



Terraprobe

Consulting Geotechnical & Environmental Engineering
Construction Materials Inspection & Testing

**FOUNDATION INVESTIGATION & DESIGN REPORT
WATERMAIN AND SANITARY SEWER INSTALLATIONS
HIGHWAY 406 AT WOODLAWN ROAD
THE CITY OF WELLAND, ONTARIO
GEOCRES No. 30M3-254**

PREPARED FOR: Giffels Associates Limited/IBI Group
30 International Boulevard
Toronto, Ontario

Attention: Mr. Stephen Chiu, P.Eng.
Manager, Transportation Engineering

File No. 1-09-4135
June 02, 2010

Terraprobe Inc.
10 Bram Court
Brampton, Ontario
L6W 3R6
Phone: (905) 796 2650
Fax: (905) 796 2250

Distribution:

1 Copy	-	Giffels Associates Limited/IBI Group
1 Copy	-	MTO Pavements and Foundations Section
1 Copy	-	MTO Central Region (Planning and Design)
1 Copy	-	City of Welland
1 Copy	-	Terraprobe Inc., Brampton

Terraprobe Inc.

Greater Toronto
10 Bram Court
Brampton, Ontario L6W 3R6
(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.
Sudbury, Ontario P3E 5P4
(705) 670-0460 Fax 670-0558
sudbury@terraprobe.ca

www.terraprobe.ca

TABLE OF CONTENTS

Part 1

1	INTRODUCTION.....	1
2	SITE DESCRIPTION & PHYSIOGRAPHY.....	1
3	SITE INVESTIGATION AND FIELD TESTING.....	2
4	LABORATORY TESTING.....	3
5	DESCRIPTION OF SUBSURFACE CONDITIONS.....	3
5.1	Watermain Alignment - Sta. 0+170 to Sta. 0+227.....	3
5.1.1	Topsoil.....	3
5.1.2	Fill – Silty Clay.....	4
5.1.3	Silt.....	4
5.1.4	Silty Clay.....	4
5.1.5	Silty Clay to Clayey Silt Till.....	5
5.1.6	Silty Sand to Sandy Silt Till.....	5
5.1.7	Bedrock.....	6
5.2	Sanitary Sewer Alignment – Sta. 0+167 to Sta. 0+222.....	6
5.2.1	Topsoil.....	6
5.2.2	Silt.....	6
5.2.3	Silty Clay.....	6
5.2.4	Silty Clay to Clayey Silt Till.....	7
5.2.5	Sandy Silt Till.....	8
5.2.6	Bedrock.....	8
5.3	Water Levels.....	9
5.4	Miscellaneous.....	9

Part 2

6	GENERAL.....	11
7	WATERMAIN AND SANITARY CROSSINGS BELOW HIGHWAY 406.....	11
7.1	General.....	11
7.1.1	Watermain Alignment (Sta. 0+170 to Sta. 0+227).....	12
7.1.2	Sanitary Sewer Alignment (Sta. 0+167 to Sta. 0+222).....	12
7.2	Tunnelling Methods.....	12
7.2.1	Pipe Jacking & Horizontal Auger Boring.....	12
7.2.2	Microtunnelling.....	14
7.2.3	Horizontal Directional Drilling.....	14
7.2.4	Pipe Ramming.....	14
8	TUNNEL SUPPORT.....	15



9	LATERAL EARTH PRESSURE.....	15
10	BASAL STABILITY	16
11	OHTA SOIL CLASSIFICATION.....	16
12	GROUND WATER CONTROL.....	17
13	MONITORING	17
14	CONSTRUCTION CONCERNS.....	18

Appendices

Appendix A	Record of Borehole Sheets
Appendix B	Laboratory Test Results
Appendix C	Drawing titled “Borehole Locations and Soil Strata”
Appendix D	Comparison of Installation Methods
Appendix E	Settlement Monitoring Guideline and Plan View of Instrument Array



FOUNDATION INVESTIGATION REPORT
WATERMAIN AND SANITARY SEWER INSTALLATIONS
HIGHWAY 406 AT WOODLAWN ROAD
THE CITY OF WELLAND, ONTARIO
Geocres No. 30M3-254
PART 1: FACTUAL INFORMATION

1 INTRODUCTION

This report presents the factual findings obtained from a foundation investigation conducted along proposed watermain and sanitary sewer alignments crossing (by tunnelling) under the existing Highway 406 north of the Woodlawn Road intersection, in the City of Welland, Ontario.

Foundation investigations for the Woodlawn Road overpasses were carried out by Terraprobe Inc. (Terraprobe) and the data from these investigations were used to supplement the field investigation programme for this work.

The purpose of this investigation was to explore the subsurface conditions along the alignments and based on the data obtained, to provide borehole location plans, records of boreholes, stratigraphic profiles, laboratory test results and descriptions of the subsurface conditions. Models of the subsurface conditions were developed from the data obtained.

Terraprobe conducted the investigation as a sub-consultant to Giffels Associates Ltd./IBI Group, under the Ministry of Transportation Ontario (MTO) Agreement Number 2008-E-0016.

For reporting purposes the investigated sections are designated as Watermain Alignment and Sanitary Sewer Alignment. Further details are outlined below.

Watermain Alignment

A 300 mm diameter watermain installed in a 56.5 m long, 500 mm diameter steel casing crossing the North Bound and South Bound lanes of Highway 406 Sta. 12+725. The casing will be installed between Sta. 0+170 and Sta. 0+227 approximately.

Sanitary Sewer Alignment

A 300 mm sanitary sewer installed in a 55 m long, 500 mm diameter steel casing crossing the North Bound and South Bound lanes of Highway 406 Sta. 12+714. The casing will be installed between Sta. 0+167 and Sta. 0+222 approximately.

2 SITE DESCRIPTION & PHYSIOGRAPHY

The site is located about 50 m north of the signalised Highway 406/Woodlawn Road intersection in the City of Welland, Ontario. Within the project limits, Highway 406 is a two-lane highway with gravel shoulders carrying both north and south bound traffic. There is a dedicated right turn lane that carries southbound traffic on Highway 406 to Woodlawn Road.



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 basins¹.

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 Age². This unit consists essentially of easily weathered, grey, very finely crystalline, laminated argillaceous dolostone with grey, calcareous shale partings and gypsum veins and lenses of varying thicknesses.

3 SITE INVESTIGATION AND FIELD TESTING

The site investigation and field testing for this project were carried out on April 28, 2010 and consisted of drilling and sampling two boreholes (WM1 and SS1) to depths of 6.6 m and 7.4 m below ground surface. The field investigation programme is supplemented with two boreholes (WS2 and WN4) drilled for the Woodlawn Overpass structures. These structure boreholes were drilled during the period December 14, 2009 and February 1, 2010 to depths of 28.9 m and 29.9 m below ground surface. The approximate borehole locations are shown on the attached Borehole Locations and Soil Strata Drawings in Appendix C.

Samples of the overburden soils were obtained at selected intervals using a split spoon sampler in conjunction with Standard Penetration Testing (SPT), as specified in ASTM Method D1586. In the cohesive (clayey) deposits the undrained shear strength of the soil was measured in-situ by means of field vane tests using an MTO type field vane. Relatively undisturbed soil samples were also collected with thin-walled Shelby Tube samplers. Boreholes WS2 and WN4 were also advanced into bedrock by NQ size diamond coring techniques.

Ground water conditions in the open boreholes were observed throughout the drilling operations and standpipe piezometers consisting of 19 mm diameter PVC pipe with a slotted screen enclosed in sand were installed in selected boreholes to permit longer term ground water level monitoring. The remaining boreholes were abandoned in accordance with MOE Regulation 903 by sealing/grouting with a bentonite slurry mixture after drilling was complete.

¹ Chapman and Putnam, "The Physiography of South Ontario", 3rd Edition, 1984.

² Ontario Division of Mines, "Quaternary Geology Of The Welland Area", Preliminary Map P.796, 1972.



The locations and completion details of the piezometers are shown in Table 3.1.

Table 3.1 – Piezometer Installation Details

Piezometer Location	Piezometer Details	
	Tip Depth/ Elevation (m)	Completion Details
Watermain Alignment		
WM1	6.8/176.1	Piezometer with 1.5 m slotted screen installed with filter sand to 5.0 m, bentonite seal from 5.0 m to 3.8 m and drill cuttings from 3.8 m to ground surface.
Sanitary Sewer Alignment		
SS1	6.0/175.8	Piezometer with 1.5 m slotted screen installed with filter sand to 4.2 m, bentonite seal from 4.2 m to 3.0 m and drill cuttings from 3.0 m to ground surface.

The drilling, sampling and coring operations were observed on a full time basis by members of Terraprobe's technical staff who logged the boreholes and rock cores and processed the recovered soil and rock samples for transport to Terraprobe's Brampton laboratory for further examination and testing.

4 LABORATORY TESTING

The recovered soil samples were subjected to Visual Identification (VI) and natural moisture content determination. Selected samples were also subjected to gradation analysis and Atterberg Limits tests. The results of the soils testing program are shown on the Record of Borehole sheets in Appendix A. The grain size distribution curves and plasticity charts are illustrated in Appendix B.

5 DESCRIPTION OF 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" drawing in Appendix C. An overall description of the stratigraphy along each alignment is given in the following paragraphs. However, the factual data presented in the Record of Borehole Sheets governs any interpretation of the site conditions.

5.1 Watermain Alignment - Sta. 0+170 to Sta. 0+227

In general, the site is underlain by surficial layer of topsoil, soft to stiff silty clay fill, compact silt, firm to very stiff silty clay, hard silty clay to clayey silt till and very dense silty sand to sandy silt till. These overburden soils are further underlain by bedrock consisting primarily of dolostone and shale of the Salina Formation.

5.1.1 Topsoil

Topsoil ranging from 150 mm to 250 mm was encountered at this site. Topsoil thickness may vary between and beyond the boreholes.



5.1.2 Fill – Silty Clay

Silty clay fill was encountered at this site extending to a depth of 3.7 m below ground surface (Elev. 178.8 m). The fill material was encountered in BH WN4 and not in BH WM1.

Grain size distribution curves of samples of this fill material are presented in Figures B1. These results show grain size distributions consisting of 0 to 5% gravel, 2 to 3% sand, 56 to 67% silt and 31 to 36% clay size particles.

A sample of the silty clay fill was also subjected to an Atterberg Limits test and the results are illustrated in Figure B2. The summarized index values from this test are presented herein.

Liquid Limit:	27%
Plastic Limit:	16%
Plasticity Index:	11%
Natural Moisture Content:	16%

These values are characteristic of clayey soils of low plasticity.

Standard Penetration tests in the silty clay fill material yielded 'N' values ranging from 3 blows to 9 blows for 0.3 m penetration. Based on these results the fill is considered to have a soft to stiff consistency.

The moisture content of samples of this fill ranged from 16% to 20% by weight.

5.1.3 Silt

A native cohesionless silt deposit was encountered at this site extending to a depth of 4.9 m below ground surface (Elev. 177.6 m). Based on visual and tactile examinations of the retrieved samples, the unit is essentially a cohesionless silt with frequent cohesive silty clay seams and partings. The silt was encountered in BH WN4 and not in BH WM1.

The silt is considered to have a compact relative density based on SPT 'N' values that ranged from 16 to 22 blows for 0.3 m penetration. The moisture content of samples from this deposit ranged from 17% to 21% by weight.

5.1.4 Silty Clay

A major silty clay deposit was encountered across the site. This deposit was fully penetrated in Borehole WN4 where it was found to extend to a depth of 14.7 m (Elev. 167.8 m) below ground surface. Borehole WM1 was terminated in this deposit at a depth of 7.4 m below ground surface (Elev. 175.5 m).

The grain size distribution plots of tested samples of the silty clay are presented in Figures B3 and B4. These results show a grain size distribution consisting of 0-17% gravel, 1-10% sand, 37-73% silt and 23-59% clay size particles.



Samples were also subjected to Atterberg Limits tests and the results are illustrated on the plasticity charts, Figures B5 and B6. The index values from these tests are summarized below:

Liquid Limit:	24-51%
Plastic Limit:	14-22%
Plasticity Index:	9-29%
Natural Moisture Content:	17-25%

These values indicate that the silty clay has a generally low to intermediate plasticity with occasional zones of high plasticity.

Standard Penetration tests in this stratum gave 'N' values that ranged from 5 to 22 blows for 0.3 m penetration. Field vane tests gave in-situ undrained shear strengths ranging from 80 kPa to in excess of 100 kPa. These values indicate that the consistency of the silty clay is generally stiff to very stiff with infrequent firm zones. The moisture content of samples of the silty clay ranged from 16% to 30% by weight.

5.1.5 Silty Clay to Clayey Silt Till

Silty clay to clayey silt till was encountered at the site extending to a depth of 17.8 m below ground (Elev. 164.7 m). The till was encountered in BH WN4 and not in BH WM1. Till soils can also be expected to contain random cobble and boulder inclusions.

Standard Penetration tests in the till yielded 'N' values ranging from 37 to 43 blows per 0.3 m penetration. Based on these results the clayey silt to silty clay till is considered to have a hard consistency. The moisture content of samples from this deposit was 10% by weight.

5.1.6 Silty Sand to Sandy Silt Till

A deposit of silty sand to sandy silt till was encountered in Borehole WN4 overlying the bedrock surface. This deposit extends to a depth of 26.0 m below ground surface (Elev. 156.5 m). The till was encountered in BH WN4 and not in BH WM1.

Samples from this deposit were subjected to grain size distribution tests and the results are illustrated in Figure B7. These results show a grain size distribution consisting of 6-18 % gravel, 35-41 % sand, 31-47 % silt and 10-12 % clay size particles. Till soils can also be expected to contain random cobble and boulder inclusions.

Standard Penetration tests in this deposit gave 'N' values that ranged from 64 to more than 100 blows per 0.3 m penetration indicating a very dense relative density. The moisture content of samples from this stratum ranged from 6% to 9% by weight.



5.1.7 Bedrock

The overburden soils described above are underlain by the Salina Formation. Bedrock was proved by coring in Borehole WN4. Table 5.1 summarizes the bedrock depth and the elevation to the top of bedrock.

Table 5.1 – Depth to Bedrock

BH No.	Depth to Bedrock (m)	Top of Bedrock Elevation (m)
WN4	26.0	156.5

The bedrock is described as unweathered and its colour is generally grey. It is thinly laminated with white unweathered gypsum and calcite veins. Total core recovery in the bedrock ranged from 92% to 100%. The RQD values ranged from 35% to 44% indicating poor rock quality.

5.2 Sanitary Sewer Alignment – Sta. 0+167 to Sta. 0+222

In general, the site is underlain by surficial layer of topsoil, firm to hard silty clay, dense silt, hard silty clay to clayey silt till and very dense sandy silt till. These overburden soils are further underlain by bedrock consisting primarily of dolostone and shale of the Salina Formation.

5.2.1 Topsoil

A 230 mm thick layer of topsoil was encountered in Borehole SS1. Topsoil thickness may vary between and beyond the boreholes.

5.2.2 Silt

A native cohesionless silt deposit was encountered at this site extending to a depth of 5.9 m (Elev. 177.2 m) below ground surface. Based on visual and tactile examinations of the retrieved samples, the unit is essentially a cohesionless silt with frequent cohesive silty clay seams and partings. The silt was encountered in BH WS2 and not in BH SS1.

The grain size distribution curve of a sample of this silt is shown in Figure B8. The results show a grain size distribution consisting of 0% gravel, 1% sand, 79% silt and 20% clay size particles.

Standard Penetration tests in this deposit gave 'N' values ranging from 36 to 37 blows per 0.3 m penetration. Based on these results the deposit is considered to have a dense relative density. The moisture content of samples from this stratum ranged from 18% to 22% by weight.

5.2.3 Silty Clay

A major silty clay deposit was encountered across the site. This deposit was fully penetrated in Borehole WS2 where it was found to extend to a depth of 14.7 m



(Elev. 168.4 m) below ground surface. Borehole SS1 was terminated in this deposit at a depth of 6.6 m below ground surface (Elev. 175.2 m).

The grain size distribution plots of tested samples of the silty clay are presented in Figures B9 and B10. These results show a grain size distribution consisting of 0-2% gravel, 1-5% sand, 37-72% silt and 26-58% clay size particles.

Samples were also subjected to Atterberg Limits tests and the results are illustrated on the plasticity charts, Figures B11 and B12. The index values from these tests are summarized below:

Liquid Limit:	26-47%
Plastic Limit:	16-23%
Plasticity Index:	10-24%
Natural Moisture Content:	17-24%

These values indicate that the silty clay has a generally low to intermediate plasticity.

Standard Penetration tests in this stratum gave 'N' values that ranged from 6 to 43 blows for 0.3 m penetration. Field vane tests gave in-situ undrained shear strengths ranging from 64 kPa to in excess of 100 kPa. These values indicate that the consistency of the silty clay is generally stiff to hard with infrequent firm zones. The moisture content of samples of the silty clay ranged from 16% to 27% by weight.

5.2.4 Silty Clay to Clayey Silt Till

Discontinuous layers of silty clay to clayey silt till were encountered at the site extending to a depth of 22.3 m below ground surface (Elev. 160.8 m). The till was encountered in BH WS2 and not in BH SS1.

The results of a grain size distribution test conducted on a sample of clayey silt till is shown in Figure B13. These results show a grain size distribution consisting of 15% gravel, 35% sand, 35% silt and 15% clay size particles. Till soils can also be expected to contain random cobble and boulder inclusions.

A sample of the clayey silt till was also subjected to an Atterberg Limits test and the results are plotted on the plasticity chart in Figure B14. The summarized index values from this test are presented herein.

Liquid Limit:	15%
Plastic Limit:	11%
Plasticity Index:	4%
Natural Moisture Content:	7%

These values are characteristic of clayey soils of low plasticity.



Standard Penetration tests in these deposits yielded 'N' values ranging from 40 blows to 87 blows for 0.3 m. Based on these results the silty clay to clayey silt till is considered to have a hard consistency.

The moisture content of samples of the till ranged from 7% to 13% by weight.

5.2.5 Sandy Silt Till

Sandy silt till strata were encountered at this site extending to a depth of 27.3 m below ground surface (Elev. 155.8 m). This till was encountered in BH WS2 and not in BH SS1.

The grain size distribution curve of a sample of this sandy silt till is shown in Figure B15. The results show a grain size distribution consisting of 26% gravel, 17% sand, 45% silt and 12% clay size particles. Till soils can also be expected to contain random cobble and boulder inclusions.

Based on recorded 'N' values of more than 100 blows for 0.3 m penetration, the deposit is considered to have a very dense relative density. The moisture content of samples of the till ranged from 3% to 8% by weight.

5.2.6 Bedrock

The overburden soils described above are underlain by the Salina Formation. Bedrock was proved by coring in Borehole WS2. Table 5.2 summarizes the bedrock depth and the elevation to the top of bedrock.

Table 5.2 – Depth to Bedrock

BH No.	Depth to Bedrock (m)	Top of Bedrock Elevation (m)
WS2	27.3	155.8

The bedrock is described as unweathered and its colour is generally grey. It is thinly laminated with white unweathered gypsum and calcite veins. Total core recovery in the bedrock ranged from 71% to 89%. The RQD values ranged from 18% to 30% indicating very poor to poor rock quality.



5.3 Water Levels

Standpipe piezometers were installed in selected boreholes and water level readings were taken on separate visits made after the completion of drilling. The water level records are presented in Table 5.3.

Table 5.3 – Water Level Measurements

Borehole	Date	Water Levels	
		Depth (m)	Elevation (m)
Watermain Alignment			
WM1	May 04, 2010	6.8	176.1
	May 06, 2010	6.8	176.1
	May 18, 2010	1.0	181.9
Sanitary Sewer Alignment			
SS1	May 04, 2010	1.3	180.5
	May 06, 2010	1.2	180.6
	May 18, 2010	1.0	180.8

The ground water table was estimated based on the recorded water levels in the standpipe piezometers and our review of moisture contents of the retrieved samples. This interpretation indicates a ground water table that is estimated to range between Elev. ± 180.8 m and Elev. ± 181.9 m.

All ground water observations at this site are short term and the levels are expected to fluctuate seasonally and after severe weather events.

5.4 Miscellaneous

The borehole locations were marked in the field by surveyors from Callon Dietz Inc. who also provided Terraprobe with their coordinates and geodetic elevations. Terraprobe obtained utility clearances and permits prior to drilling.

The drilling, sampling and in-situ testing operations were conducted with track-mounted drill rigs owned and operated by Groundworks Drilling Limited of Toronto, Ontario and Determination Drilling & Soil Investigations of Hamilton, Ontario.

The boreholes were advanced using hollow-stem augers and rock cores were retrieved by NQ size diamond coring techniques.

Messrs. Alexander Winkelmann, E.I.T, and Phil Khuu, B.A.T, carried out the field work. The laboratory testing was performed at Terraprobe's Brampton laboratory. The report was written by Rehman Abdul, P.Eng. and reviewed by Michael Tanos, P.Eng.





Prepared by:
R. Abdul, P.Eng.,
Senior Geotechnical Engineer



Report Reviewed by:
Michael Tanos, P.Eng.,
Review Principal



FOUNDATION DESIGN REPORT
WATERMAIN AND SANITARY SEWER INSTALLATIONS
HIGHWAY 406 AT WOODLAWN ROAD
THE CITY OF WELLAND, ONTARIO
Geocres No. 30M3-254

PART 2: ENGINEERING DISCUSSION AND RECOMMENDATIONS

6 GENERAL

This report presents interpretation of the geotechnical data in the factual report and provides geotechnical design recommendations for the proposed watermain and sanitary sewer installations below Highway 406. The watermain and sanitary sewer are to be installed (by tunnelling) under the current two lanes of Highway 406 and the existing dedicated right turn lane that carries Highway 406 south bound traffic to Woodlawn Road.

The watermain alignment crosses Highway 406 from west to east at about Sta. 12+725, north of the Woodlawn Road/Highway 406 at grade intersection. The watermain will be installed below Highway 406 in a 56.5 m long, 500 mm diameter steel casing along an alignment that extends from Sta. 0+170 to Sta. 0+227. The approximate invert elevations of the steel casing are Elev. 179.6 m (west limit) and Elev. 179.3 m (east limit) and the depth below existing grade is about ± 3.5 m. The minimum overburden cover measured from the lowest ground elevation to the crown of the tunnel exceeds three tunnel excavation diameters or 1.5 m, in accordance with MTO Tunnelling Guidelines.

The sanitary sewer alignment crosses Highway 406 from west to east at about Sta. 12+714, north of the Woodlawn Road/Highway 406 at grade intersection. The sanitary sewer will be installed below Highway 406 in a 55 m long, 500 mm diameter steel casing along an alignment that extends from Sta. 0+167 to Sta. 0+222. The approximate invert elevations of the steel casing are Elev. 178.9 m (west limit) and Elev. 179.2 m (east limit) and the depth below ground surface ranges from ± 2.7 m to ± 4.2 m. The minimum overburden cover measured from the lowest ground elevation to the crown of the tunnel exceeds three tunnel excavation diameters or 1.5 m, in accordance with MTO Tunnelling Guidelines.

The discussion and recommendations presented in this report are based on our understanding of the project and on the factual data obtained in the course of the investigations.

7 WATERMAIN AND SANITARY CROSSINGS BELOW HIGHWAY 406

7.1 General

This report presents discussions and recommendations for the trenchless installations (tunnelling) of the watermain and sanitary sewer below Highway 406 only. This report does not address watermain and sewer installations beyond the limits identified in this report.



Watermain Alignment (Sta. 0+170 to Sta. 0+227)

A 500 mm diameter steel casing will be installed below Highway 406 at an invert elevation that ranges from Elev. 179.6 m (west limit) to Elev. 179.3 m (east limit). The length of the crossing is approximately 56.5 m extending from Sta. 0+170 to Sta. 0+227. The casing will be installed in native silty clay and silty clay fill material below the ground water table.

7.1.1 Sanitary Sewer Alignment (Sta. 0+167 to Sta. 0+222)

A 500 mm diameter steel casing will be installed below Highway 406 at an invert elevation that ranges from Elev. 178.9 m (west limit) to Elev. 179.2 m (east limit). The length of the crossing is approximately 55 m extending from Sta. 0+167 to Sta. 0+222. The casing will be installed in native silty clay soil below the ground water table.

7.2 Tunnelling Methods

The diameter, length and anticipated subsurface conditions limit the range of trenchless installation techniques that would be economically viable at this site. Each method considered has advantages; disadvantages or limitations and these are discussed. The methods that were considered are:

1. Pipe Jacking and Horizontal Auger Boring
2. Micro Tunnelling
3. Horizontal Directional Drilling
4. Pipe Ramming

Tunnelling shall be undertaken in accordance with OPSS 415, 416 and 450 as appropriate. The choice of equipment and the method of tunnelling is the Contractor's responsibility.

7.2.1 Pipe Jacking & Horizontal Auger Boring

A pipe jacking operation involves pushing an oversized liner pipe horizontally into the ground by jacking. A range of excavation methods are available for removing the soil from inside the pipe as it is advanced. Augering is one common excavation method. Precision is normally $\pm 1\%$ of the driven length.

Horizontal auger boring requires an auger boring machine that is used to bore horizontally through soil or rock with a cutting head and auger. The cutting head can be located either inside or outside of the casing pipe that is being jacked forward. The auger boring machine can accept many types of cutting attachments ranging from backhoe teeth cutters for excavating soil to small boring units equipped with mini disc cutters for excavating rock. Small boring units can be steered to maintain line and grade.



Watermain Alignment

The borehole data indicates that if the watermain design inverts are maintained (Elev. 179.6 m to Elev. 179.3 m) the tunnelling operation will be made in native silty clay and silty clay fill material. The native silty clay possesses sufficient cohesion and is expected to have a stand-up time of several hours. However, the silty clay fill material could be fast ravelling and there could be potential loss of ground when tunnelling through this material. The tunnelling contractor must ensure that the tunnelling equipment is suitably designed to deal with these soil conditions.

Given the potential risk involved in tunnelling through the fill material (watermain alignment) we recommend that the casing design invert be lowered to at least Elev. 178.3 m to ensure that the reach is tunnelled through native soils. The casing should closely follow the advancing cutting head to minimize settlements.

Sanitary Sewer Alignment

The borehole data indicates that the tunnelling operation will be made in native silty clay soils. The tunnelling contractor must ensure that the tunnelling equipment is appropriate for these soil conditions.

The silty clay soil possesses sufficient cohesion and is expected to have a stand-up time of several hours depending on the composition of the soil matrix. Nevertheless, the casing should closely follow the advancing cutting head to minimize settlements.

For both alignments, when excavation is halted, the casing should be in close contact with the cutting head in order to maintain stability. Ground closure around the liner is expected to be minimal. The application of a bentonite slurry under pressure may be required to reduce frictional resistance.

Settlement at the ground surface on both alignments is estimated to be negligible when tunnelling within the overburden soils. This estimate is based on the assumption that the work will be carried out by experienced tunnellers with great care and good workmanship. Under “normal” tunnelling operations, ground loss can be limited to acceptable levels. However, excessive ground loss, and settlement can occur when unusual conditions (such as boulder removal and water-bearing sand lenses) are encountered. A great deal of care is required under these conditions.

The silty clay soils have relatively low permeabilities and ground water seepage is expected to be in small quantities at a slow rate. This seepage can be handled by gravity drainage into the entry shaft from where it could be removed by pumping from filtered sumps.



7.2.2 Microtunnelling

This technique is similar to horizontal auger boring where a liner pipe is jacked horizontally into the ground. The liner follows closely behind a remote controlled cutting head that can be designed to excavate soil and rock.

Microtunnelling is a very precise method of tunnelling and with the suitable choice of cutting tools a wide soil spectrum as well as rock can be excavated. Additionally, there is relatively little settlement with this method if handled properly.

This method is feasible for consideration at this site. However, due to the specialized type of machinery required it might be prohibitively expensive for this relatively short run.

7.2.3 Horizontal Directional Drilling

Horizontal directional drilling is a trenchless construction method that involves drilling a small pilot hole, using technology that allows the drill to be steered and tracked from the surface. The pilot hole is enlarged (usually approximately 1.5 times the largest outside diameter of the new pipe) by pulling back increasingly larger reamers, or reaming heads, from the insertion point to the rig side.

To achieve the appropriate bore path size it may be necessary to perform several reaming operations. Generally, all reaming procedures prior to the actual product installation are referred to as pre-reams, and the final ream to which the product pipe is attached is referred to as the back ream.

After the pre-reams, the pulling head and connecting product pipe are attached to the reamer using a swivel, a device that isolates the product pipe from the rotation of the drill pipe. The product pipe is then pulled behind the final reamer back through the horizontal directional drill path to the exit pit on the rig side.

This method is feasible and practical and the equipment is readily available in Ontario. However, proper care must be taken at all phases of construction to ensure that proper grade and line is achieved even after a successful pilot bore is completed.

7.2.4 Pipe Ramming

Pipe ramming is a trenchless method for installing steel pipes or casings in which a pneumatic tool is used to hammer the pipe or the casing into the ground. The soils inside the pipe can be removed either during or after the installation by augering, compressed air or water jetting.

Pipe ramming is not-steerable, meaning that subsurface obstructions or improperly aligned pipes may result in significant deviations from the desired line and grade.

Although pipe ramming can be applied in a wide variety of soils, some soils are better suited for this method than others.



One drawback is the possibility of significant soil disturbance if a blockage is created at the end of the installed pipe especially if this occurs below the existing Highway 406. Other issues that require careful consideration include the length of the installation and the high noise levels.

Based on the foregoing pipe ramming is not recommended.

8 TUNNEL SUPPORT

In the completed tunnel the maximum residual stress would be expressed in the spring-line of the tunnel diameter where the unbalanced horizontal stress is a maximum. The horizontal and tangential pressure on the steel casing is a function of the vertical in situ pressure, which is given by:

$$P_h = \gamma (h - h_w) + \gamma' h_w + h_w \gamma_w$$

γ = bulk unit weight of soil

γ_w = unit weight of water (9.81 kN/m³)

h = depth below surface (m)

h_w = depth below the ground water level (m)

For design purposes assume a unit weight of 21 kN/m³ for the soil overlying the springline of the tunnel. An allowance should be made for additional surcharge loads.

9 LATERAL EARTH PRESSURE

The entry and exit shafts will have to be supported by a vertical shoring system. The shape of the soil pressure distribution diagram behind the shoring system depends upon the type of soil to be encountered and the amount of movement that can be permitted. The sequence of work may also alter the shape of the pressure diagram during the various construction phases.

Decisions regarding shoring methods and sequencing are the responsibility of the Contractor. Temporary shoring should be designed by a licensed Professional Engineer experienced in shoring design.

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.



The appropriate values of the parameters for use in the design of structures subject to unbalanced earth pressures are given in Table 9.1 and Table 9.2.

Table 9.1 – Earth Pressure Coefficients (Watermain Alignment)

Stratum	ϕ	γ	K_a	K_o	K_p
Fill – Silty Clay	25	18	0.40	0.58	2.46
Silt	28	19	0.36	0.53	2.77
Silty Clay	30	20	0.33	0.50	3.00
Silty Clay to Clayey Silt Till	33	21	0.30	0.45	3.40
Silty Sand to Sandy Silt Till	35	21	0.27	0.43	3.70

Table 9.2 – Earth Pressure Coefficients (Sanitary Sewer Alignment)

Stratum	ϕ	γ	K_a	K_o	K_p
Silty Clay	30	20	0.33	0.50	3.00
Silt	28	19	0.36	0.53	2.77
Silty Clay to Clayey Silt Till	33	21	0.30	0.45	3.40
Silty Sand to Sandy Silt Till	35	21	0.27	0.43	3.70

The factors in the table above are “ultimate” values and require certain movements for the active and passive conditions to be mobilized. The values to use in design can be estimated from Figure C6.9.1 (a) in the Commentary to the CHBDC, 2006.

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 (less than performance Level 1) 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).

If a system of soldier piles and lagging is considered, the ultimate horizontal resistance for the design of the soldier pile toes in the silty clay soils can be estimated as $4C_u$ where C_u is the undrained shear strength of the silty clay in this zone. The undrained shear strength can be taken as a nominal value of 100 kPa.

10 BASAL STABILITY

Tunnelling will require the construction of entry and exit shafts on both alignments. The borehole data shows that the excavation bases will be made in firm silty clay fill and very stiff silty clay. The base of the excavations will be stable with respect to bottom heave.

11 OHSA SOIL CLASSIFICATION

All excavations must be carried out in accordance with the Occupational Health and Safety Act (OHSA). For the purposes of the OHSA, the silty clay fill and the silt may be classified as Type 3 soils above the ground water table and Type 4 soils below the ground water table. The native silty clay soils at this site may be classified as Type 2 soils above the ground water table and Type 3 soils below the ground water table.



Open cut excavations above the water table may be sloped at 1.5H:1V. Below the ground water table the silty clay soils may be excavated at 1.5H:1V. The allowable side slope for excavations made in submerged silts should be at least 2H:1V or flatter. Excavations at steeper inclinations will require shoring.

12 GROUND WATER CONTROL

The ground water table at this site is estimated to range between Elev. ±180.8 m and Elev. ±181.9 m. Ground water will be encountered in the excavations.

The Contractor must implement suitable ground water control and ground support systems as required to install the watermain and sanitary sewer in a safe, stable, unwatered excavation. The design of the unwatering system should be the responsibility of the Contractor.

Ground water seepage into excavations made through the silty clay fill and silty clay, should be minimal due to the relatively low permeability of these soils. It is believed that this seepage can be controlled by gravity drainage and pumping from strategically located filtered sumps as and where required.

At shaft locations it is recommended that an allowance be made to pour a 150 mm thick layer of lean concrete (mud mat) on the foundation bearing surfaces as soon as possible after excavation. This construction strategy will assist in controlling water infiltration at the base of the excavation and will also provide a stable working platform for construction equipment.

The estimated range of hydraulic conductivities³ of the silty clay fill material, native silty clay and the silt are provided below.

- Silty Clay Fill 10^{-8} to 10^{-9} m/s
- Silty Clay 10^{-9} to 10^{-11} m/s
- Silt 10^{-7} to 10^{-8} m/s

13 MONITORING

The contract documents should require the contractor to monitor the roadway surface before, during and after the trenchless installation. A precondition survey is also required prior to tunnelling. A recommended settlement monitoring guideline is included in Appendix E.

It is also necessary to check the amount of spoil removal to determine if there is over excavation and if there are any possible voids outside of the casing. Voids must be grouted with approved grouting materials using approved methods.

³ Freeze, R, & Cherry, J. (1979) "Groundwater", (pp 29), Prentice-Hall, Inc.



14 CONSTRUCTION CONCERNS

During construction, the Contract Administrator should employ experienced geotechnical staff to observe construction activities related to the watermain and sanitary sewer installations.

Potential construction concerns include, but are not necessarily limited to:

- maintaining accurate line and grade if the sewer is installed by horizontal directional drilling.
- the potential for ground water levels to be higher at the time of construction than those recorded in this report.

R. Abdul

Engineering Analysis and Report Preparation by:
R. Abdul, P.Eng.,
Senior Geotechnical Engineer



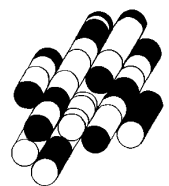
Michael Tanos

Report Reviewed by:
Michael Tanos, P.Eng.,
Review Principal



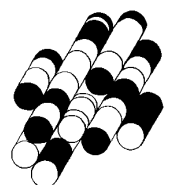
APPENDICES

TERRAPROBE INC.



APPENDIX A

TERRAPROBE INC.



LIMITATIONS AND RISK

Procedures

The soil conditions were confirmed at the borehole and test pit 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.

This report was prepared for the express use of the Ministry of Transportation, its retained design consultants and Giffels Associates Ltd./IBI Group. It is not for use by others. This report is copyright of Terraprobe Inc. and no part of this report may be reproduced by any means, in any form, without the prior written permission of Terraprobe Inc. The Ministry of Transportation, its retained design consultants and Giffels Associates Ltd./IBI Group, are authorized users.

EXPLANATION OF TERMS USED IN REPORT

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

DYNAMIC CONE PENETRATION TEST: CONTINUOUS PENETRATION OF A CONICAL STEEL POINT (51mm O.D. 60° CONE ANGLE) DRIVEN BY 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	kPa	PORE WATER PRESSURE
u_v	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
$\epsilon_1, \epsilon_2, \epsilon_3$	%	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_{ve}	kPa	EFFECTIVE OVERBURDEN PRESSURE
σ_p	kPa	PRECONSOLIDATION PRESSURE
τ_i	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_u	kPa	REMOULDED SHEAR STRENGTH
S_r	1	SENSITIVITY = c_u/τ_u

PHYSICAL PROPERTIES OF SOIL

ρ_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_p	1	DENSITY INDEX = $\frac{e_{max} - e}{e_{max} - e_{min}}$
ρ_w	kg/m ³	DENSITY OF WATER	w	1, %	WATER CONTENT	D	mm	GRAIN DIAMETER
γ_w	kN/m ³	UNIT WEIGHT OF WATER	S_r	%	DEGREE OF SATURATION	D_n	mm	n PERCENT - DIAMETER
ρ	kg/m ³	DENSITY OF SOIL	w_L	%	LIQUID LIMIT	C_u	1	UNIFORMITY COEFFICIENT
γ	kN/m ³	UNIT WEIGHT OF SOIL	w_p	%	PLASTIC LIMIT	h	m	HYDRAULIC HEAD OR POTENTIAL
ρ_d	kg/m ³	DENSITY OF DRY SOIL	w_s	%	SHRINKAGE LIMIT	q	m ³ /s	RATE OF DISCHARGE
γ_d	kN/m ³	UNIT WEIGHT OF DRY SOIL	I_p	%	PLASTICITY INDEX = $(w - w_p)$	v	m/s	DISCHARGE VELOCITY
ρ_{sat}	kg/m ³	DENSITY OF SATURATED SOIL	I_L	1	LIQUIDITY INDEX = $(w - w_p)/I_p$	i	1	HYDRAULIC GRADIENT
γ_{sat}	kN/m ³	UNIT WEIGHT OF SATURATED SOIL	I_c	1	CONSISTENCY INDEX = $(w - w_p)/I_p$	k	m/s	HYDRAULIC CONDUCTIVITY
ρ'	kg/m ³	DENSITY OF SUBMERGED SOIL	e_{max}	1, %	VOID RATIO IN LOOSEST STATE	j	kN/m ²	SEEPAGE FORCE
γ'	kN/m ³	UNIT WEIGHT OF SUBMERGED SOIL						

RECORD OF BOREHOLE No WM1

1 OF 1

METRIC

W.P. 280-99-00 LOCATION Coords: N:4764185.0 E:327299.1 ORIGINATED BY PK
 DIST HWY 406 BOREHOLE TYPE Hollow Stem Augers COMPILED BY DB
 DATUM Geodetic DATE 04.28.10 CHECKED BY RA

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT			PLASTIC LIMIT w _p	NATURAL MOISTURE CONTENT w	LIQUID LIMIT w _L	UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%)			
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa								WATER CONTENT (%)		
								○ UNCONFINED	+ FIELD VANE	● QUICK TRIAXIAL							× LAB VANE	
182.9	Ground Surface							20	40	60	80	100						
0.0	250mm TOPSOIL							20	40	60	80	100						
182.7																		
0.3	trace rootlets		1	SS	5													
	SILTY CLAY trace sand, trace gravel, firm to very stiff, brown / reddish brown, moist		2	SS	16		182										0 3 38 59	
			3	SS	18		181											
			4	SS	22		180											
			5	SS	18		179										0 1 47 52	
			6	SS	11		178										0 2 55 43	
			7	SS	12		177											
			8	SS	11		176											
			9	SS	11												0 2 47 51	
			10	SS	10													
175.5	End of Borehole																	
7.4	Borehole was dry (not stabilized) and hole open to full depth on completion. Piezometer installation consists of a 19mm diameter, Schedule 40 PVC pipe with a 1.52m slotted screen. Water Level Readings: Date Depth(m) Elevation(m) May 04.10 6.8 176.1 May 06.10 6.8 176.1 May 18.10 1.0 181.9																	

RECORD OF BOREHOLE No WN4

1 OF 3

METRIC

W.P. 280-99-00 LOCATION Coords: N:4764228.4 E:327343.4 ORIGINATED BY PK
 DIST HWY 406 BOREHOLE TYPE Hollow Stem Augers / NQ Rock Coring COMPILED BY DB
 DATUM Geodetic DATE 12.14.09 - 12.15.09 CHECKED BY RA

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT			PLASTIC LIMIT w _p	NATURAL MOISTURE CONTENT w	LIQUID LIMIT w _L	UNIT WEIGHT γ kN/m ³	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							× LAB VANE
182.5	Ground Surface					20	40	60	80	100	10	20	30				
182.4	150mm TOPSOIL																
0.2	soft		1	SS	3												
	FILL - Silty Clay, trace sand, trace gravel, firm to stiff, brown, damp		2	SS	6										0 2 67 31		
			3	SS	9												
			4	SS	8										5 3 56 36		
			5	SS	5												
178.8																	
3.7	SILT trace clay, trace sand, frequent silty clay seams and partings, compact, brown, damp		6	SS	16												
			7	SS	22												
177.6																	
4.9	SILTY CLAY trace to some gravel, trace sand, stiff to very stiff, brown, damp		8	SS	5										17 10 37 36		
			9	SS	10												
			10	TW	PH												
			11	SS	9										1 2 72 25		
			12	SS	8										1 3 73 23		
			13	SS	12										Dec.14		
															Dec.15		
			14	SS	12												
167.8																	
14.7																	

Continued Next Page

+ 3, X 3: Numbers refer to Sensitivity ○ 3% STRAIN AT FAILURE

METRIC

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT W _p	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W _L	UNIT WEIGHT γ	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV. DEPTH	DESCRIPTION	STRAT. PLOT	NUMBER	TYPE	"N" VALUES			20	40					
								SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE						
								20 40 60 80 100						
								WATER CONTENT (%)						
								10 20 30						

DEPTH (m)	DEPTH (ft)	UNIT	TEST	VALUE	DEPTH (m)	DEPTH (ft)	UNIT	TEST	VALUE	DEPTH (m)	DEPTH (ft)	UNIT	TEST	VALUE
164.7	17.8	SILTY CLAY TO CLAYEY SILT sandy, trace to some gravel, occasional cobbles, hard, brown, damp (GLACIAL TILL)	15	SS	37	167								
	16		SS	43	166									
	17		SS	64	165									
	18		SS	100/ 13cm	164									
	19		SS	89	163									
	20		SS	84	162									
156.5	26.0	SILTY SAND TO SANDY SILT trace to some clay, trace to some gravel, very dense, brown, damp (GLACIAL TILL) ----- frequent cobbles	21	SS	90	161								
	22		SS		160									
	23		SS		159									
	24		SS		158									
153.6	28.9	BEDROCK - INTERBEDDED DOLOSTONE AND SHALE Unweathered, thinly laminated, grey, medium strength, argillaceous with unweathered, laminated, white, very low strength gypsum and calcite layers / veins and frequent unweathered, white, low strength, coarse grained calcitic vugs.	1	RUN	NQ	157								
	2		RUN	NQ	156									
	3		RUN	NQ	155									
		End of Borehole				154								

Continued Next Page

+ 3, × 3: Numbers refer to Sensitivity ○ 3% STRAIN AT FAILURE

○ 3% STRAIN AT FAILURE

ONTARIO MOT 1-09-4135 WM & SS.GPJ ONTARIO MOT.GDT 05/31/10

RECORD OF BOREHOLE No WN4

3 OF 3

METRIC

W.P. 280-99-00 LOCATION Coords: N:4764228.4 E:327343.4 ORIGINATED BY PK
DIST HWY 406 BOREHOLE TYPE Hollow Stem Augers / NQ Rock Coring COMPILED BY DB
DATUM Geodetic DATE 12.14.09 - 12.15.09 CHECKED BY RA

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT W _p	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W _L	UNIT WEIGHT γ	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			20	40	60	80	100					
	<p>Borehole open to full depth and filled with drill water upon completion of drilling.</p> <p>Borehole sealed with bentonite slurry to ground surface.</p> <p>Resistance to augering at 22.9m and 24.3m.</p> <p>Unable to push vane beyond 13.1m and 14.2m.</p>																

RECORD OF BOREHOLE No SS1

1 OF 1

METRIC

W.P. 280-99-00 LOCATION Coords: N:4764215.0 E:327350.7 ORIGINATED BY PK
DIST HWY 406 BOREHOLE TYPE Hollow Stem Augers COMPILED BY DB
DATUM Geodetic DATE 04.28.10 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 kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			20 40 60 80 100	W _p W W _L	20 40 60 80 100	10 20 30	GR SA SI CL		
181.8	Ground Surface													
0.0 181.6	230mm TOPSOIL													
0.2	trace rootlets		1	SS	22								44	0 1 48 51
	SILTY CLAY trace sand, trace gravel, firm to very stiff, brown / reddish brown, moist		2	SS	26									
			3	SS	18									
			4	SS	20								41	0 1 49 50
			5	SS	18									
			6	SS	20									
			7	SS	13									
			8	SS	12									
			9	SS	6									0 4 67 29
175.2 6.6	End of Borehole													
Borehole was dry (not stabilized) and hole open to full depth on completion.														
Piezometer installation consists of a 19mm diameter, Schedule 40 PVC pipe with a 1.52m slotted screen.														
Water Level Readings:														
Date Depth(m) Elevation(m)														
May.04.10 1.3 180.5														
May.06.10 1.2 180.6														
May.18.10 1.0 180.8														

RECORD OF BOREHOLE No WS2

1 OF 3

METRIC

W.P. 280-99-00 LOCATION Coords: N:4764174.7 E:327313.4 ORIGINATED BY AW
 DIST HWY 406 BOREHOLE TYPE Hollow Stem Augers / NQ Rock Coring COMPILED BY DB
 DATUM Geodetic DATE 01.28.10 - 02.01.10 CHECKED BY RA

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT W _p	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W _L	UNIT WEIGHT γ	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			20 40 60 80 100	20 40 60 80 100					
183.1 0.0	Ground Surface						183							
	firm		1	SS	7						○			

	SILTY CLAY trace sand, trace gravel, hard, brown, damp		2	SS	38		182				○	45		2 3 37 58
			3	SS	43						○			
			4	SS	36		181				○	47		0 1 51 48
			5	SS	29		180				○			
			6	SS	24		179				○			
178.7 4.4	SILT trace sand, frequent silty clay seams and partings, dense, brown, damp		7	SS	37		178				○			0 1 79 20
			8	SS	36						○			
177.2 5.9	SILTY CLAY trace sand, trace gravel, stiff to very stiff, brown, damp to moist		9	SS	21		177				○			0 5 68 27
			10	SS	22		176				○			
			11	TW	PH		174				○			
			12	SS	10		173	1.6	1.2		○			0 3 70 27
			13	SS	15		172	1.1			○			0 2 72 26
			14	SS	28		170	1.3	2.5		○			
168.4 14.7							169							

Continued Next Page

+ 3, X 3: Numbers refer to Sensitivity ○ 3% STRAIN AT FAILURE

METRIC

SOIL PROFILE				SAMPLES		GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI C
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			20 40 60 80 100		W _p	W	W _L		
								SHEAR STRENGTH kPa						
								○ UNCONFINED	+	FIELD VANE				
								● QUICK TRIAXIAL	×	LAB VANE				
								20 40 60 80 100						
									WATER CONTENT (%)					
									10	20	30			

[illegible]

Continued Next Page

+ 3, x 3: Numbers refer to Sensitivity ○ 3% STRAIN AT FAILURE

○ 3% STRAIN AT FAILURE

RECORD OF BOREHOLE No WS2

3 OF 3

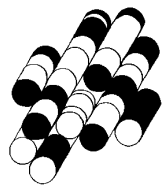
METRIC

W.P. 280-99-00 LOCATION Coords: N:4764174.7 E:327313.4 ORIGINATED BY AW
 DIST HWY 406 BOREHOLE TYPE Hollow Stem Augers / NQ Rock Coring COMPILED BY DB
 DATUM Geodetic DATE 01.28.10 - 02.01.10 CHECKED BY RA

SOIL PROFILE		SAMPLES				GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT W _p	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W _L	UNIT WEIGHT γ	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			20	40	60	80	100					
29.9	End of Borehole No sample recovery at SS12. Sampler redriven and disturbed sample collected. Unable to push vane beyond 12m. Borehole open to full depth and filled with drill water upon completion of drilling. Borehole sealed with bentonite slurry to ground surface.																

APPENDIX B

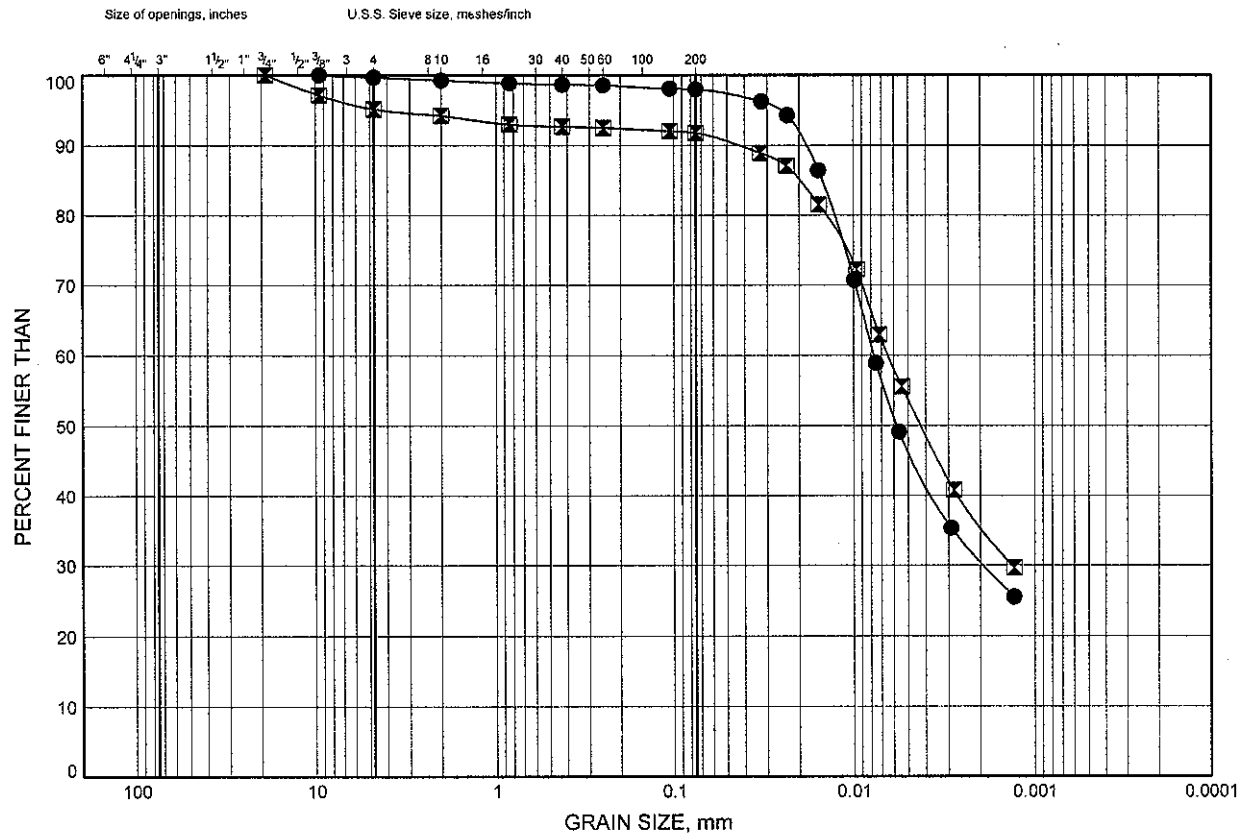
TERRAPROBE INC.



GRAIN SIZE DISTRIBUTION

FIGURE B1

FILL - Silty Clay

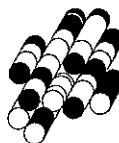


COBBLE SIZE	COARSE	FINE	COARSE	MEDIUM	FINE	SILT and CLAY
	GRAVEL		SAND			FINE GRAINED

SYMBOL	BOREHOLE	DEPTH (m)	ELEVATION (m)
●	WN4	1.0	181.5
⊠	WN4	2.5	180.0

Date May 2010

Project 1-09-4135



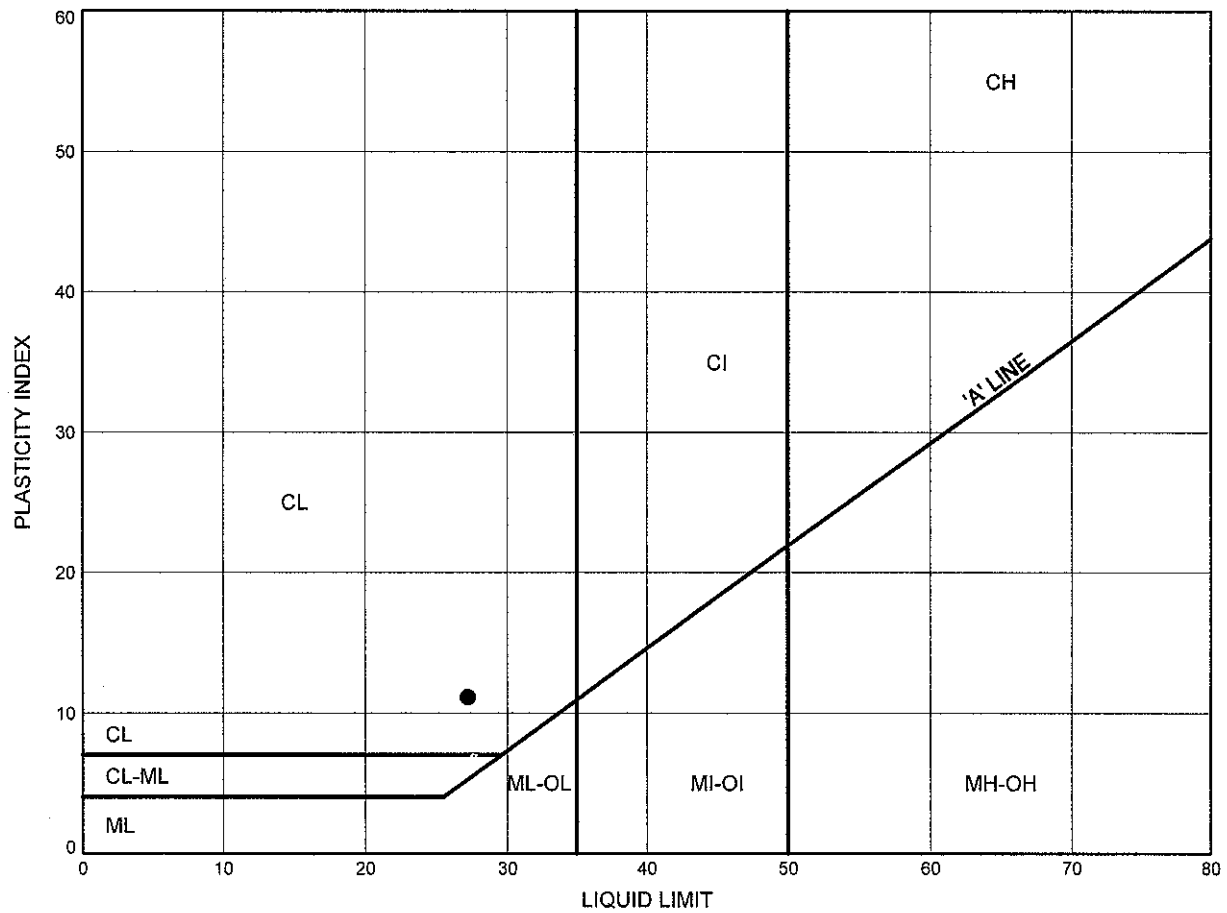
Prep'd DB

Chkd. HA

ATTERBERG LIMITS TEST RESULTS

FIGURE B2

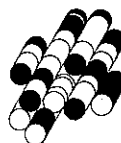
FILL - Silty Clay



SYMBOL	BOREHOLE	DEPTH (m)	ELEVATION (m)
●	WN4	1.0	181.5

Date May 2010

Project 1-09-4135



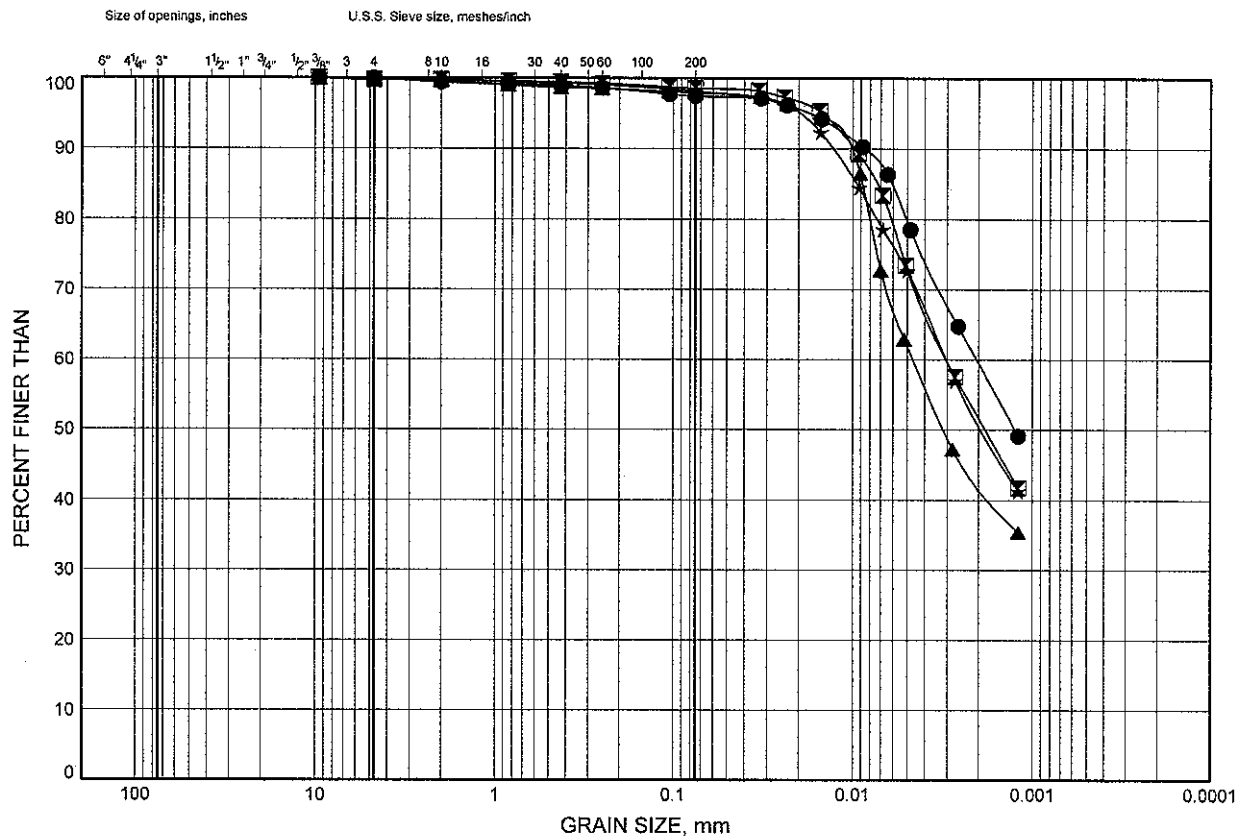
Prep'd DB

Chkd. HA

GRAIN SIZE DISTRIBUTION

FIGURE B3

SILTY CLAY



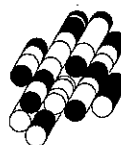
COBBLE SIZE	COARSE	FINE	COARSE	MEDIUM	FINE	SILT and CLAY
	GRAVEL		SAND			FINE GRAINED

SYMBOL BOREHOLE DEPTH (m) ELEVATION (m)

●	WM1	1.0	181.9
⊠	WM1	3.2	179.7
▲	WM1	4.0	178.9
★	WM1	6.3	176.6

Date May 2010

Project 1-09-4135



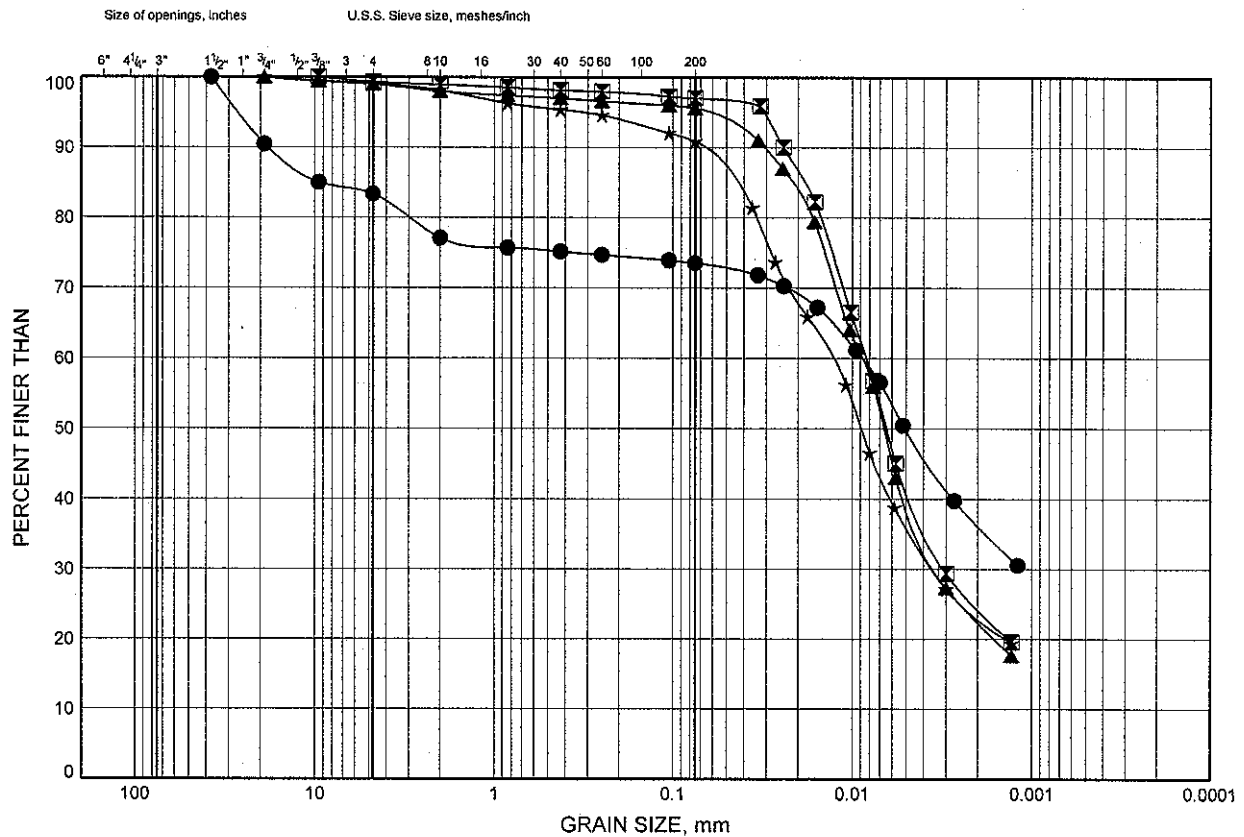
Prep'd DB

Chkd HA

GRAIN SIZE DISTRIBUTION

FIGURE B4

SILTY CLAY



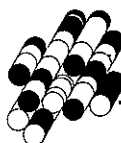
COBBLE SIZE	COARSE	FINE	COARSE	MEDIUM	FINE	SILT and CLAY
	GRAVEL		SAND			FINE GRAINED

SYMBOL BOREHOLE DEPTH (m) ELEVATION (m)

●	WN4	5.5	177.0
⊠	WN4	9.3	173.2
▲	WN4	10.9	171.6
★	WN4	13.9	168.6

Date May 2010

Project 1-09-4135



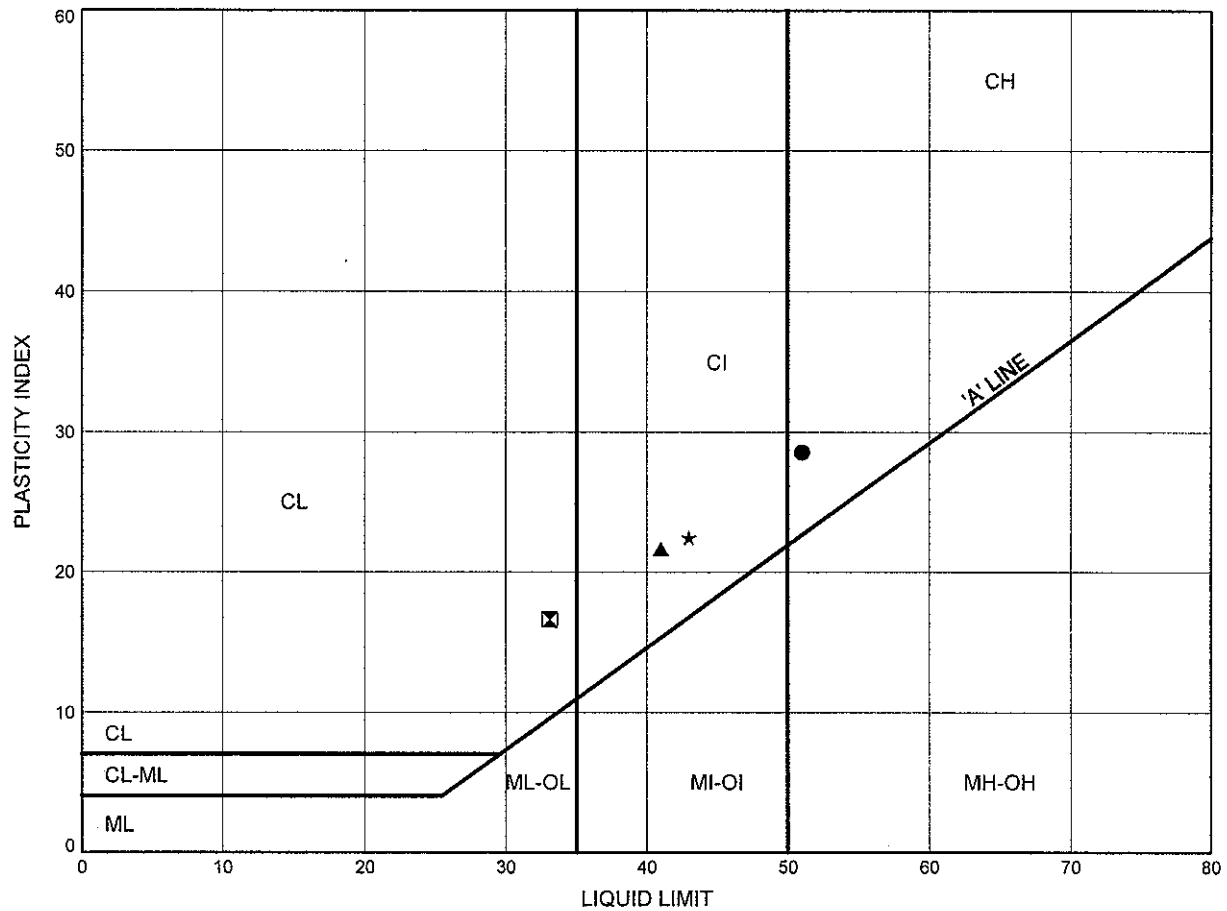
Prep'd DB

Chkd. HA

ATTERBERG LIMITS TEST RESULTS

FIGURE B5

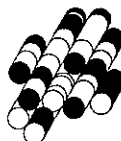
SILTY CLAY



SYMBOL	BOREHOLE	DEPTH (m)	ELEVATION (m)
●	WM1	1.0	181.9
⊠	WM1	4.0	178.9
▲	WM1	6.3	176.6
★	WN4	5.5	177.0

Date May 2010

Project 1-09-4135



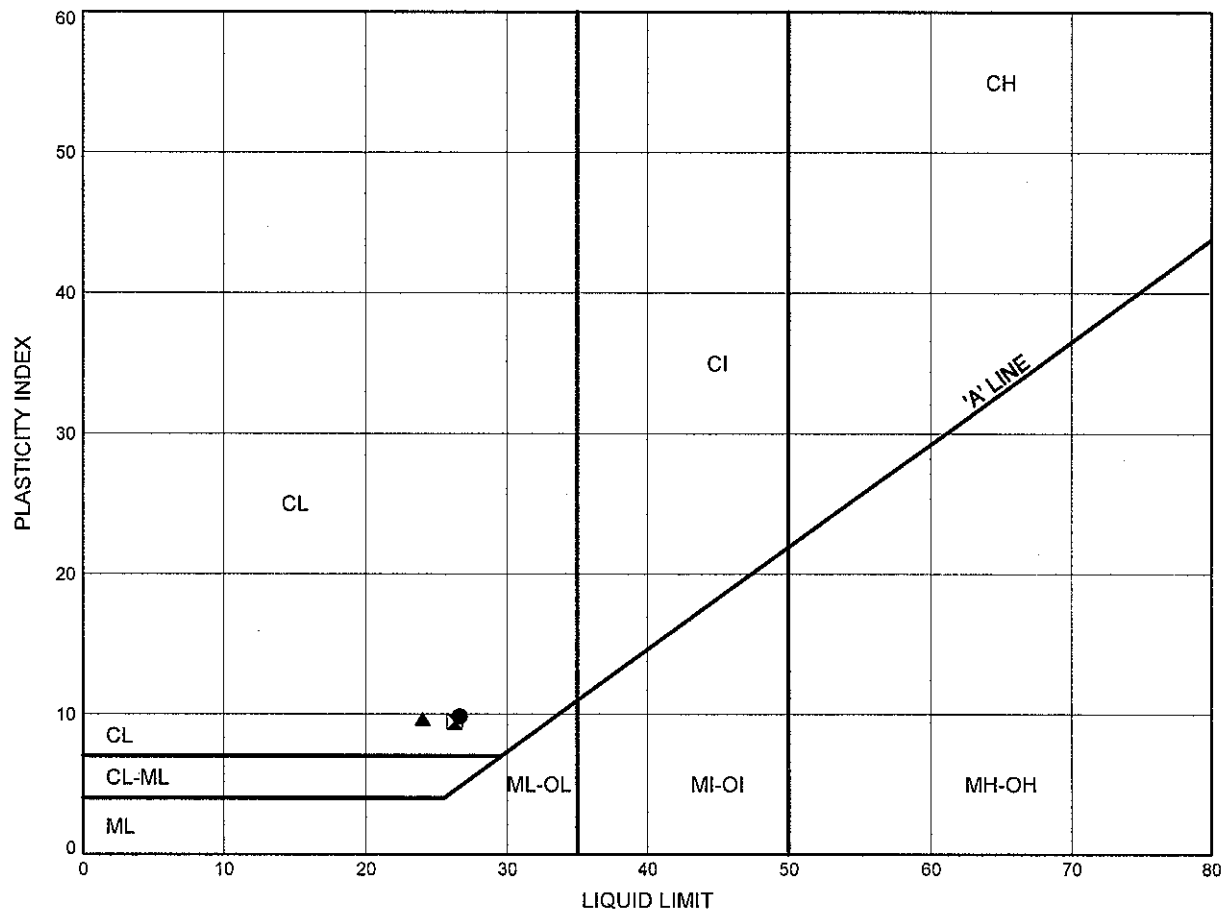
Prep'd DB

Chkd. HA

ATTERBERG LIMITS TEST RESULTS

FIGURE B6

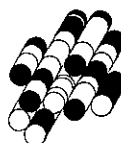
SILTY CLAY



SYMBOL	BOREHOLE	DEPTH (m)	ELEVATION (m)
●	WN4	9.3	173.2
⊠	WN4	10.9	171.6
▲	WN4	13.9	168.6

Date May 2010

Project 1-09-4135



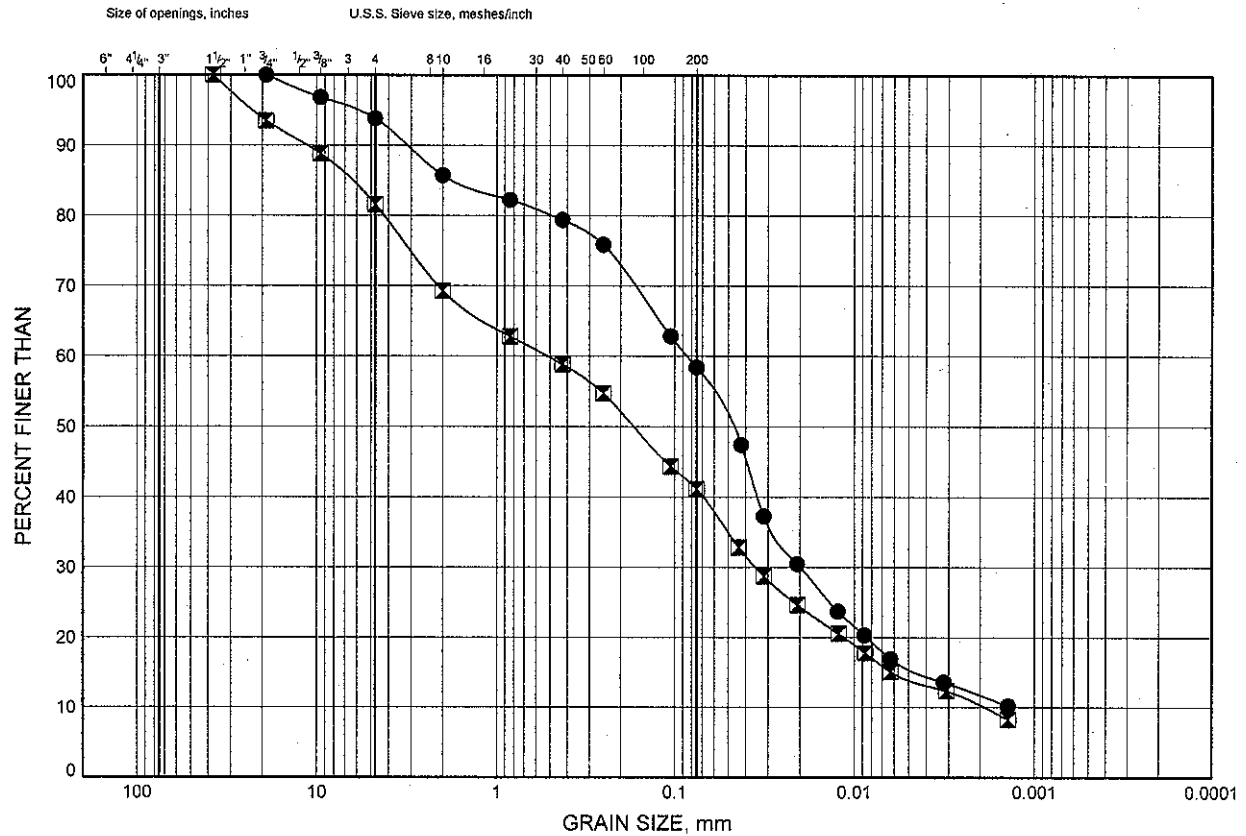
Prep'd DB

Chkd. HA

GRAIN SIZE DISTRIBUTION

FIGURE B7

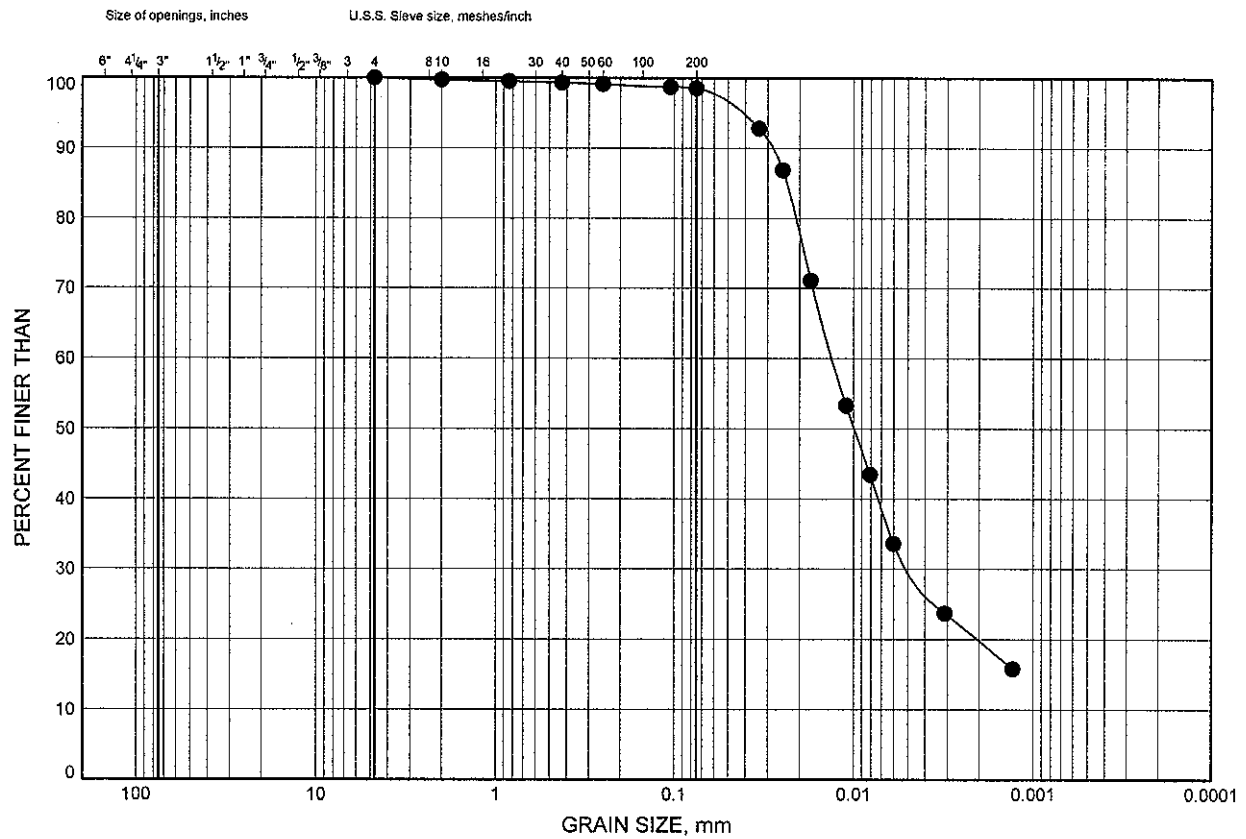
SILTY SAND TO SANDY SILT TILL



GRAIN SIZE DISTRIBUTION

FIGURE B8

SILT

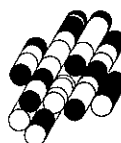


COBBLE SIZE	COARSE	FINE	COARSE	MEDIUM	FINE	SILT and CLAY
	GRAVEL		SAND			FINE GRAINED

SYMBOL	BOREHOLE	DEPTH (m)	ELEVATION (m)
●	WS2	4.7	178.4

Date May 2010

Project 1-09-4135



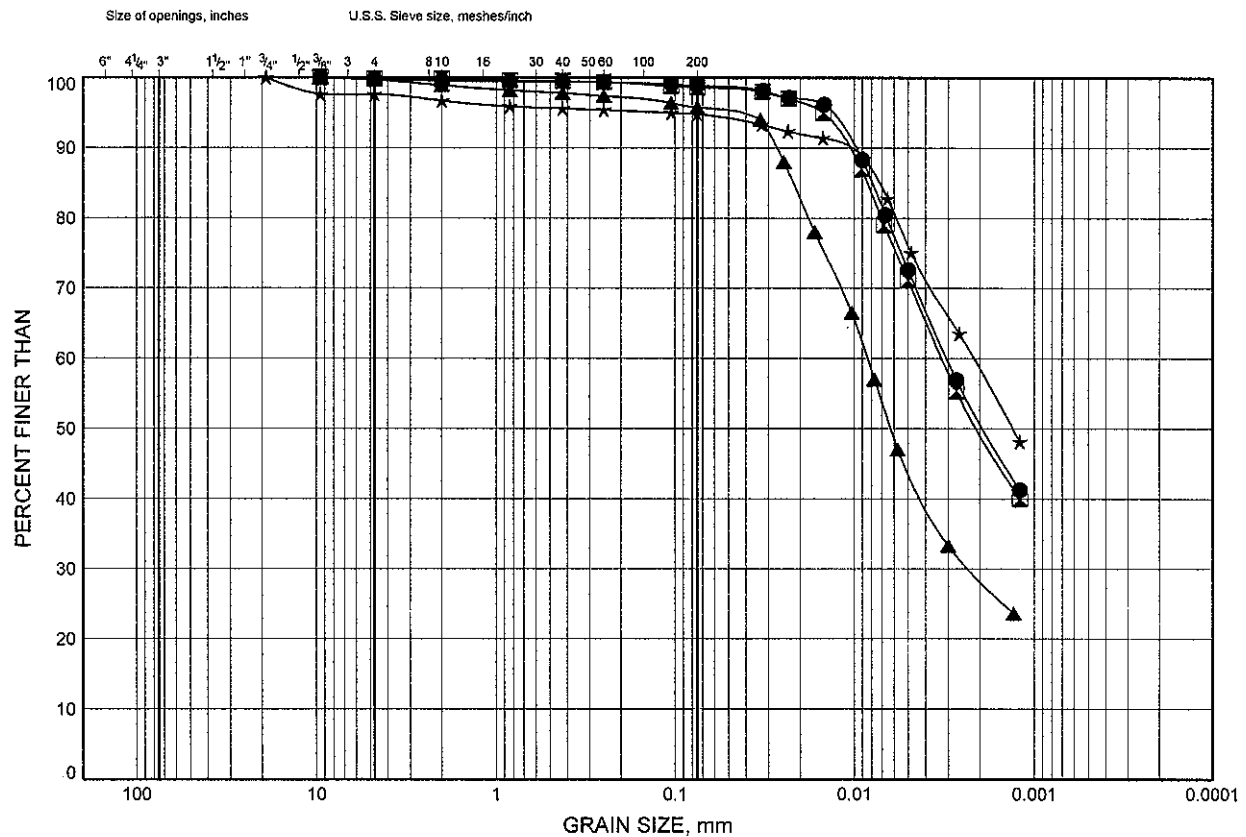
Prep'd DB

Chkd. HA

GRAIN SIZE DISTRIBUTION

FIGURE B9

SILTY CLAY



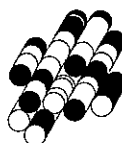
COBBLE SIZE	COARSE	FINE	COARSE	MEDIUM	FINE	SILT and CLAY
	GRAVEL		SAND			FINE GRAINED

SYMBOL	BOREHOLE	DEPTH (m)	ELEVATION (m)
--------	----------	-----------	---------------

●	SS1	0.3	181.5
⊠	SS1	2.5	179.3
▲	SS1	5.5	176.3
★	WS2	1.0	182.1

Date May 2010

Project 1-09-4135



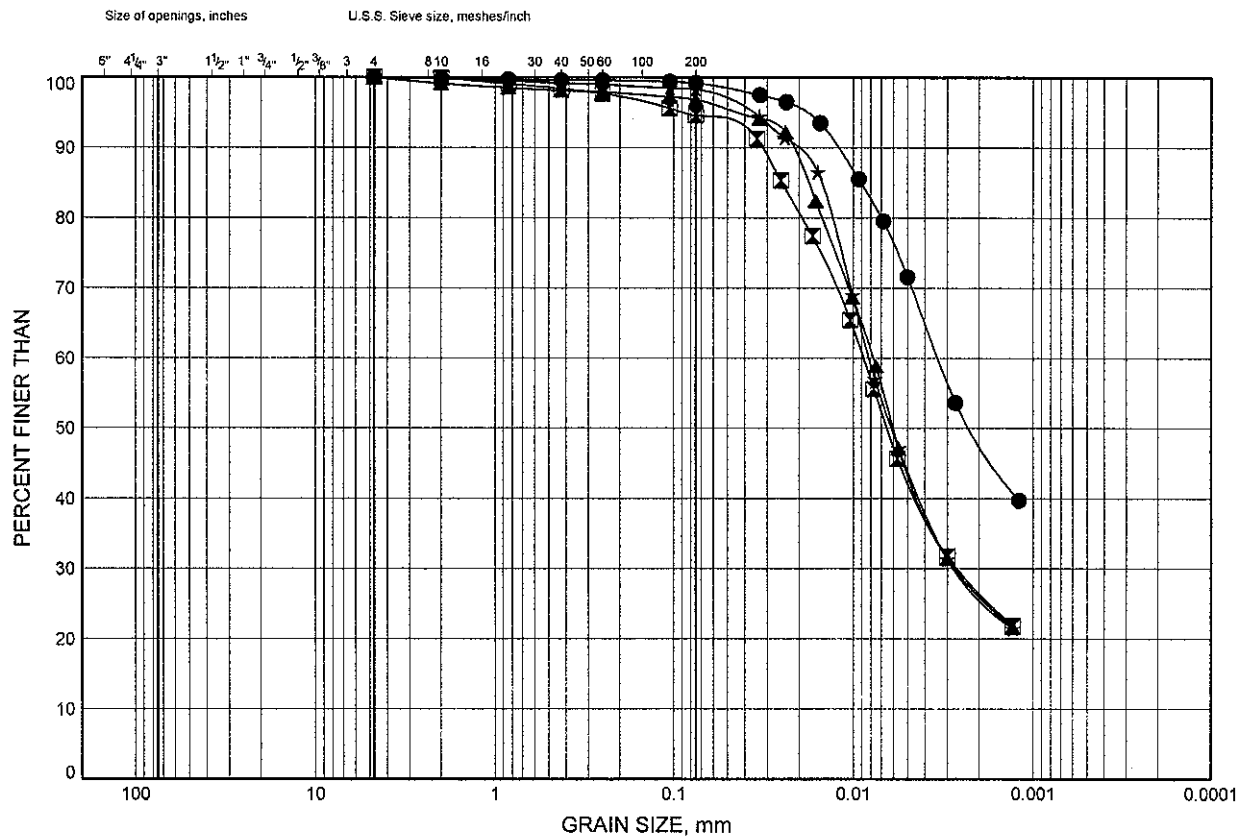
Prep'd DB

Chkd. HA

GRAIN SIZE DISTRIBUTION

FIGURE B10

SILTY CLAY

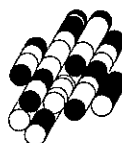


COBBLE SIZE	COARSE	FINE	COARSE	MEDIUM	FINE	SILT and CLAY
	GRAVEL		SAND			FINE GRAINED

SYMBOL	BOREHOLE	DEPTH (m)	ELEVATION (m)
●	WS2	2.5	180.6
⊠	WS2	6.3	176.8
▲	WS2	10.9	172.2
★	WS2	12.4	170.7

Date May 2010

Project 1-09-4135



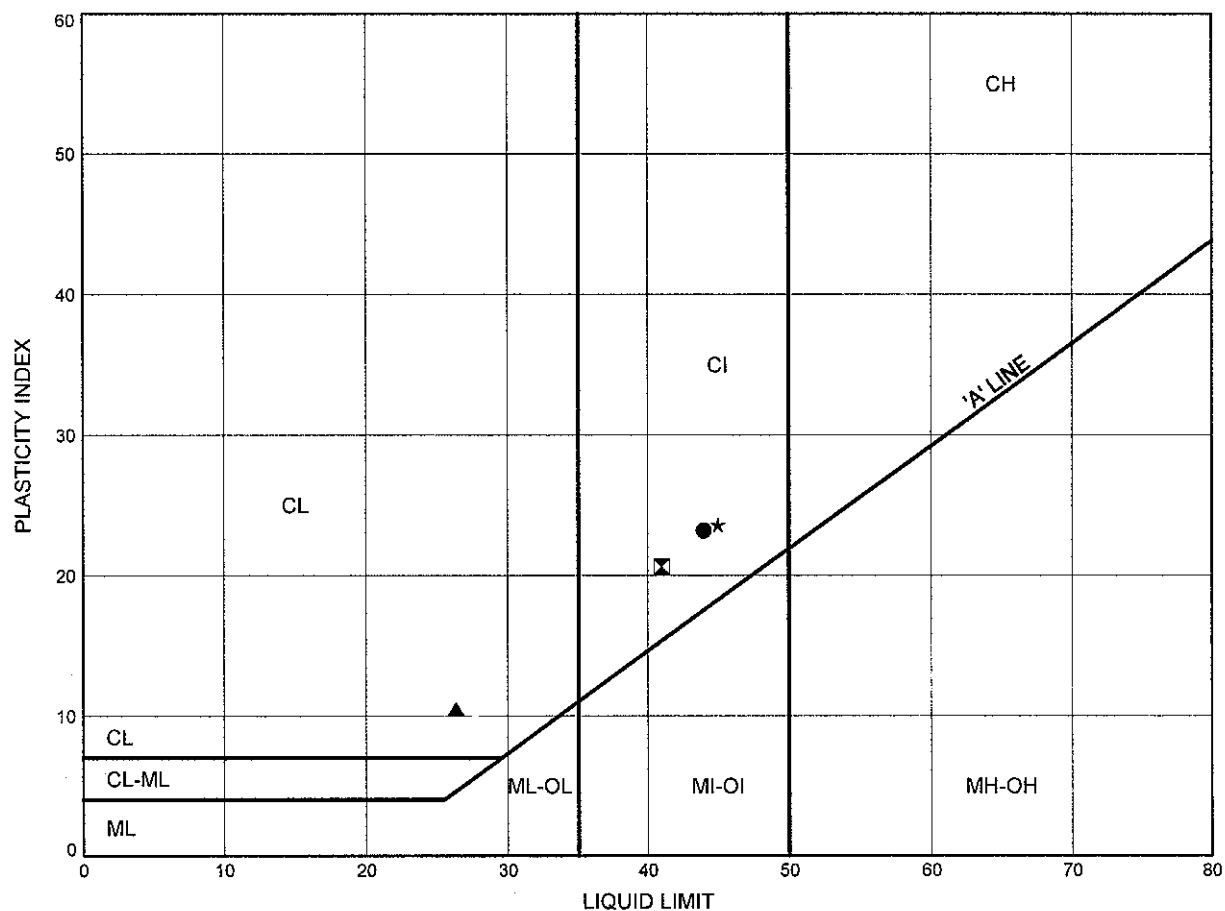
Prep'd DB

Chkd. HA

ATTERBERG LIMITS TEST RESULTS

FIGURE B11

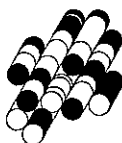
SILTY CLAY



SYMBOL	BOREHOLE	DEPTH (m)	ELEVATION (m)
●	SS1	0.3	181.5
⊠	SS1	2.5	179.3
▲	SS1	5.5	176.3
★	WS2	1.0	182.1

Date May 2010

Project 1-09-4135



Prep'd DB

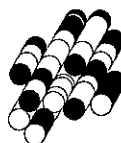
Chkd. HA

FIGURE B12

SYMBOL	BOREHOLE	DEPTH (m)	ELEVATION (m)
●	WS2	2.5	180.6
☒	WS2	6.3	176.8
▲	WS2	10.9	172.2
★	WS2	12.4	170.7

Date May 2010

Project 1-09-4135...



Prep'd DB

Chkd. HA

FIGURE B13

Size of openings, inches

U.S.S. Sieve size, meshes/inch

PERCENT FINER THAN

GRAIN SIZE, mm

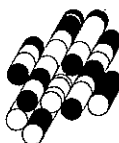
Grain Size (mm)	U.S.S. Sieve Size (meshes/inch)	Size of Opening (inches)	Percent Finer (%)
100	10	2.0	100
75	20	1.0	93
60	25	0.85	90
40	40	0.425	85
30	60	0.25	80
20	80	0.18	74
10	20	0.075	69
7.5	25	0.063	63
60	25	0.25	53
50	30	0.20	50
40	40	0.15	44
30	60	0.10	39
20	80	0.075	33
15	100	0.063	26
10	20	0.0425	23
7.5	25	0.0355	20
6.0	30	0.025	17
4.75	40	0.0375	13

COBBLE SIZE	COARSE	FINE	COARSE	MEDIUM	FINE	SILT and CLAY
	GRAVEL		SAND			FINE GRAINED

SYMBOL	BOREHOLE	DEPTH (m)	ELEVATION (m)
●	WS2	21.5	161.6

Date May 2010

Project 1-09-4135...



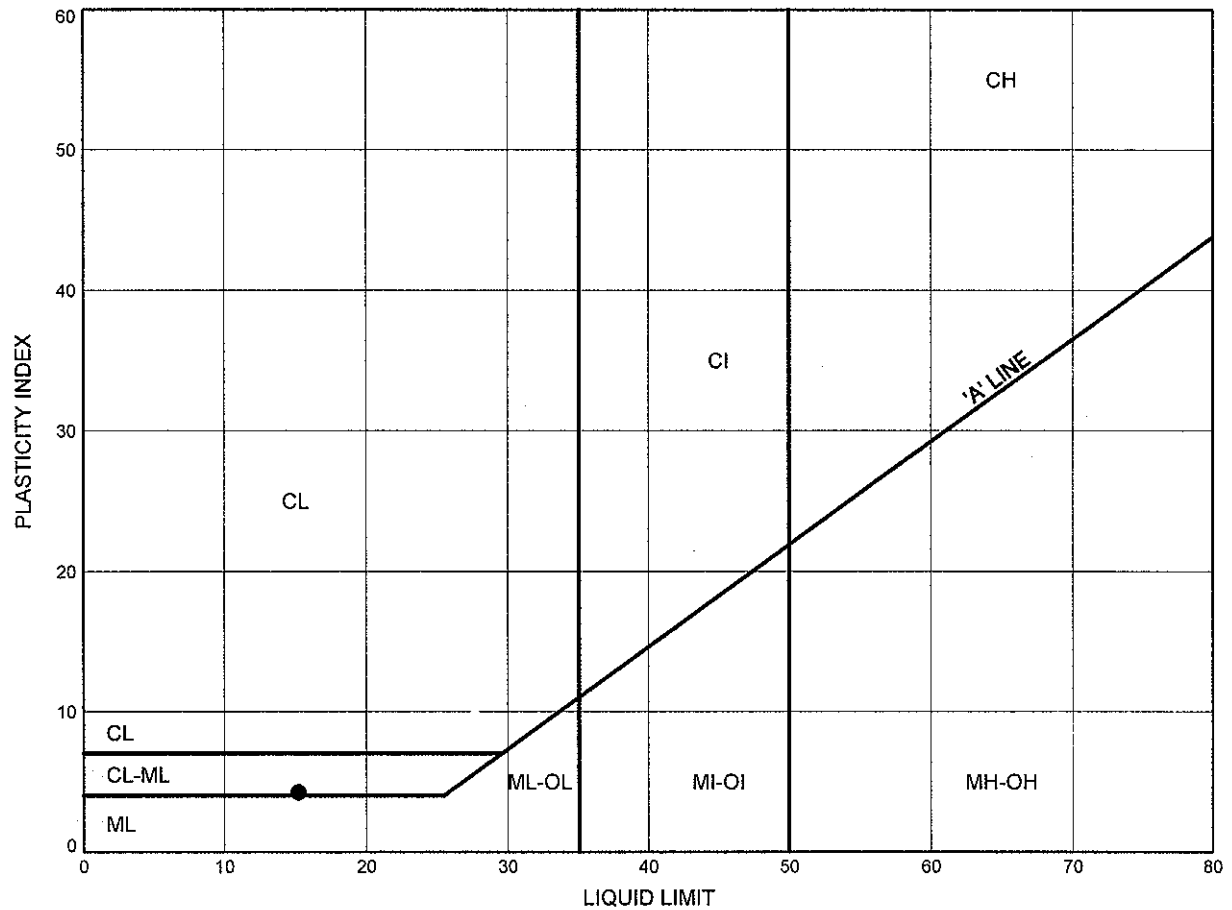
Prep'd DB.....

Chkd. HA

ATTERBERG LIMITS TEST RESULTS

FIGURE B14

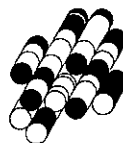
CLAYEY SILT TILL



SYMBOL	BOREHOLE	DEPTH (m)	ELEVATION (m)
●	WS2	21.5	161.6

Date May 2010

Project 1-09-4135



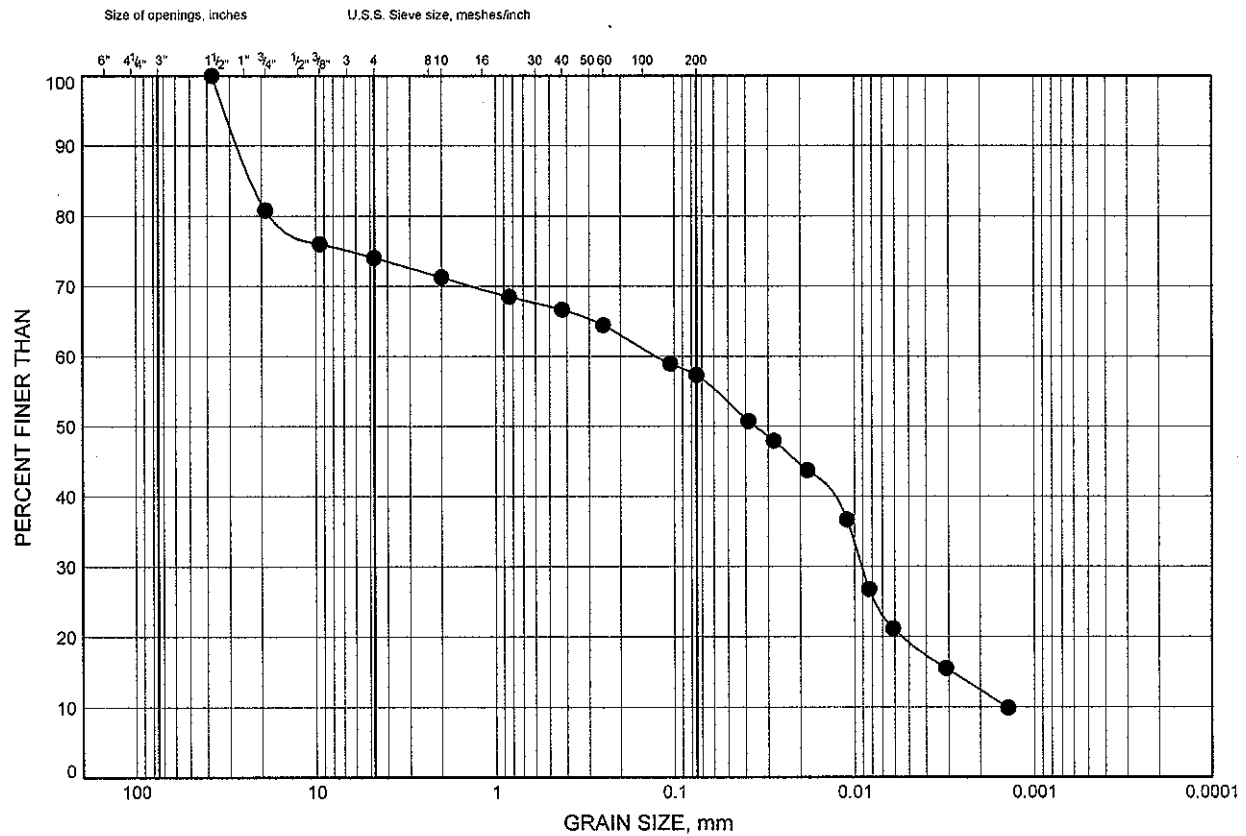
Prep'd DB

Chkd. HA

GRAIN SIZE DISTRIBUTION

FIGURE B15

SANDY SILT TILL

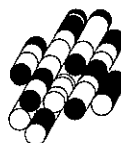


COBBLE SIZE	COARSE	FINE	COARSE	MEDIUM	FINE	SILT and CLAY
	GRAVEL		SAND			FINE GRAINED

SYMBOL	BOREHOLE	DEPTH (m)	ELEVATION (m)
●	WS2	18.5	164.6

Date May 2010

Project 1-09-4135

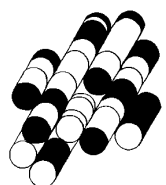


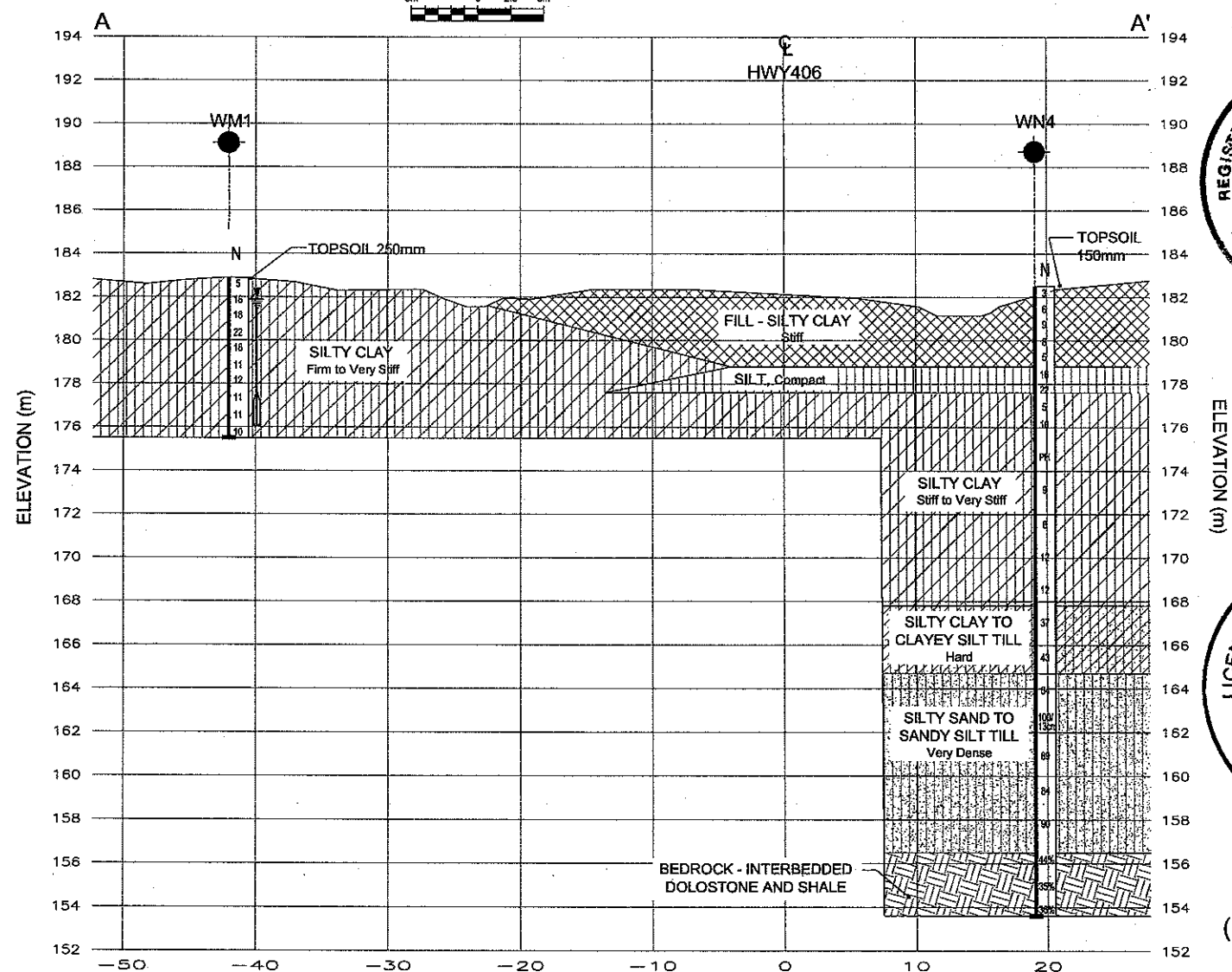
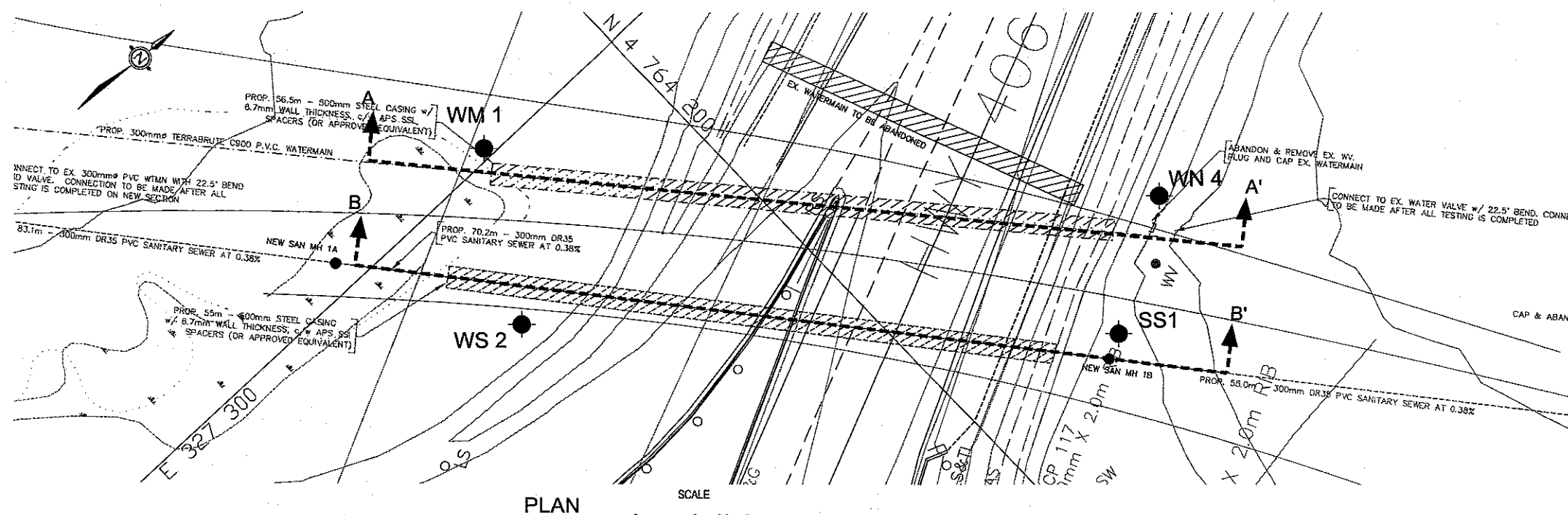
Prep'd DB

Chkd. HA

APPENDIX C

TERRAPROBE INC.





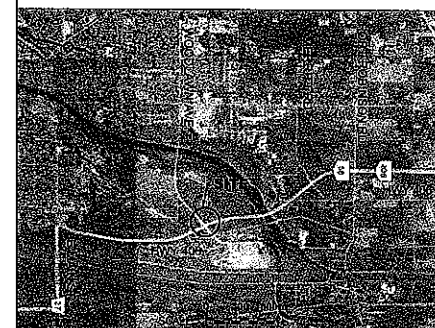
METRIC
DIMENSIONS ARE IN METRES
AND/OR MILLIMETERS
UNLESS OTHERWISE SHOWN







CONT No
WP No 280-99-00

HIGHWAY 406
CITY OF WELLAND
WATERMAIN AND SANITARY SEWER

SHEET
1 OF

Giffels Associates Limited
Consulting Engineers and Architects
An IBI Group Company



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 (MAY 2010)
	Piezometer
90%	Rock Quality Designation
A/R	Auger Refusal

No	ELEV.	COORDINATES	
		NORTHING	EASTING
WM1	182.9	4 764 185	327 299.1
WN4	182.5	4 764 228.4	327 343.4
WS2	183.1	4 764 174.7	327 313.4
SS1	181.8	4 764 215	327 350.7

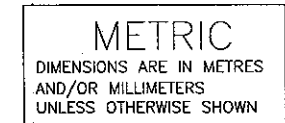
GEOCRES No. 30M3-254

NOTE

The boundaries between soil strata have been established only at Bore Hole locations. Between Bore holes the boundaries are assumed from geological evidence.

The drawing is for subsurface information only. Surface details are for conceptual illustration.

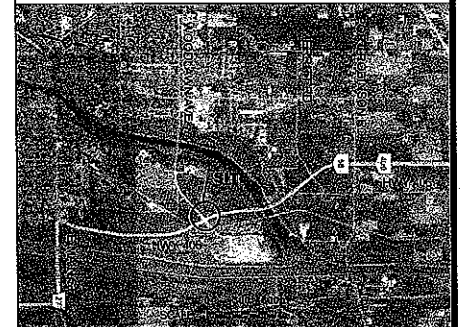
REVISIONS						
	DATE	BY	DESCRIPTION			
DESIGN	R.A.	CODE	CHBDC2006	LOAD	DATE	JUNE 201
DRAWN	J.B.	CHK	R.A.	STRICT		









CONT. No.
WP No 280-99-00

HIGHWAY 406
CITY OF WELLAND
WATERMAIN AND SANITARY SEWER

Giffels Associates Limited
Consulting Engineers and Architects
An IBI Group Company



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 (MAY 2010)
	Piezometer
90%	Rock Quality Designation
A/R	Auger Refusal

No	ELEV.	COORDINATES	
		NORTHING	EASTING
WM1	182.9	4 764 185	327 299.1
WN4	182.5	4 764 228.4	327 343.4
WS2	183.1	4 764 174.7	327 313.4
SS1	181.8	4 764 215	327 350.7

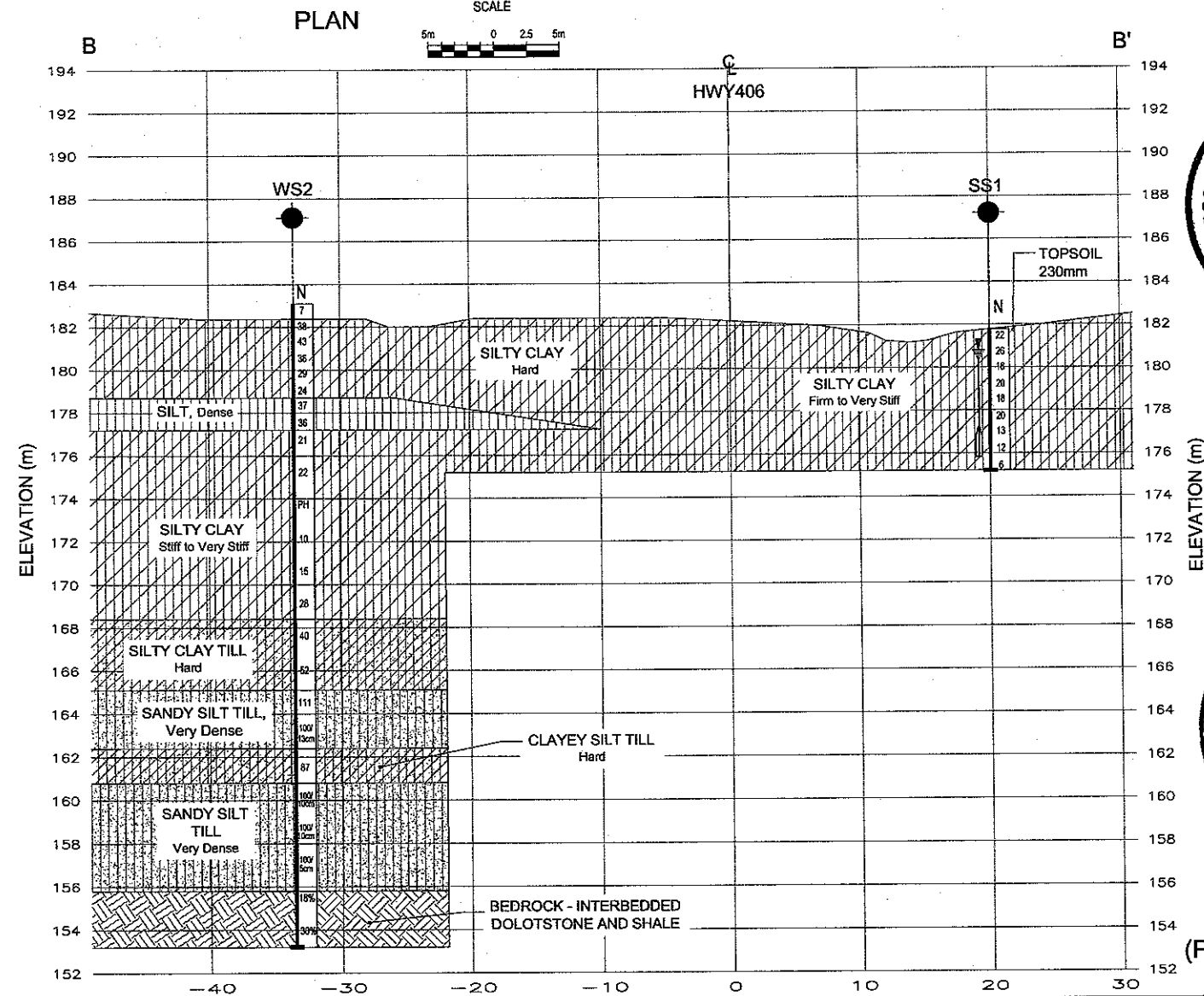
GEOCRES No. 30M3-254

NOTE

The boundaries between soil strata have been established only at Bore Hole locations. Between Bore holes the boundaries are assumed from geological evidence.

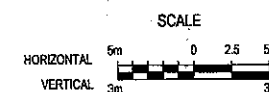
The drawing is for subsurface information only. Surface details are for conceptual illustration.

REVISIONS					
	DATE	BY	DESCRIPTION		
DESIGN	R.A	CODE	CHBDC2005	LOAD	DATE JUNE 2010
DRAWN	J.B	CHK	R.A	STRUCT	



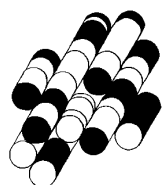
A circular professional engineer seal for the Province of Ontario. The outer ring contains the text "LICENSED PROFESSIONAL ENGINEER" at the top and "PROVINCE OF ONTARIO" at the bottom. The center of the seal is divided into three horizontal sections. The top section contains a handwritten signature "R.A. Abdul". The middle section contains the printed name "R.A. ABDUL". The bottom section contains the handwritten date "June 03, 2010".

SECTION B-B'
(Proposed Sanitary Sewer)



APPENDIX D

TERRAPROBE INC.



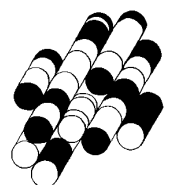
COMPARISON OF TRENCHLESS INSTALLATION METHODS

Pipe Jacking/Horizontal Auger Boring	Microtunnelling	Horizontal Directional Drilling	Pipe Ramming
<p>Advantages:</p> <ul style="list-style-type: none"> i. Avoids open cut excavation, highway closure and traffic diversion. ii. Readily available equipment/technology. iii. More economical than Microtunnelling. iv. Accuracy/Tolerance ± 25 mm. v. Relatively good control of potential settlement. <p>Disadvantages:</p> <ul style="list-style-type: none"> i. More expensive than open cut excavation. ii. Requires constructing special jacking and receiving pits. iii. Requires good care and workmanship by experienced tunnellers in order to reduce ground settlement above the existing freeway. iv. Contact with cohesionless water bearing soils can cause ground loss during tunnelling which can result in excessive ground settlement. 	<p>Advantages:</p> <ul style="list-style-type: none"> i. Avoids open cut excavation, highway closure and traffic diversion. ii. Well tested technology. iii. Smaller jacking and receiving pits compared to Pipe Jacking and Horizontal Auger Boring. iv. Accuracy/Tolerance ± 25 mm. v. Relatively good control of potential settlement. <p>Disadvantages:</p> <ul style="list-style-type: none"> i. More expensive than open cut excavation. ii. Requires constructing special jacking and receiving pits. iii. Requires good care and workmanship by experienced tunnellers in order to reduce ground settlement above the existing freeway. iv. Equipment may not be readily available. v. More expensive than Pipe Jacking 	<p>Advantages:</p> <ul style="list-style-type: none"> i. Avoids open cut excavation, highway closure and traffic diversion. ii. Readily available equipment/technology. iii. More economical than microtunnelling. iv. Does not require constructing jacking and receiving pits adjacent to the highway. v. Relatively good control of potential settlement. <p>Disadvantages:</p> <ul style="list-style-type: none"> i. More expensive than open cut excavation. ii. Casings not typically used in directional drilling because they require an additional step in the construction process and thus increase cost. iii. Requires good care and workmanship by experienced tunnellers in order to reduce ground settlement above the existing freeway. iv. Accuracy/Tolerance ± 100 mm. v. Requires careful control in order to maintain the line and grade tolerances for the sanitary sewer. vi. Relatively large area required to accommodate bore pit and to lay out pipe. 	<p>Advantages:</p> <ul style="list-style-type: none"> i. Avoids open cut excavation, highway closure and traffic diversion. ii. More economical than microtunnelling. iii. Perhaps best control over potential settlement. <p>Disadvantages:</p> <ul style="list-style-type: none"> i. Potential for significant soil disturbance if a blockage is created at the end of the pipe during installation. ii. Accuracy/Tolerance > 25 mm. iii. Relatively large area required to accommodate bore pit and to lay out pipe.



APPENDIX E

TERRAPROBE INC.



SETTLEMENT MONITORING GUIDELINE

Instruments

Two types of settlement monitoring points are required:

- Surface points are placed within the asphalt portion of the highway
- In-ground points, approximately 2 m deep, are proposed next to the outer shoulders of Highway 406 NBL and SBL of each alignment. The in-ground points are important for detecting settlements before they are transferred to the surface.

Instrumentation Arrays

In-Ground Monitoring Points

The lateral extent of the monitoring array shall cover a distance on both sides of the tunnel alignment as defined by a 45 degree line extending from one radius of the centerline at the invert level to the ground surface.

As a minimum, four (4) instrument arrays shall be utilized, two for each alignment. An array is to be installed next to the north bound and south bound shoulders perpendicular to the proposed watermain and sewer alignments. At each location the array of in-ground monitoring points should consist of a minimum of three in-ground monitors, with one point directly over the centerline of the tunnel, and one point each at approximately 3 m on either side of the tunnel.

Surface Monitoring Points

Surface monitoring points will be installed on the pavements.

Surface monitoring points will be located on each traveled lane of Highway 406 NBL, SBL as well as the dedicated right turn lane. The surface monitoring points will be identified using paint marks on the pavement.

The final instrumentation plan should be finalized when the Contractor's proposed construction method is available.

Condition Survey

A condition survey of the pavement will be carried out prior to commencement of construction and documented for the purpose of requiring restoration, if necessary. The condition survey will be carried out using the surface monitoring points installed on each travelled lane. This surface survey will be completed when the in-ground monitors and settlement points are installed and again when the tunnel has been completed. Interim surveys will be required should movement be detected in the in-ground monitoring points.



Reading Frequency

In-ground and surface monitoring points shall be read and the data recorded continually by the Contractor during the construction period. Readings shall continue to be made after construction to a time at which all parties agree that there is no further movement.

It is recommended that at least three (3) sets of readings be taken during each shift, provided that movements are within anticipated limits. Otherwise, the frequencies should increase according to a pre-planned interval.

Monitoring of movements is required during work stoppages, such as during a non-operation period (off-shifts) or weekends. At least three (3) sets of readings should be taken daily.

Data Collection and Data Transfer

A procedure is required to be established in consultation with MTO so that the monitoring data and the interpreted data will reach all parties as soon as necessary. The responsible prime Consultant and the Contractor should interpret monitoring data as needed for the purpose of on-going construction. The Geotechnical Engineer should be contacted for technical support to the prime Consultant in the interpretation of ground movements and review of the Contractor's response when Review and Alert Levels are reached.

Criteria for Assessment

The suggested acceptable surface settlement (or heave) is 10 mm, or at criteria specified by MTO. The baseline reading, alert level and review level should be established with input from MTO.

Baseline Reading – A baseline reading of the instrumentation shall be taken prior to commencement of the work. All parties should recognize and accept the baseline level in writing.

Review Level – A maximum value of 6 mm relative to the baseline readings is suggested for this project. If this level is reached, the method, rate or sequence of construction, or ground stabilization measures should be reviewed or modified to mitigate further ground displacements.

Alert Level – A maximum value of 15 mm relative to the baseline readings is suggested for this project. If this level is reached, the Contractor shall cease construction operations and execute pre-planned measures to secure the site, to mitigate further movements and to assure safety of the public and maintain uninterrupted traffic flow.

Review of Contractor's Proposed Method

The Contractor's proposed method of construction should be reviewed by MTO, the Proponent's prime consultant and Geotechnical Engineer. The proposed method should include a description of the potential loss of ground, calculation of the maximum settlement in relation to the Contractor's



procedure and equipment, alternative/remedial measures if the review level of measurement is reached; and contingency/remedial measures if the alert level of measurement is reached.

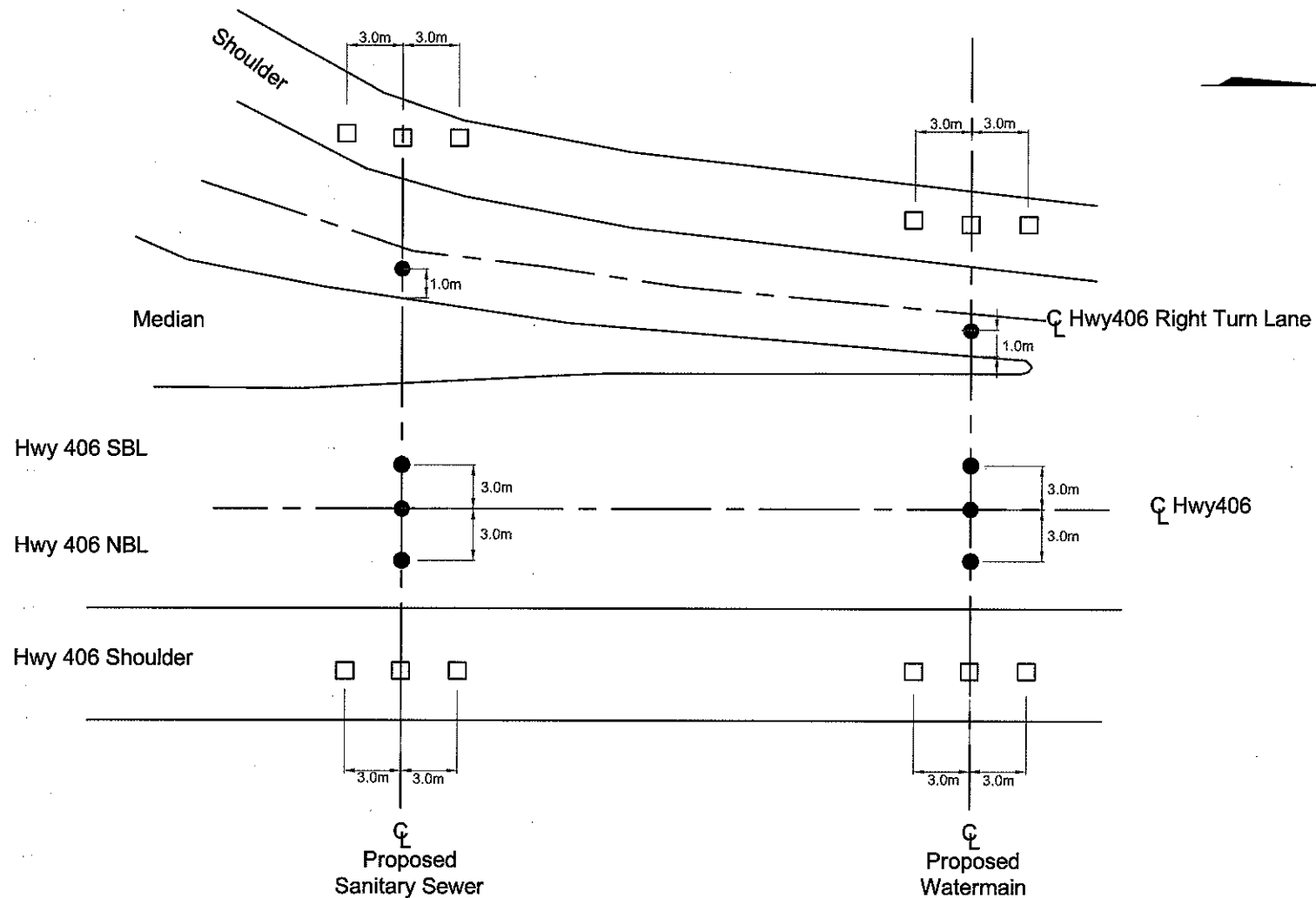
Contractor's Responsibility For Restoration and Warranty Provision

Notwithstanding the monitoring program to assess the adequacy of the tunnelling construction method to control potential ground movements and ground water, the Contractor is responsible for reinstatement (such as surface paving) should movements or other surface distresses occur. The Contract is also required to provide a reasonable warranty period for the works acceptable to MTO.

Construction Monitoring

The Proponent shall retain a qualified Geotechnical Consultant to supervise the installation of surface and subsurface settlement points on site and to provide direction, technical input and field inspection on this project.





LEGEND

- In Ground Monitoring Points
- Surface Monitoring Points

N.T.S.

INSTRUMENT ARRAY PLAN

TERRAPROBE

FIGURE E1