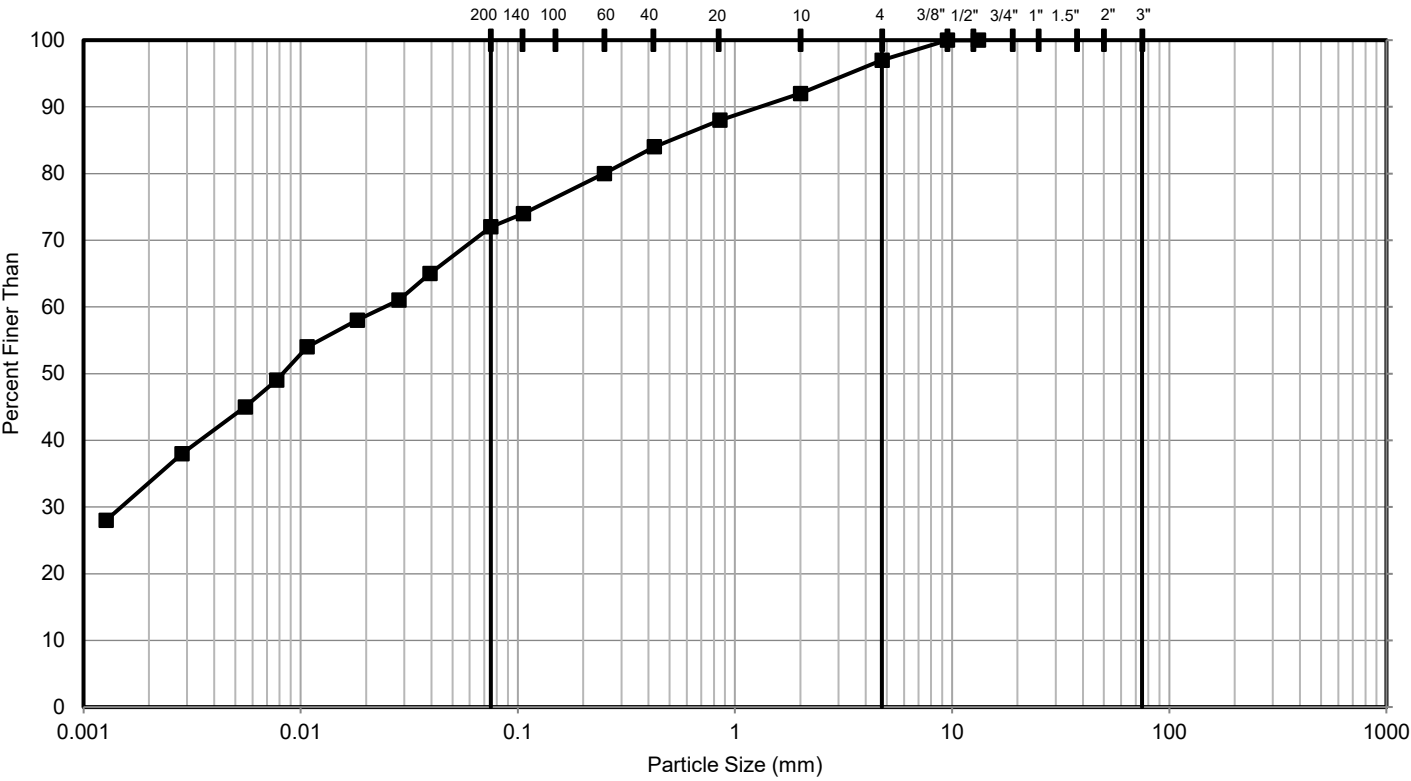
	Sample Location	Sample / Specimen Number	Depth (m)	Natural Water Content (%)	Liquid Limit	Plastic Limit	Plasticity Index	
■	LS-1	4	2.3 - 2.9	18.3	30	16	14	
◆	LS-2	3	1.5 - 2.1	11.3	24	13	11	
▲	LS-2	8	6.1 - 6.7	16.1	29	15	14	
●	LS-2	10	9.1 - 9.8	21.6	38	18	20	
*	LS-3	2	0.8 - 1.4	-	46	19	27	

CLIENT		
PARSONS / MTO		
CONSULTANT	YYYY-MM-DD	2023-08-11
	DESIGNED	TT
	PREPARED	TT
	REVIEWED	MH
	APPROVED	MH
		

PROJECT			
LANGSTAFF ROAD SOUTHEAST EMBANKMENT HIGHWAY 400 WIDENING, GWP 2836-02-00			
TITLE			
PLASTICITY CHART CLAYEY SILT (CL) to SILT CLAY (CI) (FILL)			
PROJECT NO.	CONTROL	REV.	FIGURE
21490972	0	0	B2



GRAIN SIZE DISTRIBUTION



FINES (Silt, Clay)	SAND			GRAVEL		COBBLES	BOULDERS
	Fine	Medium	Coarse	Fine	Coarse		

Symbol	Sample Location	Sample Number	Depth (m)	Elevation (m)
■	LS-3	4	2.3 - 2.9	203.1 to 202.5

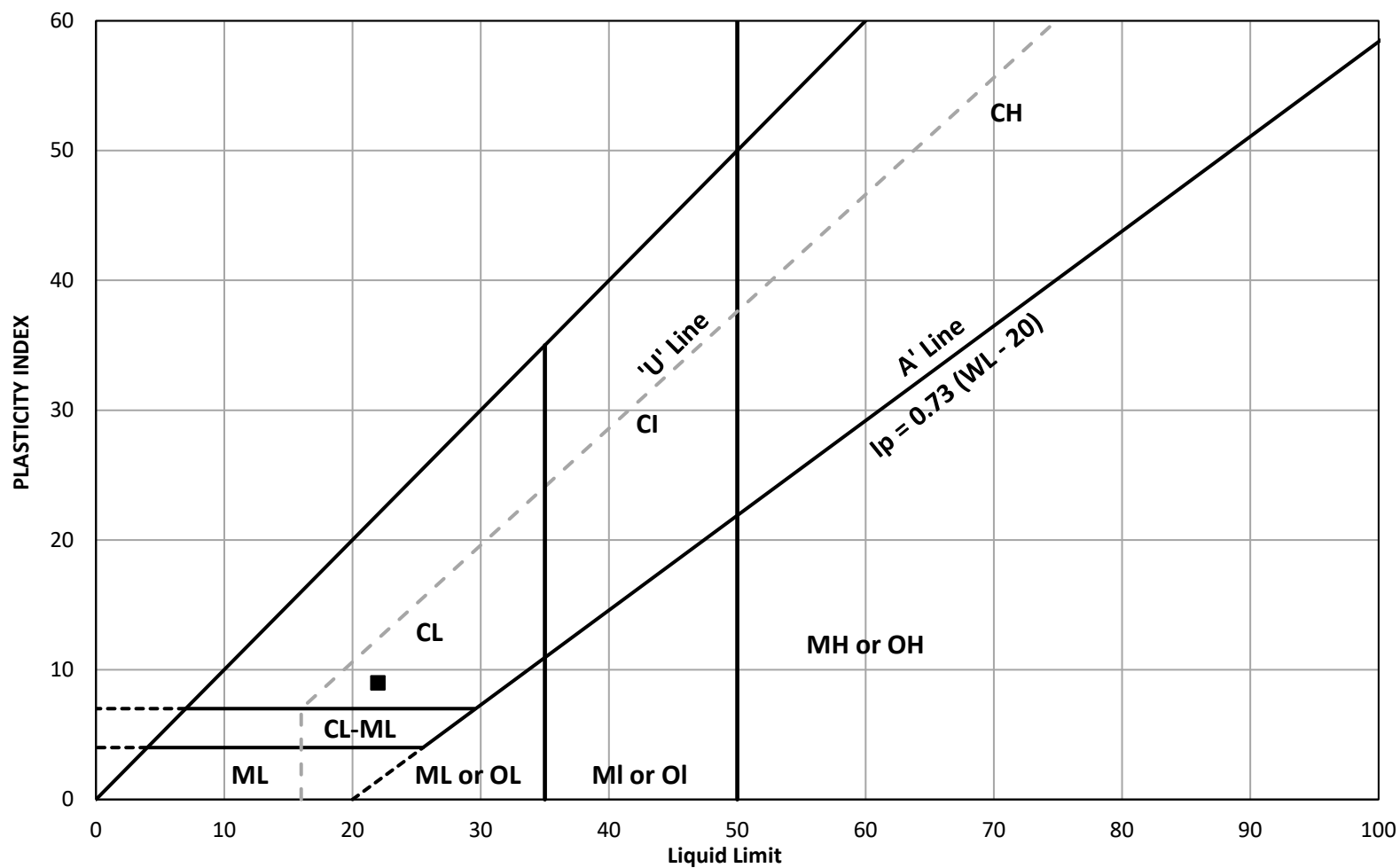
CLIENT	
PARSONS / MTO	
CONSULTANT	YYYY-MM-DD 2023-08-11
	DESIGNED TT
	PREPARED TT
	REVIEWED MH
	APPROVED LCC

 **GOLDER**

PROJECT			
LANGSTAFF ROAR UNDERPASS SOUTHEAST EMBANKMENT			
HIGHWAY 400 WIDENING			
GWP 2836-02-00			
TITLE			
GRAIN SIZE DISTRIBUTION			
CLAYEY SILT (CL)			
PROJECT NO.	CONTROL	REV.	FIGURE
21490972	0	0	B3

PATh: https://wsponline-my.sharepoint.com/personal/mark\_henderson\_wsp\_com/Documents/MT0/FIDR/21490972 | FILE NAME: LS\_Embankment Atterberg Working File.xlsm

PLASTICITY CHART

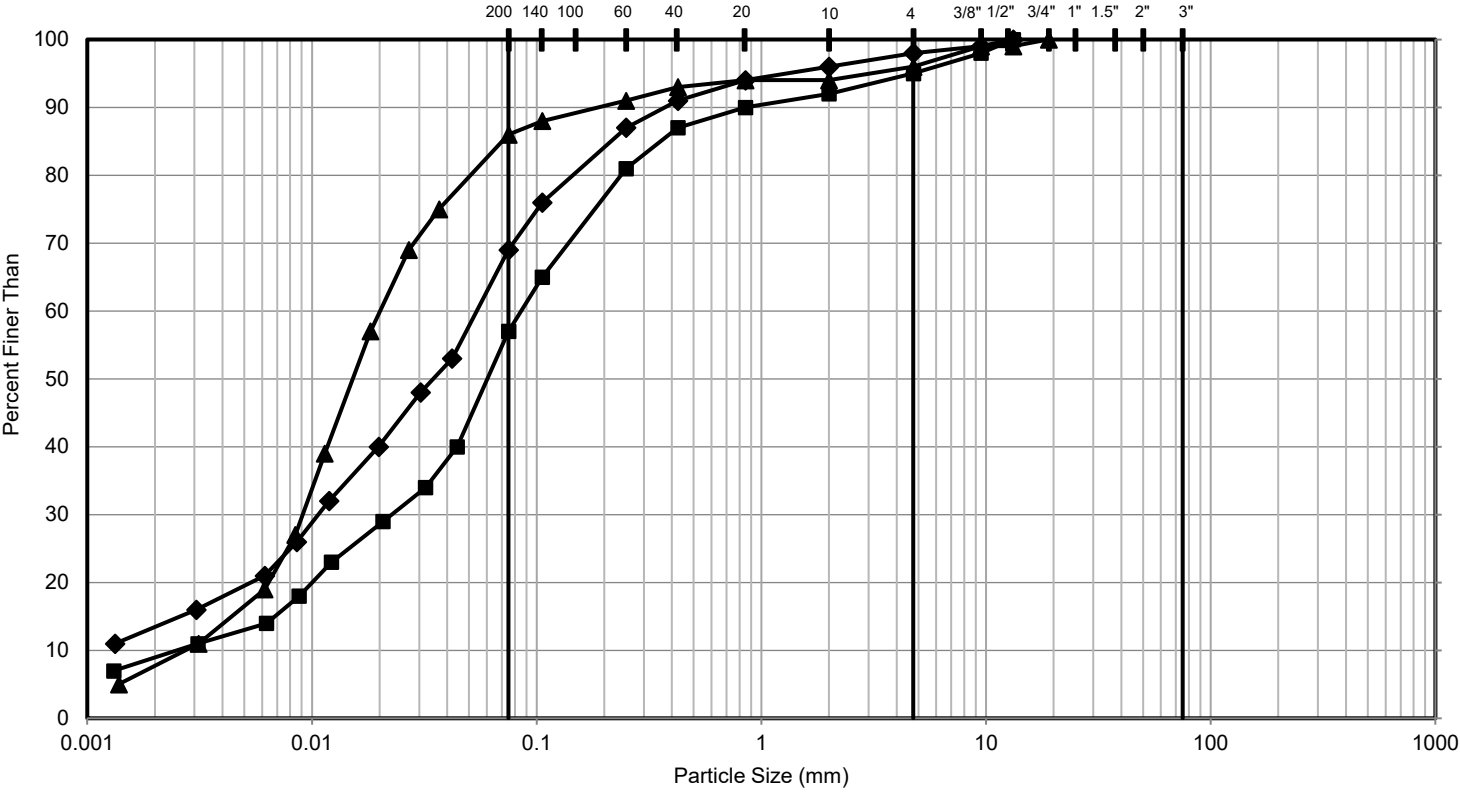


	Sample Location	Sample / Specimen Number	Depth (m)	Natural Water Content (%)	Liquid Limit	Plastic Limit	Plasticity Index	
■	LS-3	4	2.3 - 2.9	-	22	13	9	

CLIENT		
PARSONS / MTO		
CONSULTANT	YYYY-MM-DD	2023-08-11
	DESIGNED	TT
	PREPARED	TT
	REVIEWED	MH
	APPROVED	LCC

PROJECT			
LANGSTAFF ROAD SOUTHEAST EMBANKMENT HIGHWAY 400 WIDENING, GWP 2836-02-00			
TITLE			
PLASTICITY CHART CLAYEY SILT (CL)			
PROJECT NO.	CONTROL	REV.	FIGURE
21490972	0	0	B4

GRAIN SIZE DISTRIBUTION



FINES (Silt, Clay)	SAND			GRAVEL		COBBLES	BOULDERS
	Fine	Medium	Coarse	Fine	Coarse		

Symbol	Sample Location	Sample Number	Depth (m)	Elevation (m)
■	LS-1	11	10.7 - 11.3	203.2 to 202.6
◆	LS-1	12	12.2 - 12.8	201.7 to 201.1
▲	LS-3	8	6.1 - 6.7	199.3 to 198.7

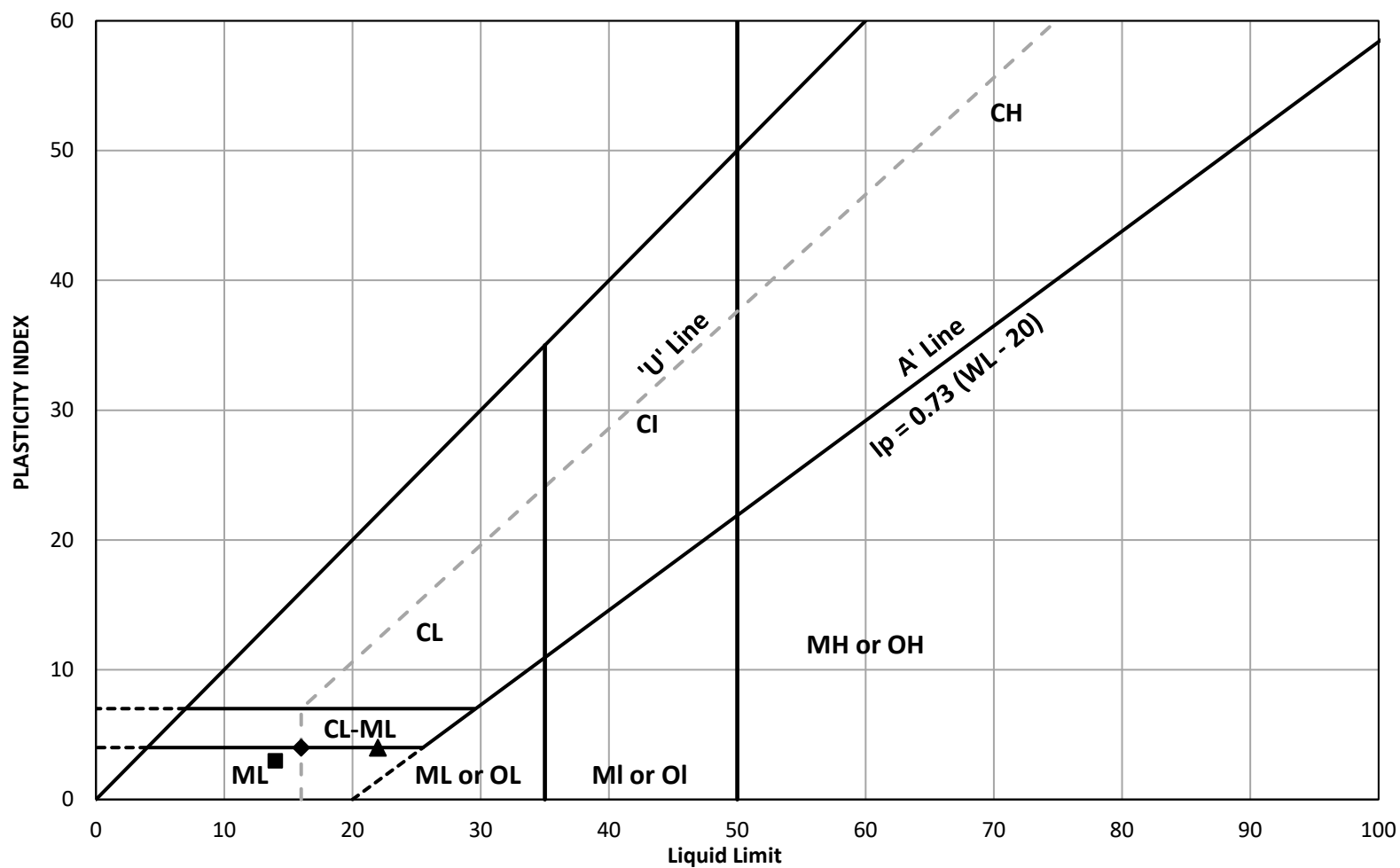
CLIENT	
PARSONS / MTO	
CONSULTANT	YYYY-MM-DD 2023-08-11
	DESIGNED TT
	PREPARED TT
	REVIEWED MH
	APPROVED LCC



PROJECT			
LANGSTAFF ROAR UNDERPASS SOUTHEAST EMBANKMENT			
HIGHWAY 400 WIDENING			
GWP 2836-02-00			
TITLE			
GRAIN SIZE DISTRIBUTION			
SILT (ML) to CLAYEY SILT-SILT (CL-ML)			
PROJECT NO.	CONTROL	REV.	FIGURE
21490972	0	0	B5

PATH: https://wsponline-my.sharepoint.com/personal/mark\_henderson\_wsp\_com/\_f/IDR/21490972 | FILE NAME: LS\_Embankment Atterberg Working File.xlsm

PLASTICITY CHART




	Sample Location	Sample / Specimen Number	Depth (m)	Natural Water Content (%)	Liquid Limit	Plastic Limit	Plasticity Index	
■	LS-1	11	10.7 - 11.3	6.6	14	11	3	
◆	LS-1	12	12.2 - 12.8	9.7	16	12	4	
▲	LS-3	8	6.1 - 6.7	-	22	18	4	

CLIENT

PARSONS / MTO

CONSULTANT

 **GOLDER**

YYYY-MM-DD

2023-08-11

DESIGNED

TT

PREPARED

TT

REVIEWED

MH

APPROVED

LCC

PROJECT

LANGSTAFF ROAD SOUTHEAST EMBANKMENT  
HIGHWAY 400 WIDENING, GWP 2836-02-00

TITLE

PLASTICITY CHART  
SILT (ML) to CLAYEY SILT-SILT (CL-ML)

PROJECT NO.

21490972

CONTROL

0

REV.

0

FIGURE

B6

