



# Terraprobe

*Consulting Geotechnical & Environmental Engineering  
Construction Materials Inspection & Testing*

**FOUNDATION INVESTIGATION & DESIGN REPORT  
RAMP WOODLAWN E/W-S BRIDGE AT TRILLIUM RAILWAY  
HIGHWAY 406 TWINNING  
PORT ROBINSION ROAD TO EAST MAIN STREET  
AGREEMENT No. 2008-E-0016, W.P. 280-99-00, SITE: 34-464/3  
GEOCRES NO. 30M3-258**

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## DESIGN SUMMARY

This project (W.P. 280-99-00) is the Ministry of Transportation of Ontario undertaking to twin Highway 406 from 0.2 km north of Port Robinson Road to its current terminus at East Main Street.

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

The project is located in the Regional Municipality of Niagara, City of Thorold and City of Welland, Ontario. Approximately 6.8 km of two lane staged freeway will be twinned from Sta. 9+970 to Sta. 6+545. Within the project limits Highway 406 has signalized intersections at Merritt Road, Woodlawn Road and East Main Street and one unsignalized intersection at Port Robinson Road.

A new interchange is proposed at Woodlawn Road and a single span bridge is required to carry traffic on the Woodlawn EW-S Ramp over the existing Trillium Railway track.

The main design recommendations are:

- The bridge should be supported on pile foundations.
- Downdrag loads should be considered in the foundation design if piles are installed prior to settlement being complete. Downdrag loads on the piles can be eliminated by preloading using a temporary RSS or by using EPS Geofoam.
- The soils at this site are settlement sensitive and the estimated settlement due to approach fill placement is expected to range between 90 mm and 130 mm depending on the material used. Detailed analyses indicate that after the first six months of embankment construction the remaining post-construction settlement will be equal to or less than the acceptable maximum of 25 mm. Therefore other means/methods (wick drains) of accelerating the settlement are not warranted.
- Given the uncertainty in accurately predicting the time rate of settlement we recommended that conventional temporary surcharging be carried out (2 m of additional earth fill height) to accelerate the settlement and ensure full consolidation within 6 months after embankment construction.
- Construction operations could have adverse effects on the railway track. A NSSP is required for track monitoring and repairs and requires specific inputs from Trillium Railway.

Notwithstanding the foregoing the designer is advised to review this report in its entirety to ensure that the geotechnical recommendations provided herein are adequately addressed in the designs and contract documents.



**FOUNDATION INVESTIGATION REPORT**  
**WOODLAWN E/W-S RAMP OVER TRILLIUM RAILWAY**  
**HIGHWAY 406 TWINNING**  
**ONTARIO**  
**AGREEMENT No. 2008-E-0016, W.P. 280-99-00, SITE: 34-464/3**  
**GEOCRES No. 30M3-258**

**PART 1: FACTUAL INFORMATION**

**1 INTRODUCTION**

This report presents the factual findings obtained from a foundation investigation conducted at the bridge site on the proposed Woodlawn Road E/W-S Ramp at Trillium Railway in the City of Welland, Ontario.

The purpose of this investigation was to explore the subsurface conditions at the site and, based on the data obtained, to provide a borehole location plan, records of boreholes, stratigraphic profile and cross-sections, laboratory test results and a written description of the subsurface conditions. A model of the subsurface conditions was 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.

**2 SITE DESCRIPTION & PHYSIOGRAPHY**

The site is located where the Trillium Railway crosses the existing Highway 406 at a signalized at grade intersection with Highway 406 about 250 m south of Woodlawn Road in the City of Welland, Regional Municipality of Niagara, Ontario.

At this site Highway 406 is a two-lane highway with gravel shoulders carrying both north and south bound traffic. The Trillium Railway consists of a single track that crosses Highway 406 at an approximately east to west orientation then heads north where it intersects Daimler Parkway.

The topography is generally flat and vegetation at this site consists primarily of deciduous trees and wild bush. There is a small east to west flowing watercourse located approximately 40 m south of the Trillium Railway track. This watercourse flows under Highway 406 via a 3.0 m x 1.5 m concrete box culvert which will be replaced.

The site is located between the Niagara Escarpment and Lake Erie in the physiographic region of Southern Ontario referred to as the Haldimand Clay Plain. The Haldimand Clay Plain is best described as falling into a series of parallel belts with the highest ground adjacent to the Escarpment. Generally this region is flat and poorly drained although it includes several distinctive



landforms such as dunes, cobble, clay and sand beaches, limestone pavements and back-shore wetland basins<sup>1</sup>.

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

The bedrock unit at this site is the Salina Formation of Upper Silurian Age<sup>2</sup>. 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 between November 04, 2009 and January 08, 2010 and consisted of drilling and sampling six boreholes to depths ranging from 11.2 m to 32.1 m. The boreholes were numbered WE-S 10+295CL, WE-S 10+345CL, TEW1, TEW2, TEW3, and TEW4 and their approximate locations are shown on the attached Borehole Locations and Soil Strata Drawing in Appendix C.

The borehole locations were marked in the field by surveyors from Callon Dietz Inc. who also provided Terraprobe with their coordinates and geodetic elevations. Access to some specific borehole locations was difficult due to locally steep slopes and poor ground conditions. The locations of these boreholes were selected to be as close as feasible to the staked out location while allowing safe operation of the drill rig. Terraprobe obtained utility clearances and permits prior to drilling.

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. The boreholes at the abutments 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.

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

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

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



**Table 3.1 – Piezometer Installation Details**

Piezometer Location	Piezometer Details	
	Tip Depth/ Elevation (m)	Completion Details
TEW1	15.2/167.3	Hole sealed to 15.2 m with bentonite, piezometer with 1.5 m slotted screen installed with filter sand to 12.8 m and bentonite seal from 12.8 m to ground surface.
TEW4	28.3/154.3	Hole sealed to 28.3 m with bentonite, piezometer with 1.5 m slotted screen installed with filter sand to 26.2 m and bentonite seal from 26.2 m to ground surface.
WE-S 10+345CL	12.6/170.2	Piezometer with 1.5 m slotted screen installed with filter sand to 10.7 m, bentonite seal from 10.7 m to 10.1 m, drill cuttings from 10.1 m to 0.6 m and bentonite seal from 0.6 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. Select samples were also subjected to a laboratory testing programme consisting of gradation analysis, Atterberg Limits tests, consolidation tests, unit weight and undrained shear strength testing with a laboratory vane. The results of this testing program are shown on the Record of Borehole sheets in Appendix A and the figures 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 and rock stratigraphy are presented in this appendix and on the "Borehole Locations and Soil Strata" drawings in Appendix C. An overall description of the stratigraphy is given in the following paragraphs. However, the factual data presented in the Record of Borehole Sheets governs any interpretation of the site conditions.

In general, the site is underlain by topsoil, silty clay fill and native overburden deposits of silty clay, clayey silt to silty clay till, sand, and silty sand to sand and silt till. These soils are underlain by bedrock consisting primarily of dolostone and shale of the Salina formation.

##### **5.1 Topsoil**

Topsoil ranging from 110 mm to 300 mm in thickness was encountered across the site. Topsoil thickness may vary between and beyond the boreholes.



## 5.2 Fill – Silty Clay

Silty clay fill material was encountered across this site extending to depths ranging from 0.7 m (Elev.182.1 m) to 1.4 m (Elev.181.4 m) below ground surface.

A sample of this silty clay fill was subjected to a grain size analysis and the results are presented in Figure B1. These results show a grain size distribution consisting of 0% gravel, 3% sand, 33% silt and 64% clay size particles.

A sample of the fill was also subjected to Atterberg Limits test and the results are presented in Figure B2. The index values from this test are summarized below:

Liquid Limit:	62%
Plastic Limit:	27%
Plasticity Index:	35%
Natural Moisture Content:	27%

These values are characteristic of clayey soils of high plasticity.

Standard Penetration tests in the silty clay fill gave ‘N’ values that ranged from 7 to 27 blows for 0.3 m penetration but generally ‘N’ values ranged from 7 to 10 blows for 0.3 m penetration. Based on these results the fill is considered to have a generally firm to stiff consistency with occasional very stiff zones. The moisture content of samples of this fill ranged from 18% to 40% by weight.

## 5.3 Silty Clay

A major silty clay deposit was encountered across the site. This deposit was fully penetrated in some of the boreholes where it was found to extend to depths ranging from 14.6 m (Elev. 168.0 m) to 15.8 m (Elev. 166.8 m). The approach boreholes were terminated in this deposit at depths of 11.2 m (Elev. 171.6 m) and 13.6 m (Elev. 169.2 m).

The grain size distribution plots of tested samples of the silty clay are presented in Figures B3 to B5 inclusive. These results show a grain size distribution consisting of 0-4% gravel, 1-7% sand, 52-75% silt and 23-47% clay size particles.

Samples were also subjected to Atterberg Limits tests and the results are illustrated on the plasticity charts, Figures B6 to B8 inclusive. The index values from these tests are summarized below:

Liquid Limit:	24-40%
Plastic Limit:	11-19%
Plasticity Index:	6-29%
Natural Moisture Content:	15-21%

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

Standard Penetration tests in this stratum gave ‘N’ values that ranged from 11 to 67 blows for 0.3 m penetration. Field vane tests gave in-situ undrained shear strengths ranging from 56 kPa to in excess of 100 kPa. An unconfined compression test gave an undrained shear strength of 65 kPa





and laboratory vane tests on a relatively undisturbed Shelby tube sample gave undrained shear strengths ranging from 34 to 140 kPa. These values indicate that the consistency of the silty clay is generally stiff to hard. Moisture content of samples of the silty clay range from 11% to 24% by weight and the unit weight of tested samples ranged from 20.6 to 20.8 kN/m<sup>3</sup>

The variation of undrained shear strength with elevation is depicted in Figure B13. The plot illustrates a wide scatter in the data with no obvious trend with depth. An interpreted dashed line is shown representing a lower bound trend with depth, for the data. The upper portion of this deposit up to about Elev. 177.0 m is estimated to have a relatively high undrained shear strength i.e. in excess of 100 kPa. Below Elev. 177.0 m the undrained shear strength decreases with depth and is about 55 kPa at Elev. 169.5 m. Below Elev. 169.5 m the trend indicates increasing undrained shear strength.

The Atterberg Limits tests results are also plotted against elevation, Figure B14. These results illustrate that the natural moisture contents are generally at or slightly above the plastic limits.

Consolidation tests were also performed on Shelby tube samples retrieved from Boreholes WE-S 10+295CL and WE-S 10+345CL and the results are presented in Figures B15 to B20. These results indicate an estimated preconsolidation pressure that ranges between 230 kPa and 370 kPa.

#### **5.4 Clayey Silt to Silty Clay Till**

Discontinuous layers of clayey silt to silty clay till were encountered in Boreholes TEW1 and TEW2. The thickness of these deposits range from 0.7 m to 4.7 m and these strata extend to depths ranging from 23.8 m (Elev. 158.9 m) to 24.2 m (Elev. 158.3 m) below ground surface. In Boreholes TEW3 and TEW4, the till deposit is undivided and extends to depths ranging from 24.7 m (Elev. 157.9 m) to 24.8 m (Elev. 157.8 m) below ground surface.

The grain size distribution plots of tested samples from these strata are presented in Figure B9. These results show a grain size distribution consisting of 4-12% gravel, 13-31% sand, 43-62% silt and 14-21% clay size particles. Till soils will also contain random cobble and boulder inclusions.

Six samples were also subjected to Atterberg Limits tests and the results are presented in Figure B10. The index values from these tests are summarized below:

Liquid Limit:	18-23%
Plastic Limit:	11-14%
Plasticity Index:	5-9%
Natural Moisture Content:	7-16%

These values are characteristic of clayey soils of low plasticity.

Standard Penetration tests in these deposits yielded 'N' values ranging from 30 to more than 100 blows per 0.3 m penetration. Field vane tests were also attempted in these deposits and the results (no-turn on vane) indicate undrained shear strengths more than 100 kPa. Based on these results the clayey silt to silty clay till is considered to have a very stiff to hard consistency. The moisture content of samples from these deposits varies from 7% to 16% by weight.



## 5.5 Sand

Discontinuous layers of sand and gravel to gravelly sand were encountered in Boreholes TEW1 and TEW2. These deposits are approximately 0.8 m to 1.8 m thick and extend to depths of 23.1 m below ground surface or to elevations ranging from 159.4 m to 159.6 m.

A sample from this stratum was subjected to a grain size distribution test and the results are illustrated in Figure B11. These results show a grain size distribution consisting of 32 % gravel, 56 % sand, 10 % silt and 2 % clay size particles.

Standard Penetration tests in these deposits gave 'N' values that ranged from 34 to more than 100 blows per 0.3 m penetration. Based on these results the deposits are considered to have a dense to very dense relative density. The moisture content of samples from these strata ranged from 8% to 12% by weight.

## 5.6 Silty Sand to Sand and Silt Till

A deposit of silty sand to sand and silt till was encountered across the site overlying the bedrock surface. This deposit extends to depths ranging from 28.7 m (Elev. 154.0 m) to 28.9 m (Elev. 153.7 m) below ground surface.

Samples from these deposits were subjected to grain size distribution tests and the results are illustrated in Figure B12. These results show a grain size distribution consisting of 2-26 % gravel, 38-95 % sand, 3-38 % silt and 7-8 % clay size particles. Till soils will also contain random cobble and boulder inclusions.

Standard Penetration tests in these deposits gave 'N' values that ranged from 21 to more than 100 blows per 0.3 m penetration indicating a compact to very dense relative density. The moisture content of samples from these strata ranged from 7% to 15% by weight.

## 5.7 Bedrock (Salina Formation)

The overburden soils described above are underlain by the Salina Formation. Bedrock was proved by coring at the abutment locations. Table 5.1 summarizes the bedrock depth and the elevations to the top of bedrock.

**Table 5.1 – Depth to Bedrock**

Location	BH Number	Depth to Bedrock (m)	Top of Bedrock Elevation (m)
South Abutment	TEW1	28.8	153.7
	TEW2	28.7	154.0
North Abutment	TEW3	28.9	153.7
	TEW4	28.7	153.9

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 50% to 100%. The RQD values ranged widely from 0% to 78% but generally, most of the RQD values were below 50%. Rubble and highly fractured zones were observed in the rock cores which contributed to the relatively low RQD values. The core data also reveals that there is no trend of



improving rock quality with depth. Based on these results the rock quality is considered to be very poor to poor with occasional zones of fair to good quality rock.

## 5.8 Water Levels

A standpipe piezometer was installed in selected boreholes. The water level readings measured on separate visits made after the completion of drilling are presented in Table 5.2.

**Table 5.2 – Water Level Measurements**

Borehole	Date	Water Levels	
		Depth (m)	Elevation (m)
TEW1	January 19, 2010	3.2	179.3
	January 27, 2010	2.4	180.1
	February 08, 2010	2.4	180.1
TEW4	January 11, 2010	10.2	172.4
	January 19, 2010	10.6	172.0
	January 27, 2010	10.5	172.1
	February 08, 2010	10.6	172.0
WE-S 10+345CL	November 19, 2009	4.0	178.8
	November 30, 2009	3.4	179.4
	December 07, 2009	3.1	179.7
	December 15, 2009	3.0	179.8
	January 11, 2010	2.6	180.2
	January 27, 2010	2.7	180.1

The ground water table was estimated based on the recorded water levels in the standpipe piezometers, our review of moisture contents of the retrieved samples and the change in colour of the soil matrix from brown to grey. This interpretation indicates an estimated ground water table of Elev.  $\pm 180.0$  m.

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

## 5.9 Miscellaneous

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 DBW Drilling Limited of Ajax, Ontario.

The boreholes were advanced using solid stem augers, hollow stem augers and casing and washboring methods. Rock cores were retrieved by NQ size diamond coring techniques.

Messrs. Lucas Yu, E.I.T, Marc Paoliello, E.I.T, and Alexander Winkelmann, E.I.T, carried out the field work.. The laboratory testing was performed at Terraprobe's Brampton laboratory and the Mississauga laboratory of Golder Associates. The report was written by Rehman Abdul, P.Eng. and reviewed by Michael Tanos, P.Eng.



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**WOODLAWN E/W-S RAMP OVER TRILLIUM RAILWAY**  
**HIGHWAY 406 TWINNING**  
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**PART 2: ENGINEERING DISCUSSION AND RECOMMENDATIONS**

**6 GENERAL**

This report presents interpretation of the geotechnical data in the factual report and presents geotechnical design recommendations to assist the design team to select and design a suitable foundation system and approaches for the proposed structure.

The Woodlawn EW-S Ramp will cross above the Trillium Railway track via a single span structure approximately 9.3 m wide and measuring  $\pm 18$  m in length between abutments. The proposed finished grades at the structure will be about Elev.  $\pm 192.6$  m at the south abutment and Elev.  $\pm 192.4$  m at the north bridge abutment. At the north and south abutments the approach fill will be about  $\pm 10$  m and  $\pm 11$  m high respectively.

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 STRUCTURE FOUNDATIONS**

The proposed bridge is a single span structure with two abutments as foundation elements.

The stratigraphy encountered at the abutment locations consist of 28.7 m to 28.9 m of overburden soils overlying bedrock of the Salina Formation. The overburden soils consist of a native compressible silty clay deposit that ranges in thickness from 13.9 m to 15.1 m. The ground water level at this site is about Elev.  $\pm 180.0$  m.

Consideration was given to the following foundation types:

- Spread footings
- Augered Caissons (drilled shafts)
- Driven piles

A comparison of the foundation alternatives based on advantages and disadvantages of each is included in Appendix D.



## 7.1 Spread Footings

Based on the proposed geometry a conventional abutment supported on spread footings is not considered to be a feasible and practical option since the abutment stems will be up to 10 m high. Moreover, the 10 m to 11 m high abutment fill will trigger time dependent consolidation settlements that are estimated to exceed 25 mm total settlement. Consequently, spread footings are not considered to be a feasible alternative.

## 7.2 Augered Caissons (Drilled Shafts)

The abutments could be supported on augered caissons designed to bear on bedrock. A factored, vertical, concentric, geotechnical resistance of 3,500 kPa ULS (excluding downdrag loads) is recommended for caissons founded on bedrock and the SLS condition will not govern as the bedrock is considered to be an “unyielding” stratum.

A reduced geotechnical resistance is recommended because of the generally very poor to poor rock quality. There is also no benefit in considering rock sockets as an option for achieving higher geotechnical resistances. Highly fractured zones exist within the bedrock and there is no evidence of increasing rock quality within the investigated depths.

The base elevations of end bearing caissons are given in Table 7.1.

**Table 7.1 - Base Elevations of End Bearing Caissons**

Support Location	Borehole No.	Estimated Base Elevation (m)	Founding Stratum
South Abutment	TEW1	153.7	Bedrock (Dolostone & Shale)
	TEW2	154.0	Bedrock (Dolostone & Shale)
North Abutment	TEW3	153.7	Bedrock (Dolostone & Shale)
	TEW4	153.9	Bedrock (Dolostone & Shale)

### 7.2.1 Caisson Installation

Caisson installation should be in accordance with OPSS 903, November 2009. A minimum caisson diameter of 900 mm, and as governed by applicable regulations, is required to allow down-the-hole hand cleaning and inspection.

The caisson installation will require excavations through silty clay, clayey silt to silty clay till, sand and silty sand to sand and silt till below the ground water table. Therefore, it is recommended that the caissons be constructed by using temporary steel liners to support the sidewalls and to provide seepage cut-off as and where required. This construction scheme will also allow for hand cleaning and inspection of the bearing surface.

Based on the site investigations and our visual inspections of the recovered soil samples the till soils contain random cobble inclusions. Boulders can also be expected in till soils. Therefore, the contractor should have on site adequate equipment to handle these obstructions. It is probable that some combination of augering with rock teeth, coring bits, pneumatic breakers or chisels will be required.



The concrete should be placed using good tremie techniques. The liner should be withdrawn as concrete is placed. During liner withdrawal, the level of concrete in the caisson hole must always be at least 0.5 m above the bottom of the temporary liner.

### 7.3 Driven Piles

The subsurface conditions at the site are considered suitable for the design of foundations supported on steel H-piles. Steel H-piles are likely to be driven to practical refusal in/on bedrock at both foundation elements. However, cobbles exist within the matrix of the underlying till soils and some piles may encounter effective refusal in these strata without reaching bedrock. The single span bridge is most likely to be designed with semi-integral abutments and therefore H-piles are the most suitable. Steel tube piles are much less suitable and not likely to be considered.

#### 7.3.1 Axial Resistance

The recommended factored, vertical, concentric, geotechnical resistance of an HP 310 x 110 section at ULS when driven to bedrock is 1600 kN (excluding downdrag loads). This reduced ULS value is recommended because of the very poor to poor rock quality. The bedrock is considered to be “unyielding” and the SLS condition will not govern for piles founded on bedrock. The structural resistance of the pile should be checked by the structural designer.

The approximate tip elevations of this pile section is presented in Table 7.2.

**Table 7.2 – Tip Elevations of Various Pile Sections Driven to Bedrock**

Reference Borehole	Support Location	Estimated Pile Tip Elevation (m)
<b>Pile Type - HP 310 x 110</b>		
TEW1	South Abutment	153.7±
TEW2*		154.0±
TEW3	North Abutment	153.7±
TEW4		153.9±

\* Piles may encounter refusal above bedrock.

The H-piles for the recommended foundation scheme will be driven to bedrock. Piles will be required to penetrate layers of cobbles and till layers (that may contain boulders). It is therefore recommended that the pile tips be fitted with rock points to provide increased cutting ability, reinforcement to the pile section and effective contact with bedrock.

The contract documents should contain a NSSP alerting the contractor to the fact that cobbles and boulders may be encountered in the overburden soils. Furthermore, it may not be possible to drive some piles to bedrock because of cobbles in the overburden. The NSSP should require the QVE to terminate driving before the pile is damaged by overdriving. Suggested wording for the NSSP is included in Appendix F.

#### 7.3.2 Downdrag

The construction of approximately ±10 m to ±11 m high embankments at the bridge abutments will cause settlement of the underlying soils which will in turn impart downdrag loads on piles that are installed before fill placement.



The downdrag forces imparted on HP 310 x 110 piles were estimated based on a compressible silty clay stratum that extends to Elev. 167.5 m. An unfactored load of 930 kN/pile is recommended for design.

It would be impractical to preload the underlying soils at the abutment locations in a conventional manner since the forward slopes will extend into the railway ROW and the track will have to be closed during the preloading period. A temporary retaining structure can be constructed in order to preload the soils prior to pile driving operations but this will likely be an expensive option. A permanent RSS wall can also be constructed with suitably sized CSP's installed to facilitate pile installations (within the CSP) after settlement is complete.

Alternatively, EPS Geofoam can be used (estimated volume of 24,500 m<sup>3</sup>) to reduce the magnitude of downdrag forces to a negligible amount provided that the geofoam extends a lateral distance of 30 m from the bridge abutments. Conventional earth fill can be used beyond this limit.

### 7.3.3 Integral Abutment Considerations

Since the skew is more than 20 degrees this bridge is not a candidate for a full integral abutment. However, a semi integral abutment design can be considered. The design requires that the piles possess flexibility in the upper 3 m of the pile length.

At the abutment locations the upper 10 m to 11 m of pile will lie in the RSS core. In order to provide the upper 3 m of the pile with the required flexibility, and to ensure that superstructure movement does not damage the RSS wall a 2-CSP system is recommended as per MTO SO-96-01. An outer CSP is placed around an inner sand filled CSP (about 600 mm in diameter).

The space between the pile and the inner CSP should be filled with sand. A NSSP should be included in the contract drawings specifying the gradation of the sand according to Table 7.3.

**Table 7.3 – Integral Abutment Sand Grading**

MTO Sieve Designation		Percentage Passing
2 mm	#10	100%
600 µm	#30	80%-100%
425 µm	#40	40%-80%
250 µm	#60	5%-25%
150 µm	#100	0%-6%

### 7.3.4 Lateral Resistance

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

$$k_s = n_h \cdot z / D \text{ [cohesionless soils] (kN/m}^3\text{)}$$

$$k_s = 67 S_u / D \text{ [cohesive soils] (kN/m}^3\text{)}$$

$$p_{ult} = 3 \cdot \gamma \cdot z \cdot K_p \text{ [cohesionless soils] (kPa)}$$

$$p_{ult} = 9 S_u \text{ [cohesive soils] (kPa)}$$





where  $z$  = depth of embedment of pile (m)  
 $D$  = pile width (m)  
 $S_u$  = undrained shear strength (Table 7.4) (kPa)  
 $n_h$  = coefficient of horizontal subgrade reaction (Table 7.4) (kN/m<sup>3</sup>)  
 $\gamma$  = unit weight (Table 7.4) (kN/m<sup>3</sup>)  
 $K_p$  = passive earth pressure coefficient

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

The spring constant,  $K$ , for analysis may be obtained by the expression,  $K = k_s \times L \times D$  (kN/m), where  $k_s$  is the coefficient of horizontal subgrade reaction (kN/m<sup>3</sup>),  $D$  is the pile width (m) and  $L$  is the length (m) of the pile segment or element used in the analysis. The ultimate lateral resistance,  $P_{ult}$ , may be obtained from the expression,  $P_{ult} = p_{ult} \times L \times D$ .

**Table 7.4 – Recommended Soil Parameters**

Area Reference Borehole No	Applicable Elevation	Soil Type	Bulk Unit Weight (kN/m <sup>3</sup> )	Angle of Internal Friction ( $\phi$ ) Degrees	Undrained Shear Strength ( $S_u$ ) (kPa)	Recommended $n_h$ Value (kN/m <sup>3</sup> )*
South Abutment TEW1	182.3 – 181.8	Fill – Silty Clay	18	0	40	-
	181.8 – 167.3	Silty Clay	20	0	100	-
	167.3 – 163.3	Clayey Silt/Silty Clay Till	21	0	200	-
	163.3 – 162.5	Sand	20	35	–	10000
	162.5 – 161.2	Clayey Silt Till	21	0	225	-
	161.2 – 159.4	Sand	20	35	–	10000
	159.4 – 158.3	Silty Clay Till	21	0	225	-
	158.3 – 153.7	Sand and Silt Till	21	35	–	9000
South Abutment TEW2	182.4 – 182.0	Fill – Silty Clay	18	0	40	-
	182.0 – 167.8	Silty Clay	20	0	100	-
	167.8 – 163.1	Clayey Silt/Silty Clay Till	21	0	200	-
	163.1 – 162.3	Sand	20	35	–	10000
	162.3 – 160.8	Clayey Silt Till	21	0	225	-
	160.8 – 159.6	Sand	20	35	–	10000
	159.6 – 158.9	Silty Clay Till	21	0	225	-
	158.9 – 154.0	Sand Till	21	35	–	9000
North Abutment TEW3	182.5 – 181.9	Fill – Silty Clay	18	0	40	-
	181.9 – 166.8	Silty Clay	20	0	100	-
	166.8 – 157.9	Clayey Silt/Silty Clay Till	21	0	225	-
	157.9 – 153.7	Silty Sand Till	21	35	–	9000
North Abutment TEW4	182.5 – 181.9	Fill – Silty Clay	18	0	50	-
	181.9 – 168.0	Silty Clay	20	0	100	-
	168.0 – 157.8	Clayey Silt/Silty Clay Till	21	0	225	-
	157.8 – 153.9	Silty Sand Till	21	35	–	9000

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

Since the piles are end bearing, the vertical resistance will not be significantly affected by the pile spacing. Pile interaction should be considered with reference to CHBDC Clause 6.8.9.2.

For lateral soil/pile group interaction analysis, the equation for  $k_s$  quoted in this section may be used in conjunction with appropriate reduction factors.



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

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

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

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

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

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

Intermediate values may be obtained by interpolation. For conventional abutments, the lateral resistance may be provided by battered piles.

### 7.3.5 Pile Tips

Due to the presence of till layers that may contain cobbles and boulders, the tips of all piles should be fitted with H-section rock points from an approved manufacturer such as Titus Steel Company (Standard “H” bearing pile point) or Associated Pile & Fitting Corp (APF Hard Bite).

The use of rock points is recommended for the following reasons:

- The piles will be penetrating into soil containing cobbles and boulders, which requires a higher level of protection.
- This requirement will assist the piles to fully penetrate zones of cobbles to achieve refusal and effective contact with the bedrock.

### 7.3.6 Pile Installation

Pile installation should be in accordance with OPSS 903, November 2009. The Contract Documents should contain a NSSP alerting the Contractor to the presence of cobbles and boulders in the till soils. Pile installation could also cause disturbance of the railway track and a NSSP is required to address track monitoring and repair. Specific inputs will be required from Trillium Railway.



### **7.3.7 Pile Driving**

Note No. 6 from Article 3.3.3 Pile Driving Notes in the MTO Structural Manual should be used on the Foundation Drawing, i.e. "Piles to be fitted with rock points and driven into bedrock in accordance with OPSS 903, November 2009".

Hammers used for pile installation must be capable of installing the piles to the depths specified in the contract documents. Since the piles will be seated on bedrock the hammer used must also be capable of delivering a controlled blow in 10% increments ranging in energy from zero to the maximum hammer energy. A typical hammer energy of 60 kilojoules/blow, with an energy transfer (efficiency) of 40% is recommended.

### **7.4 Recommended Foundation**

The use of H-piles at the abutments allows for the design of a semi-integral abutment structure. From a geotechnical point of view, it is recommended that all foundations for this bridge be supported on steel H-piles.

### **7.5 Frost Cover**

Pile caps and footings should be provided with a minimum of 1.2 m of earth cover over the footing base (founding elevation).

## **8 EXCAVATION AND BACKFILL**

### **8.1 General**

All excavations must be carried out in accordance with the Occupational Health and Safety Act (OHSA). For the purposes of the OHSA, the native soils at this site may be classified as Type 2 soils above the water table and Type 4 soils below the water table. Excavations may be sloped at 2H:1V.

### **8.2 Foundations**

The excavation and backfilling for foundations must be carried out in accordance with OPSS 902, November 2009.

## **9 GROUND WATER CONTROL**

The local ground water level at this site exists at about Elev.  $\pm 180.0$  m and it is unlikely that excavations will extend below the ground water level.

If dewatering is required the design of the unwatering system should be the responsibility of the Contractor. A suitable system that might be employed can include gravity drainage and pumping from strategically placed filtered sumps.



Any accumulation of water from the base of excavations should be removed prior to placing concrete or compacting fill. Placement of concrete or compacting engineered fill must be done in the dry.

## 10 APPROACH EMBANKMENTS

### 10.1 Stability

Embankments constructed at conventional 2H:1V slopes in the Niagara area have historically performed below par. Shallow surficial failures usually occur on the face of these slopes thereby requiring frequent maintenance in order to prevent more significant deep-seated failures.

Recent studies conducted by the Ministry indicate that these shallow surficial failures occur because of the mineralogy of the local soils and its inherent effect on the effective shear strength of the local clay fill. Poor performance was also attributed to climatic effects including precipitation, wetting and drying cycles, snow melt and freezing and thawing cycles.

The historical performance of existing embankments was considered when selecting approach embankment alternatives for this bridge and the options that were considered are:

- Embankments constructed with local earth borrow.
- Embankments constructed with rock fill.
- Embankments constructed with SSM imported from a designated source.
- Reinforced Earth Embankments.
- Embankments constructed with light weight and ultra light weight fill.

The global, internal and surficial stability of the embankments will depend on their slope geometries and also to a large degree on the material used to construct the embankment. For the purpose of embankment stability analyses, the commercially available slope stability program Slide 5.0 developed by Rocscience Inc. was used. The Janbu, Morgenstern-Price and Bishop's simplified method for stability analysis were employed and a minimum target factor of safety of 1.3 was established. The soil parameters used for the slope stability analyses are presented in Table 10.1 and the minimum factors of safety obtained for the various embankment options are included in Table 10.2.

**Table 10.1 – Soil Parameters**

Material Type	Short-Term Analysis			Long-Term Analysis		
	$\phi$ (degrees)	$c$ (kPa)	$\gamma$ (kN/m <sup>3</sup> )	$\phi'$ (degrees)	$c'$ (kPa)	$\gamma$ (kN/m <sup>3</sup> )
Local Earth Fill	31	0	19.0	31	0	19.0
Rock Fill	42	0	19.0	42	0	19.0
Select Subgrade Material	32	0	20.0	32	0	20.0
Light Weight Fill*	35	0	14.5	35	0	14.5
Ultra Light Weight Fill*	35	0	11.5	35	0	11.5
Silty Clay	0	55 – 150	20.0 – 20.5	27 – 29	5 – 7	20.0 – 20.5
Silty Clay Till	0	200	21.0	27	5	21.0

\* Pelletized Blast Furnace Slag – Reference: Lafarge Canada Inc.



**Table 10.2 – Factors of Safety**

<b>Embankment Composition</b>	<b>Design Side Slope</b>	<b>Minimum Factor of Safety Short-Term</b>	<b>Minimum Factor of Safety Long-Term</b>
Local Earth Fill	3H:1V	2.0	1.9
Rock Fill	1.25H:1V	1.3	1.3
SSM	2H:1V	1.4	1.4
RSS Embankment (local earth fill)	2H:1V	1.7	1.5
Light Weight Fill	2H:1V	1.6	1.6
Ultra Light Weight Fill	2H:1V	1.6	1.6

The analysis indicates that the factors of safety with respect to shallow surficial failures in the embankment fill and deep seated failures in the underlying soils will be equal to or greater than the target factor of safety of 1.3 for the recommended design side slopes.

Where earth fill, SSM or light weight fill embankments are higher than 8 m, mid-height berms should be incorporated in the design. The berms should:

- extend for the length through which the embankment height exceeds 8 m
- be at least 2 m wide
- have 2% positive drainage to shed run-off water.

Where rock fill embankments are higher than 10 m, mid-height berms should be incorporated in the design. The berms should:

- extend for the length through which the embankment height exceeds 10 m
- be at least 2 m wide
- have 2% positive drainage to shed run-off water.

## **10.2 Settlement**

To predict the magnitude and time rate of settlement of the underlying silty clay soils the commercially available program Settle 3D developed by Rocscience Inc. was used. The highest embankment sections (next to the bridge approaches) were selected as critical sections.

The deformation parameters used for the analyses were established from data obtained from consolidation tests as well as from predictions based on undrained shear strengths, laboratory index tests and soil moisture contents.

Pre-consolidation pressures were estimated from the consolidation test e-log p curves and the Strain-Energy method proposed by Becker (1987). The empirical correlation suggested in the literature by Skempton (1957) was also used to estimate preconsolidation pressures. Profiles of the preconsolidation pressure design lines versus elevation are illustrated in Figure E1. The vertical effective overburden stress is also plotted on these figures.

Values of the compression index ( $C_c$ ) and recompression index ( $C_r$ ) were estimated from the consolidation tests as well as from laboratory index test data using empirical correlations proposed in literature by Kulhawy & Mayne (1990), Terzaghi & Peck (1967), Nagaraj & Murty (1985) and Das (1993). Profiles of the design lines versus elevation are shown on Figures E2 and E3.



Initial void ratio ( $e_o$ ) values were estimated from the consolidation tests as well as from empirical correlations proposed in the literature by Cozzolino (1961), and Azzouz et al (1976). A profile of the design line versus elevation is shown in Figure E4.

The data indicates that an over-consolidated desiccated upper crust exists within the silty clay stratum. The parameters used for the settlement calculations are tabulated below. There is a wide scatter in the data. The two rows of data for  $P_c$  represent the range of values for the upper and lower half of the two strata.

**Table 10.3 – Settlement Parameters**

Parameter	Upper Silty Clay	Lower Silty Clay
Preconsolidation Pressure Range - $P_c$ (kPa)	600 to 450 500 to 400	450 to 300 400 to 300
Coefficient of Compressibility - $C_c$	0.19 to 0.22	0.15 to 0.18
Recompression Index - $C_r$	0.03	0.02 to 0.025
Initial Void Ratio - $e_o$	0.9	0.7

Settlement analyses were undertaken for various embankment compositions and geometries and the estimated range of total settlements are provided in Table 10.4 and in Figure E5. Where the loads induced by the embankments do not exceed the estimated preconsolidation pressure the recompression index ( $C_r$ ) was used for settlement calculations. Where the embankment loads exceed the preconsolidation pressure the analysis was based on soil recompression and consolidation and both the recompression index ( $C_r$ ) and the coefficient of consolidation ( $C_c$ ) were used.

**Table 10.4 – Approach Embankments Centreline - Estimated Consolidation Settlements**

Type of Fill	Unit Weight of Fill ( $kN/m^3$ )	Side Slope Geometry	Settlement (mm)
Local Earth Fill	19.0	3H:1V	115 – 130
Rock Fill	19.0	1.25H:1V	115 – 130
Select Subgrade Material	20.0	2H:1V	115 – 130
Lightweight Fill*	14.5	2H:1V	95 – 110
Ultra Lightweight Fill*	11.5	2H:1V	90 – 100
EPS Geofoam	0.31	2H:1V	Negligible

\* Pelletized Blast Furnace Slag – Reference: Lafarge Canada Inc.

The approach embankments comprised of local earth fill or select subgrade material, will also settle during construction (fill compression) and this settlement is expected to be about 1% of the fill height. This settlement should be immediate in nature and essentially be complete shortly after construction is complete. The lightweight and ultra lightweight fill is expected to settle about 0.5% of the fill height. For rock fill, compression is expected to be:

- 0.5% of fill height for embankments up to 5 m high,
- 0.75% of fill height for embankments of 5 to 10 m high,
- 1% of fill height for embankments of 10 to 15 m high.



The length of time required to complete consolidation settlement of the underlying soils is a function of the value of the coefficient of consolidation of the native silty clay strata and the assumed depth of drainage path. Given the heavily over-consolidated and likely fractured nature of the silty clay soils above the water table, it is reasonable to assume that consolidation/recompression will occur quickly in this layer and that the rate of consolidation will be primarily controlled by the coefficient of consolidation and thickness of the underlying silty clay stratum below the water table. The coefficient of consolidation was estimated to range between  $6.0 \times 10^{-3} \text{ cm}^2/\text{s}$  and  $1.2 \times 10^{-2} \text{ cm}^2/\text{s}$ .

Tabulated below is the range of predicted settlements (below embankment centreline) at various time periods after embankment construction.

Ramp Woodlawn E/W-S Ramp					
Embankment Type	Settlement At Various Time Periods (mm)				Total Settlement (mm)
	6 months	12 months	18 months	24 months	
Local Earth Fill	100 – 110	110 – 120	115 – 125	115 – 130	115 – 130
Rock Fill	100 – 110	110 – 120	115 – 125	115 – 130	115 – 130
Select Subgrade Material	100 – 110	110 – 120	115 – 125	115 – 130	115 – 130
Lightweight Fill	85 – 95	90 – 100	95 – 105	95 – 110	95 – 110
Ultra Lightweight Fill	75 – 85	80 – 90	85 – 95	90 – 100	90 – 100

It is understood that a maximum allowable post-construction settlement of about 25 mm would be considered acceptable. This data shows that after 6 months, the post-construction consolidation settlement will be 25 mm or less (required performance) for all embankment material types. Therefore other means/methods (wick drains) of accelerating the settlement are not warranted. However, a settlement monitoring program (Appendix G) must be conducted to confirm the anticipated settlement performance.

Given the uncertainty in accurately predicting the time rate of settlement, we recommend that conventional temporary surcharging be carried out (2 m of additional earth fill height) to accelerate the settlement and ensure full consolidation within the target 6 months after embankment construction (Figures H1 to H3). Surcharged embankments were analysed for stability in accordance with the recommended side slopes and the analyses yielded factors of safety greater than a target factor of safety of 1.3.

Temporary surcharging will require a temporary retaining system to retain the forward slopes of the fill at the abutments. The temporary retaining system can consist of either gabion baskets or stacked concrete blocks installed with a 1H:1V inclination (Figure H4).

### 10.3 Embankment Construction

It is recommended that the topsoil, any deleterious material and soft/loose and other unsuitable soils be removed within an envelope given by an imaginary slope not steeper than 1H:1V from the toe of the proposed embankment. Borrow material must meet the requirements of OPSS 212, (2008). Grading shall be undertaken in accordance with OPSS 201, (2007) and OPSS 206, (2009).



The recommended stripping depths and elevations of the proposed embankments are:

Location	Average Stripping Depth (m)	Recommended Stripping Elevation (m)
North Approach	±0.3	±182.5
South Approach	±0.3	±182.5

After stripping, the exposed soils should be inspected, approved and properly compacted from the surface in accordance with OPSS 501. Embankment construction should be in accordance with OPSS 501 and OPSS 206.

Wet silty clay soils at this site will be weakened when subjected to construction traffic. To facilitate construction operations in inclement weather (when stripping to the recommended elevation) surface water runoff should be controlled by gravity drainage and a system of interceptor trenches. In wet weather an approximately 200 mm thick free draining granular layer would also be required to minimize disturbance and maintain trafficability of construction equipment.

Proper erosion control measures should be implemented both during construction and permanently. Temporary erosion and sediment control must be provided in accordance with OPSS 577. Fill slopes must be provided with permanent erosion protection in accordance with OPSS 571 and/or OPSS 572.

It is also imperative that the designs include provisions for preventing the flow of surface water down the face of slopes. Surface water must be directed to armoured outfalls/outlets designed to drain into roadside ditches.

## 11 RETAINED SOIL SYSTEMS

The general arrangement drawings indicate that retaining walls will be used at both abutments to retain the forward slope of the approach fills. The soils at this site are settlement sensitive and this aspect must be taken into account when designing RSS walls for this site.

A standard one-stage MSE wall is not recommended because the facing panels cannot accommodate the estimated settlement. However, a two-stage RSS system can be used at this site for a false abutment as well as for wing walls. This RSS system has provisions for constructing a cast-in-place facing after settlement is complete

RSS walls should be specified to be “High Performance” and “High Appearance”. The contract drawings should include information on the longitudinal alignment of the wall in plan, the top and base elevations of the wall in profile, cross-sectional space constraints and a NSSP for the RSS wall. The design, supply, and construction of RSS should be in accordance with SP 599S22. Materials quality control and quality assurance testing and acceptance criteria for precast concrete facing elements should be in accordance with SP 599S23.





## 11.1 Foundation

The performance of an RSS is dependent, among other factors, on the characteristics of its foundation. Failure to provide an adequate foundation may lead to settlement and distortion of the RSS and, in severe cases, to possible failure of the system.

At this site, it is recommended that the levelling pad be centred on top of a pad of engineered fill consisting of OPSS Granular A compacted in accordance with the OPSS 501, Method A. The engineered fill pad should be at least 500 mm thick and should be at least twice as wide as the levelling pad.

In addition to the requirements for the levelling pad, the RSS can be founded on the native silty clay or well compacted approach fill. All topsoil, organics and soft soils should be removed from the subgrade of the RSS wall prior to placement of the fill. The founding subgrades should be inspected and evaluated by the Quality Verification Engineer (QVE), at the time of construction.

The recommended geotechnical resistances and construction details for the proposed RSS walls are tabulated below.

RSS Location	RSS Wall Base Elev. (m)	Max. Wall Height (m)	Required SLS Bearing Resistance (kPa)	Recommended Geotechnical Resistances (kPa) **		Relevant Borehole & Subgrade Soil	Additional Requirements
				ULS	SLS		
North Abutment Face	±182.0	9.0	265	475	N/A*	TEW3/TEW4 Silty Clay	Settlement monitoring required.
South Abutment Face	±182.0	9.0	265	475	N/A*	TEW1/TEW2 Silty Clay	Settlement monitoring required.

\* Settlement will be greater than 25 mm and a geotechnical resistance for 25 mm settlement is not provided.

\*\* ULS values are factored.

The settlement of RSS walls founded on native soils at this site will depend on the material used, the foundation soils and the quality of construction. Time dependent consolidation settlement will occur in the underlying silty clay deposit and the total settlement at the abutment locations (where a vertical wall is proposed) is expected to range between 100 mm and 110 mm. The facing should be designed to accommodate the settlements outlined in Table 10.4 and a 12 month target time for facing installation is recommended. However, the timing for installation will be contingent upon approval by the geotechnical engineer and the contract documents should contain an NSSP for this aspect of the work.

The following parameters may be used for the design of the RSS:

- Bearing resistance for the levelling pad on engineered fill:
  - Factored ULS 150 kPa, SLS 100 kPa
- Ultimate coefficient of sliding resistance of cast in-situ concrete levelling pad on Granular A = 0.70
- Ultimate coefficient of sliding resistance of RSS mass on Granular A = 0.70
- Ultimate coefficient of sliding resistance of RSS mass on native silty clay = 0.5



The entire block of reinforced earth must also be designed against various modes of failure including sliding and overturning.

## **11.2 Global Stability**

The global stability of the RSS wall is dependent on the characteristics of the embankment fill and the foundation soils, the geometry of the embankment and location of the RSS within the embankment. The RSS wall will be in the form of a rectangular block from ground surface extending to the full height, or in the form of a triangular wedge resting on a lower embankment slope. RSS walls are likely to be used for a false abutment and could also be used as wing walls at the abutments.

Stability analyses on selected configurations were carried out considering the following variables:

- RSS founded at the base of the embankment on native stiff to hard silty clay soils.
- Fill behind the RSS is horizontal.
- RSS block with full retained height and block width (length of RSS reinforcement) equal to 70% of the height.
- Water Level at Elev.  $\pm 180.0$  m.

Analysis carried out on RSS walls located at the base of the embankment next to the abutment locations indicates that a minimum anchor length equivalent to 70% of the wall height is required in order to obtain a target factor of safety of 1.3 or greater.

Consequently, it may be assumed that RSS walls founded at the base of the embankment will be stable against global failure. For an RSS wall founded in the embankment slope, the specific geometry and soil conditions must be analyzed to determine the requirements for global stability. The actual design configuration must be checked for global stability prior to finalization.

The internal stability of the RSS wall should be analyzed by the supplier/designer of the proprietary product selected for this site.

## **12 BACKFILL TO ABUTMENTS**

In the case of integral or semi-integral abutments, backfill to the abutment should be granular material. In the case of a conventional abutment, granular backfill is recommended but rock backfill can be permitted. A NSSP is required to specify grading limits for the rock fill. The rock fill used as backfill to the abutment should be limited to fragments no greater than 250 mm and should include adequate spalls to fill voids in the rock fill.

In all cases where the approach embankment consists of rock fill and granular backfill to the abutment wall is used, the granular backfill must consist of OPSS Granular B Type II.

The backfill to the abutment walls should be in accordance with OPSS 902. Granular backfill should be placed to the extents shown in OPSD 3101.150, and rock backfill should be placed to the extents shown in OPSD 3101.200.



All granular material should meet the specifications of Special Provision 110S13 “Amendment to OPSS 1010, April 2004”.

Compaction equipment to be used adjacent to retaining structures should be restricted in accordance with Special Provision 105S10 “Amendment to OPSS 501, February 1996”.

The design of the abutment should incorporate a subdrain as shown in OPSD 3101.150 or OPSD 3101.200, as applicable.

### 13 EARTH PRESSURE

For cases where backfill to the abutment is placed in accordance with OPSD 3101.150 or OPSD 3102.200, as recommended, the lateral earth pressure will be governed by the properties of the material within the backfill limits shown in the respective OPSD, i.e. a line projected up at 1.5H:1V for granular backfill and 1.25H:1V for rock backfill.

If the support system allows yielding of the wall (unrestrained system), active horizontal earth pressure may be used in the geotechnical design of the structure. If the support system does not allow yielding (restrained system), at-rest horizontal earth pressures should be used. The amount of wall movement required for the development of active, passive and at-rest earth pressures may be interpreted using Figure C6.9.1(a) in the Commentary to the CHBDC.

Earth pressures acting on the structure should be computed in accordance with Clause 6.9 of the CHBDC but generally are given by the expression:

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

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

$K$  = earth pressure coefficient (see table 13.1)

$\gamma$  = unit weight of retained soil (see table 13.1)

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

$q$  = value of any surcharge (kPa)

In accordance with Clause 6.9.3 of the CHBDC, a compaction surcharge should be added. The magnitude should be 12 kPa at the top of fill and decreasing to 0 kPa at a depth of 1.7 m for Granular B Type I or at a depth of 2.0 m for Granular A or Granular B Type II.

Earth pressure coefficients for backfill to the abutment wall are dependent on the material used as backfill. Typical values are given in Table 13.1.



**Table 13.1 – Earth Pressure Coefficients**

Wall Condition	Earth Pressure Coefficient (K)					
	OPSS Granular A or OPSS Granular B Type II $\phi = 35^\circ; \gamma = 22.8 \text{ kN/m}^3$		OPSS Granular B Type I $\phi = 32^\circ; \gamma = 21.2 \text{ kN/m}^3$		Rock Fill $\phi = 42^\circ; \gamma = 19.0 \text{ kN/m}^3$	
	Horizontal Surface Behind Wall	Sloping Surface Behind Wall (2H:1V)	Horizontal Surface Behind Wall	Sloping Surface Behind Wall (2H:1V)	Horizontal Surface Behind Wall	Sloping Surface Behind Wall (2H:1V)
Active (Unrestrained Wall)	0.27	0.40*	0.30	0.48*	0.20	0.28*
At Rest (Restrained Wall)	0.43	-	0.47	-	0.33	-
Passive (Movement Towards Soil Mass)	3.70	-	3.30	-	5.0	-

\* For wing walls.

In conventional design, the use of a material with a high friction angle and low active pressure coefficient (e.g. Granular A, Granular B Type II) might be preferred as it results in lower earth pressures acting on the wall. In the case of integral or semi-integral abutments, material with a lower passive pressure coefficient (e.g. Granular B Type I) might be preferred as it results in lower forces acting on the ballast wall as the wall moves toward the soil mass. However, the use of Granular B Type I may be restricted if the approach embankment consists of rock fill.

The factors in the table above are “ultimate” values and require certain movements for the respective 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.

## 14 SEISMIC CONSIDERATIONS

### 14.1 Seismic Design Parameters

The site is treated as lying in Seismic Zone 0. The following seismic parameters (Welland ) should be used for design:

- Velocity Related Seismic Zone 0
- Zonal Velocity Ratio 0
- Acceleration Related Seismic Zone 1
- Zonal Acceleration Ratio 0.05
- Peak Horizontal Acceleration 0.08

The soil profile type at this site has been classified as Type I. Therefore, according to Table 4.4.6.1 of the CHBDC, a Site Coefficient “S” (ground motion amplification factor) of 1.0 should be used in seismic design.



## 14.2 Liquefaction Potential

The potential for liquefaction of the foundations soils was assessed using the Seed and Idriss (1971) method<sup>1</sup>. There is no potential for liquefaction of the foundation soils below the abutments.

Furthermore, since the foundation loads will be transferred by steel piles to bedrock, the vertical geotechnical resistance of the piles will not be compromised.

The immediate approach embankments will bear on stiff to hard silty clay soils above the ground water level and therefore there is negligible potential for soil liquefaction below the embankments. Some toe failure may occur but is expected to be limited and readily repairable.

## 14.3 Retaining Wall Dynamic Earth Pressures

In accordance with Clause 4.6.4 of the CHBDC, retaining structures should be designed using active ( $K_{AE}$ ) and passive ( $K_{PE}$ ) earth pressure coefficients that incorporate the effects of earthquake loading.

In calculating the active, passive and at rest earth pressure coefficients the angle of friction between the wall and backfill material is assumed to be  $0.5 \phi$ . For the design of retaining walls, the coefficients of horizontal earth pressure in Table 14.1 may be used:

**Table 14.1 – Earth Pressure Coefficient for Earthquake Loading**

Earth Pressure Coefficient (K) for Earthquake Loading						
Wall Condition	Granular A or Granular B Type II $\phi = 35^\circ$ ; $\delta = 17.5^\circ$ $\gamma = 22.8 \text{ kN/m}^3$		OPSS Granular B Type I $\phi = 32^\circ$ ; $\delta = 16^\circ$ $\gamma = 21.2 \text{ kN/m}^3$		Rock Fill $\phi = 42^\circ$ ; $\delta = 21^\circ$ $\gamma = 19.0 \text{ kN/m}^3$	
	Horizontal Surface Behind Wall	Sloping Surface Behind Wall (2H:1V)	Horizontal Surface Behind Wall	Sloping Surface Behind Wall (2H:1V)	Horizontal Surface Behind Wall	Sloping Surface Behind Wall (2H:1V)
Active ( $K_{AE}$ )*	0.28	0.45	0.32	0.55	0.21	0.30
Passive ( $K_{PE}$ )	3.69	-	3.26	-	5.05	-
At Rest ( $K_{OE}$ )**	0.53	-	0.58	-	0.44	-

\* After Mononobe and Okabe, passive case assumes a horizontal surface in front of the wall.

\*\* After Woods

## 15 CONSTRUCTION CONCERNS

During construction, the Contract Administrator should employ experienced geotechnical staff to observe construction activities related to foundation construction.

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

<sup>1</sup> Seed, H.B. and Idriss, I.M. 1971, "Simplified Procedure for Evaluating Soil Liquefaction Potential" *Journal of Soil Mechanics and Foundations Division*, ASCE, Vol. 101, No. SM9, September, pp. 1249-1273.



- the potential for construction (pile driving operations and settlement of the underlying soils) to have adverse effects on the railway track e.g. track settlement/heave and distortions of rail geometry. A NSSP should be prepared for track monitoring and repairs with specific inputs from Trillium Railway.
- the possibility of piles encountering cobbles and boulders and "hanging up" before reaching bedrock.
- the nature and geotechnical properties of the local earth fill used in the approach fills.

*R. Abdul*

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



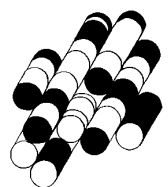
*Michael Tanos*

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



# TABLE

**TERRAPROBE INC.**



**TABLE 1**

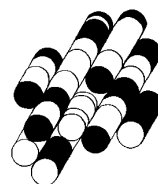
<b>DOCUMENT</b>	<b>TITLE</b>
OPSS 201	Construction Specification for Clearing, Close Cut Clearing, Grubbing and Removal of Surface and Piled Boulders.
OPSS 206	Construction Specification for Grading.
OPSS 212	Construction Specification of Borrow.
OPSS 501	Construction Specification for Compacting.
OPSS 571	Construction Specification for Sodding.
OPSS 572	Construction Specification for Seed and Cover.
OPSS 577	Construction Specification for Temporary Erosion and Sediment Control Measures.
OPSS 902	Construction Specification for Excavation & Backfilling of Structures
OPSS 903	Construction Specification for Deep Foundations
OPSS 1010	Material Specifications for Aggregates, Select Subgrade, Backfill
OPSD 3101.150	Walls, Abutment Backfill – Min. Granular Requirement
OPSD 3101.200	Walls, Abutment Backfill – Rock





# APPENDICES

**TERRAPROBE INC.**



## 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

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

### MECHANICAL PROPERTIES OF SOIL

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

## PHYSICAL PROPERTIES OF SOIL

$\rho_s$	kg/m <sup>3</sup>	DENSITY OF SOLID PARTICLES	e	1.0%	VOID RATIO	$e_{min}$	1.0%	VOID RATIO IN DENSEST STATE
$\gamma_s$	kN/m <sup>3</sup>	UNIT WEIGHT OF SOLID PARTICLES	n	1.0%	POROSITY	$I_D$	1	DENSITY INDEX = $\frac{e_{max} - e}{e_{max} - e_{min}}$
$\rho_w$	kg/m <sup>3</sup>	DENSITY OF WATER	w	1.0%	WATER CONTENT	D	mm	GRAIN DIAMETER
$\gamma_w$	kN/m <sup>3</sup>	UNIT WEIGHT OF WATER	$S_r$	%	DEGREE OF SATURATION	$D_n$	mm	n PERCENT - DIAMETER
$\rho$	kg/m <sup>3</sup>	DENSITY OF SOIL	$w_L$	%	LIQUID LIMIT	$C_u$	1	UNIFORMITY COEFFICIENT
$\gamma$	kN/m <sup>3</sup>	UNIT WEIGHT OF SOIL	$w_p$	%	PLASTIC LIMIT	h	m	HYDRAULIC HEAD OR POTENTIAL
$\rho_d$	kg/m <sup>3</sup>	DENSITY OF DRY SOIL	$w_s$	%	SHRINKAGE LIMIT	q	m <sup>2</sup> /s	RATE OF DISCHARGE
$\gamma_d$	kN/m <sup>3</sup>	UNIT WEIGHT OF DRY SOIL	$I_p$	%	PLASTICITY INDEX = $(w_L - w_p)$	v	m/s	DISCHARGE VELOCITY
$\rho_{sat}$	kg/m <sup>3</sup>	DENSITY OF SATURATED SOIL	$I_L$	1	LIQUIDITY INDEX = $(w - w_p)/I_p$	i	1	HYDRAULIC GRADIENT
$\gamma_{sat}$	kN/m <sup>3</sup>	UNIT WEIGHT OF SATURATED SOIL	$I_c$	1	CONSISTENCY INDEX = $(w_L - w)/I_p$	k	m/s	HYDRAULIC CONDUCTIVITY
$\rho'$	kg/m <sup>3</sup>	DENSITY OF SUBMERGED SOIL	$e_{max}$	1.0%	VOID RATIO IN LOOSEST STATE	j	kN/m <sup>2</sup>	SEEPAGE FORCE
$\gamma'$	kN/m <sup>3</sup>	UNIT WEIGHT OF SUBMERGED SOIL						

## EXPLANATORY SHEET FOR CORE LOG

### Column Number

1. Elevation of borehole collar.
2. Depth of geotechnical boundary in borehole
3. Geologic symbol for rock or soil material
4. General description of geotechnical unit - qualitative description, including rock type(s), percentage rock types, frequency and sizes of interbeds, colour, texture.

### Joint (discontinuity) Characteristics

5. Number of joint sets: a rock mass can be intersected by a number of joint sets of varying orientations.
6. Joint type: B = Bedding joint C = Cross joint
7. Orientation: only variations in dip can be identified in core; dip direction is from field mapping or oriented core:  
F = Flat = 0 - 20° D = Dipping = 20 - 50° V = Vertical = 50 - 90°
8. Joint spacing: this is an approximate measure of spacing between joints in specific joint sets.

SPACING	> 3 m	1 m - 3 m	0.3 m - 1 m	50 mm - 300 mm	< 50 mm
	VERY WIDE	WIDE	MODERATE	CLOSE	VERY CLOSE

9. Roughness:

RU = Rough Undulating  
SU = Smooth Undulating  
LU = Slickensided Undulating

RP = Rough Planar  
SP = Smooth Planar  
LP = Slickensided Planar

10. Filling:

T = Tight, hard, non-softened

O = Oxidation surface staining only

SA = Slightly altered; clay-free

S = Sandy particles; clay-free

Si = Sandy and silty, minor clay

NC = Non-softening Clays; 5mm

SC = Swelling Clay fillings; 5mm

#### Approximate $\phi$

25 - 35

25 - 30

25 - 30

20 - 25

16 - 24

6 - 12

11. Aperture: estimated size of joint opening.

12. Degree of weathered rock material:

DEGREE	DESCRIPTION				
UNWEATHERED	NO SIGNS OF DISCOLOURATION OR OXIDIZATION				
SLIGHTLY WEATHERED	PARTIAL DISCOLOURATION; FRACTURES (JOINTS), TYPICALLY OXIDIZED				
MODERATELY WEATHERED	TOTAL DISCOLOURATION				
HIGHLY WEATHERED	TOTAL DISCOLOURATION; TYPICALLY FRIABLE AND PITTED				
COMPLETELY WEATHERED	RESEMBLE A SOIL; ROCK STRUCTURE - USUALLY PRESERVED				

13. Strength of rock material:

		MPa				
VERY HIGH STRENGTH	SPECIMEN CAN ONLY BE CHIPPED BY GEOLOGICAL HAMMER	> 200				
HIGH STRENGTH	SPECIMEN REQUIRES A NUMBER OF BLOWS OF A GEOLOGICAL HAMMER TO FRACTURE IT; CANNOT BE SCRAPPED WITH POCKET KNIFE	50 - 200				
MEDIUM STRENGTH	SPECIMEN CANNOT BE FRACTURED BY A SINGLE, FIRM BLOW OF GEOLOGICAL HAMMER; CAN BE SCRAPPED WITH POCKET KNIFE, NOT PEELED	15 - 50				
LOW STRENGTH	SHALLOW INDENTATIONS MADE BY FIRM BLOW WITH POINT OF GEOLOGICAL HAMMER; CAN BE PEELED WITH POCKET KNIFE WITH DIFFICULTY	4 - 15				
VERY LOW STRENGTH	CRUMBLES UNDER FIRM BLOW WITH POINT OF GEOLOGICAL HAMMER; CAN BE PEELED	1 - 4				

14. Fracture frequency: number of natural joints occurring over a meter length of core. All natural joints are counted irrespective of the number of joint sets.

FRACTURE FREQUENCY	JOINT SPACING	LENGTH				
0.3 m	VERY WIDE	> 3 m				
0.3 - 1 m	WIDE	1 m - 3 m				
1 - 3 m	MODERATE	0.03 m - 1 m				
3 - 20 m	CLOSE	0.005 m - 0.03 m				
20 m	VERY CLOSE	< 0.005 m				

15. Run number and Core Recovery

- (i) Drill run number

- (ii) Total Core Recovery is the total length of core pieces, irrespective of their individual lengths obtained in a core run, and expressed as a percentage of the length of that core run.

16. Rock Quantity Designation (RQD): The total length of those pieces of sound core which are 0.01 metres or greater in length in a core run, expressed as a percentage of the total length of that core run. Sound pieces of rock are those pieces separated by natural breaks and not machine breaks or subsequent artificial breaks.

#### Rock Mass Classification (after Deare)

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

17. Core and Casing sizes: changes of core and casing sizes are indicated.

18. Water recovery, level and tests:

- (i) percentage drill water recovery

- (ii) water level depth

- (iii) positions and results of tests, e.g., permeability and packer tests

## **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.

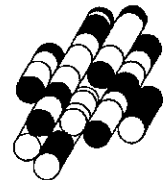
The design advice is based on the factual data obtained from this investigation made at the site by Terraprobe and are intended for use by the owner and its retained designers in the design phase of the project. If there are changes to the project scope and development features, or there is any additional 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

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# **APPENDIX A**

## **Record of Boreholes Sheets, Core Logs and Core Photos**

**Terraprobe Inc.**



# RECORD OF BOREHOLE No TEW1

1 OF 3

METRIC

W.P. 280-99-00

LOCATION

Coords: N:4763851.9 E:327450.6

ORIGINATED BY MP

DIST HWY. 406

BOREHOLE TYPE

Hollow Stem Augers / Casing and Washboring / NQ Rock Coring

COMPILED BY DB

DATUM Geodetic

DATE \_\_\_\_\_

12.23.09 - 01.08.10

CHECKED BY RA

[illegible]

Continued Next Page

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

ONTARIO MOT 1-09-4135 TRILLUM RAILRD.GPJ ONTARIO MOT.GDT 05/17/10

# RECORD OF BOREHOLE No TEW1

2 OF 3

METRIC

W.P. 280-99-00 LOCATION Coords: N:4763851.9 E:327450.6 ORIGINATED BY MP  
 DIST HWY 406 BOREHOLE TYPE Hollow Stem Augers / Casing and Washboring / NQ Rock Coring COMPILED BY DB  
 DATUM Geodetic DATE 12.23.09 - 01.08.10 CHECKED BY RA

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT W <sub>p</sub>	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W <sub>L</sub>	UNIT WEIGHT γ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL				
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa							WATER CONTENT (%)			
167.3							20	40	60	80	100							
15.2	CLAYEY SILT TO SILTY CLAY sandy, trace to some gravel, hard, brown, damp  (GLACIAL TILL)   occasional cobbles		14	SS	33													
			15	SS	79											11 30 43 16		
			16	SS	170											commence casing and washboring		
163.3																Dec.23		
19.2	SAND and gravel, trace to some silt, very dense, grey, wet															Jan.05		
162.5			17	SS	94													
20.0	CLAYEY SILT sandy, trace to some gravel, hard, brown, damp (GLACIAL TILL)																	
161.2			18	SS	70											32 56 10 2		
21.3	SAND gravelly, trace clay, trace silt, dense to very dense, grey, wet																	
159.4			19	SS	34													
23.1	SILTY CLAY some gravel, trace to some sand, hard, brown, damp (GLACIAL TILL)																	
158.3			20	SS	75													
24.2	SAND AND SILT some gravel, trace clay, occasional cobbles, very dense, brown, moist to wet  (GLACIAL TILL)																	
			21	SS	99											15 40 38 7		
			22	SS	125													
153.7																Jan.05		
28.8	BEDROCK		1	RUN	NQ											Jan.08		
																RUN#1 TCR=88% SCR=78% RQD=48%		

ONTARIO MOT 1-09-4135 TRILLUM RAILRD.GPJ ONTARIO MOT.GDT 05/17/10

Continued Next Page

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

# RECORD OF BOREHOLE No TEW1

3 OF 3

METRIC

W.P. 280-99-00 LOCATION Coords: N:4763851.9 E:327450.6 ORIGINATED BY MP  
 DIST HWY 406 BOREHOLE TYPE Hollow Stem Augers / Casing and Washboring / NQ Rock Coring COMPILED BY DB  
 DATUM Geodetic DATE 12.23.09 - 01.08.10 CHECKED BY RA

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT w <sub>p</sub>	NATURAL MOISTURE CONTENT w	LIQUID LIMIT w <sub>L</sub>	UNIT WEIGHT γ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)  GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa									
								○ UNCONFINED + FIELD VANE									
								● QUICK TRIAXIAL × LAB VANE									
					20	40	60	80	100	10	20	30					
150.5	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.		2	RUN	NQ		152									RUN#2 TCR=82% SCR=68% RQD=31%	
32.0	End of Borehole  Borehole was open to 20.7m 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) Jan.19.10      3.2      179.3 Jan.27.10      2.4      180.1 Feb.08.10      2.4      180.1						151										



# CORE LOG



**Terraprobe**

Project	Highway 406 Twinning	Orientation	Vertical	Ground Elevation	182.5m	Datum	Geodetic	Borehole No.	TEW1
Location	Welland, Ontario	Date Started	January 8, 2010	Completed	January 8, 2010	Logged By	AW	Sheet	1 of 1
W.P.:	280-99-00	Drilling Agency	DBW	Drill Type	Track-Mount	Core Barrel & Bit Design	NQ	Project No.	1-09-4135

ELEVATION (m)	DEPTH (m)	SYMBOL	GENERAL DESCRIPTION	Joint Characteristics							WEATHERING	STRENGTH	FRACTURE FREQUENCY	RUN NO.	CORE RECOVERY %	R Q D %	CORE SIZE/CASING	MPa UNCONFINED COMPRESSIVE STRENGTH	UNIT WEIGHT (kN/m³)
				No. OF SETS	JOINT TYPE	ORIENTATION	SPACING	ROUGHNESS	FILLING	APERTURE									
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
154.5	28.0																		
154.0	28.5		Overburden, see Borehole Log TEW1																
153.7	28.8																		
153.5	29.0		SALINA FORMATION BEDROCK	1	B	F	C	SU	T										
			INTERBEDDED DOLOSTONE AND SHALE	1	B	F	VC	SU	T										
			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.																
153.0	29.5			1	B	F	C	SU	T	0 to 1									
152.5	30.0			1	B	F	VC	SU	T										
				1	B	F	C	SU	T										
152.0	30.5			1	B	F	VC	SU	T	0 to 1									
				1	B	F	C	SU	T										
151.5	31.0																		
151.0	31.5			1	B	F	C	SP	T	0 to 2									
150.5	32.0			2	BC	FV	C	SP	T	0 to 1									
			End of Core Log																
150.0	32.5		Highly fractured zones at: 29.3–29.35m; 30.0–30.05m; 30.45–30.65m; 31.3–31.4m, 31.9–32.0m.																
149.5	33.0																		
149.0	33.5																		
148.5	34.0																		

Remarks:

# RECORD OF BOREHOLE No TEW2

1 OF 3

METRIC

W.P. 280-99-00 LOCATION Coords: N:4763860.7 E:327455.5 ORIGINATED BY MP  
DIST HWY 406 BOREHOLE TYPE Hollow Stem Augers / NQ Rock Coring COMPILED BY DB  
DATUM Geodetic DATE 12.18.09 - 12.22.09 CHECKED BY RA

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT W <sub>p</sub>	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W <sub>L</sub>	UNIT WEIGHT γ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			20 40 60 80 100	20 40 60 80 100					
182.7	Ground Surface													
0.0 182.4	300mm TOPSOIL		1	SS	8									
0.3 182.0	FILL - Silty Clay, trace sand, trace organics, firm to stiff, brown, moist													
0.7	SILTY CLAY trace sand, occasional gravel inclusions, stiff to hard, brown, damp to moist		2	SS	27		182							
			3	SS	28		181							
			4	SS	28		180							0 1 52 47
			5	SS	42		179							
			6	SS	36		178							
			7	SS	14		177							
			8	SS	19		176							
			9	SS	17		175							
			10	SS	22		174							
			11	TW	PH		173							
			12	TW	PH		172							
			13	SS	21		171							
							170							
							169							4 6 66 24
							168							

Continued Next Page

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

## 2 OF 3

METRIC

SOIL PROFILE	SAMPLES	NO.	DYNAMIC CONE PENETRATION				
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ONTARIO MOT 1-09-4135 TEW BRIDGE.GPJ ONTARIO MOT.GDT 09/09/10

+3, X3: Numbers refer to Sensitivity      ○ 3% STRAIN AT FAILURE

3 OF 3

## METRIC

[illegible]

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

# CORE LOG



**Terraprobe**

Project	Highway 406 Twinning	Orientation Vertical	Ground Elevation 182.7m	Datum Geodetic	Borehole No. TEW2
Location	Welland, Ontario	Date Started December 22, 2009	Completed December 22, 2009	Logged By AW	Sheet 1 of 1
W.P.:	280-99-00	Drilling Agency DBW	Drill Type Track-Mount	Core Barrel & Bit Design NQ	Project No. 1-09-4135

ELEVATION (m)	DEPTH (m)	SYMBOL	GENERAL DESCRIPTION	Joint Characteristics								STRENGTH	FRACTURE FREQUENCY	RUN NO. CORE RECOVERY %	R Q D %	CORE SIZE/CASING	MPa UNCONFINED COMPRESSIVE STRENGTH	UNIT WEIGHT (kN/m <sup>3</sup> )
				No. OF SETS	JOINT TYPE	ORIENTATION	SPACING	ROUGHNESS	FILLING	APERTURE	WEATHERING							
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
154.7	28.0																	
154.2	28.5		Overburden, see Borehole Log TEW2															
154.0	28.7																	
153.7	29.0		SALINA FORMATION BEDROCK	1	B	F	C	SP	T	0 to 1				#1				
			INTERBEDDED DOLOSTONE AND SHALE											TCR	46	NQ		
			Unweathered, thinly laminated, grey, medium strength, argillaceous with											93				
			unweathered, laminated, white, very low											SCR				
			strength gypsum and calcite layers /											75				
			veins and frequent unweathered, white,															
			low strength, coarse grained calcitic															
			vugs.															
153.2	29.5			1	B	F	VC	RP	NC	T				#2				
				1	B	F	VC	RP	T					TCR	78	NQ		
														100				
														98				
152.7	30.0			1	B	F	C	RP	T	0 to 2								
152.2	30.5																	
151.7	31.0			2	BC	FD	C	RP	T									
151.2	31.5			1	B	F	C	SP	T	0 to 1				#3				
														TCR	39	NQ		
														82				
														SCR				
														66				
150.9	31.8			1	B	F	C	SP	T									
150.7	32.0		End of Core Log															
			Highly fractured zones at:															
			29.55-29.67m; 31.25-31.40m.															
150.2	32.5		Slightly weathered zone at:															
			29.55-29.62m.															
149.7	33.0																	
149.2	33.5																	
148.7	34.0																	

Remarks:

# RECORD OF BOREHOLE No TEW3

1 OF 3

METRIC

W.P. 280-99-00 LOCATION Coords: N:4763877.2 E:327436.9 ORIGINATED BY AW  
 DIST HWY 406 BOREHOLE TYPE Hollow Stem Augers / NQ Rock Coring COMPILED BY DB  
 DATUM Geodetic DATE 12.07.09 - 12.10.09 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  $\gamma$  kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV. DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa		w <sub>p</sub>	w	w <sub>L</sub>		
								○ UNCONFINED ● QUICK TRIAXIAL	+ FIELD VANE × LAB VANE					
182.6	Ground Surface						20 40 60 80 100							
182.6 0.1	120mm TOPSOIL						20 40 60 80 100							
181.9	FILL - Silty Clay, trace sand, trace organics, firm to stiff, brown, moist		1	SS	8									
0.7	SILTY CLAY trace sand, occasional gravel inclusions, very stiff to hard, brown, damp to moist		2	SS	33									
		3	SS	26										
		4	SS	31										
		5	SS	25										
		6	SS	33										
		7	SS	26										
		8	SS	31										
		9	SS	33										
		10	SS	38										
		11	SS	32										
		12	SS	23										
		13	TW	PH										
		14	SS	22										

Continued Next Page

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

# RECORD OF BOREHOLE No TEW3

2 OF 3

METRIC

W.P. 280-99-00 LOCATION Coords: N:4763877.2 E:327436.9 ORIGINATED BY AW  
 DIST HWY 406 BOREHOLE TYPE Hollow Stem Augers / NQ Rock Coring COMPILED BY DB  
 DATUM Geodetic DATE 12.07.09 - 12.10.09 CHECKED BY RA

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT w <sub>p</sub>	NATURAL MOISTURE CONTENT w	LIQUID LIMIT w <sub>L</sub>	UNIT WEIGHT γ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa						
								20 40 60 80 100						
								○ UNCONFINED + FIELD VANE						
								● QUICK TRIAXIAL × LAB VANE						
								20 40 60 80 100						
166.8			15	SS	26		167							
15.8	CLAYEY SILT TO SILTY CLAY some sand to sandy, trace gravel, hard, brown, damp to moist  (GLACIAL TILL)						166							4 13 62 21
			16	SS	61		165							
							164							
			17	SS	42		163							
							162							
			18	SS	38		161							5 30 46 19
							160							Dec.07
							159							Dec.08
			19	SS	31		158							
							157							
			20	SS	38		156							
							155							25 38 29 8
			21	SS	100/ 13cm		154							Dec.08
157.9	SILTY SAND some gravel to gravelly, trace clay, compact to dense, brown, damp to moist  (GLACIAL TILL)						153							Dec.09
24.7			22	SS	29									RUN#1 TCR=52% SCR=40% RQD=0%
														RUN#2 TCR=85% SCR=83% RQD=49%
			23	SS	38									
	frequent cobbles													
153.7	BEDROCK		1	RUN	NQ									
28.9														

Continued Next Page

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

ONTARIO MOT 1-09-4135 TEW BRIDGE.GPJ ONTARIO MOT.GDT 09/09/10

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



# CORE LOG



**Terraprobe**

Project	Highway 406 Twinning	Orientation	Vertical	Ground Elevation	182.6m	Datum	Geodetic	Borehole No.	TEW3
Location	Welland, Ontario	Date Started	December 9, 2009	Completed	December 9, 2009	Logged By	AW	Sheet	1 of 1
W.P.:	280-99-00	Drilling Agency	DBW	Drill Type	Track-Mount	Core Barrel & Bit Design	NQ	Project No.	1-09-4135

ELEVATION (m)	DEPTH (m)	SYMBOL	GENERAL DESCRIPTION	Joint Characteristics								WEATHERING	STRENGTH	FRACTURE FREQUENCY	RUN NO. CORE RECOVERY %	R Q D %	CORE SIZE/CASING	MPa UNCONFINED COMPRESSIVE STRENGTH	UNIT WEIGHT (KN/m³)
				No. OF SETS	JOINT TYPE	ORIENTATION	SPACING	ROUGHNESS	FILLING	APERTURE									
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
154.6	28.0																		
154.1	28.5		Overburden, see Borehole Log TEW3																
153.8	28.8		Overburden, SILTY SAND TILL																
153.6	29.0		frequent cobbles, see Borehole Log TEW3																
			SALINA FORMATION BEDROCK	1	B	F	VC	SP	T	0 to 1				#1 TCR 52 SCR 40	0	NQ			
153.1	29.5		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	B	F	VC	SP	T	0 to 1				#2 TCR 95 SCR 83	49	NQ			
152.6	30.0			1	B	F	C	SU	T	0 to 4									
152.1	30.5			1	B	F	VC	SP	T	0 to 2									
151.6	31.0			1	B	F	C	SP	T	0 to 1				#3 TCR 98 SCR 83	28	NQ			
151.1	31.5			1	B	F	C	RP	T	0 to 2									
150.6	32.0																		
150.5	32.1																		
			End of Core Log																
150.1	32.5		Highly fractured zones at: 28.9-29.61m; 30.75-30.90m; 31.18-31.28m.																
149.6	33.0																		
149.1	33.5																		
148.6	34.0																		

Remarks:

## LEGEND:

	Interbedded Dolostone and Shale
	Silty Sand Till

# RECORD OF BOREHOLE No TEW4

1 OF 3

METRIC

W.P. 280-99-00 LOCATION Coords: N:4763885.4 E:327439.2 ORIGINATED BY AW  
 DIST HWY 406 BOREHOLE TYPE Hollow Stem Augers / Casing and Washboring / NQ Rock Coring COMPILED BY DB  
 DATUM Geodetic DATE 12.10.09 - 12.15.09 CHECKED BY RA

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					UNIT WEIGHT $\gamma$ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			20	40	60	80	100		
182.6	Ground Surface													
180.9	110mm TOPSOIL		1	SS	9		182							
181.9	FILL - Silty Clay, trace sand, trace organics, stiff, brown, moist		2	SS	47		181							0 2 58 40
0.7	SILTY CLAY trace sand, occasional gravel inclusions, very stiff to hard, brown, damp to moist		3	SS	55		180							
			4	SS	49		179							
			5	SS	55		178							0 3 67 30
			6	SS	42		177							
			7	SS	41		176							
			8	SS	30		175							
			9	SS	30		174							
			10	SS	24		173							0 7 69 24
			11	SS	24		172							Dec.10 Dec.11
			12	SS	12		171							
			13	SS	19		170							
			14	TW	PH		169							
168.0							168							
14.6														

ONTARIO MOT 1-09-4135 TEW BRIDGE.GPJ ONTARIO MOT.GDT 09/09/10

Continued Next Page

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

# RECORD OF BOREHOLE No TEW4

2 OF 3

METRIC

W.P. 280-99-00 LOCATION Coords: N:4763885.4 E:327439.2 ORIGINATED BY AW  
 DIST HWY 406 BOREHOLE TYPE Hollow Stem Augers / Casing and Washboring / NQ Rock Coring COMPILED BY DB  
 DATUM Geodetic DATE 12.10.09 - 12.15.09 CHECKED BY RA

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT W <sub>p</sub>	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W <sub>L</sub>	UNIT WEIGHT γ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL	
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa							WATER CONTENT (%)
								○ UNCONFINED ● QUICK TRIAXIAL	+ FIELD VANE × LAB VANE						
							20 40 60 80 100	20 40 60 80 100							
	CLAYEY SILT TO SILTY CLAY some sand to sandy, trace to some gravel, occasional cobbles, very stiff to hard, brown, damp to moist  (GLACIAL TILL)		15	SS	30		167							5 17 58 20	
			16	SS	100/ 0cm		166							commence casing and washboring	
			17	SS	70		164								
			18	SS	78		163								
			19	SS	60		161							Dec.11 Dec.14	
			20	SS	68		160							12 31 43 14	
157.8 24.8	SILTY SAND some gravel to gravelly, trace clay, occasional cobbles, dense to very dense, brown, damp to moist  (GLACIAL TILL)		21	SS	87		158								
			22	SS	34		157								
			23	SS	100/ 14cm		155								
153.9 28.7	frequent cobbles		1	RUN	NQ		154							RUN#1 TCR=50% SCR=40% RQD=13%	
	BEDROCK		2	RUN	NQ		153							RUN#2 TCR=71% SCR=57% RQD=0%	

Continued Next Page

+ 3 x 3: Numbers refer to  
Sensitivity

○ 3% STRAIN AT FAILURE

ONTARIO MOT 1-09-4135 TEW BRIDGE.GPJ ONTARIO MOT.GDT 09/09/10

RECORD OF BOREHOLE No TEW4

3 OF 3

METRIC

W.P. 280-99-00 LOCATION Coords: N:4763885.4 E:327439.2 ORIGINATED BY AW  
DIST HWY 406 BOREHOLE TYPE Hollow Stem Augers / Casing and Washboring / NQ Rock Coring COMPILED BY DB  
DATUM Geodetic DATE 12.10.09 - 12.15.09 CHECKED BY RA

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

# CORE LOG



**Terraprobe**

Project	Highway 406 Twinning	Orientation	Vertical	Ground Elevation	182.6m	Datum	Geodetic	Borehole No.	TEW4
Location	Welland, Ontario	Date Started	December 15, 2009	Completed	December 15, 2009	Logged By	AW	Sheet	1 of 1
W.P.:	280-99-00	Drilling Agency	GW	Drill Type	Track-Mount	Core Barrel & Bit Design	NQ	Project No.	1-09-4135

ELEVATION (m)	DEPTH (m)	SYMBOL	GENERAL DESCRIPTION	Joint Characteristics								WEATHERING	STRENGTH	FRACTURE FREQUENCY	RUN NO.	CORE RECOVERY %	R Q D %	CORE SIZE/CASING	UNCONFINED COMPRESSIVE STRENGTH MPa	UNIT WEIGHT (kN/m³)
				No. OF SETS	JOINT TYPE	ORIENTATION	SPACING	ROUGHNESS	FILLING	APERTURE										
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19		
155.1	27.5																			
155.6	28.0																			
154.2	28.4		Overburden, see Borehole Log TEW4																	
154.1	28.5		Overburden, SILTY SAND TILL frequent cobbles, see Borehole Log TEW4																	
153.6	29.0		SALINA FORMATION BEDROCK	1	B	F	C	RP	T	0 to 1										
			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	B	F	VC	RP	T											
153.1	29.5			1	B	F	C	SP	T	0 to 1										
				1	B	F	VC	SP	T											
152.6	30.0			1	B	F	C	RP	T	0 to 3										
				1	B	F	VC	RP	T	0 to 3										
152.1	30.5			1	B	F	C	RU	T	0 to 6										
				1	B	F	VC	RP	T											
151.6	31.0			1	B	F	C	SP	T	0 to 2										
				1	B	F	C	SP	T											
151.2	31.4																			
151.1	31.5		End of Core Log																	
			Highly fractured zones at: 29.23-29.33m; 29.82-29.90m; 30.22-30.62m; 30.72-30.77m; 30.97-31.07m.																	
150.6	32.0																			
150.1	32.5																			
149.6	33.0																			
149.1	33.5																			

Remarks:

## LEGEND:

	Interbedded Dolostone and Shale
	Silty Sand Till

# RECORD OF BOREHOLE No WE-S 10+295CL

1 OF 1

METRIC

W.P. 280-99-00 LOCATION Coords: N:4763889.2 E:327432.2 ORIGINATED BY AW  
 DIST HWY 406 BOREHOLE TYPE Hollow Stem Augers COMPILED BY DB  
 DATUM Geodetic DATE 11.04.09 CHECKED BY RA

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT w <sub>p</sub>	NATURAL MOISTURE CONTENT w	LIQUID LIMIT w <sub>L</sub>	UNIT WEIGHT γ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL			
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa										WATER CONTENT (%)		
								○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE												
182.8	Ground Surface						20	40	60	80	100	10	20	30						
0.0	FILL - Silty Clay, trace sand, stiff to very stiff, brown, damp to moist		1	SS	8								○							
			2	SS	27								○							
181.4													○							
1.4	SILTY CLAY trace sand, trace gravel, very stiff to hard, brown, damp to moist		3	SS	32								○							
			4	SS	45								○	—		0 3 66 31				
			5	SS	40								○							
			6	SS	67								○							
			7	SS	32								○							
	grey																			
			8	SS	33								○							
			9	SS	37								○	—		2 4 66 28				
			10	TW	PH								○	—		20.8 0 3 73 24				

ONTARIO MOT 1-09-4136 TRILLUM RAILRD.GPJ ONTARIO MOT.GDT 05/17/10

# RECORD OF BOREHOLE No WE-S 10+345CL

1 OF 2

METRIC

W.P. 280-99-00 LOCATION Coords: N:4763845.9 E:327457.4 ORIGINATED BY AW  
 DIST HWY 406 BOREHOLE TYPE Hollow Stem Augers COMPILED BY DB  
 DATUM Geodetic DATE 11.04.09 CHECKED BY RA

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT w <sub>p</sub>	NATURAL MOISTURE CONTENT w	LIQUID LIMIT w <sub>L</sub>	UNIT WEIGHT γ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa						
182.8	Ground Surface							20 40 60 80 100						
0.0	290mm TOPSOIL		1	SS	10									
0.3	FILL - Silty Clay, with organics and rootlets, trace sand, stiff, grey / black, moist													
182.1	Weathered		2	SS	32									
0.7	SILTY CLAY trace sand, trace gravel, very stiff to hard, brown, damp to moist		3	SS	32									
	stiff to very stiff, grey		4	SS	47									
			5	SS	26									
			6	SS	11									
			7	SS	16									
			8	SS	17									
			9	SS	*									
			10	TW	PH									
			11	SS	12									
169.2	End of Borehole													
13.6	* TW sampling attempted at 9.1m. No recovery, split spoon sample collected.													
	Consolidation test performed on TW 10.													

Continued Next Page

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

ONTARIO MOT 1-09-4135 TRILLIUM RAILRD.GPJ ONTARIO MOT.GDT 05/17/10

# RECORD OF BOREHOLE No WE-S 10+345CL

2 OF 2

METRIC

W.P. 280-99-00 LOCATION Coords: N:4763845.9 E:327457.4 ORIGINATED BY AW  
 DIST HWY 406 BOREHOLE TYPE Hollow Stem Augers COMPILED BY DB  
 DATUM Geodetic DATE 11.04.09 CHECKED BY RA

SOIL PROFILE		SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT W <sub>p</sub>	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W <sub>L</sub>	UNIT WEIGHT γ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL																					
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE			"N" VALUES	SHEAR STRENGTH kPa																													
	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: <table border="1"> <thead> <tr> <th>Date</th> <th>Depth(m)</th> <th>Elevation(m)</th> </tr> </thead> <tbody> <tr><td>Nov.19.09</td><td>4.0</td><td>178.8</td></tr> <tr><td>Nov.30.09</td><td>3.4</td><td>179.4</td></tr> <tr><td>Dec.07.09</td><td>3.1</td><td>179.7</td></tr> <tr><td>Dec.15.09</td><td>3.0</td><td>179.8</td></tr> <tr><td>Jan.11.10</td><td>2.6</td><td>180.2</td></tr> <tr><td>Jan.27.10</td><td>2.7</td><td>180.1</td></tr> </tbody> </table>	Date	Depth(m)	Elevation(m)	Nov.19.09	4.0	178.8	Nov.30.09	3.4	179.4	Dec.07.09	3.1	179.7	Dec.15.09	3.0	179.8	Jan.11.10	2.6	180.2	Jan.27.10	2.7	180.1															
Date	Depth(m)	Elevation(m)																																			
Nov.19.09	4.0	178.8																																			
Nov.30.09	3.4	179.4																																			
Dec.07.09	3.1	179.7																																			
Dec.15.09	3.0	179.8																																			
Jan.11.10	2.6	180.2																																			
Jan.27.10	2.7	180.1																																			

ONTARIO MOT 1-09-4135 TRILLIUM RAILRO.GPJ ONTARIO MOT.GDT 05/17/10



**Foundation Investigation Report**  
**Highway 406 Twinning - Port Robinson Road to East Main Street**  
Agreement No. 2008-E-0016; W.P. 280-99-00

---



**Bedrock Core Sample**

Borehole: TEW1

Runs: 1 & 2

Depth: 28.8m – 32.0m



**Foundation Investigation Report**  
**Highway 406 Twinning - Port Robinson Road to East Main Street**  
Agreement No. 2008-E-0016; W.P. 280-99-00

---



**Bedrock Core Sample**

Borehole: TEW2

Runs: 1, 2 & 3

Depth: 28.7m – 31.8m



**Foundation Investigation Report**  
**Highway 406 Twinning - Port Robinson Road to East Main Street**  
Agreement No. 2008-E-0016; W.P. 280-99-00

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**Bedrock Core Sample**

Borehole: TEW3

Runs 1, 2 & 3

Depth: 28.8m – 32.1m



**Foundation Investigation Report**  
**Highway 406 Twinning - Port Robinson Road to East Main Street**  
Agreement No. 2008-E-0016; W.P. 280-99-00

---



**Bedrock Core Sample**

Borehole: TEW4

Runs: 1, 2 & 3

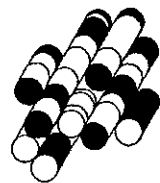
Depth: 28.4m – 31.4m



# **APPENDIX B**

## **Laboratory Test Results**

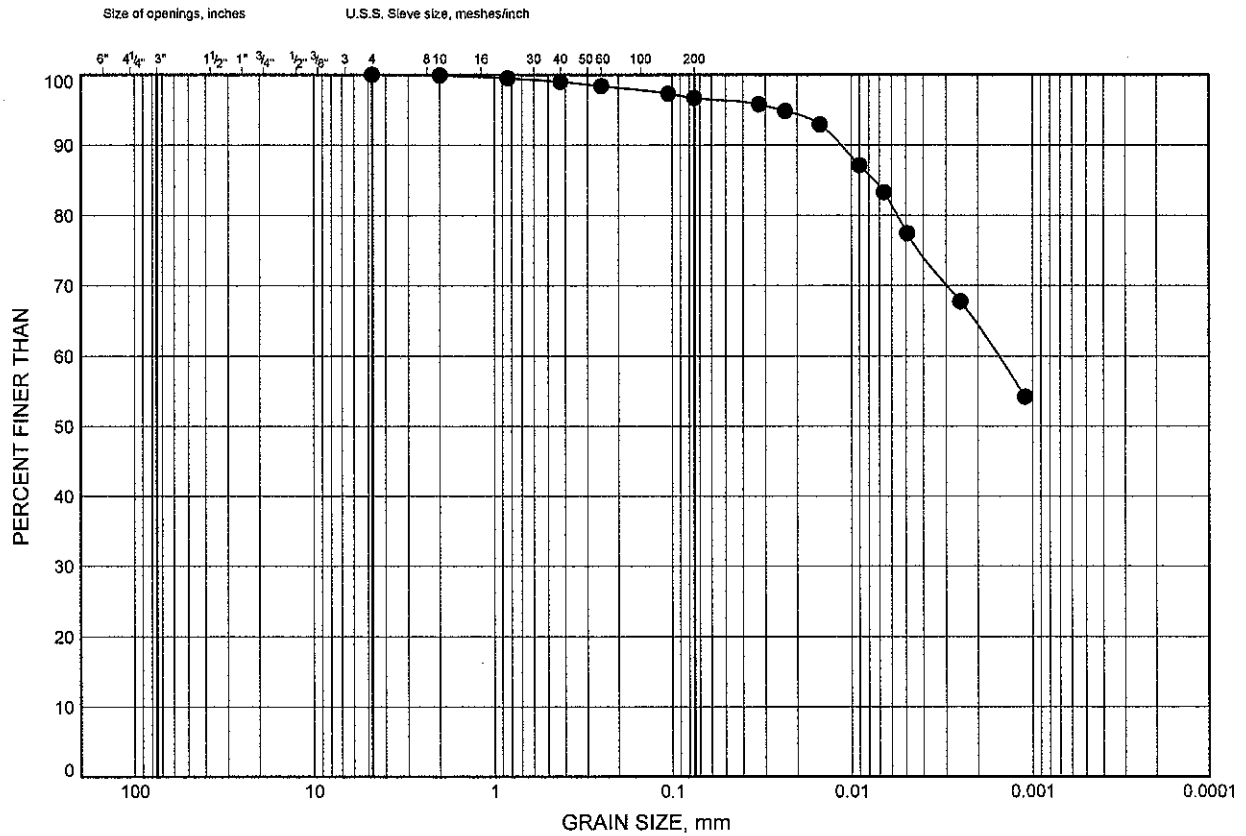
**Terraprobe Inc.**



# GRAIN SIZE DISTRIBUTION

FIGURE B1

## FILL - Silty Clay

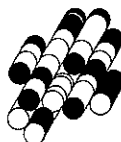


COBBLE SIZE	COARSE	FINE	COARSE	MEDIUM	FINE	SILT and CLAY
	GRAVEL		SAND			FINE GRAINED

SYMBOL	BOREHOLE	DEPTH (m)	ELEVATION (m)
●	TEW1	0.3	182.2

Date May 2010

Project 1-09-4135



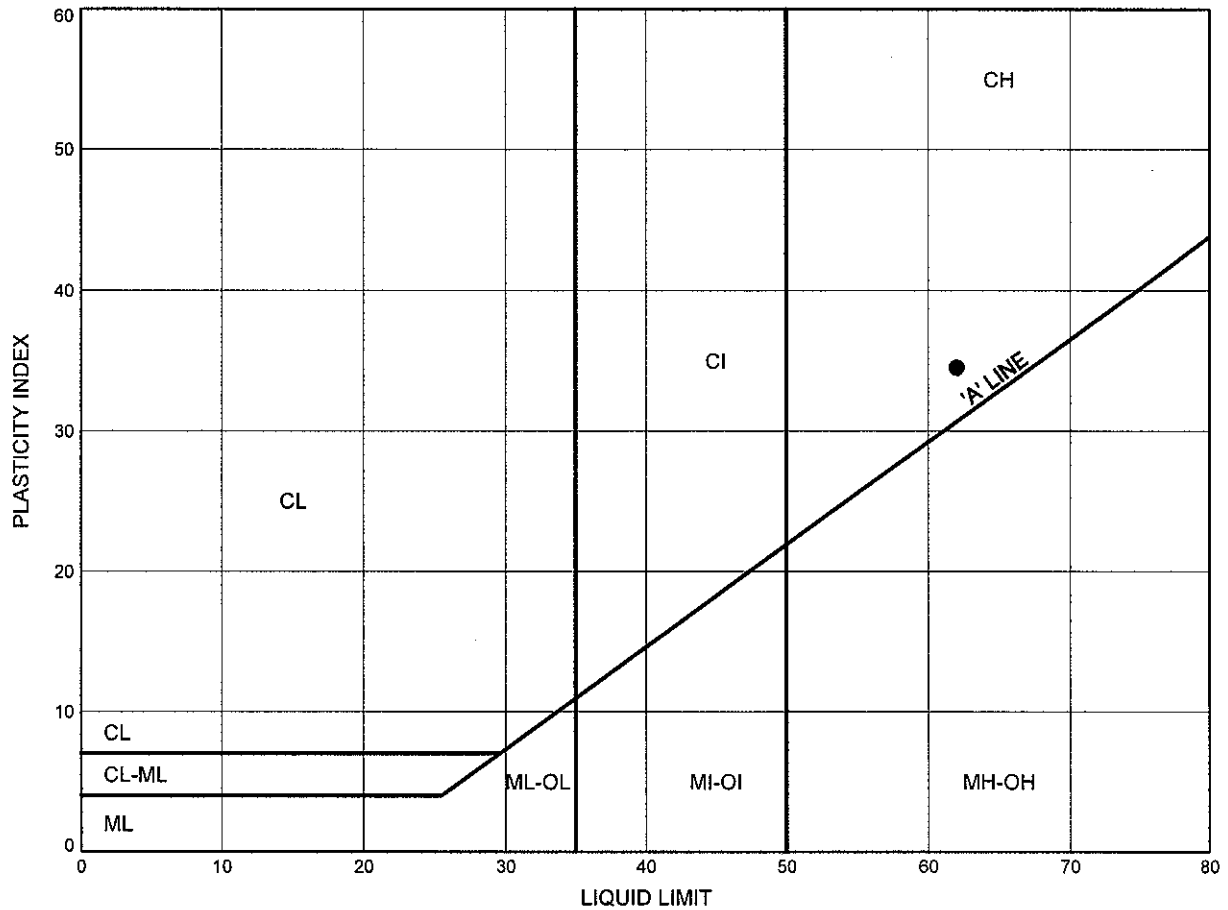
Prep'd DB

Chkd. HA

# ATTERBERG LIMITS TEST RESULTS

FIGURE B2

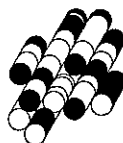
## FILL - Silty Clay



SYMBOL	BOREHOLE	DEPTH (m)	ELEVATION (m)
●	TEW1	0.3	182.2

Date May 2010

Project 1-09-4135



Prep'd DB

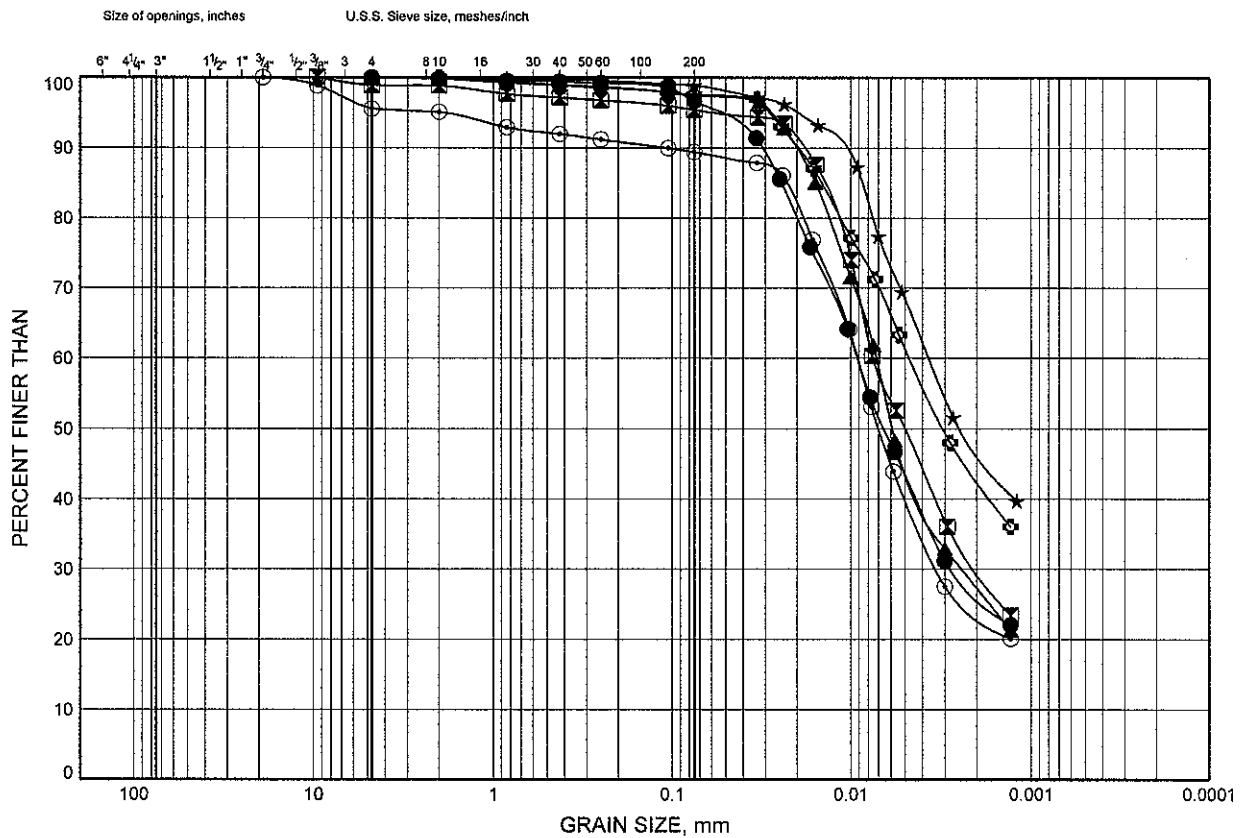
Chkd. HA



# GRAIN SIZE DISTRIBUTION

FIGURE B3

## SILTY CLAY

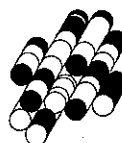


COBBLE SIZE	COARSE	FINE	COARSE	MEDIUM	FINE	SILT and CLAY
	GRAVEL		SAND			FINE GRAINED

SYMBOL	BOREHOLE	DEPTH (m)	ELEVATION (m)
●	TEW1	2.5	180.0
⊠	TEW1	4.7	177.8
▲	TEW1	9.3	173.2
★	TEW2	2.5	180.2
⊙	TEW2	13.9	168.8
⊛	TEW3	3.2	179.4

Date May 2010

Project 1-09-4135



Prep'd DB

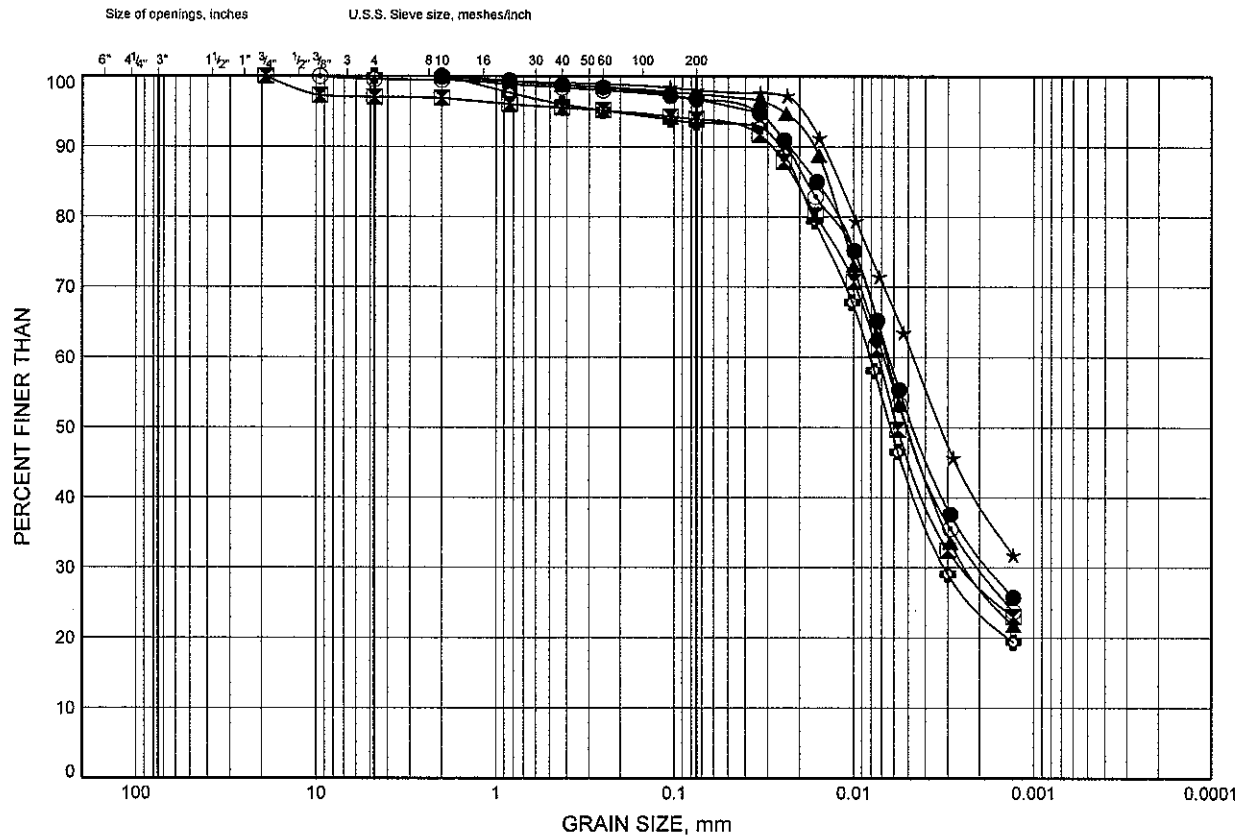
Chkd. HA



# GRAIN SIZE DISTRIBUTION

FIGURE B4

## SILTY CLAY



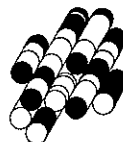
COBBLE SIZE	COARSE	FINE	COARSE	MEDIUM	FINE	SILT and CLAY
	GRAVEL		SAND			FINE GRAINED

SYMBOL    BOREHOLE    DEPTH (m)    ELEVATION (m)

●	TEW3	4.7	177.9
⊠	TEW3	7.8	174.8
▲	TEW3	10.9	171.7
★	TEW4	1.0	181.6
⊙	TEW4	4.7	177.9
⊛	TEW4	9.3	173.3

Date May 2010

Project 1-09-4135



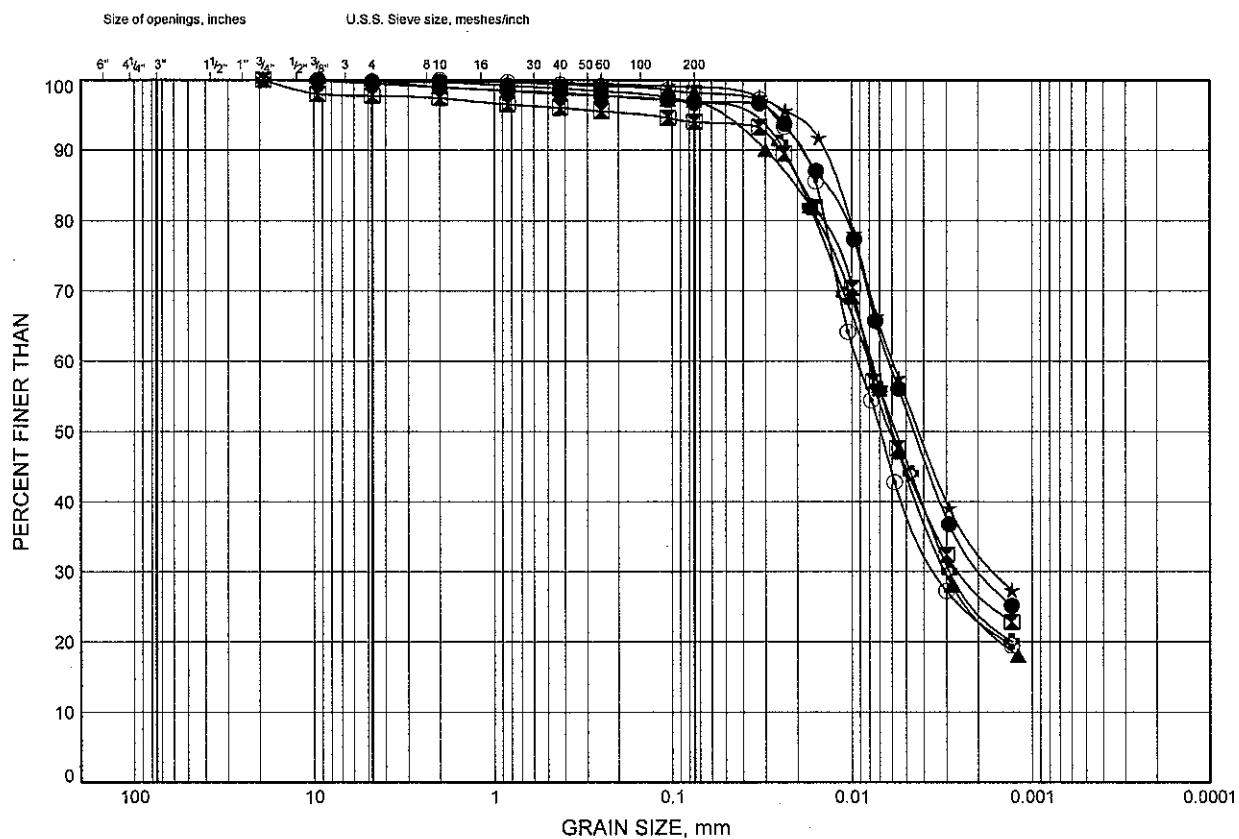
Prep'd DB

Chkd. HA

# GRAIN SIZE DISTRIBUTION

FIGURE B5

## SILTY CLAY



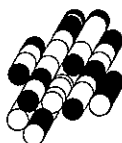
COBBLE SIZE	COARSE	FINE	COARSE	MEDIUM	FINE	SILT and CLAY
	GRAVEL		SAND			FINE GRAINED

SYMBOL BOREHOLE DEPTH (m) ELEVATION (m)

●	WE-S 10+295CL	2.5	180.3
⊠	WE-S 10+295CL	7.8	175.0
▲	WE-S 10+295CL	9.3	173.5
★	WE-S 10+345CL	2.5	180.3
⊙	WE-S 10+345CL	7.8	175.0
⊛	WE-S 10+345CL	10.9	171.9

Date May 2010

Project 1-09-4135



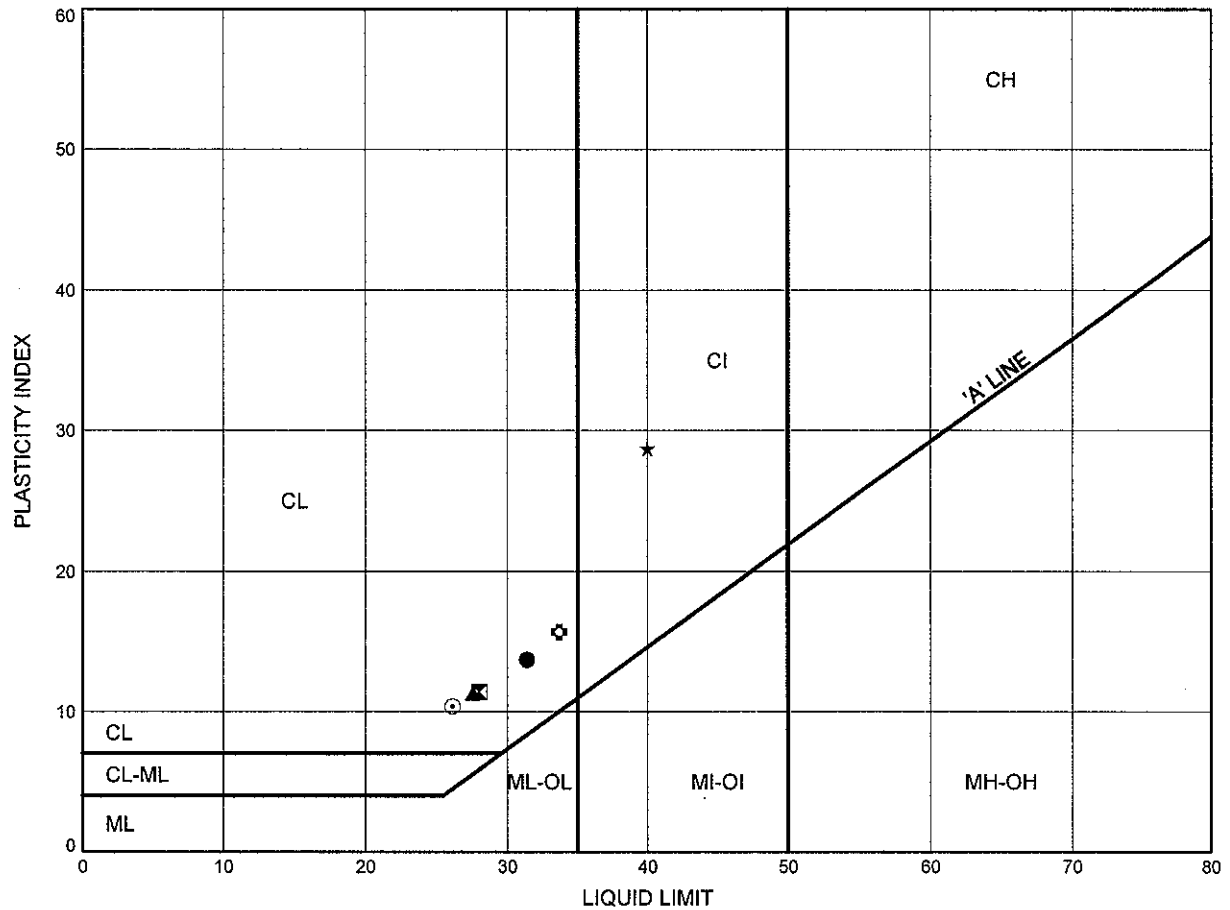
Prep'd DB

Chkd. HA

# ATTERBERG LIMITS TEST RESULTS

FIGURE B6

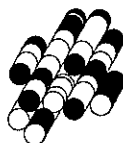
## SILTY CLAY



SYMBOL	BOREHOLE	DEPTH (m)	ELEVATION (m)
●	TEW1	2.5	180.0
⊠	TEW1	4.7	177.8
▲	TEW1	9.3	173.2
★	TEW2	2.5	180.2
⊙	TEW2	13.9	168.8
⊛	TEW3	3.2	179.4

Date May 2010

Project 1-09-4135



Prep'd DB

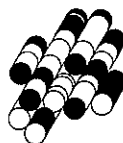
Chkd. HA

## FIGURE B7

SYMBOL	BOREHOLE	DEPTH (m)	ELEVATION (m)
●	TEW3	4.7	177.9
⊗	TEW3	7.8	174.8
▲	TEW3	10.9	171.7
★	TEW4	1.0	181.6
⊙	TEW4	4.7	177.9
⊕	TEW4	9.3	173.3

Prep'd ..... DB.....

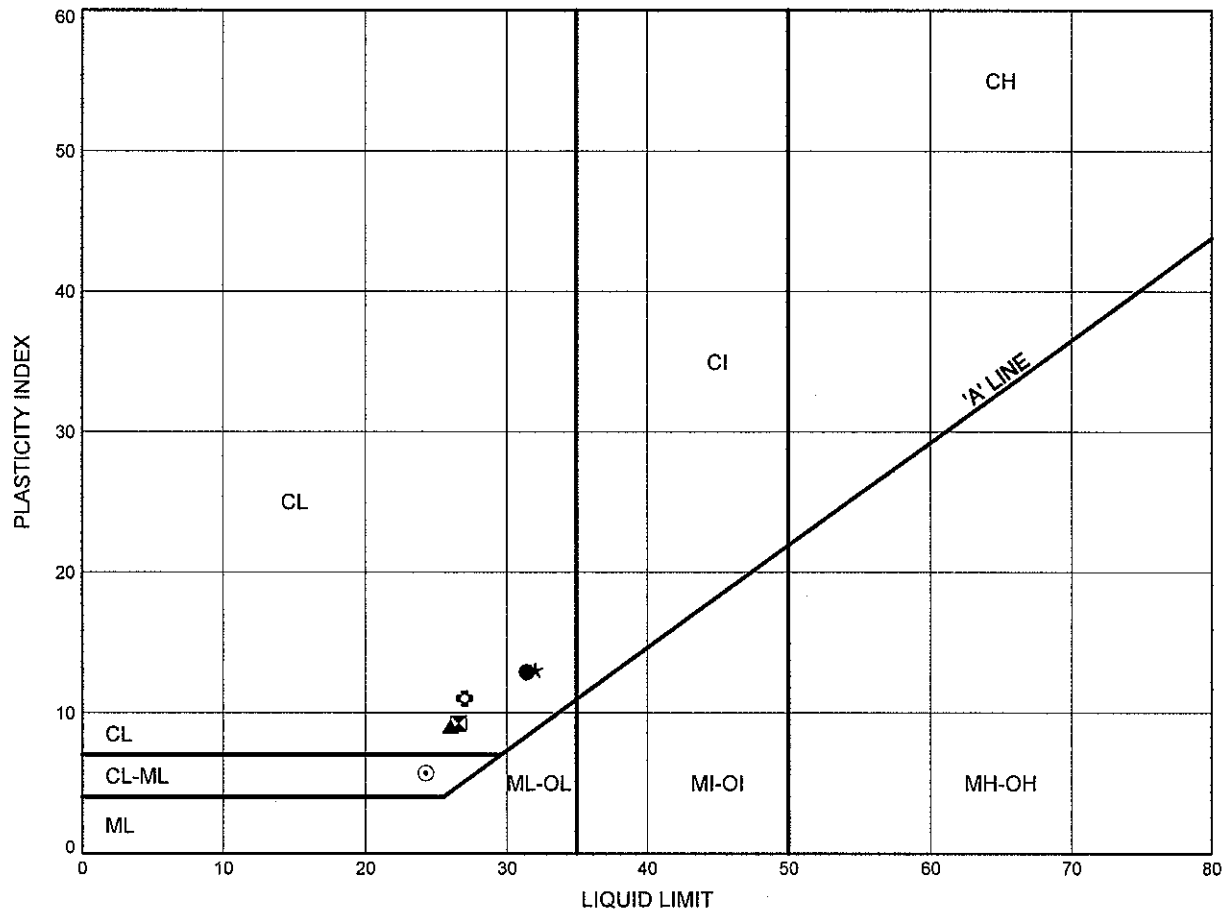
Chkd. .... HA



# 

FIGURE B8

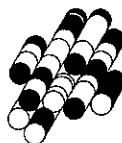
### 



SYMBOL	BOREHOLE	DEPTH (m)	ELEVATION (m)
●	WE-S 10+295CL	2.5	180.3
⊠	WE-S 10+295CL	7.8	175.0
▲	WE-S 10+295CL	9.3	173.5
★	WE-S 10+345CL	2.5	180.3
⊙	WE-S 10+345CL	7.8	175.0
⊛	WE-S 10+345CL	10.9	171.9

Date May 2010

Project 1-09-4135



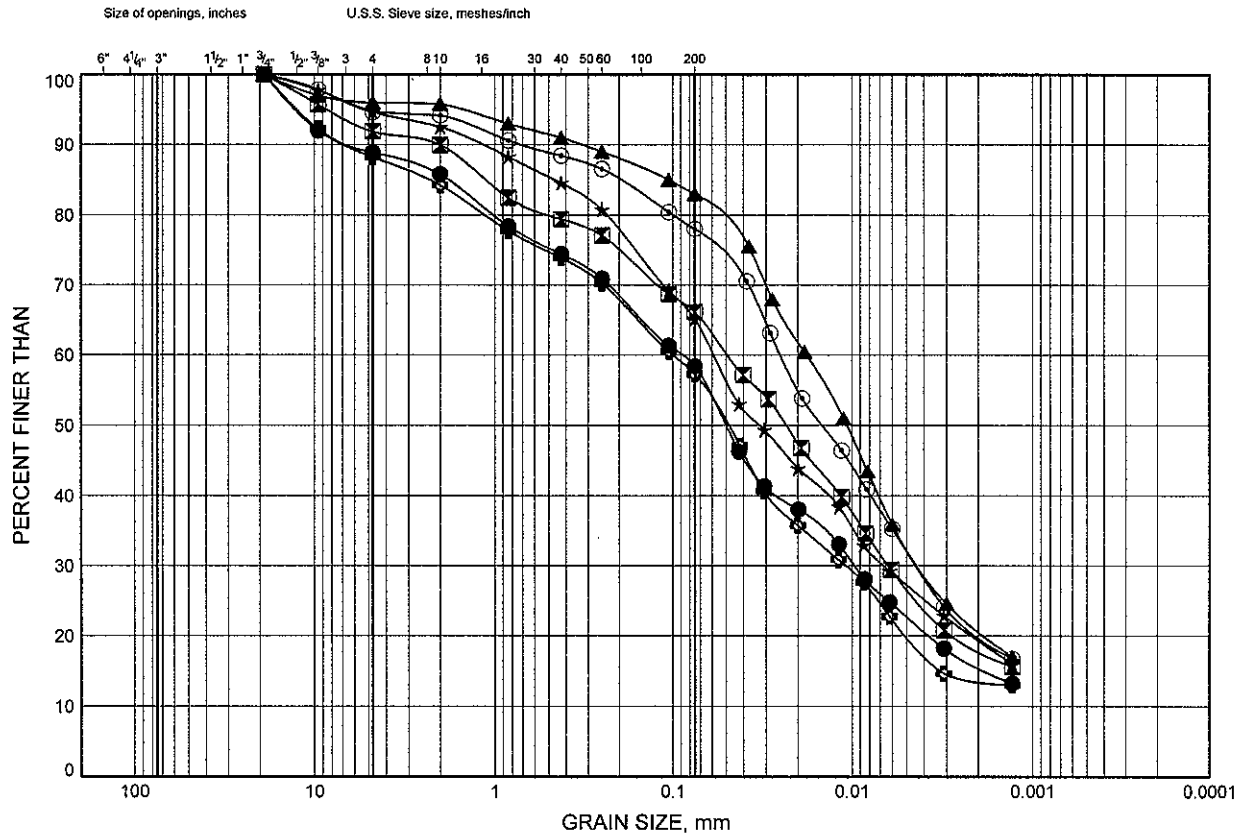
Prep'd DB

Chkd. HA

# GRAIN SIZE DISTRIBUTION

FIGURE B9

## CLAYEY SILT TO SILTY CLAY TILL

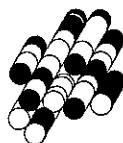


SYMBOL    BOREHOLE    DEPTH (m)    ELEVATION (m)

●	TEW1	17.0	165.5
⊠	TEW2	15.4	167.3
▲	TEW3	17.0	165.6
★	TEW3	21.5	161.1
⊙	TEW4	15.4	167.2
⊛	TEW4	20.0	162.6

Date May 2010

Project 1-09-4135



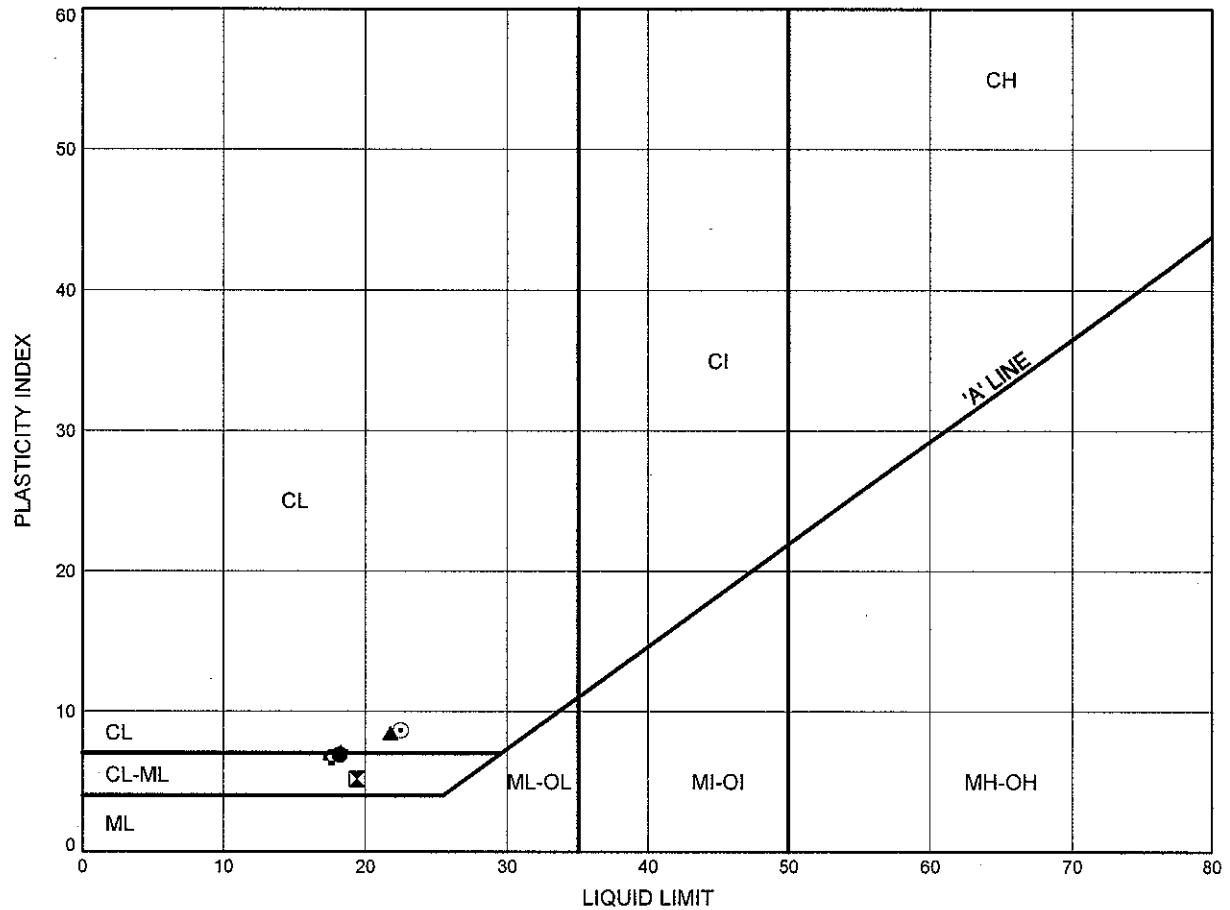
Prep'd DB

Chkd. HA

# ATTERBERG LIMITS TEST RESULTS

FIGURE B10

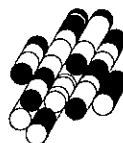
## CLAYEY SILT TO SILTY CLAY TILL



SYMBOL	BOREHOLE	DEPTH (m)	ELEVATION (m)
●	TEW1	17.0	165.5
⊠	TEW2	15.4	167.3
▲	TEW3	17.0	165.6
★	TEW3	21.5	161.1
⊙	TEW4	15.4	167.2
⊛	TEW4	20.0	162.6

Date May 2010

Project 1-09-4135



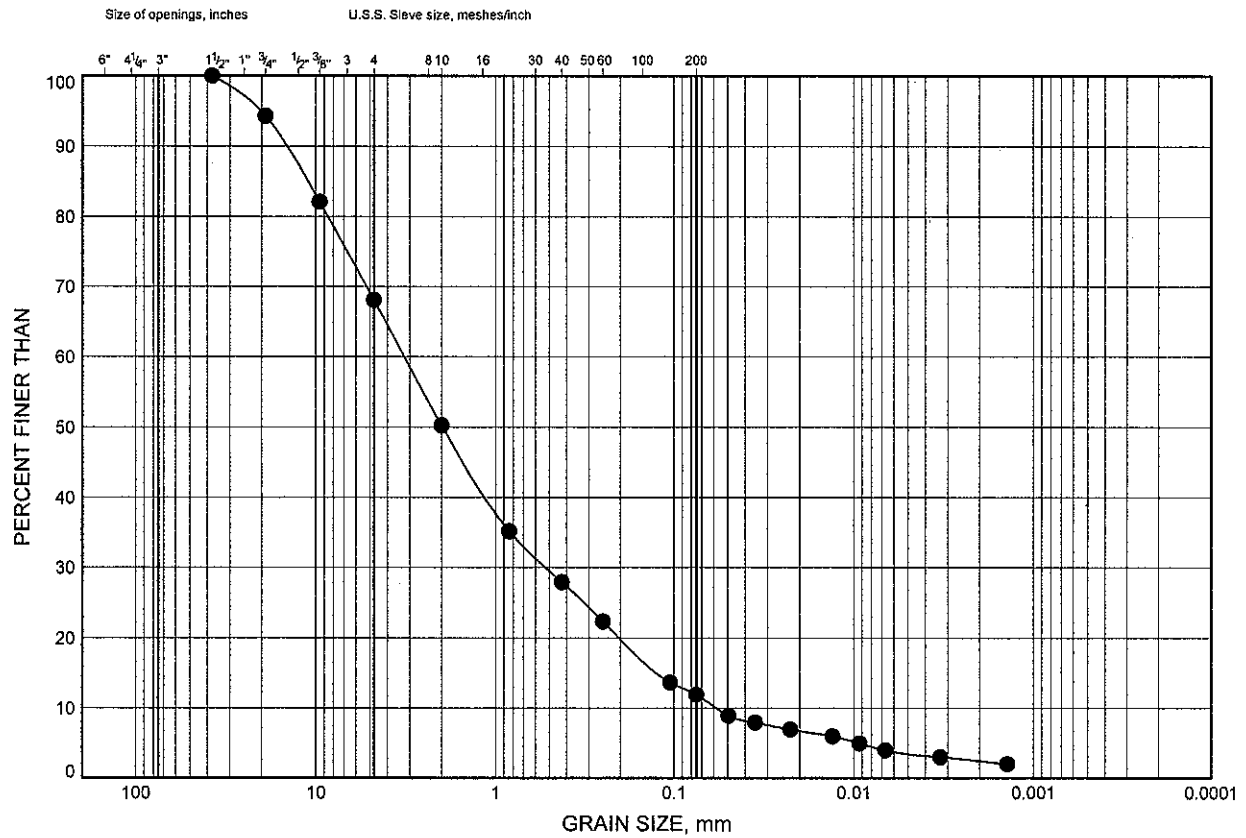
Prep'd DB

Chkd. HA

# GRAIN SIZE DISTRIBUTION

FIGURE B11

## SAND

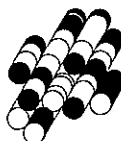


COBBLE SIZE	COARSE	FINE	COARSE	MEDIUM	FINE	SILT and CLAY
	GRAVEL		SAND			FINE GRAINED

SYMBOL	BOREHOLE	DEPTH (m)	ELEVATION (m)
●	TEW1	21.5	161.0

Date May 2010

Project 1-09-4135



Prep'd DB

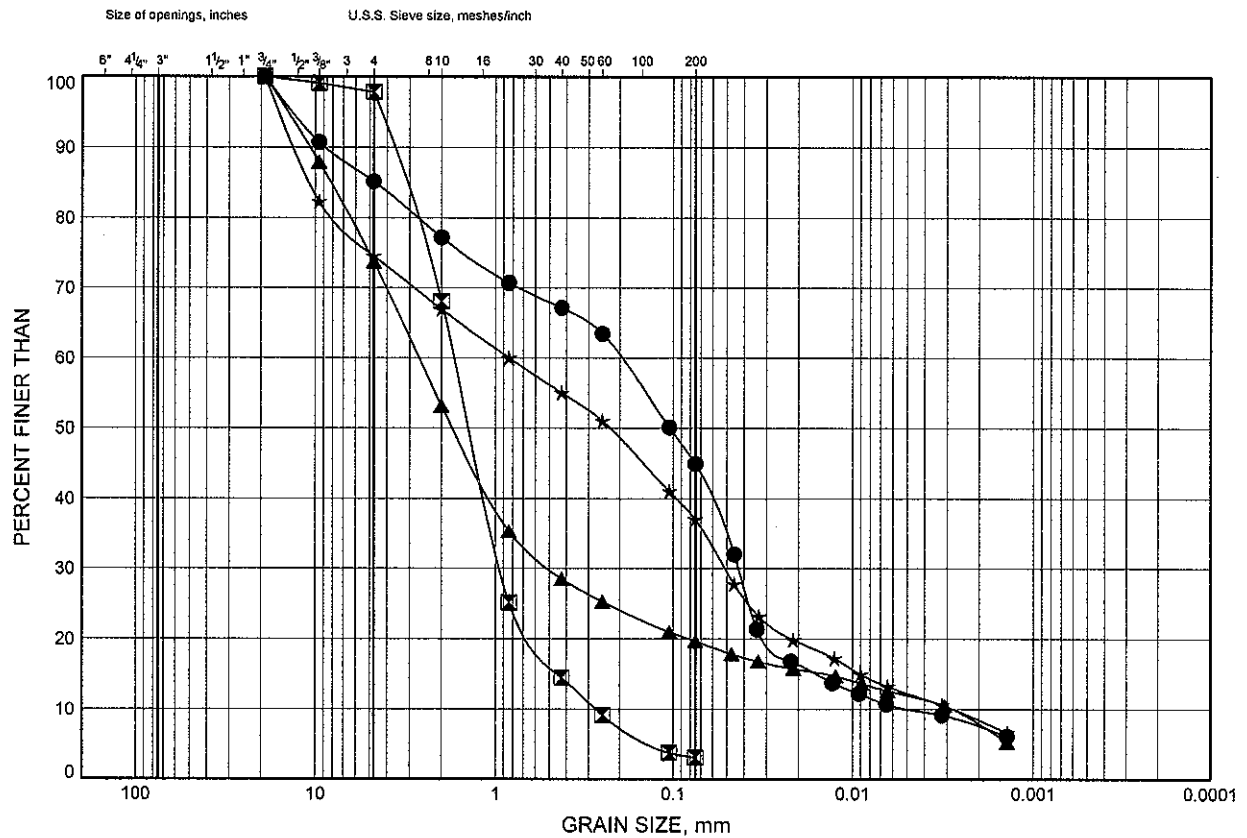
Chkd. HA



# GRAIN SIZE DISTRIBUTION

FIGURE B12

## SILTY SAND TO SAND AND SILT TILL

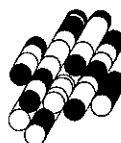


COBBLE SIZE	COARSE	FINE	COARSE	MEDIUM	FINE	SILT and CLAY
	GRAVEL		SAND			FINE GRAINED

SYMBOL	BOREHOLE	DEPTH (m)	ELEVATION (m)
●	TEW1	26.2	156.3
⊠	TEW2	24.6	158.1
▲	TEW2	27.6	155.1
★	TEW3	27.6	155.0

Date May 2010

Project 1-09-4135



Prep'd DB

Chkd. HA

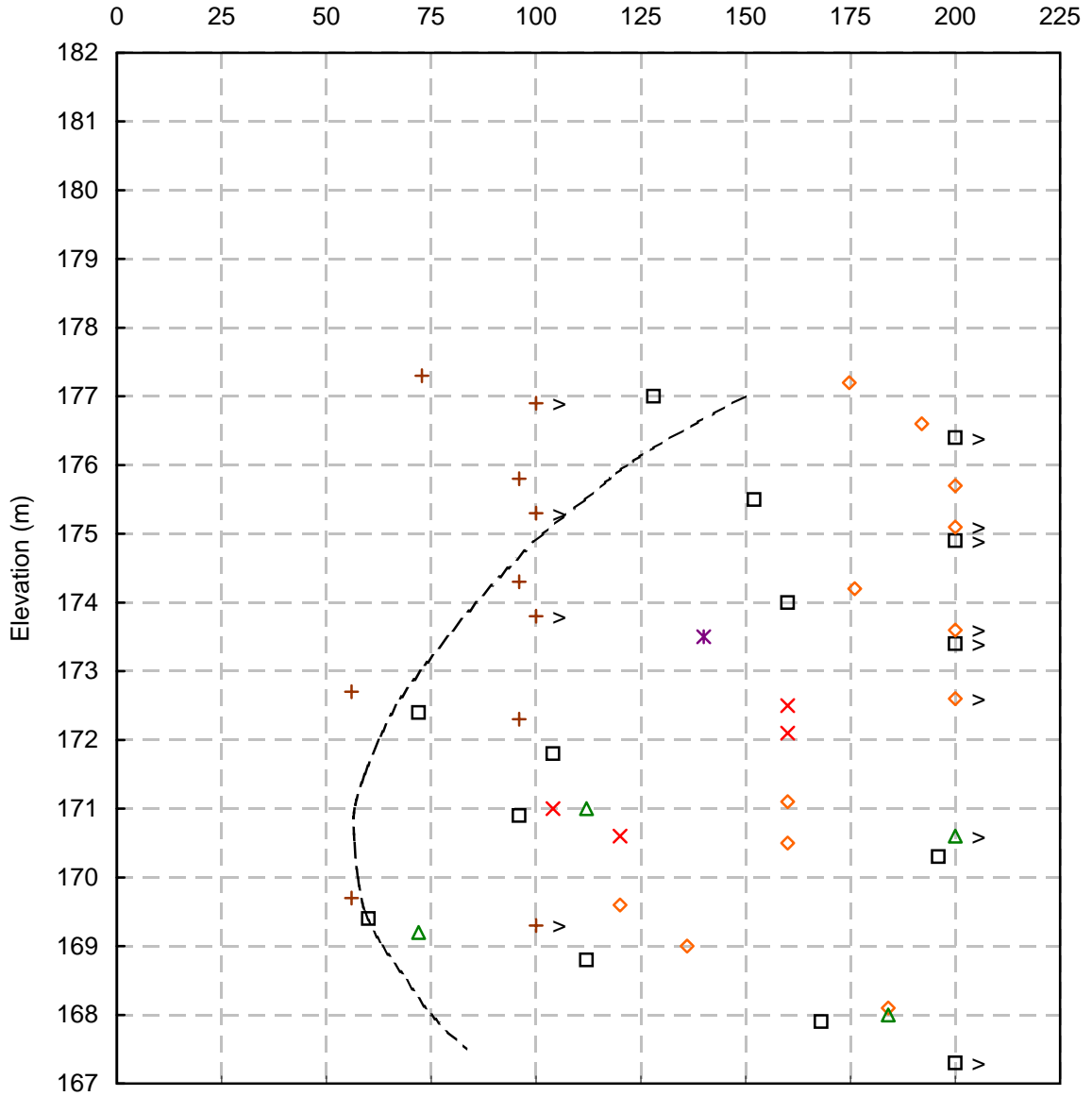
# CORRECTED UNDRAINED SHEAR STRENGTH

FIGURE B13

HWY 406 TWINNING - WOODLAWN EW-S RAMP

Silty Clay

Corrected Cu (kPa)



□ TEW1    ◇ TEW2    △ TEW3    × TEW4    × WES 10+295 CL    + WES 10+345 CL

## Field Shear Vane Correction

## Applied Correction Factors

Morris & Williams (1994)

0.91 (Elev.>177m)

1.00 (Elev.<177m)

( $\mu = 1.18 \text{ EXP}(-0.08 \text{ Ip}) + 0.57$ )

Project No. : 1-09-4135

Date : September, 2010



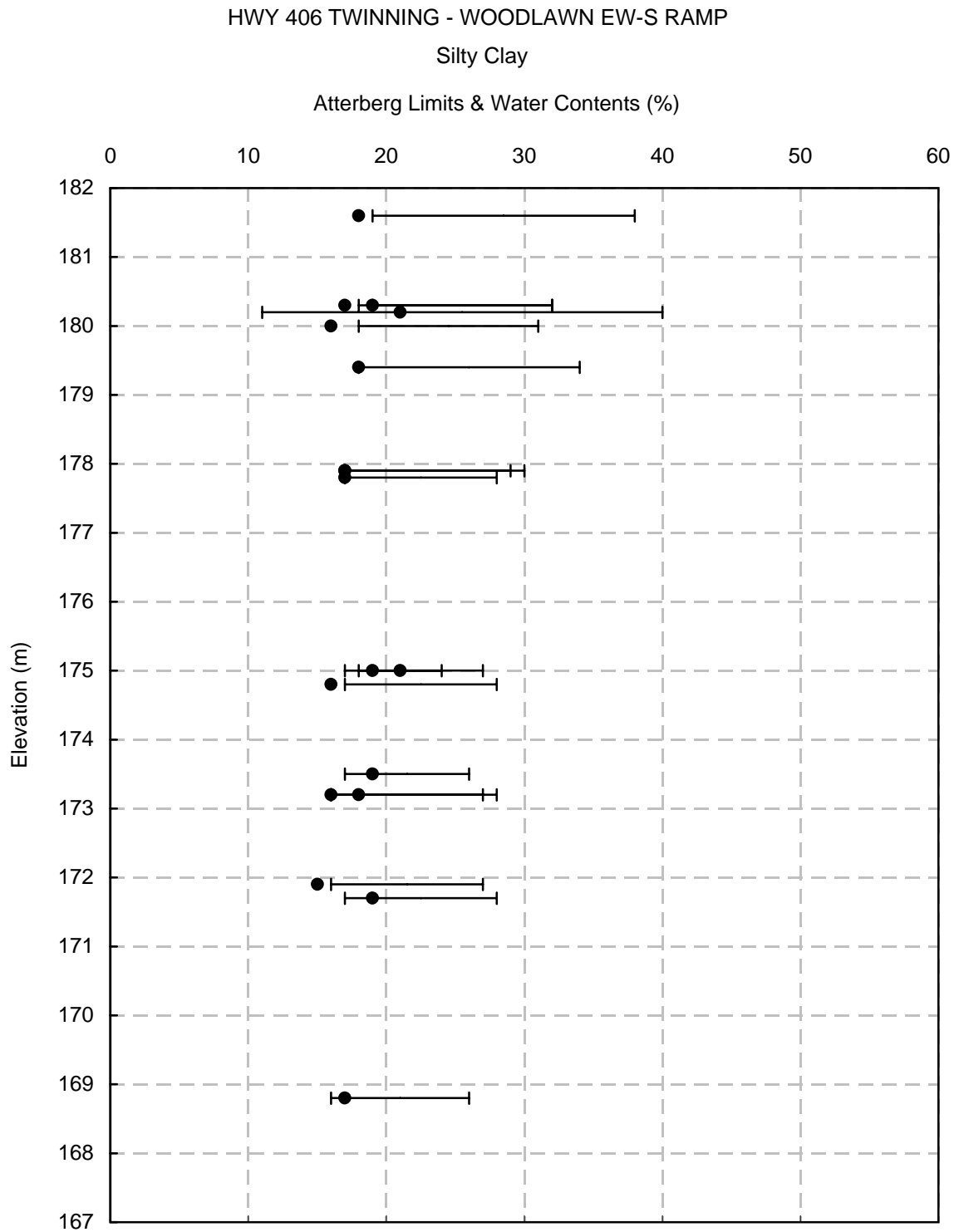
**Terraprobe Inc.**

Prepared By : HW

Checked By : RA

# ATTERBERG LIMITS AND WATER CONTENTS

FIGURE B14



Project No. : 1-09-4135

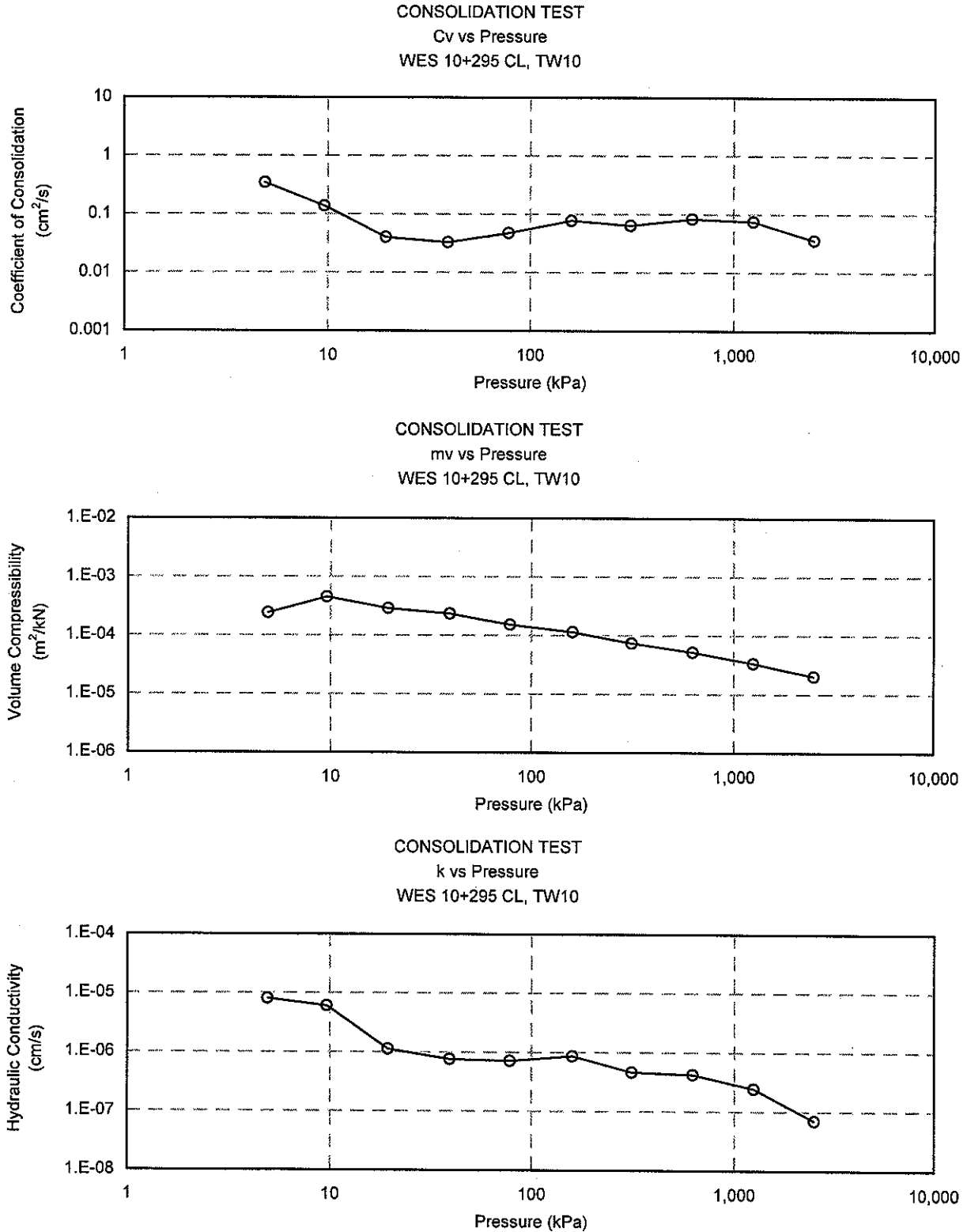
Date : September, 2010



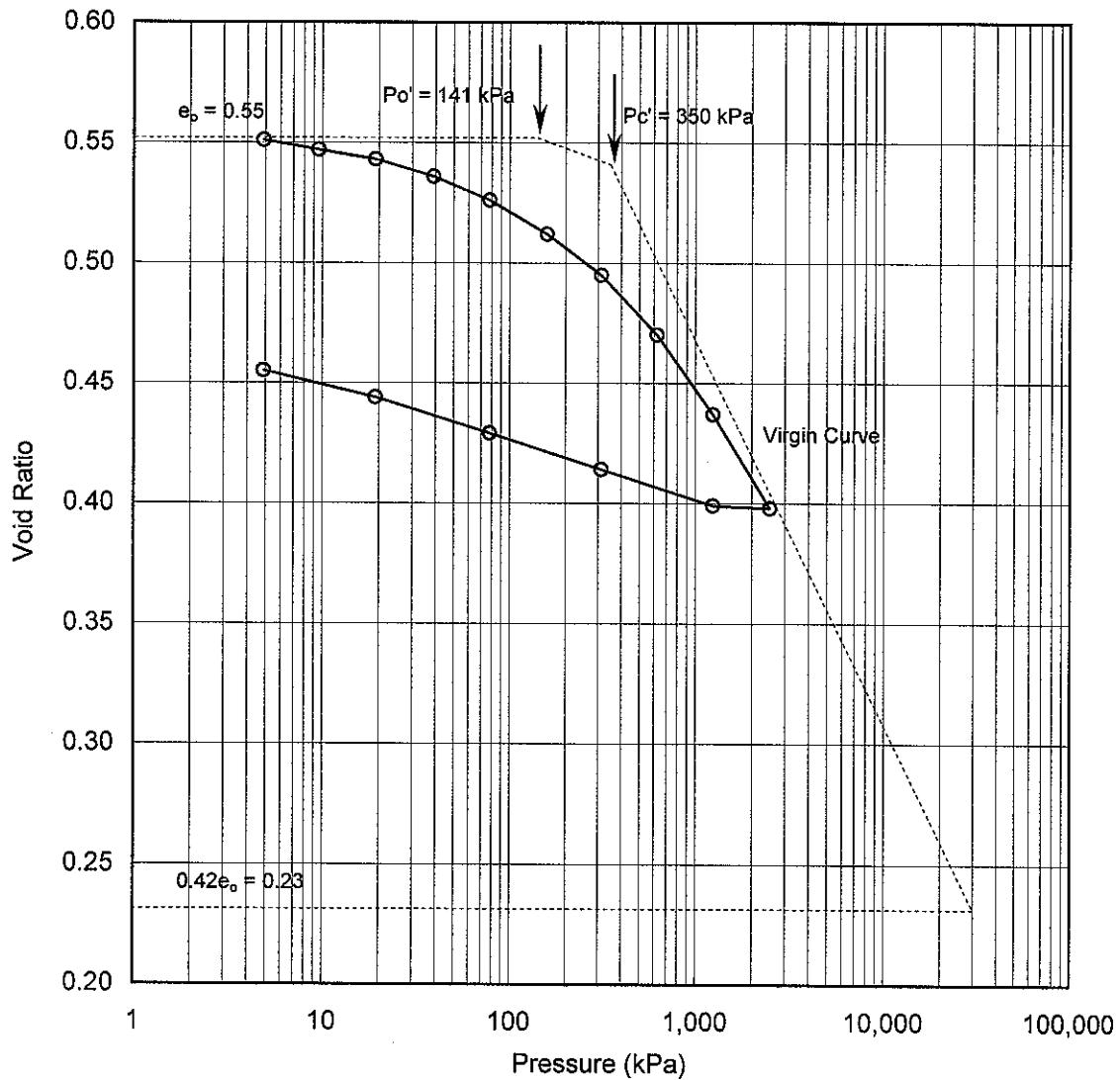
**Terraprobe Inc.**

Prepared By : HW

Checked By : RA



CONSOLIDATION TEST  
e vs Pressure  
WES 10+295 CL, TW10



Soil Type : Silty Clay

$e_o =$	0.55	$\omega_L =$	26%	$P_o' =$	141 kPa
$\omega =$	19%	$\omega_p =$	17%	$P_c' =$	350 kPa
$\gamma =$	20.8 kN/m <sup>3</sup>	PI =	9%	Cc =	0.160
Gs =	2.77			Cr =	0.028

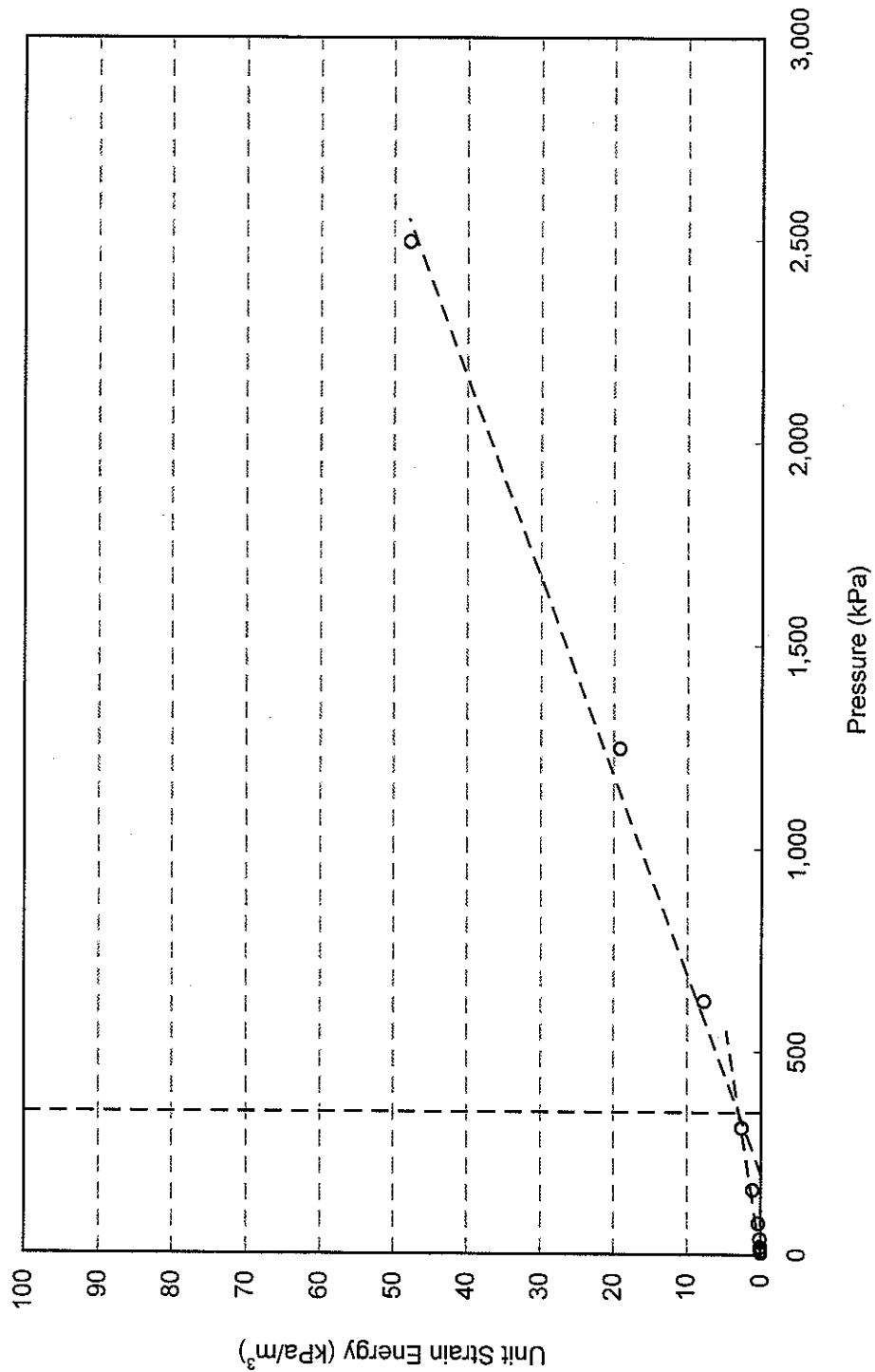
Project No. : 1-09-4135  
Date : May 2010



**Terraprobe Inc.**

Prepared By : HW  
Checked By : RA

CONSOLIDATION TEST  
Unit Strain Energy vs Pressure  
WES 10+295 CL, TW10

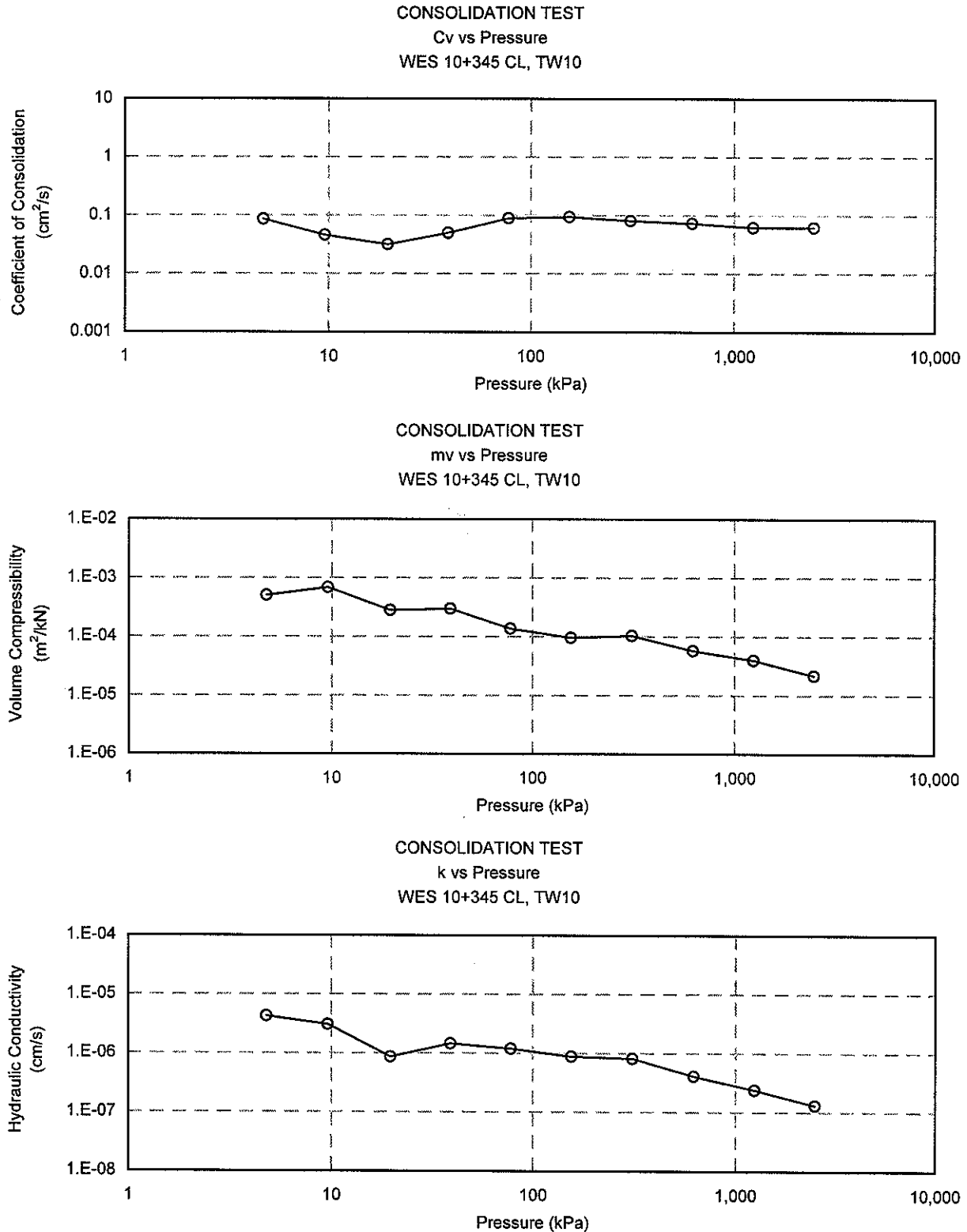


Project No. : 1-09-4135  
Date : May 2010



**Terraprobe Inc.**

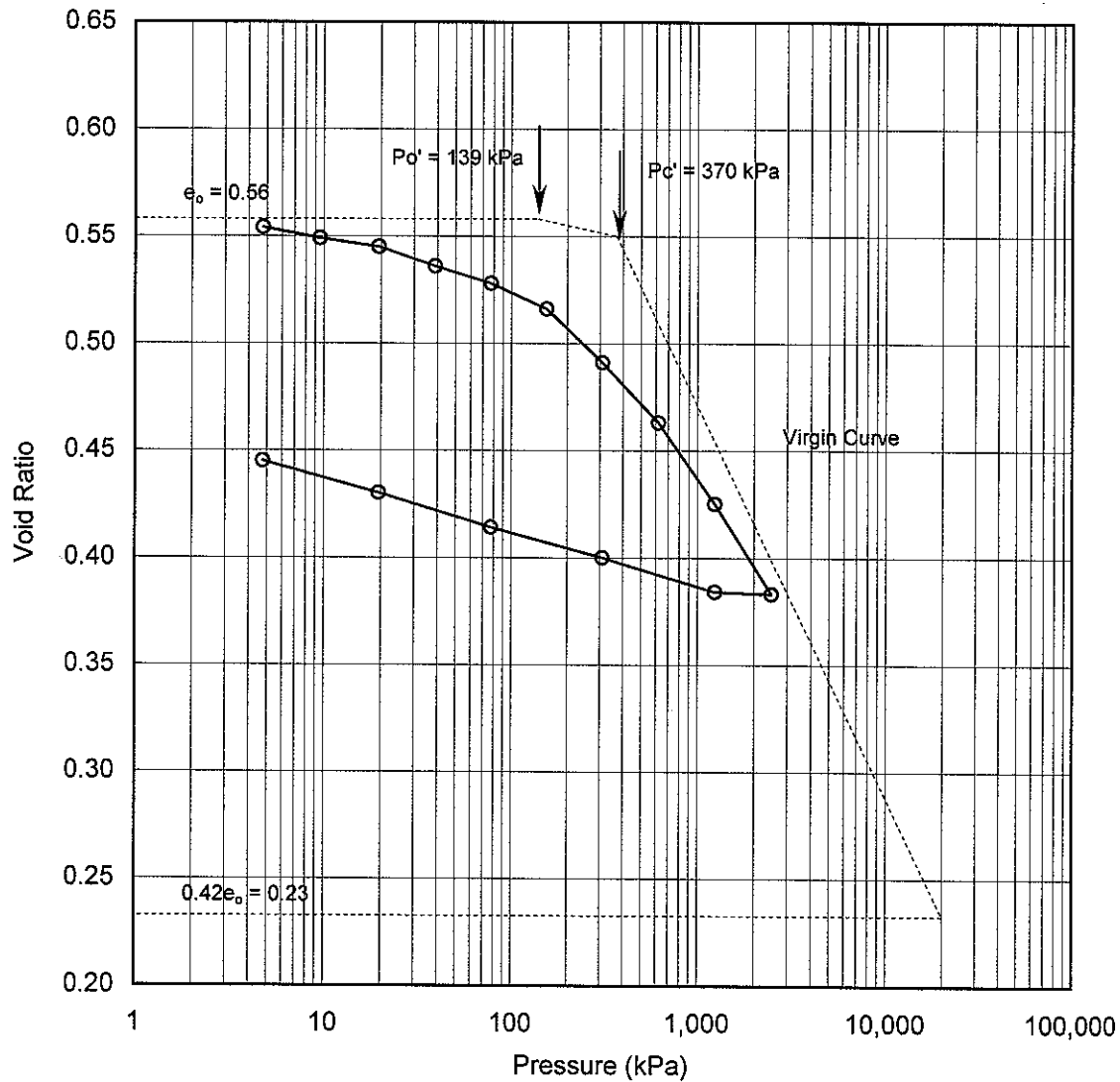
Prepared By : HW  
Checked By : RA



## CONSOLIDATION TEST

e vs Pressure

WES 10+345 CL, TW10



Soil Type : Silty Clay

$e_o =$	0.56	$\omega_L =$	27%	$P_o' =$	139 kPa
$\omega =$	21%	$\omega_p =$	16%	$P_c' =$	370 kPa
$\gamma =$	20.7 kN/m <sup>3</sup>	PI =	11%	Cc =	0.183
Gs =	2.70			Cr =	0.019

Project No. : 1-09-4135  
 Date : May 2010

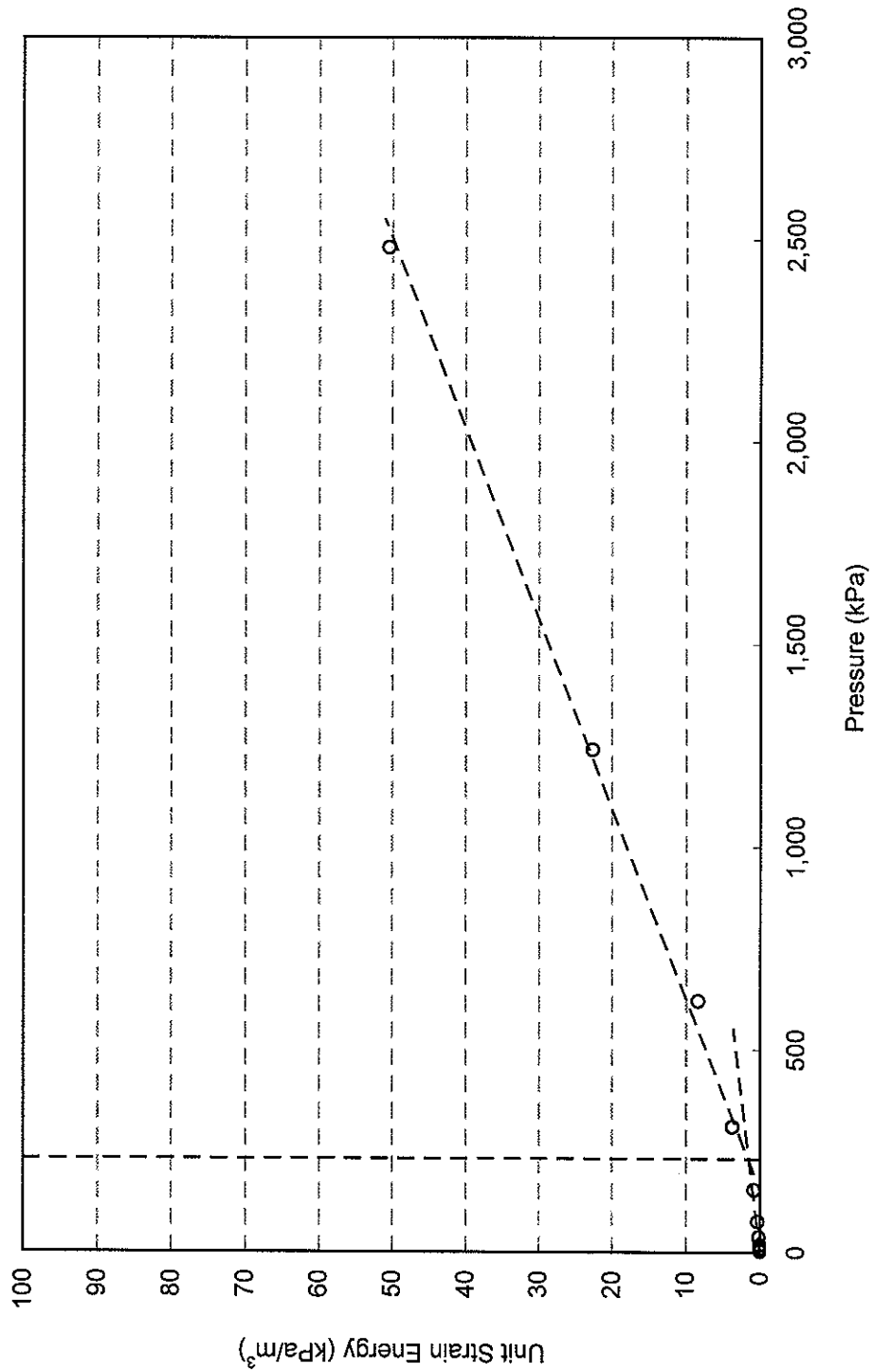


Terraprobe Inc.

Prepared By : HW  
 Checked By : RA



CONSOLIDATION TEST  
Unit Strain Energy vs Pressure  
WES 10+345 CL, TW10



$P_c = 230 \text{ kPa}$

Project No. : 1-09-4135

Date : May 2010



**Terraprobe Inc.**

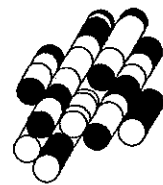
Prepared By : HW

Checked By : RA

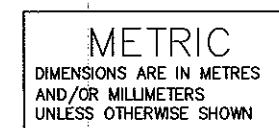
# **APPENDIX C**

## **Drawings**

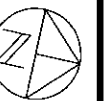
**Terraprobe Inc.**







CONT No  
WP No 280-99-00

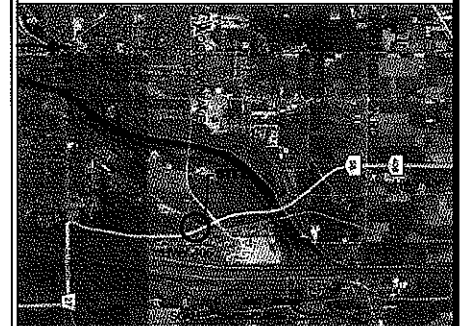


HIGHWAY 406  
WOODLAWN E/W-S RAMP  
TRILLIUM RAILWAY OVERHEAD  
BOREHOLE LOCATIONS AND SOIL STRATA







SHEET  
1 OF

**Giffels Associates Limited**  
Consulting Engineers and Architects  
An IBI Group Company

 **Terraprobe Inc.**  
Consulting Geotechnical & Environmental Engineering  
Construction Materials Engineering, Inspection & Testing  
10 Bram Court - Brampton Ontario L6W 3R6 (905) 796-2650



## KEY PLAN

LEGEND	
	Bore Hole
	Dynamic Cone Penetration Test
	Bore Hole And Cone
'N'	Blows/0.3m (Std Pen Test, 475 J/blow)
CONE	Blows/0.3m (60" Cone, 475 J/blow)
	WL at Time of Investigation
	WL in Piezometer (MAY 2010)
	Piezometer
90%	Rock Quality Designation
A/R	Auger Refusal

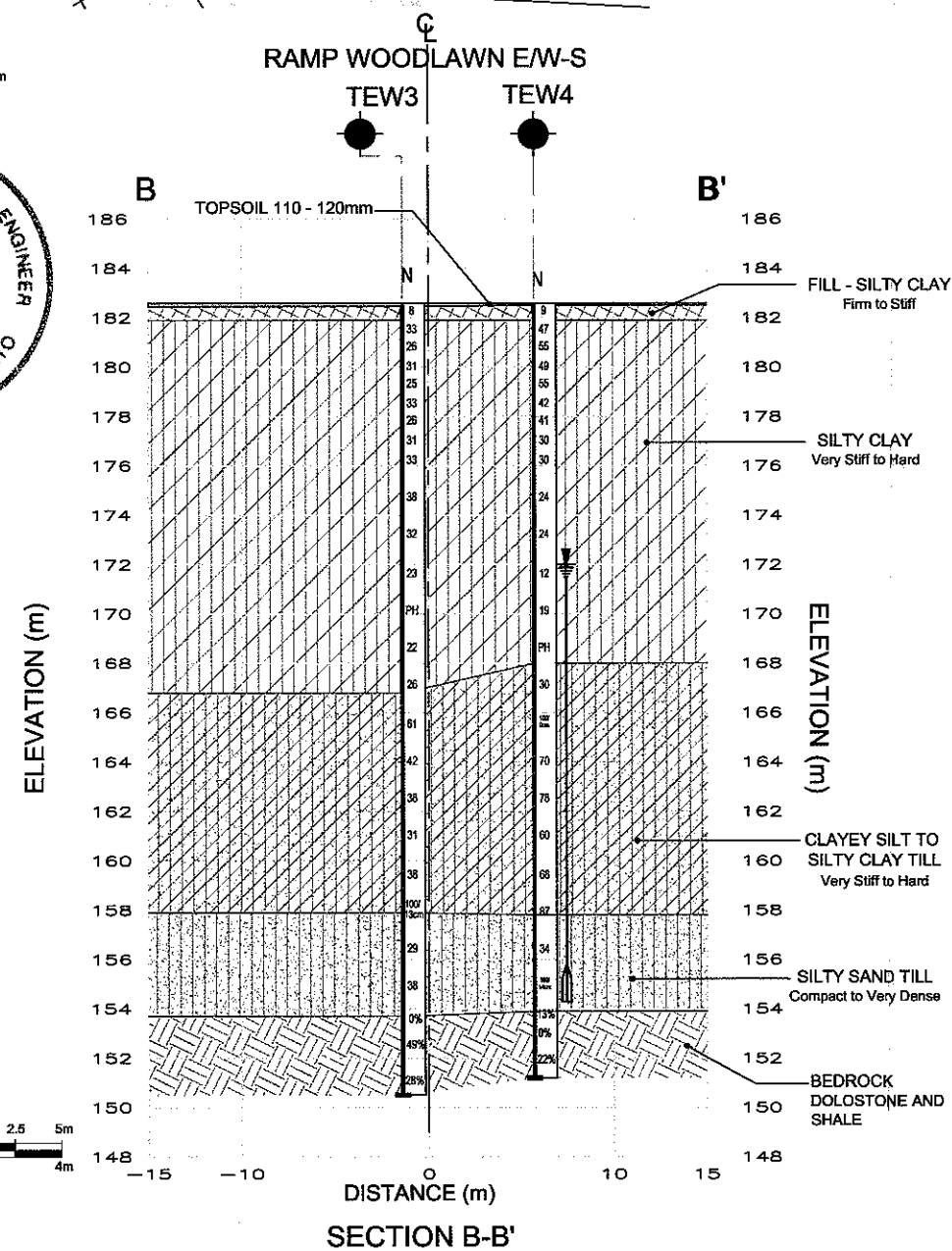
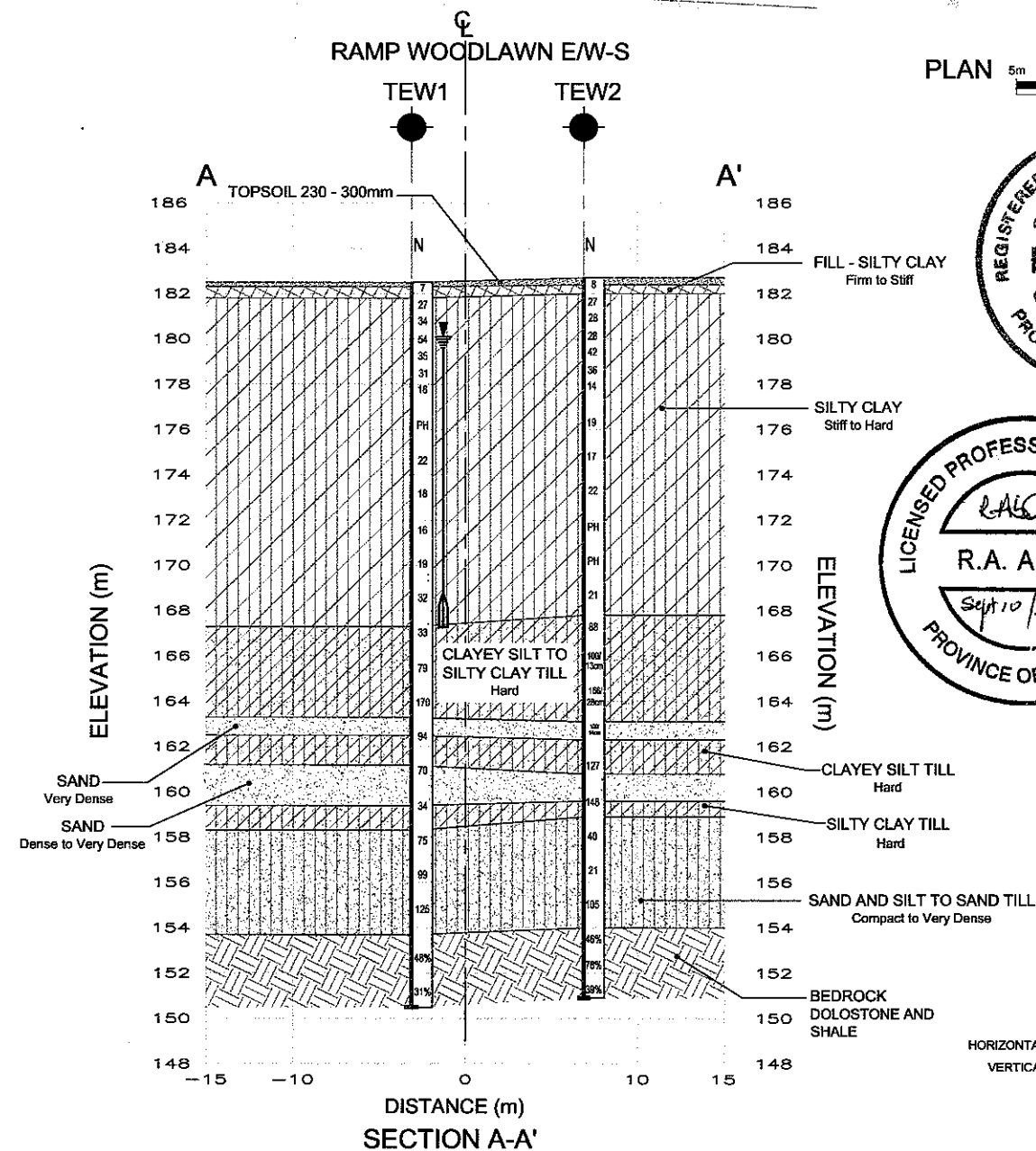
[illegible]

**NOTE**

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

This drawing is for subsurface information only. Surface details and features are for conceptual illustration.

REVISIONS					
	DATE		BY	DESCRIPTION	
DESIGN	RA	CODE CHBDC2006		LOAD	DATE SEPT. 2010
DRAWN	K.C	CHK RA	STRUCT		GEOCRETS 30M3-258

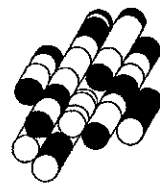


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# **APPENDIX D**

## **Foundation Comparison**

**Terraprobe Inc.**



**COMPARISON OF FOUNDATION ALTERNATIVES FOR EACH FOUNDATION ELEMENT**

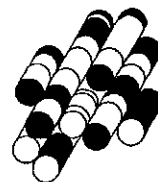
Foundation Element	Driven Piles	Augered Caissons	Footing on Native Soil	Footing on Engineered Fill
North and South Abutments	<p><b>Advantages:</b></p> <ul style="list-style-type: none"> <li>i. High geotechnical resistances available by driving piles to bedrock.</li> <li>ii. Readily installed.</li> <li>iii. Reliable performance and low risk.</li> <li>iv. Allows for the design of an integral or semi-integral abutment.</li> </ul> <p><b>Disadvantages:</b></p> <ul style="list-style-type: none"> <li>i. Construction concerns related to the possibility of piles being obstructed by a boulder during driving.</li> <li>ii. May cause adverse vibrations at the site that could affect the integrity of the railway track.</li> </ul>	<p><b>Advantages:</b></p> <ul style="list-style-type: none"> <li>i. High geotechnical resistances available by founding caissons on bedrock.</li> <li>ii. Reliable performance and low risk.</li> </ul> <p><b>Disadvantages:</b></p> <ul style="list-style-type: none"> <li>i. High unit cost compared to other footing options such as driven piles.</li> <li>ii. Relatively high construction effort required to install caissons to bedrock compared to driven piles.</li> <li>iii. Higher risk of encountering potential construction problems compared to driven piles.</li> <li>iv. Precludes consideration of a semi-integral abutment structure.</li> </ul>	<p><b>Advantages:</b></p> <p>None</p> <p><b>Disadvantages:</b></p> <ul style="list-style-type: none"> <li>i. Uneconomically large footings due to low geotechnical resistance of soils.</li> <li>ii. Unreliable performance and high risk due to settlement sensitive soils. Potential for unacceptable settlements and differential settlements.</li> <li>iii. Relatively long abutment stems required.</li> </ul>	<p><b>Advantages:</b></p> <p>None</p> <p><b>Disadvantages:</b></p> <ul style="list-style-type: none"> <li>i. Unreliable performance and high risk due to settlement sensitive soils. Potential for unacceptable settlements and differential settlements.</li> <li>ii. Requires placement on an RSS Core</li> </ul>



# **APPENDIX E**

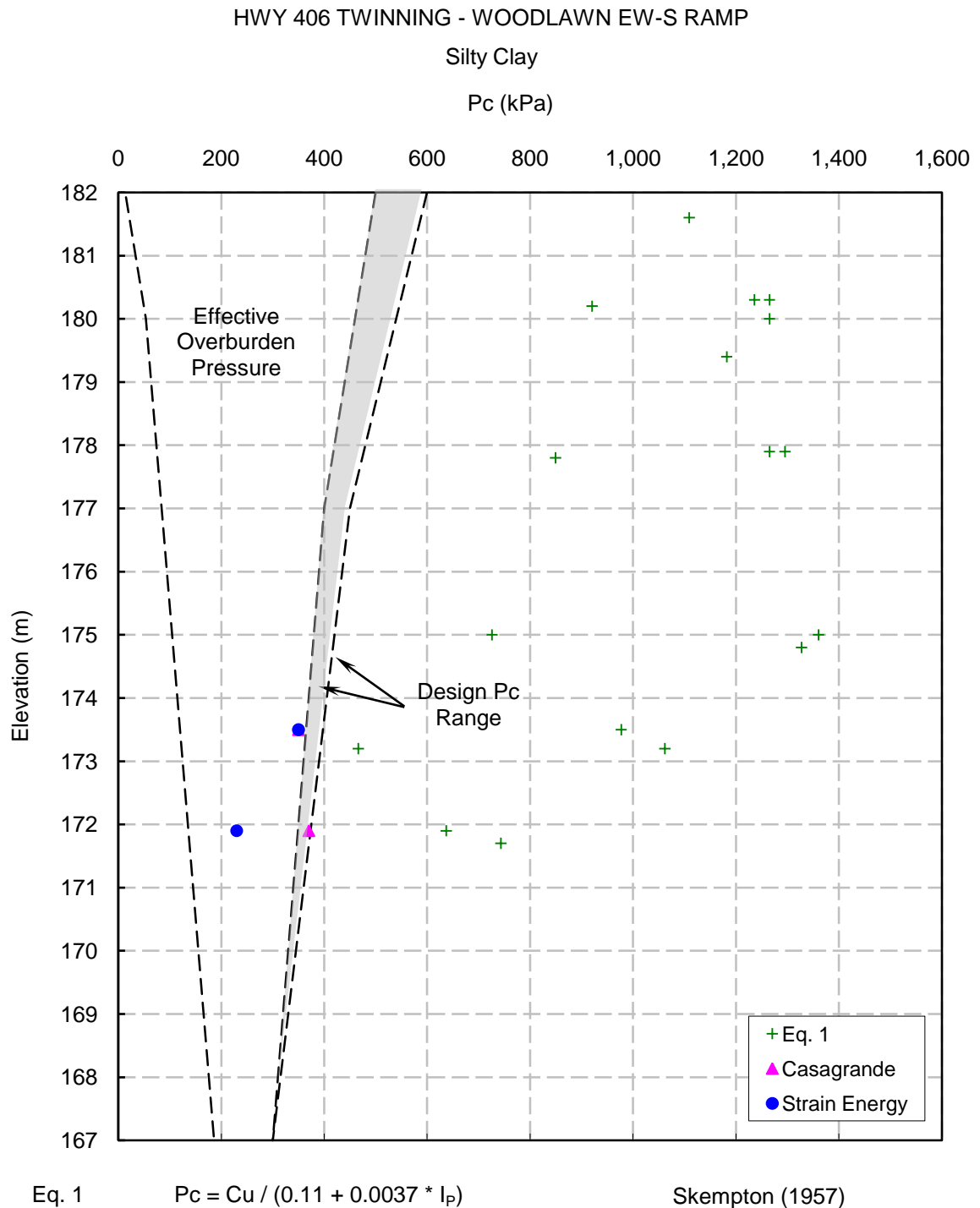
## **Settlement Parameters and Results**

**Terraprobe Inc.**



# PREDICTED AND MEASURED PRECONSOLIDATION STRESS

FIGURE E1



C:\Users\CHRISA\Documents\1111-09-4135 Soil Parameter Estimation-TEW1.xls

Project No. : 1-09-4135

Date : September, 2010



**Terraprobe Inc.**

Prepared By : HW

Checked By : RA



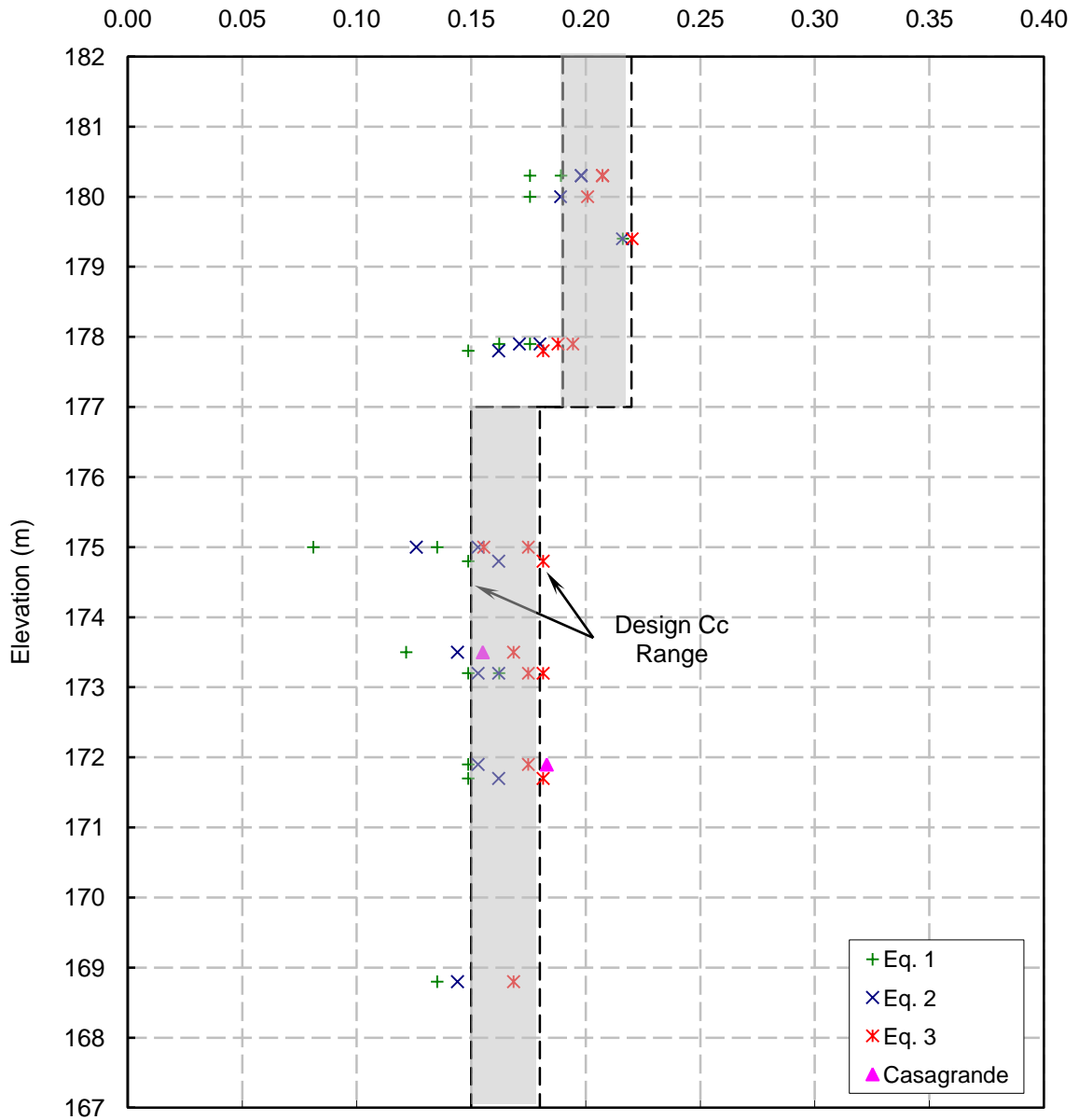
# PREDICTED AND MEASURED COMPRESSION INDEX

FIGURE E2

## HWY 406 TWINNING - WOODLAWN EW-S RAMP

Silty Clay

$C_c$



Eq. 1  $C_c = I_p / 74$

Kulhawy & Mayne (1990)

Eq. 2  $C_c = 0.009 * (LL - 10)$

Terzaghi & Peck (1967)

Eq. 3  $C_c = 0.2343 * LL * G_s$

Nagaraj & Murty (1985)

Project No. : 1-09-4135

Date : September, 2010



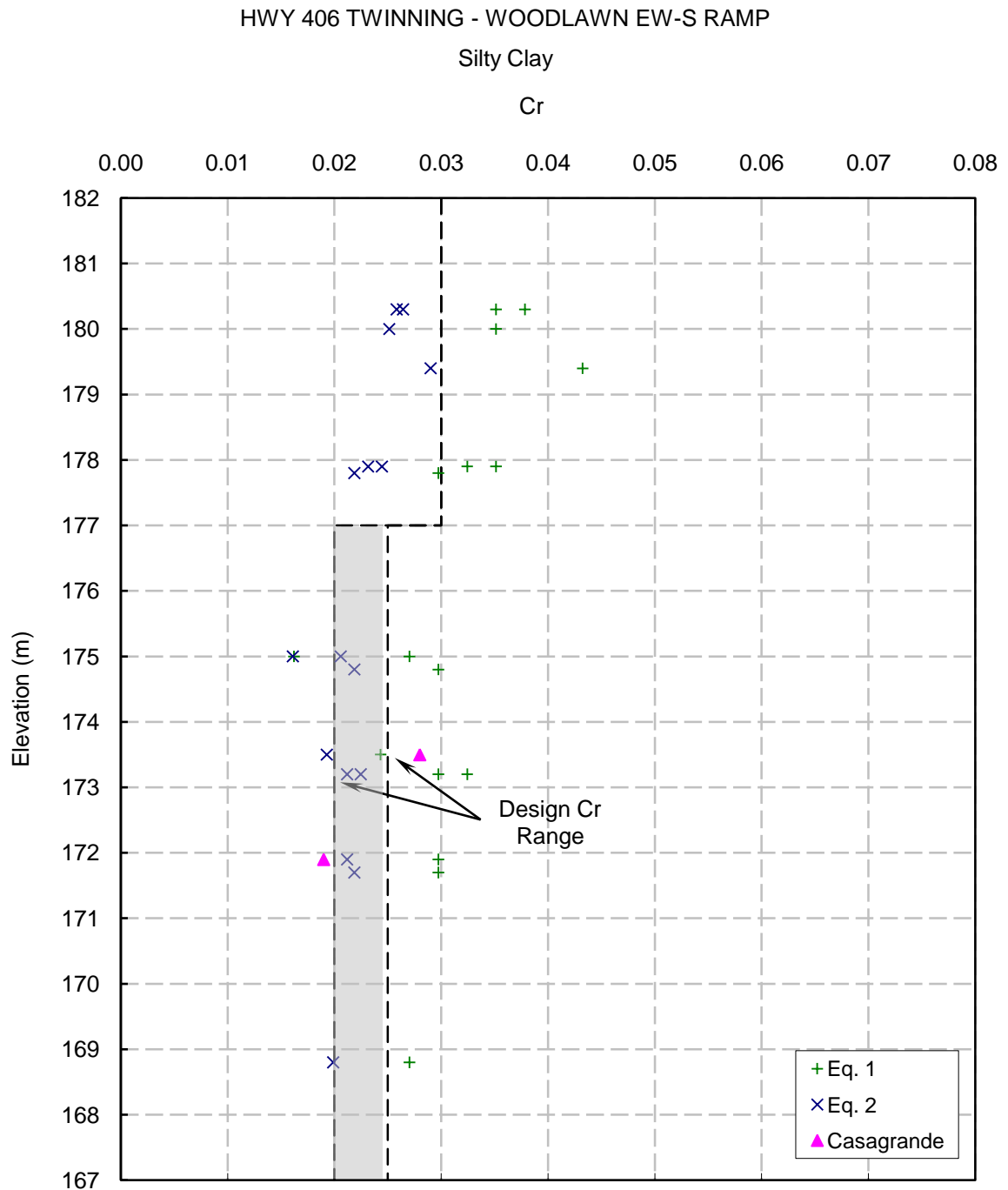
**Terraprobe Inc.**

Prepared By : HW

Checked By : RA

# PREDICTED AND MEASURED RECOMPRESSION INDEX

FIGURE E3



Eq. 1  $Cr = Ip / 370$

Kulhawy & Mayne (1990)

Eq. 2  $Cr = Cc / 5 \sim Cc / 10$

Das (1993)

Project No. : 1-09-4135

Date : September, 2010



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Checked By : RA

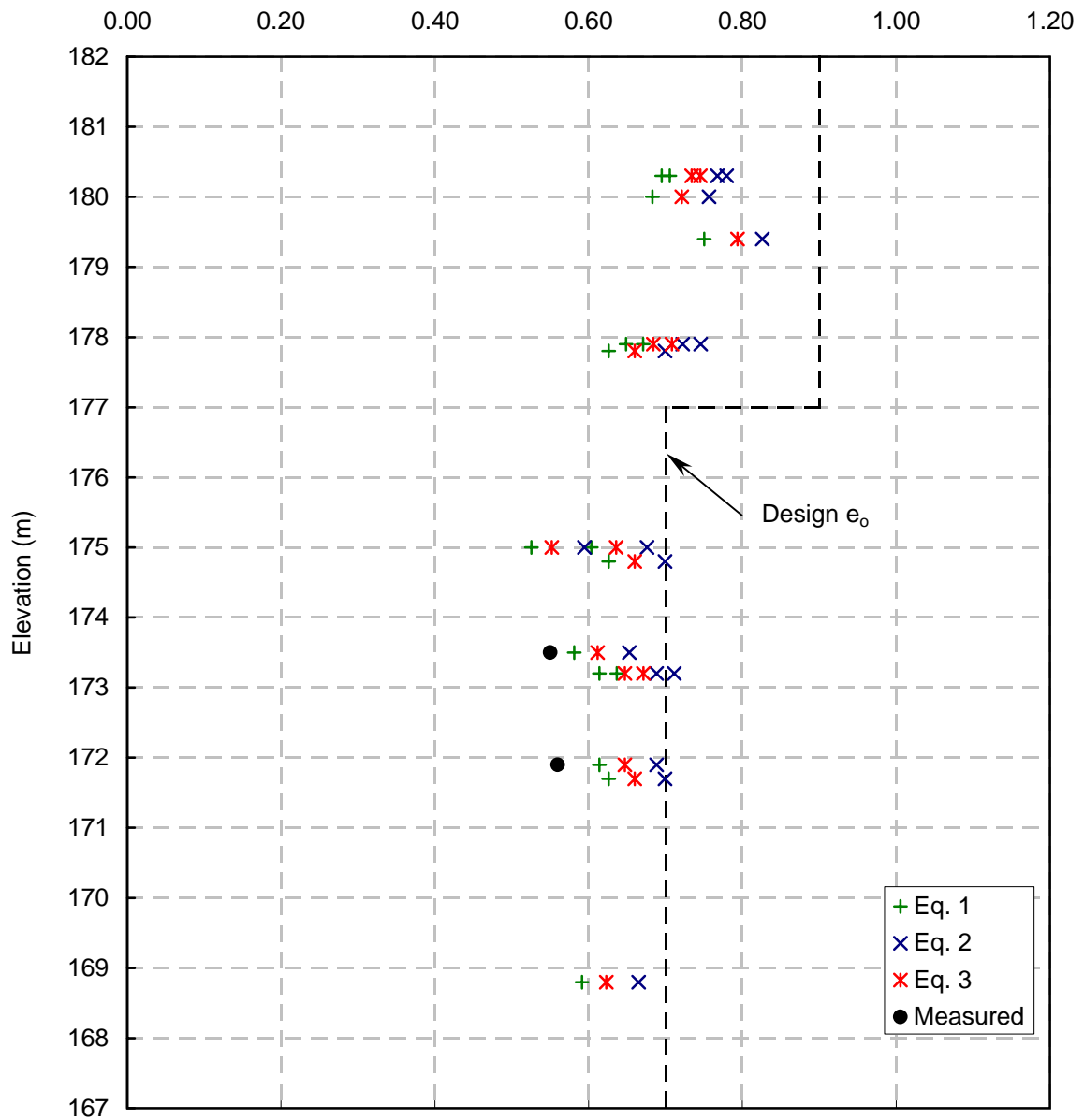
# PREDICTED AND MEASURED VOID RATIO

FIGURE E4

HWY 406 TWINNING - WOODLAWN EW-S RAMP

Silty Clay

$e_o$



Eq. 1  $e_o = ( Cc - 0.256 ) / 0.43 + 0.84$

derived from Cozzolino (1961)

Eq. 2  $e_o = Cc / 0.37 - 0.003 * LL + 0.34$

derived from Azzouz et al. (1976)

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

derived from Lav & Ansal (2001)

Project No. : 1-09-4135

Date : September, 2010



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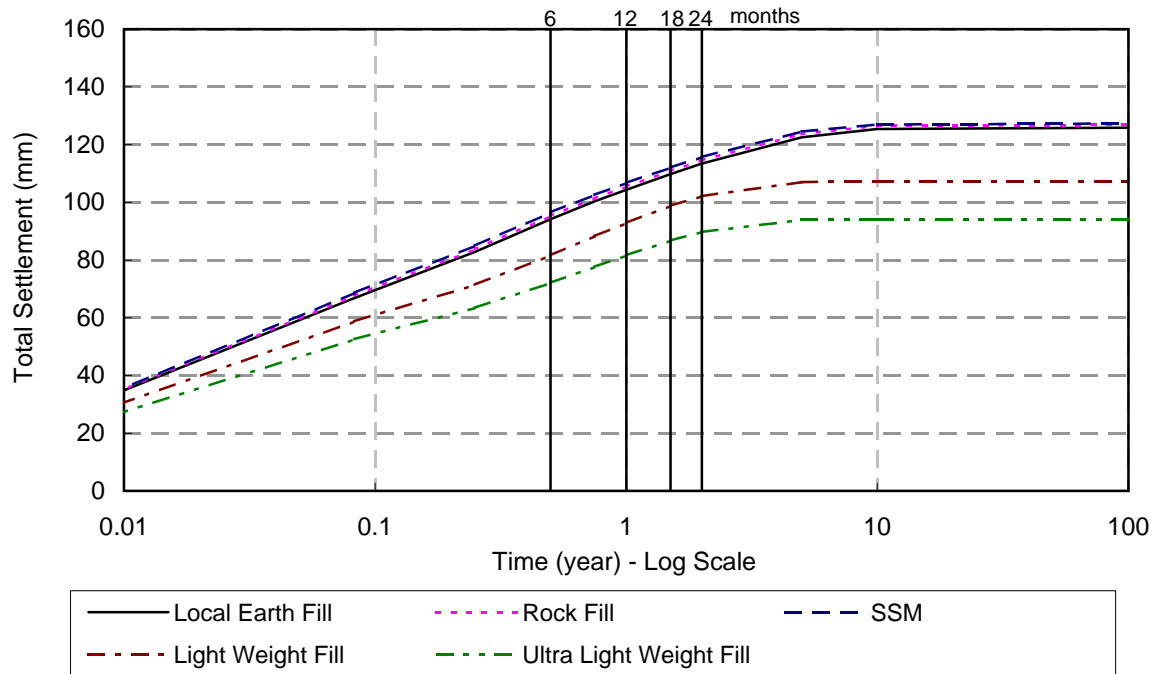
Prepared By : HW

Checked By : RA

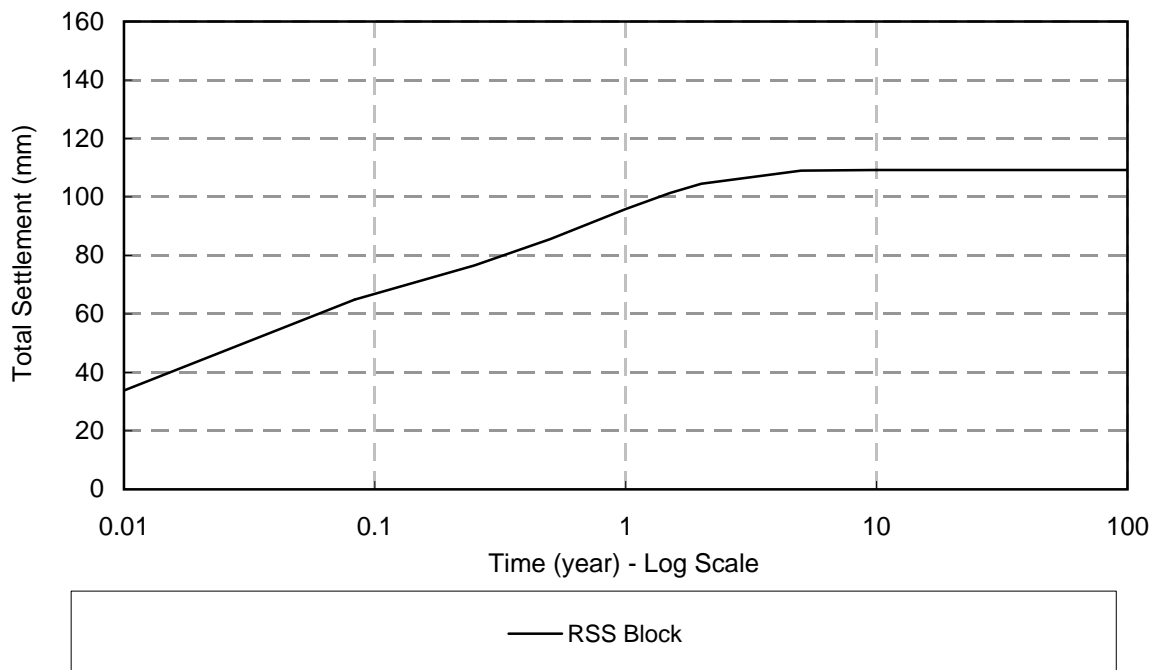
# SETTLEMENT VS. LOG TIME

FIGURE E5

## HWY 406 TWINNING - WOODLAWN EW-S RAMP Embankment



## RSS Block



Project No. : 1-09-4135

Date : September, 2010



**Terraprobe Inc.**

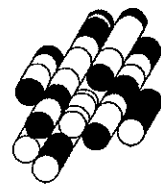
Prepared By : HW

Checked By : RA

# **APPENDIX F**

## **Suggested NSSP Wording**

**Terraprobe Inc.**



In this report reference is made to the following Provincial Standard:

- OPSSS 903, November 2009

The contract documents should contain a NSSP containing the following wording:

**Cobbles and Boulders**

“The Contractor is informed that the soils at this site may contain cobbles and boulders that could impede the progress of pile driving operations. The soil conditions are described in the Foundation Investigation Report prepared for this site”.

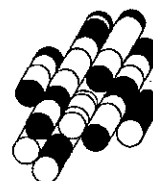
If a pile encounters refusal on cobbles and boulders the QVE should terminate driving before the pile is damaged by overdriving. If a pile has not been driven to bedrock and further driving is likely to cause damage to the pile, pile driving should cease and the contract administrator should be notified.



# **APPENDIX G**

## **Settlement Monitoring Programme**

**Terraprobe Inc.**



## **SUPPLY AND INSTALLATION OF EMBANKMENT MONITORING EQUIPMENT – Item No.**

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### **Special Provision**

---

#### **1.0 GENERAL**

##### **1.1 Scope**

This special provision contains the requirements for the supply and installation of the following geotechnical instruments:

- Settlement Rods (SR)
- Vibrating Wire Piezometers (VWP)
- Standpipe Piezometers (SSP)
- Survey Benchmark/s (BM)

##### **1.2 Purpose**

The purpose of these instruments is to monitor settlements and pore water pressures in the foundation soils under the new approach embankments. The data will be used for planning the commencement of pile driving operations, construction scheduling, and final paving operations. Settlements will be measured by level surveying of the top of the settlement rods.

The piling at the foundation elements, the fill placement, timing for the removal of the preload, and final paving operations shall be controlled by the instrumentation readings.

##### **1.3 Personnel**

The Contractor shall retain a Geotechnical Consultant with MTO classification of “Geotechnical (Structures and Embankments) – High Complexity”, to undertake the supply and installation of geotechnical instruments.

The Contractor (as referenced herein) shall be understood to refer to the Contractor and their Geotechnical Consultant.

##### **1.4 Or equal**

The term “or equal” shall be understood to indicate that the equal product is the same or better than the specified product in function, performance, reliability, quality and general configuration. Only one supplier shall be selected for the supply of data acquisition system and vibrating wire instruments (piezometers).

##### **1.5 Notification**

The Contract Administrator shall be notified a minimum of 15 working days in advance of commencing the installation of instruments.



## **1.6 Submission Requirements**

The Contractor shall submit details of proposed installations including:

- Design and construction drawings, including equipment layout;
- Installation methodology and timing;
- Equipment and material specifications, data sheets;
- Location and types of survey benchmarks; and
- Installation schedule.

Submissions shall be made to the Contract Administrator a minimum of 15 days before the start of the instrument installation.

## **1.7 Subsurface Conditions**

The subsurface conditions at the site(s) are described in the report:

- Foundation Investigation Report – Ramp Woodlawn EW-S Bridge at Trillium Railway, Highway 406 Twinning, Ontario. Site No., W.P. 280-99-00, Site #34-464/3, Geocres No. 30M3-258, dated September 10, 2010, by Terraprobe Inc.

The owner warrants that the information provided in the report can be relied upon with the following exceptions.

1. Any interpretations of the data or opinions expressed in the report are not warranted; and
2. Although the raw measured data presented is warranted, the Contractor must satisfy himself as to the sufficiency of the information presented and obtain any updated or additional information, and perform any studies, analysis or investigations the Contractor deems necessary in order to prepare his design, at no additional cost to the Owner.

## **1.8 Equipment Operation and Weather Conditions**

All installations and monitoring equipment and associated materials shall be capable of withstanding the range of temperatures possible for their location within the ground or on the surface. The instruments shall be capable of operating within the manufacturer's stated accuracy throughout the temperature range. Monitoring shall be conducted year round and the Contractor is advised that the equipment should be accessible for monitoring throughout the duration of the Contract.

## 2.0 INSTALLATION

A summary of instrumentation requirements is given in Table 2.1. Details and specific material requirements are presented elsewhere in this special provision.

**Table 2.1 – Settlement Rods & Benchmark Quantities and Locations**

INSTRUMENT I.D.	STATION	OFFSET FROM CENTRELINE	NO. OF INSTRUMENTS		
			SP	VWP	SSP
North Approach					
SP1	Ramp E/W-S 10+280	4 m Lt.	1		
SP2	Ramp E/W-S 10+280	2 m Rt.	1		
SP3	Ramp E/W-S 10+287	CL	1		
VWP1	Ramp E/W-S 10+294	CL		1	
SSP1	Ramp E/W-S 10+300	Outside of construction area			1
SP4	Ramp E/W-S 10+300	4 m Lt.	1		
SP5	Ramp E/W-S 10+302	2 m Rt.	1		
BM1	N/A	N/A			
South Approach					
SP6	Ramp E/W-S 10+339	4 m Lt.	1		
SP7	Ramp E/W-S 10+340	2 m Rt.	1		
SP8	Ramp E/W-S 10+347	CL	1		
VWP2	Ramp E/W-S 10+353	CL		1	
SSP2	Ramp E/W-S 10+355	Outside of construction area			1
SP9	Ramp E/W-S 10+360	4 m Lt.	1		
SP10	Ramp E/W-S 10+360	2 m Rt.	1		
Total Instruments			10	2	2

### 2.1 Instrument Location

Prior to the installation of instruments, the Contractor shall accurately survey and stake the location of each instrument and obtain a ground surface elevation at each instrument location.

## **2.2 Survey Benchmarks (BM)**

The Contractor shall provide a minimum of one non-yielding deep seated survey benchmarks (BM) at the site. Alternatively the contractor may select stable non-settling points on existing structures within the area subject to approval by the contract administrator.

The number and locations(s) of benchmark(s) shall be such that direct sighting is possible from all settlement rods (SR) to at least one benchmark.

## **2.3 Accuracy of Surveying for Elevations**

Elevations shall be surveyed referenced to Geodetic datum to an accuracy of  $\pm 2$  mm or better.

## **2.4 Monitoring Instrument Location**

All monitoring instruments shall be located in MTM NAD83 northing and easting coordinates.

## **2.5 Materials and Equipment**

The Contractor shall supply all materials and equipment required for the installation of instrumentation unless noted otherwise.

## **2.6 Underground Utilities**

The Contractor shall be responsible for locating and protecting all underground utilities prior to drilling boreholes for installing instruments. Any damage to underground utilities caused by the Contractor's work shall be repaired by the Contractor, at no cost to the Ministry.

## **2.7 Marking and Labelling**

The location of any above ground monitoring fixture shall be made clearly visible to nearby traffic before, during and after embankment construction. Marking shall be of sufficient size to be visible from a reversing vehicle and after heavy snow falls.

Instruments shall be clearly labelled in the field, each instrument having a unique identifier. The labelling shall remain legible for at least 1 year.

## **2.8 Protection of Instruments**

All instruments shall be adequately protected by the Contractor such that they are not damaged during construction. Any instrument damaged by the Contractor's work shall be immediately replaced at no cost to the Ministry.

## **2.9 Boreholes**

The Contractor shall make a basic stratigraphic log of boreholes as they are being drilled. In situ or laboratory testing is not required.

Boreholes shall be advanced using conventional drilling methods and shall be as straight and vertical as practical.

## **2.10 Installation Program**

Instrument installation shall be completed before any piling installation and before any embankment construction. Table 2.2 provides a summary of the installation schedule requirements.

**Table 2.2 – Installation Program**

<b>TYPE</b>	<b>START INSTALLATION</b>	<b>FINISH INSTALLATION</b>
SR	After excavating to recommended stripping elevation of embankment	On completion of embankment/RSS construction
VWP	Before Piling and Embankment Construction	Before Piling and Embankment Construction
SSP	Before Piling and Embankment Construction	Before Piling and Embankment Construction
BM	Before commencement of embankment/RSS construction	Before commencement of embankment/RSS construction

### **3.0 BENCHMARK (BM) – SUPPLY & INSTALLATION**

#### **3.1 GENERAL**

##### **3.1.1 Scope**

This Section contains the requirements for the supply and installation of benchmark/s (BM).

The purpose of the benchmark is to provide non-settling references for the surveying of settlement rods.

##### **3.1.2 General Procedure**

The benchmark shall be installed prior to embankment construction. The number and locations of benchmarks shall be such that direct sighting is possible from all settlement rods (SR) to at least one benchmark. Elevations shall be surveyed to an accuracy of  $\pm 2\text{mm}$  or better.

Prior to the installation of instruments, the Contractor shall accurately survey and stake the locations of each instrument and obtain a ground elevation at each instrument location.

##### **3.1.3 Location**

Benchmarks shall be located and installed outside of the area of construction activity. Notwithstanding the installation details provided herein the contractor may select stable non-settling points on existing structures within the area subject to approval by the contract administrator.

**Table 3 – Approximate Bench Mark Locations**

<b>Station</b>	<b>Offset (m)</b>	<b>No. of BM</b>	<b>Estimated Rod Anchor Elevation (m)</b>
Outside of Construction Area	N/A	BM1	165.0

#### **3.2 MATERIALS**

##### **3.2.1 General**

The Contractor shall supply all materials and equipment required for the installation of the benchmark.

##### **3.2.2 Rod**

The Contractor shall supply a steel pipe Schedule 40 with an outside diameter not less than 25.4 mm (1”), supplied in lengths as required to complete the installation as described.

The top end of each length of rod shall be threaded to receive a cap. A rounded cap shall be installed at the top of the rod in such a way that a single survey point can be clearly identified and returned to.

### **3.2.3 Sand**

The Contractor shall supply clean washed sand. The sand shall be Sakcrete washed general-purpose sand – or equal.

### **3.2.4 Grout**

The Contractor shall supply cement-bentonite grout. A suitable grout mix design consists of 23 kg of bentonite (OPSS 1205), 143 litres of water and 40 kg of cement (Type G.U. – OPSS 1301).

### **3.2.5 Rod Anchor Grout**

The Contractor shall supply cement-bentonite grout. A suitable grout mix design consists of 14 kg of bentonite (OPSS 1205), 49 litres of water and 40 kg of cement (Type G.U. – OPSS 1301).

### **3.2.6 Friction Reducing Sleeve**

The Contractor shall supply a friction reducing sleeve consisting of Schedule 50 – 50.8 mm (2”) O.D. PVC pipe cut perpendicular to the axis of the pipe.

## **3.3 INSTALLATION**

### **3.3.1 General**

The Contractor shall install the benchmark in accordance with the information below.

### **3.3.2 Borehole Installation**

The borehole shall be advanced to the rod anchor elevation provided in Table 3 using suitable drilling techniques. The diameter of the borehole shall be sufficient to fit the rod, friction reducing sleeve and rod anchor. The sides of the borehole shall be stable and the borehole shall be free of drilling mud and debris.

### **3.3.3 Rod**

The coupling of the rods shall be such that all sections have the same axis and no separation or contraction will occur at the couplings.

### **3.3.4 Rod Anchor**

The rod shall be installed vertically in the borehole with its bottom end resting at the bottom of the borehole. The bottom portion of the rod shall be fixed against the surrounding native soil by grouting the bottom 0.5 m of the borehole to form a concrete/soil anchor.

Once grouting is completed and the rod anchor grout has set, the Contractor shall pour 0.5 m of clean sand in the borehole above the concrete/soil anchor to create a base for the end of the friction reducing sleeve to rest on.

The elevation of the bottom of the rod anchor shall be determined by measuring the length of the rod to the ground surface elevation.

### **3.3.5 Friction Reducing Sleeve**

The friction reducing sleeve shall be over the entire length of the rod above the rod anchor and sand.

### **3.3.6 Installation Details**

The elevation, easting and northing of the top of the benchmark rod shall be surveyed.

## **3.4 COORDINATION WITH MONITORING**

### **3.4.1 Notification**

The Contractor shall notify the Contract Administrator no later than 3 days after installing a benchmark. At this time the Contractor shall also supply the following information to the Contract Administrator.

- Location of the rod anchor and elevation top of rod;
- Dates of installation;
- Stratigraphic log of subsurface conditions at the benchmark, including drilling method notes;
- Installation notes/sketches; and
- Description of benchmarks, sleeve and rod anchor.

### **3.4.2 Monitoring**

Monitoring of settlements with reference to the benchmark shall be done by others. Monitoring shall be conducted during and following the embankment construction at the north and south approaches. The Contractor shall provide installation information as specified above and provide access to the benchmark for monitoring including, but not limited to snow clearing in the winter. The Contractor shall provide electric power and general area lighting as needed.

## **3.5 REPORTING**

The Contractor shall record and report relevant installation details to the Contract Administrator. These include, but are not limited to:

- Benchmark easting, northing in MTM NAD83 coordinates;
- Elevation of bottom of rod anchor and top of rod relative to Geodetic datum;
- Dates of installation; and
- Installation notes/sketches.

## **4.0 SETTLEMENT PLATES (SP) – SUPPLY & INSTALLATION**

### **4.1 GENERAL**

#### **4.1.1 Scope**

This Section contains the requirements for the supply and installation of settlement plates.

The purpose of the settlement plates is to monitor settlements of the foundation soils below the embankment base. The settlement readings shall help to establish the timing for the removal of the preload fill, the commencement of pile driving operations, as well as final paving operations. Settlement is measured by survey of the top of the rod with reference to stable, non-settling benchmarks.

#### **4.1.2 General Procedure**

The settlement rods shall be attached to a plate at the existing ground surface. As embankment construction proceeds the rods shall be extended above the new top of embankment.

Sleeves around the rods shall be installed to reduce friction and allow uninhibited movement of the rod with the plate.

A protective surround shall be extended with the rods as embankment construction proceeds.

#### **4.1.3 Location**

The locations of the settlement rods are shown on the Contract Drawings and are given in Table 4.

**Table 4 – Approximate Settlement Plate Locations**

<b>Station</b>	<b>Offset (m)</b>	<b>No. of SP</b>	<b>Estimated Fill Thickness (m)*</b>
<b>North Approach</b>			
Ramp E/W-S 10+280	4 m Lt.	1	9.0
Ramp E/W-S 10+280	2 m Rt.	1	9.0
Ramp E/W-S 10+287	CL	1	9.5
Ramp E/W-S 10+300	4 m Lt.	1	9.5
Ramp E/W-S 10+302	2 m Rt.	1	9.5
<b>South Approach</b>			
Ramp E/W-S 10+339	4 m Lt.	1	10.5
Ramp E/W-S 10+340	2 m Rt.	1	10.5
Ramp E/W-S 10+347	CL	1	10.5
Ramp E/W-S 10+360	4 m Lt.	1	10.5
Ramp E/W-S 10+360	2 m Rt.	1	10.5

Notes: \* Embankment thickness based on surface elevation of removal levels/stripping depths.



## **4.2 MATERIALS**

### **4.2.1 General**

The Contractor shall supply all materials and equipment required for the installation of the settlement plates.

### **4.2.2 Plate**

The Contractor shall supply a steel plate with thickness of at least 6.35 mm. The plate shall be at least 0.5 m by 0.5 m.

### **4.2.3 Rod**

The Contractor shall supply a steel pipe Schedule 40 with an outside diameter not less than 25.4 mm (1"), supplied in lengths as required to complete the installation as described in Section 4.3.

The top end of each length of rod shall be threaded to receive a cap. A rounded cap shall be installed at the top of the rod in such a way that a single survey point can be clearly identified and returned to.

### **4.2.4 Friction Reducing Sleeve**

The Contractor shall supply a friction reducing sleeve consisting of Schedule 40 – 50.8mm (2") O.D. PVC pipe cut perpendicular to the axis of the pipe.

### **4.2.5 Protective Surround**

The Contractor shall supply a protective surround for the portion of the rod within the embankment. The surround shall consist of 300 mm diameter corrugated steel pipe (CSP – OPSS 1801) with the ends cut perpendicular to the axis of the pipe and free of burrs and sharp edges. The space between the CSP and the Friction Reduction Sleeve (PVC pipe) shall be filled with medium to coarse sand.

## **4.3 INSTALLATION**

### **4.3.1 General**

The Contractor shall install settlement rods as per the Contract Drawings provided in addition to what is stated or emphasized below.

### **4.3.2 Settlement Plate**

The settlement plate shall be installed horizontally after subgrade preparation is completed and prior to fill placement.

The elevation of the base of the plate shall be surveyed before backfilling.

#### **4.3.3 Rod**

The rod shall be fixed to the center of the plate and installed perpendicular to the plate.

The coupling of the rods shall be such that all sections have the same axis and no separation or contraction will occur at the couplings.

#### **4.3.4 Friction Reducing Sleeve**

The friction reducing sleeve shall be over the entire length of the rod that is below ground and within the embankment fill except that the cap on top of the settlement rod shall extend 25 mm above the top of the friction sleeve at all times.

### **4.4 EXTENSION OF ROD**

The settlement rods shall be extended upwards as the embankment is constructed so that the top of the rod is always at least 0.3 m but not more than 2 m above the surrounding fill.

#### **4.4.1 Protective Surround**

The CSP, Friction Reducing Sleeve and sand protective surround shall be extended with the rods.

The settlement rod shall be in the center of the CSP and friction-reducing sleeve.

The annulus between the CSP and the friction-reducing sleeve shall be filled with sand to a level not higher than the top of the sleeve.

#### **4.4.2 Installation Details**

The elevation, easting and northing of the center of the base of the plate shall be surveyed.

The elevation, easting and northing of the top of the rod shall be surveyed.

The total distance from the base of the plate to the top of the rod shall be measured to an accuracy of  $\pm 2$  mm or better.

### **4.5 COORDINATION WITH MONITORING**

#### **4.5.1 Notification**

The Contractor shall notify the Contract Administrator no later than 3 days after installing a settlement rod. At this time the Contractor shall also supply the following information to the Contract Administrator.

- Elevation of plate and rod referenced to Geodetic datum;
- Dates of installation;
- Installation notes/sketches; and
- Description of settlement rods, sleeve and plate.

Adjustments in the length of any settlement rod shall be coordinated with the Contract Administrator to allow surveying by others of the elevation of the top of the rod immediately before and immediately after adjustment. This surveying is necessary to accurately track the settlement data.

#### **4.5.2 Monitoring**

Monitoring of the settlement rods shall be done by others. Monitoring shall be conducted during the embankment construction and preload period. A target settlement of 110 mm is specified. A minimum preload period of 4 months is required. The Contractor shall provide installation information as specified above and provide access to the settlement rods for monitoring including, but not limited to a level scaffolding platform and ladder, if required and snow clearing in the winter. The Contractor shall provide electric power and general area lighting as needed for reading the instruments.

#### **4.6 REPORTING**

The Contractor shall record and report relevant installation details to the Contract Administrator. These include, but are not limited to:

- Settlement rod easting, northing referenced to MTM NAD83 coordinates;
- Elevation of the plate and the top of the rod referenced to Geodetic datum;
- Distance between base of plate and top of rod;
- Dates of installation; and
- Installation notes/sketches.

## **5.0 VIBRATING WIRE PIEZOMETER (VWP) – SUPPLY & INSTALLATION**

### **5.1 GENERAL**

#### **5.1.1 Scope**

This Section contains the requirements for the supply and installation of vibrating wire (VW) piezometers.

The purpose of the piezometers is to monitor piezometric head at depth within the foundation soil below the embankments. The piezometer readings shall help to establish the timing and sequence of the piling at the foundation elements, the removal of embankment preload, and final paving operations.

#### **5.1.2 General Procedure**

The piezometers shall be installed in boreholes prior to the start of any embankment construction, any preload fill construction, and any piling. Prior to installation of instruments adjacent to new construction features (including limit of pile cap, edge of unwatering system, extent of sub-excavation and backfilling), the construction features shall be laid out in the field to ensure there are no conflicts with the instruments.

The VW signal cables for the VWPs shall be extended out of the embankment and preload footprint area (where applicable) and away from the piling area through a metal or plastic conduit buried in trenches and/or attached to the existing bridge structure (where applicable), as shown in the Contract Drawings.

The conduits for the VW signal cables for the VWPs may be routed so that they may be connected to a single data acquisition system (data-logger).

#### **5.1.3 Locations**

The Contractor shall install VW sensors at the locations and depths given in Table 5.

**Table 5 – VW Piezometer Locations**

<b>Station</b>	<b>Offset (m)*</b>	<b>No. of VWP</b>	<b>Approximate Elevation of Ground Surface (m)</b>	<b>Tip Elevations (m)</b>
Ramp E/W-S 10+294	CL	1	182.7	174.0
Ramp E/W-S 10+353	CL	1	182.7	174.0

Notes: \* Offset from centerline of Ramp E/W Woodlawn - 406S..

## **5.2 MATERIALS**

### **5.2.1 VW Piezometers**

The Contractor shall supply VW borehole piezometers by Slope Indicator model 52611020 (-5 to 50 psi), RST model VW2100-0.35 – or equal; compatible with the Slope Indicator CR1000 data-logger, RST model ELGL1200 – or equal. All VW piezometers (and Settlement Cells) shall be of the same make.

All piezometers shall be calibrated prior to installation and the calibration data for each piezometer shall be provided for the Contract Administrator.

### **5.2.2 Signal Cable**

The Contractor shall supply Slope Indicator model 50613524 cable, RST model EL380004 cable – or equal. The length of cable for each piezometer shall be carefully estimated from the construction Contract Drawings to ensure that there is enough signal cable for each piezometer to provide enough slack in the borehole and along the trenches (or routes over the existing bridge) until each cable is out of the construction area where they shall be protected from earthmoving equipment.

### **5.2.3 Bentonite**

The Contractor shall supply bentonite (OPSS 1205) in pellet form in sufficient quantity to form borehole plugs as required.

### **5.2.4 Filter Sand**

The Contractor shall supply clean washed sand for filter around VWP sensors. The sand shall be Sakcrete washed general-purpose sand – or equal.

### **5.2.5 Grout**

The Contractor shall supply cement-bentonite grout. A suitable grout mix design consists of 23 kg of bentonite (OPSS 1205), 143 litres of water and 40 kg of cement (Type G.U. – OPSS 1301).

### **5.2.6 Trench Burial and Conduit**

The signal cable for each piezometer shall be buried in a shallow trench and taken out of the construction area. The Contractor shall supply suitable conduits (e.g. Schedule 40 – 75 mm (3”) – steel pipe or Schedule 80 - 75 mm (3”) – rigid PVC pipe) to protect the signal cables in the trenches and above ground surface. If appropriate, several signal cables may be housed in a single conduit and laid in a common trench.

The signal cables and conduits shall be routed such that future grading works do not interfere with the cables or conduits.

### **5.2.7 Data Acquisition System (Data-Logger)**

The signal cables from the vibrating wire piezometers shall be connected to a data-logger (to be located away from the proposed approach embankment), Slope Indicator model 56701000 (CR1000), RST model ELGL1200 – or equal. The data-logger shall consist of the following:

- ENC 16/18 Water-proof Enclosure model 56705020, model ELF0638 – or equal;
- SC32A Serial Interface (with RS232 transfer cable) model 56704010, model CS-SC32A – or equal;
- VW Interface model 56701510 or 56701500, model CS-AVW200 – or equal;
- AM16/32 Multiplexer model 56702110, model ELGL2042 – or equal;
- A suitable power supply which shall be able to last for 2 years (i.e. large capacity rechargeable battery coupled with solar panel); and
- LoggerNet Software model 56708020, model CS-Loggernet – or equal.

A minimum of one data logger shall be installed. The Contractor shall submit a detailed proposal on the setup of the data-logging system (i.e. number and location of the data-logging unit(s) to the Contract Administrator for review, prior to ordering the data-logger(s). The Contractor shall program the data-logger according to the following:

- Recording Software: VWP data shall be recorded at 5 minutes intervals during piling and four times a day (one reading every 6 hours) when not piling
- Test Software: once this program is transferred to the data-logger, one shall be able to test the system and record data manually on site

The real-time data shall be retrieved on site by direct wire (i.e. RS232 Cable) with a portable laptop computer as specified in the next section.

### **5.2.8 Portable Laptop Computer**

The Contractor shall supply:

- A New Portable Laptop Computer (with a Three year warranty): Intel Pentium M or IV or better (1.6 GHz or above) with Windows 7 Professional Operating System, minimum 1GB memory, Network Card: 10/100 Integrated Ethernet LAN, a minimum of 80GB hard drive storage, a DVD/CD-RW ROM and Microsoft Office Standard 2007, to retrieve, read and store the VW piezometer readings.
- Extra battery pack and cigarette lighter charger.

The portable laptop computer will become property of the MTO and shall be handed to the Contract Administrator after the installation of instruments for the Monitoring program.

The calibration factors for all vibrating wire instruments shall be entered in the portable laptop computer by the Contractor for initialization of the instruments.

### **5.2.8 Wooden Posts**

Wooden posts: 100 mm x 100 mm (4"x4"), minimum 3 m (10") long, if required.

## **5.3 INSTALLATION**

### **5.3.1 General**

Installation of the VW piezometers shall be as per the manufacturer's recommendations in addition to what is stated or emphasized below.

The VWP's shall not be installed closer than 1.5 m to the nearest adjacent edge of shoring or unwatering system.

The exact location of the VWP installations shall be determined in the field after sub-excavation and backfilling to original ground surface.

### **5.3.2 Protection for Long-term Monitoring (Monitoring Shed)**

The Data-logger shall be installed in a walk-in Monitoring Shed to prevent vandalism and prolonged wear-out of the data-loggers against extreme weather. The Monitoring Shed shall be a lockable and weathered proof enclosure surrounded by 2 m high chainlink fence and a lockable gate. The Monitoring Shed shall also be seating on a gravel pad and securely tied down to the ground. The location of the Monitoring Shed shall not be susceptible to ground settlement. The Contractor shall submit a detailed proposal of the Monitoring Shed (i.e. materials and location(s) etc.) to the Contract Administrator for review, prior to construction.

The Contractor shall ensure to the Monitoring Shed at all times, including but not limited to snow clearing in the winter.

### **5.3.3 Completion of Installation**

It is known that the process of installing VW piezometers can temporarily alter the pore water pressure acting on the piezometer tip. The installation of a VW piezometer shall not be considered to be complete until the pore pressure acting on the piezometer has returned to and stabilized at the value prevailing in the surrounding, unaffected soil mass. The Contractor shall take daily reading of the pore pressures until the value has stabilized. Stabilization shall be deemed to have occurred:

- a) When no change in the measured value has occurred over a period of 5 days and the measured value is within 10% of the anticipated hydrostatic value.
- b) When the daily rate of change is less than four (4) kPa per day for three consecutive days and the measured value is within 5% of the anticipated hydrostatic value.
- c) Failing either of the two above conditions, as determined by the Contract Administrator.

The Contractor shall be prepared to wait for a period of 10 to 15 days after completion of installation of instruments for the baseline readings to stabilize prior to the commencement of the construction works.

## **5.4 COORDINATION WITH MONITORING**

### **5.4.1 Notification**

The Contractor shall notify the Contract Administrator no later than 3 days after installing a VW piezometer. At this time, the Contractor shall also supply the following information to the Contract Administrator.

- VW piezometer location, easting, northing referenced to MTM NAD83 coordinates;
- Elevations of VW sensor referenced to Geodetic datum;
- Stratigraphic log of subsurface conditions, including drilling method notes;
- Dates of installation;
- Installation notes/sketches;
- Model, make and serial numbers of VW sensors, readout unit and signal cable; and
- Calibration details of VW sensors.

### **5.4.2 Monitoring**

Monitoring of the VW piezometers shall be done by others. Monitoring shall be conducted during and after piling at the foundation elements, during embankment fill construction and during the preload period at the south approach. The Contractor shall provide installation information as specified above and provide access to the data-loggers for monitoring.

The Contractor shall transfer the Portable Laptop Computer to the Contract Administrator, including all the data-logging softwares and hardware, operation instructions and calibration constants. The Contractor shall also transfer the keys for the locks of the Monitoring Shed(s). The Contractor shall be available for one site meeting with the Contract Administrator to transfer and explain about any questions from the Contract Administrator regarding the data-logging system.



## **6.0 STANDPIPE PIEZOMETER (SSP) – SUPPLY & INSTALLATION**

### **6.1 General**

#### **6.1.1 Scope**

This Section contains the requirements for the supply and installation of standpipe piezometers.

The purpose of the standpipe piezometer is to monitor the hydrostatic piezometric head at depth within the foundation soil below the approach embankment fill.

#### **6.1.2 General Procedure**

The standpipes shall be installed prior to any piling and embankment fill construction.

Standpipes shall be installed in vertical boreholes.

#### **6.1.3 Location**

The locations of the standpipes shall be outside of the construction area near the given Station. The depths of the standpipes are given in Table 6

**Table 6 – Standpipe Piezometer Locations and Depths**

<b>Station</b>	<b>Offset* (m)</b>	<b>No. of SSP</b>	<b>Tip Elevations (m)</b>
Ramp E/W-S 10+300	30 RT	1	174.0
Ramp E/W-S 10+355	30 RT	1	174.0

Note: \* Approx. offset from centerline of Ramp

## **6.2 MATERIALS**

### **6.2.1 General**

The Contractor shall supply material and equipment, required for installation of the standpipe piezometers.

### **6.2.2 Pipe and Couplings**

The Contractor shall supply Schedule 40 flush jointed – 19 mm (3/4”) PVC pipe (e.g. 75x5R or 75x10R – Canadian Pipe Supply Ltd.).

### **6.2.3 Perforated Section**

The Contractor shall supply one 1.5 m long slotted Schedule 40 flush-jointed – 19 mm (3/4”) PVC slotted pipe (e.g. 75x5S Slot 10 Sch 40 – F/J – PVC – Canadian Pipe Supply Ltd.) for each SSP.

### **6.2.4 Bottom Cap**

The Contractor shall supply bottom caps Schedule 40 flush-jointed – 19 mm (3/4”) PVC (e.g. 448-007FJ – Canadian Pipe Supply Ltd.) to fit the perforated section.

### **6.2.5 Top Caps**

The Contractor shall supply vented top caps Schedule 40 – 19 mm (3/4”) PVC (e.g. 448-007FJ-perforated – Canadian Pipe Supply Ltd.) to fit the pipe.

### **6.2.6 Filter Sand**

The Contractor shall supply clean washed sand for backfilling around perforated section. The sand shall be Sakcrete washed general purpose sand – or equal.

### **6.2.7 Bentonite**

The Contractor shall supply bentonite (OPSS 1205) in pellet form for backfilling above the filter sand.

### **6.2.8 Grout**

The Contractor shall supply cement-bentonite grout for general backfilling. A suitable grout mix design consists of 23 kg of bentonite (OPSS 1205), 143 litres of water and 40 kg of cement (Type G.U. – OPSS 1301).

### **6.2.9 Protective Housing**

The Contractor shall supply a protective housing consisting of 100 mm minimum diameter galvanized steel pipe with a locking cap.

## **6.3 INSTALLATION**

### **6.3.1 General**

Installation of the standpipe shall be as per the Contract Drawings provided in addition to what is stated or emphasized below.

The borehole shall be advanced to 300 mm below the tip elevation using suitable drilling techniques. The sides of the borehole shall be stable and the borehole shall be free of debris.

The standpipe piezometers must be of sufficient length above the ground surface to accommodate the piezometric head and to allow for snow accumulation.

The standpipe piezometer location shall be at sections indicated on the Contract Drawings.

## **6.4 COORDINATING WITH MONITORING**

### **6.4.1 Notification**

The Contractor shall notify the Contract Administrator no later than 3 days after installing a standpipe. At this time, the Contractor shall also supply the following information to the Contract Administrator.

- Standpipe piezometer location, easting, northing referenced to MTM NAD83 coordinates;
- Elevation of ground level referenced to Geodetic datum;
- Stratigraphic log of subsurface conditions at the standpipe;
- Dates of installation;
- Depth of pipe, stick-up; and
- Installation notes/backfilling notes.

### **6.4.2 Monitoring**

Monitoring of standpipe piezometers shall be done by others. Monitoring shall be conducted during and after the piling and embankment fill construction and preload period at the south approach. The Contractor shall provide installation information as specified above and provide access to the standpipe piezometers for monitoring including, but not necessarily limited to snow clearing in the winter. The Contractor shall provide electric power and general area lighting as needed for reading the instruments.

## **7.0 DECOMMISSING OF INSTRUMENTS**

### **7.1 General**

The Contractor shall decommission all the Settlement Plates (SP), VW piezometers (VWP), and Standpipe Piezometers (SSP) at the end of the monitoring program following construction unless advised otherwise by the Contract Administrator. Decommissioning of instrumentation shall be carried out according to the Ontario Water Resources act, R.R.O. 1990, Regulation 903 (as amended by Ontario Reg. 372).

## **8.0 PAYMENT**

### **8.1 Basis Of Payment**

Payment at the Lump Sum price for this tender item shall be full compensation for all labour, monitoring equipment and material to do the work.

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

CONT No  
WP No 280-99-00

HWY 406  
WOODLAWN RAMP E/W-S  
SETTLEMENT MONITORING  
INSTRUMENT LAYOUT  
TRILLIUM OVERHEAD

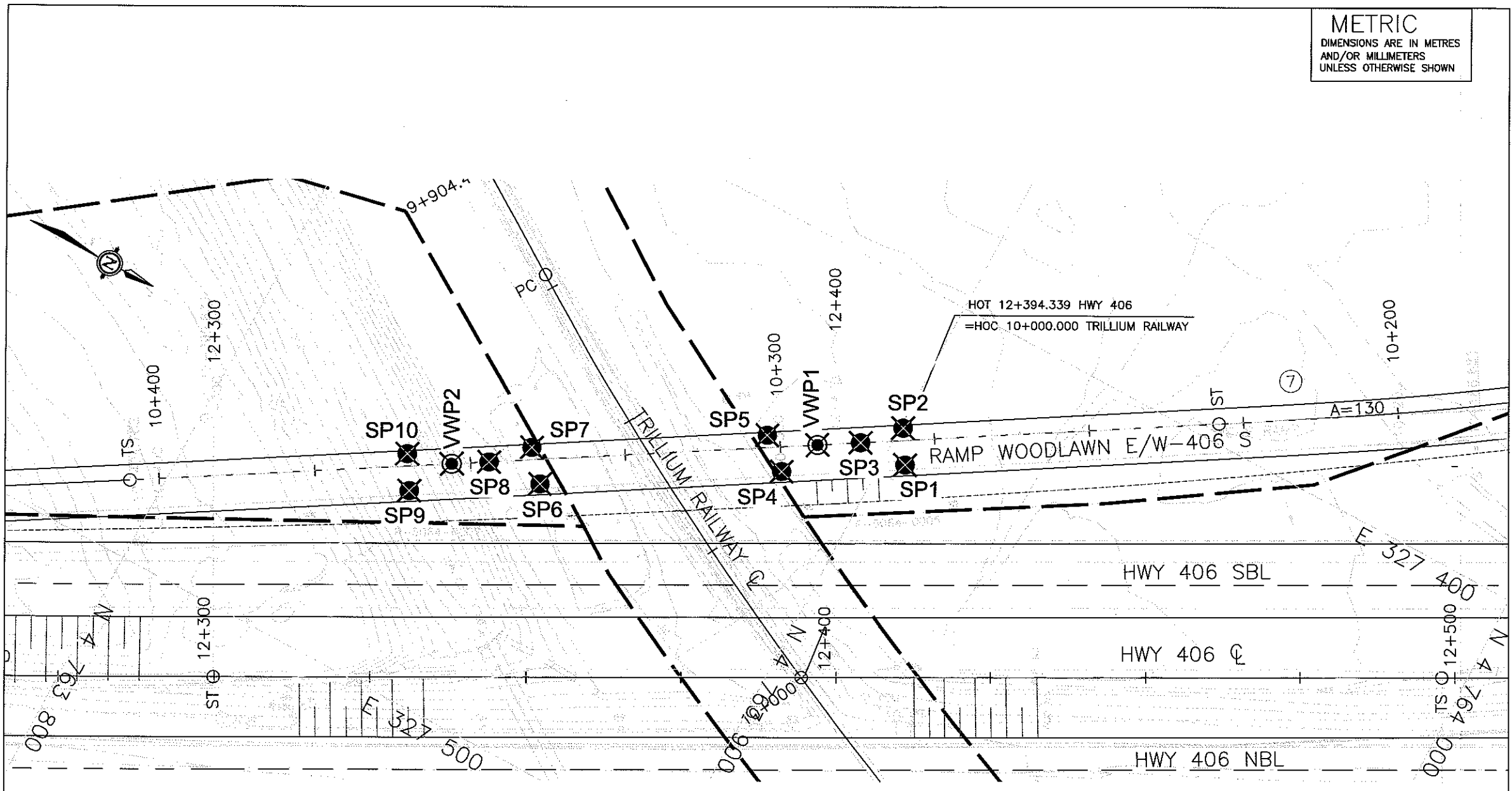


GENERAL NOTES:  
1. THIS DRAWING TO BE READ IN CONJUNCTION  
WITH INSTRUMENT DETAILS DRAWING.

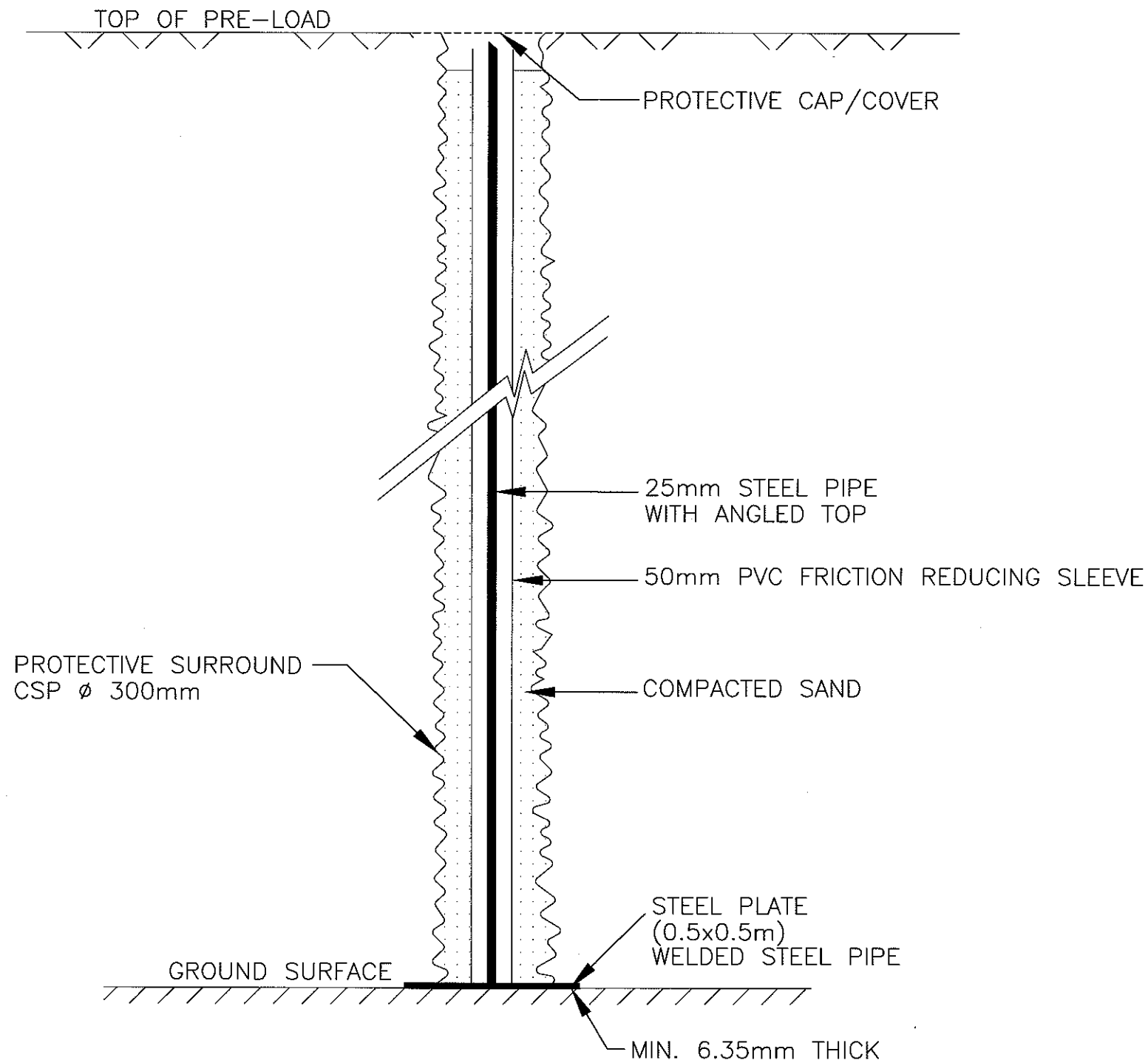
- LEGEND
- SP1 APPROXIMATE LOCATION OF  
SETTLEMENT PLATE (SP)
  - VWP1 APPROXIMATE LOCATION OF  
VIBRATING WIRE PIEZOMETER  
(VWP)

INSTRUMENT LOCATIONS			
I.D.	LOCATION	STATION	OFFSET FROM CENTRELINE(m)
WOODLAWN RAMP E/W-S			
SP1	RAMP E/W-S	10+280	4.0 Lt
SP2	RAMP E/W-S	10+280	2.0 Rt
SP3	RAMP E/W-S	10+287	0
SP4	RAMP E/W-S	10+300	4.0 Lt
SP5	RAMP E/W-S	10+302	2.0 Rt
SP6	RAMP E/W-S	10+339	4.0 Lt
SP7	RAMP E/W-S	10+340	2.0 Rt
SP8	RAMP E/W-S	10+347	0
SP9	RAMP E/W-S	10+360	4.0 Lt
SP10	RAMP E/W-S	10+360	2.0 Rt
VWP1	RAMP E/W-S	10+294	0
VWP2	RAMP E/W-S	10+353	0

REVISIONS			
DATE	BY	DESCRIPTION	
DESIGN R.A.	CODE CHB0C2006	LOAD	DATE SEPT. 2010
DRAWN K.C.	CHK R.A.	STRUCT	



C:\Users\javed\Documents\11-09-4135 HWY 406 BRIDGES\Woodlawn Ramp E/W-S\11-09-4135 HWY 406 SETTLEMENT PLATE DETAIL.dwg, KAVAI



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

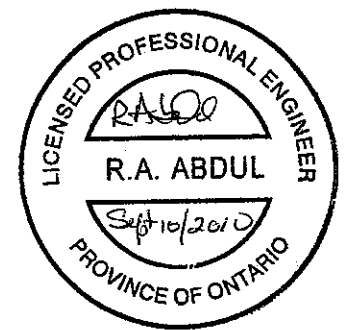
CONT No  
WP No 280-99-00

HWY 406  
WOODLAWN RAMP E/W-S  
SETTLEMENT MONITORING  
INSTRUMENT DETAILS  
TRILLIUM OVERHEAD



GENERAL NOTES:

1. THIS DRAWING TO BE READ IN CONJUNCTION WITH THE SETTLEMENT MONITORING INSTRUMENT LAYOUT DWG.

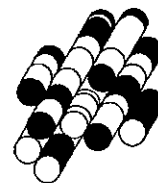


REVISIONS		DATE	BY	DESCRIPTION
DESIGN	R.A.	CODE	CHBDC2006	LOAD
DRAWN	K.C.	CHK	R.A.	STRUCT
		DATE	SEPT. 2010	

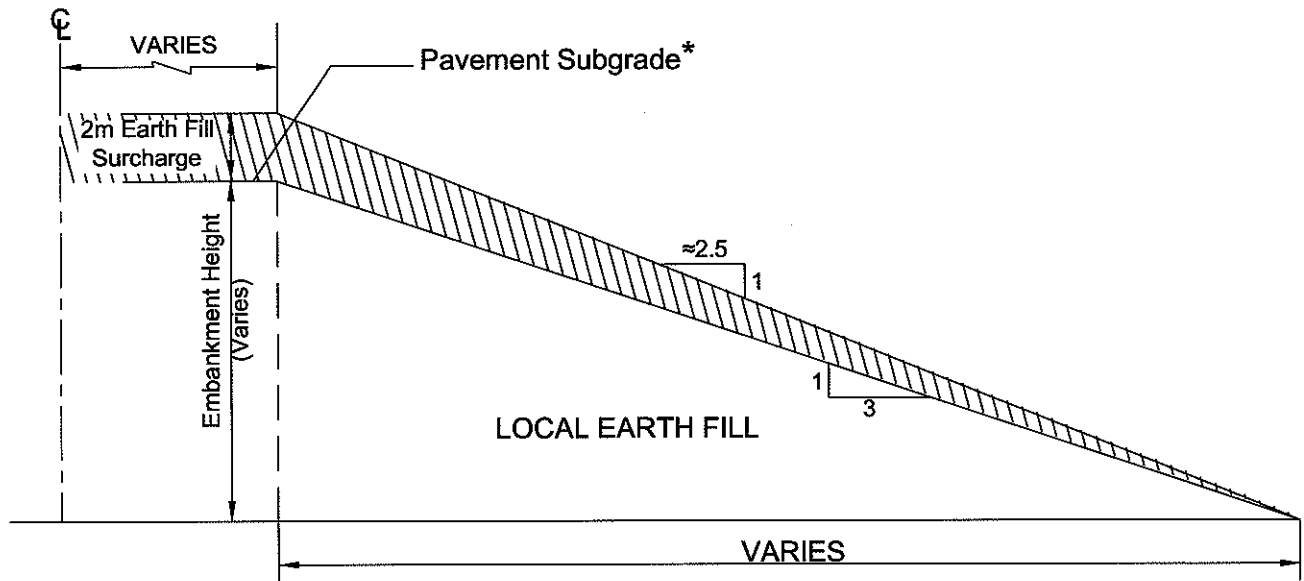
# **APPENDIX H**

## **Figures**

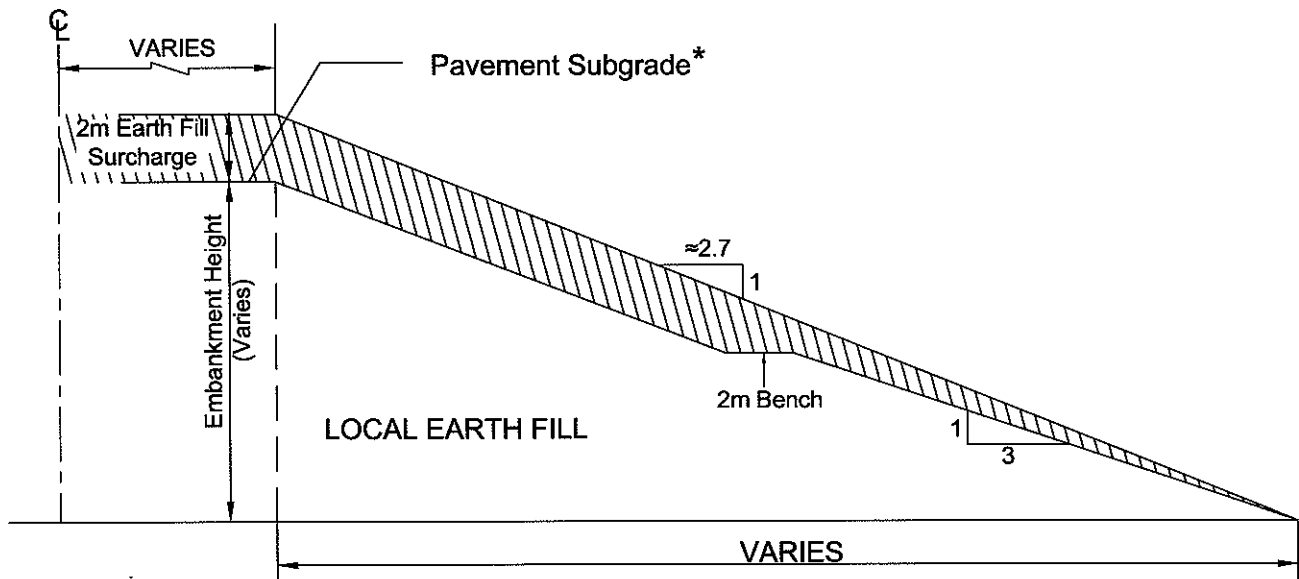
**Terraprobe Inc.**







Local Earth Fill Embankment < 8m



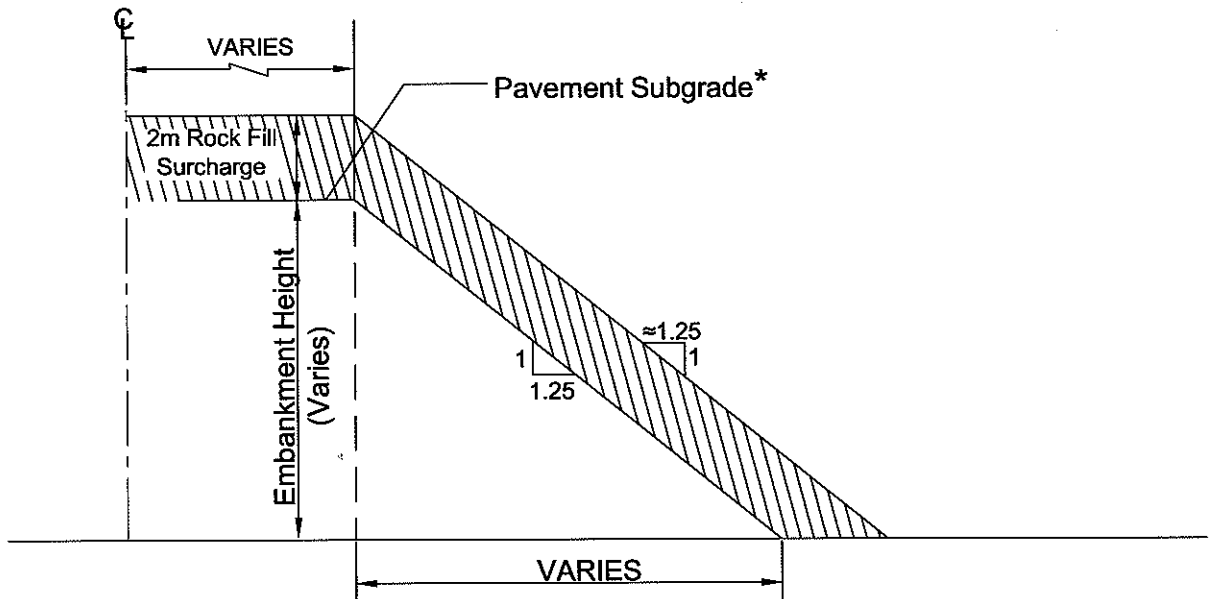
Local Earth Fill Embankment  $8m \geq 12m$

\* Notes- Pavement subgrade to be established after removal of surcharge

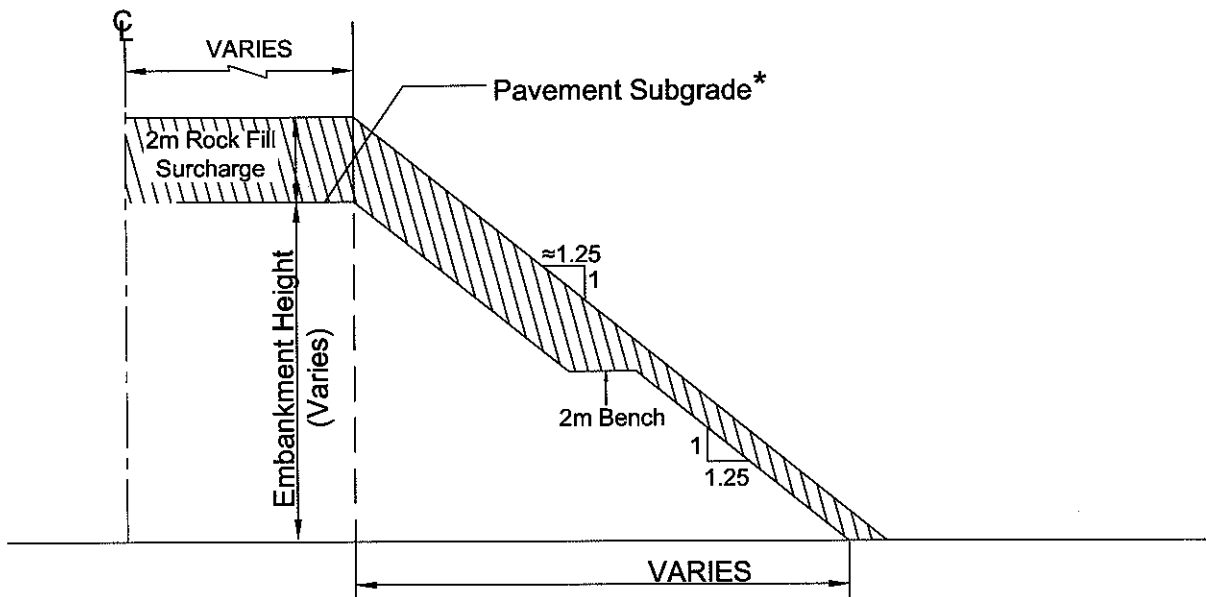
N.T.S

## SURCHARGE ARRANGEMENT

FIGURE H1



Rock Fill Embankment <10m



Rock Fill Embankment 10m  $\geq$  12m

\* Notes- Pavement subgrade to be established after removal of surcharge.

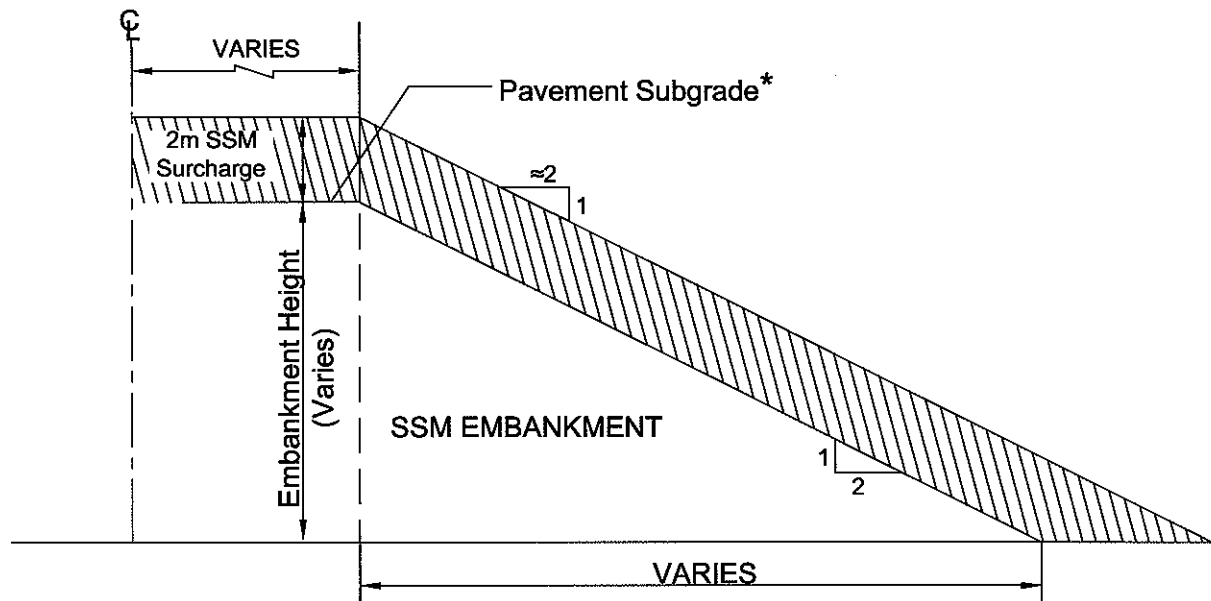
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## SURCHARGE ARRANGEMENT

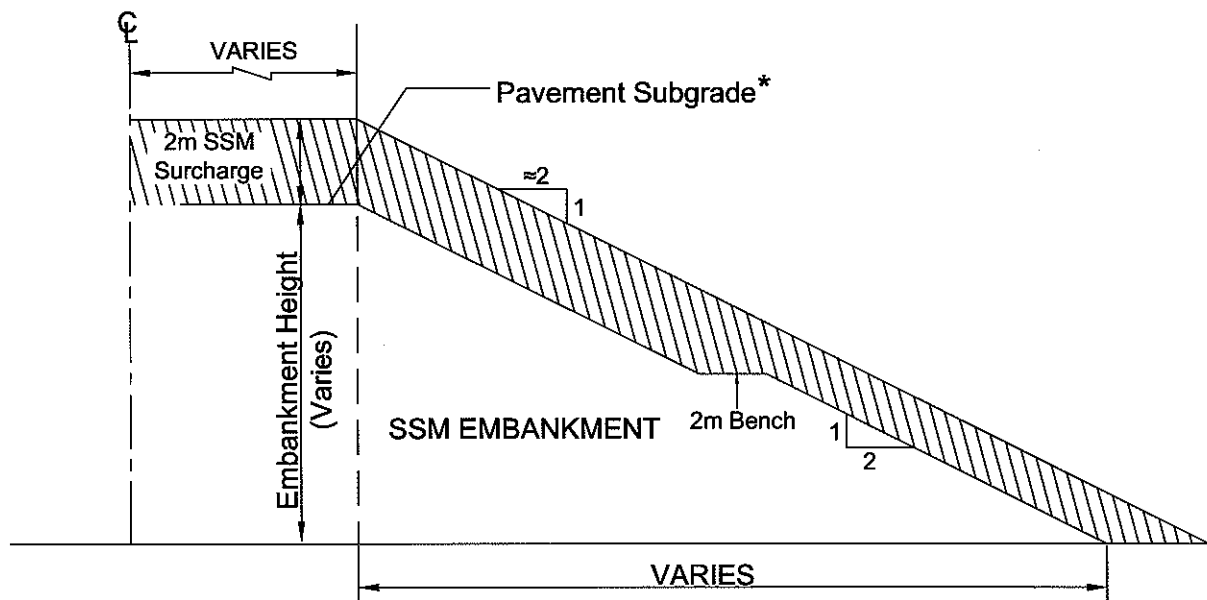
TERRAPROBE

File No. 1-09-4135

FIGURE H2



SSM Embankment <8m

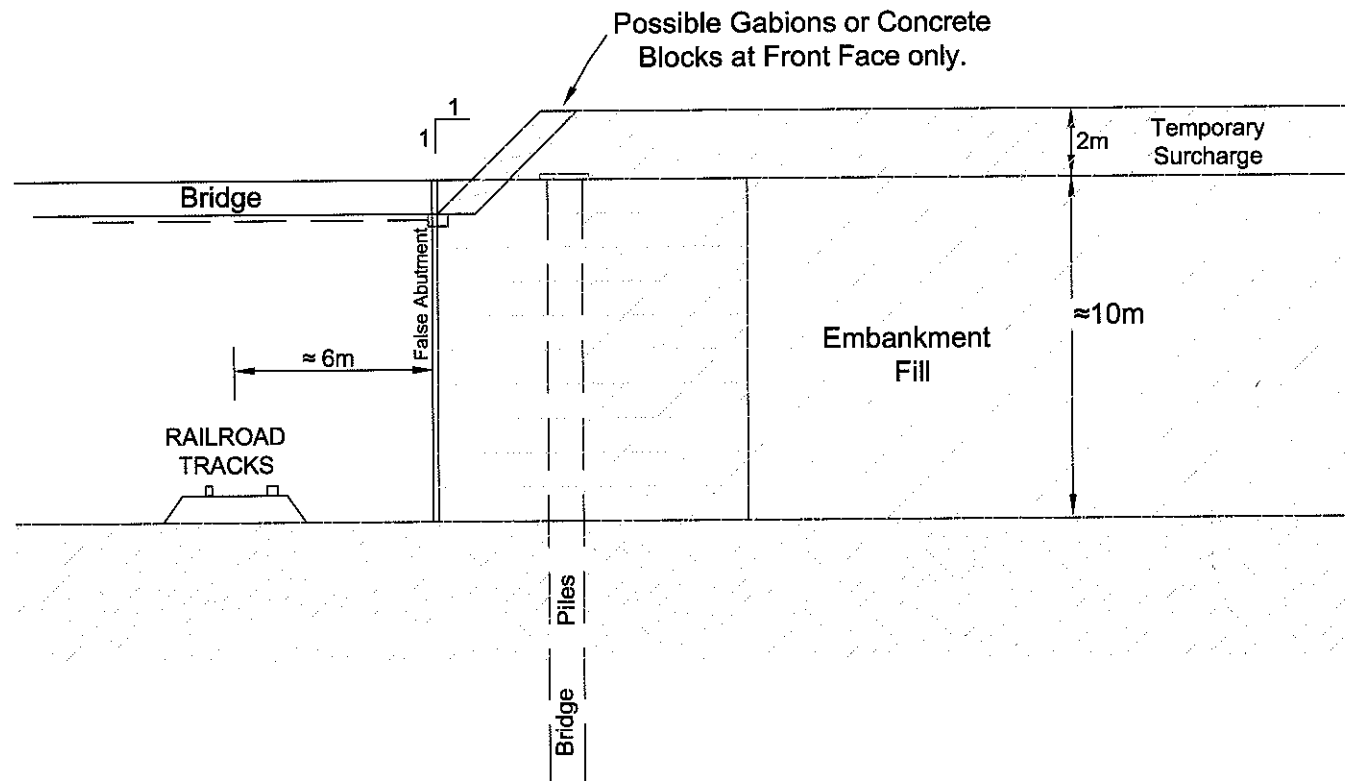


SSM Embankment 8m  $\geq$  12m

\* Notes- Pavement subgrade to be established after removal of surcharge.  
Only SSM surcharge recommended in order to minimize handling/sorting and compaction of dissimilar materials.

N.T.S

## SURCHARGE ARRANGEMENT



N.T.S

## TEMPORARY RETAINING WALL ARRANGEMENT

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FIGURE H4