GEOCRES No: 30M3-235

Golder Associates Ltd.

2390 Argentia Road
Mississauga, Ontario, Canada L5N 5Z7
Telephone 905-567-4444
Fax 905-567-6561

Golder Associates

REPORT ON

FOUNDATION INVESTIGATION AND DESIGN SLOPE RESTORATION AT STATION 15+718 HIGHWAY 405 W-N/S RAMP AT STANLEY AVENUE HIGHWAY 405 REHABILITATION FROM QEW TO QUEENSTON–LEWISTON BORDER CROSSING G.W.P. 2445-04-00

Submitted to:

McCormick Rankin Corporation
2655 North Sheridan Way
Mississauga, Ontario
L5K 2P8

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QUEENSTON–LEWISTON BORDER CROSSING
G.W.P. 2445-04-00

1.0 INTRODUCTION

Golder Associates Ltd. (Golder) has been retained by McCormick Rankin Corporation (MRC) on behalf of the Ministry of Transportation, Ontario (MTO) to provide foundation engineering services associated with the rehabilitation of Highway 405 from the QEW to the Queenston-Lewiston Border Crossing, in the Region of Niagara. Foundation engineering services are required for slope restoration work on the currently distressed south embankment slope at approximately Station 15+718 on the Highway 405 W- N/S ramp at Stanley Avenue; foundation engineering services may also be required for a proposed retaining wall along the Stanley Avenue W-N/S Ramp and a new overhead sign structure, if widening of the Stanley Avenue W-NS Ramp is determined to be necessary.

This report addresses the geotechnical investigation component of the rehabilitation works carried out for the slope restoration at approximately Station 15+718 on the Highway 405 W-NS ramp at Stanley Avenue.

The terms of reference and scope of work for the geotechnical investigation are outlined in MTO's Request for Quotation (RFQ) document for Agreement No. 2005-E-0058, issued in April 26, 2006, and in Section 3.5.6 of MRC's *Technical Proposal* for G.W.P. 2445-04-00.

2.0 SITE DESCRIPTION

The site of the slope distress is located some 200 m west of Stanley Avenue on Highway 405 W-N/S ramp at approximately Station 15+718, in the Region of Niagara. At the distress location, the existing slope is approximately 6.5 m high, with current grades at the toe and crest of the slope at approximately Elevation 180.4 m and Elevation 186.5 m, respectively.

The site is bordered by Stanley Avenue about 200 m to the east, Highway 405 and Townline Road to the north, Saint Paul Avenue to the west and Mountain/Portage Road to the south. An old farm of relatively flat land is located directly south of the site extending back from the crest of the slope; a small farm pond is located about 250 m south of the slope.

A site visit by Golder geotechnical staff was conducted on September, 7 2006 to observe the conditions of the embankment slope. The embankment slope was approximately 6.5 m in height and was inclined at about 25.5 degrees to the horizontal (approximately 2.3 horizontal to 1 vertical), based on slope inclination measurements taken using a hand-held Abney level. The distress has manifested as an erosion gully that is about 4 m wide within the upper slope and approximately 1.5 m to 2 m deep; the erosion gully extends down-slope becoming narrower near the toe of the slope. A 200 mm diameter clay drainage tile was protruding from the face of the eroded area at a depth of about 1.5 m from the crest of the slope; a broken piece of the clay pipe had been placed at the top of the slope during our site visit and sloughed soils were observed on the erosion gully below the tile. The erosion gully was partially filled with rock blocks. During the site visit, about 25 mm depth of water was flowing from the drainage tile; during a subsequent visit while taking water level measurement in a borehole on October 19, 2006, the drainage tile appeared to be flowing about one-quarter full and the outflow appeared to be relatively free of sediment. Tall vegetation surrounded the sloughed area (refer to Photographs 1 to 4 in Appendix A).

The adjacent areas of the embankment slope were generally well vegetated with no visual signs of surficial erosion, sloughing or slope instability at the time of the site visit.

3.0 INVESTIGATION PROCEDURES

The field work for the subsurface investigation was carried out on September 20 and 21, 2006, at which time two boreholes, Boreholes 1 and 2, were respectively put down at the toe and crest of the slope, immediately to the west of the distressed area approximately at the locations shown on Drawing 1. The boreholes were advanced using a CME 55 track mounted drill rig supplied and operated by DBW Drilling Ltd. of Ajax, Ontario.

Boreholes 1 and 2 were advanced to 4.6 m and 11.7 m depth below present ground surface, respectively. Samples of the overburden were obtained at 0.75 m to 1.5 m intervals of depth using 50 mm outside diameter split-spoon samplers in accordance with the Standard Penetration Test (SPT) procedure. The boreholes were advanced 2.5 m and 2.9 m into the bedrock using an 'NQ' size rock core barrel. Bedrock was encountered in Boreholes 1 and 2 at about 2.1 m and 8.8 m of depth, respectively.

A standpipe piezometer was installed in Borehole 2, screened within the lower silt deposit. The piezometer consists of 25 mm diameter PVC pipe with a slotted tip installed within a 2.1 m long filter sand pack. A 0.3 m bentonite seal was placed on top of the filter sand followed by cement grout to about 1.8 m below the ground surface, where a 1.8 m bentonite seal was placed around the piezometer casing extending to the ground surface.

The field work was monitored on a full-time basis by a member of Golder's staff who located the boreholes in the field, directed the sampling and in situ testing operations, and logged the boreholes. The soil and bedrock samples were identified in the field, placed in labelled containers and transported to Golder's laboratory in Mississauga for further examination and laboratory testing. Index and classification tests, consisting of water content determinations, Atterberg limits and grain size distribution analyses, were carried out on selected soil samples.

The borehole locations were surveyed by J.D. Barnes, Ontario Land Surveyor (OLS) following completion of the drilling operations. The borehole locations (including NAD83 MTM northing and easting coordinates) and ground surface elevations (referenced to geodetic datum) provided by MRC are summarized below and are shown on Drawing 1.

Borehole Number	*Borehole Location*	*MTM NAD83 Northing (m)*	*MTM NAD83 Easting (m)*	*Ground Surface Elevation (m)*
1	Toe of Embankment	4778453	338192	180.5
2	Crest of Embankment	4778438	338200	186.9

4.0 SITE GEOLOGY AND STRATIGRAPHY

4.1 Regional Geology

The area of the Highway 405 W-N/S ramp at Stanley Avenue lies within the Iroquois Plain physiographic region, as delineated in *The Physiography of Southern Ontario*[1] and *Urban Geology of Canadian Cities*[2].

The area of the slope distress is located on the Niagara Escarpment, which separates the lower Iroquois Plain to the north from the Haldimand Clay Plain physiographic region to the south of the escarpment. In the Niagara Region, the escarpment base is located at about Elevation 105 m and the top reaches to about Elevation 190 m. The escarpment itself consists of dolostone, limestone, sandstone and shale bedrock, mantled by relatively thin deposits of silty clay till, sandy silt till, sands, and silts. The depth to bedrock on the escarpment is shallow, varying typically between about 1 m and 6 m.

4.2 Site Stratigraphy

As part of the subsurface investigation at this site, two boreholes were advanced at the toe and the crest of the south slope of the W-N/S ramp approximately 200 m east of Stanley Avenue, at the locations shown on Drawing 1.

The detailed subsurface soil and groundwater conditions encountered in the boreholes, and the results of in-situ and laboratory testing carried out on selected soil samples, are given on the Record of Borehole/Drillhole sheets and Figures 1 and 2. The stratigraphic boundaries shown on the borehole records are inferred from non-continuous sampling and, therefore, represent transitions between soil types rather than exact planes of geological change. Subsoil conditions will vary between and beyond the borehole locations. The inferred soil stratigraphy based on the results of the boreholes at the toe and crest of the slope is also shown on Drawing 1.

In summary, the soils encountered in Borehole 1 drilled at the toe of the slope consist of a layer of rip-rap at the ground surface underlain by a sandy silt deposit, and by bedrock at about Elevation 178.5 m. In Borehole 2 at the crest of the south embankment slope, the subsoils encountered consist of a layer of topsoil underlain by a clayey silt deposit which is in turn underlain by a silt deposit. The silt deposit extends to approximately Elevation 178.1 m where bedrock was encountered.

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[1] Chapman, L.J. and D.F. Putnam. *The Physiography of Southern Ontario*, Ontario Geological Survey Special Volume 2, Third Edition, 1984. Accompanied by Map P.2715, Scale 1:600,000.

[2] J. Menzies and E.M. Taylor. "Urban Geology of St. Catharines-Niagara Falls, Region Niagara". In *Urban Geology of Canadian Cities*, Geological Association of Canada Special Paper 42, Ed. P.F. Karrow and O.L. White, 1998.

In both boreholes, bedrock consists of dolostone with interlayers of limestone with occasional calcium carbonate inclusions.

A more detailed description of the subsurface conditions encountered in the boreholes is provided in the following sections.

4.2.1 Topsoil / Rip-Rap

About 500 mm of 100 mm-to-150 mm size stone rip-rap was encountered in Borehole 1, which was advanced at the toe of slope. At the crest of the slope an approximately 200 mm thick layer of topsoil was encountered in Borehole 2.

4.2.2 Clayey Silt

A 1.1 m thick layer of reddish brown clayey silt containing trace sand and gravel was encountered in Borehole 2 at about Elevation 186.7 m, directly below the topsoil. Two SPT "N" values obtained within this material recorded 26 and 20 blows per 0.3 m of penetration, indicating that this material has a very stiff consistency.

The result of an Atterberg limit test on a sample of this deposit is provided on Figure 1 and indicates a plastic limit of 18 percent and a liquid limit of 34 percent, which corresponds to a plasticity index of 16 percent; this material is classified as a clayey silt of low plasticity. The natural water content from the same sample is about 22 percent.

4.2.3 Sandy Silt to Silt

A layer of reddish brown to brown sandy silt to silt containing trace clay and trace to some gravel was encountered directly below the rip-rap layer in Borehole 1 and below the clayey silt deposit in Borehole 2. This deposit is 1.6 m and 6.5 m thick at the locations of Boreholes 1 and 2, respectively. The surface of the sandy silt to silt deposit was encountered at Elevation 180.1 m at the location of Borehole 1 and at Elevation 184.6 m at the location of Borehole 2.

The results of two grain size distribution tests carried out on selected samples of this material are provided on Figure 2 and indicate that the deposit is slightly coarser in Borehole 1. Measured SPT "N" values within the sandy silt to silt deposit typically range from 44 to greater than 100 blows per 0.3 m of penetration, with the exception of one SPT "N" value measured at 28 blows per 0.3 m of penetration obtained within the saturated zone just above the bedrock surface in Borehole 2. The SPT "N" results indicate that the sandy silt to silt deposit typically has a dense to very dense relative density.

Seven natural water content measurements obtained on select samples from the sandy silt to silt deposit ranged from about 5 percent to 24 percent.

4.2.5 Bedrock

Bedrock, consisting of dolostone containing interlayers of limestone, underlies the sandy silt to silt deposit at this site. The depth to the bedrock surface and its elevation as encountered at the locations of Boreholes 1 and 2 is presented below.

Borehole Location	*Borehole Number*	*Ground Surface Elevation (m)*	*Depth to Bedrock (m)*	*Bedrock Surface Elevation (m)*
Toe of Slope	1	180.5	2.1	178.4
Crest of Slope	2	186.9	8.8	178.1

The bedrock was confirmed by coring 2.5 m and 2.9 m at the two borehole locations. The dolostone bedrock at the site is a member of the Clinton Group; it is moderately to slightly weathered, thinly bedded, grey, medium strong rock. Rock Quality Designation (RQD) values measured on recovered bedrock core samples typically ranged from about 16 percent to 87 percent, indicating that the bedrock ranges from very poor to good quality. The discontinuities observed in the rock core are typically horizontal, associated with the bedding planes.

A description of some of the terms used in the description of the bedrock samples from this site is provided on the *Lithological and Geotechnical Rock Description Terminology* sheet which precedes the Record of Borehole sheets included with this report.

4.3 Groundwater Conditions

The water levels noted during and after the drilling and coring operations in the boreholes are presented on the Record of Borehole sheets and summarized below. One piezometer was installed in Borehole 2 within the very dense to compact sandy silt to silt stratum. Details of the piezometer installation are shown in the Record of Borehole Sheet 2 following the text of this report. The water level in the piezometer is summarized in the table below.

Borehole	Installations	Ground Surface Elevation (m)	Ground Water Level Depth (m)	Ground Water Level Elevation (m)	Date
1	Open Borehole	180.5	Dry	-	September 21, 2006
2	Piezometer	186.9	7.8	179.1	September 22, 2006
			8.4	178.5	October 19, 2006

5.0 CLOSURE

This Geotechnical Investigation Report was prepared by Mr. Brian Lapos, EIT and reviewed by Mrs. Houda Jadi, P.Eng., a Geotechnical Engineer with Golder. Mr. Jorge Costa, a Designated MTO Contact and Principal with Golder, conducted an independent review of the report.

GOLDER ASSOCIATES LTD.

Brian Lapos, E.I.T.
Geotechnical Group

Houda Jadi, P.Eng.
Geotechnical Engineer

LICENSED PROFESSIONAL ENGINEER
H. JADI
100078783
PROVINCE OF ONTARIO

Jorge M. A. Costa, P.Eng.
Principal, Designated MTO Contact

LICENSED PROFESSIONAL ENGINEER
J. M. A. COSTA
PROVINCE OF ONTARIO

BML/HJ/LCC/JMAC/bml/hj/sm/ah

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PART B

FOUNDATION DESIGN REPORT
SLOPE RESTORATION AT STATION 15+718
HIGHWAY 405 W-N/S RAMP AT STANLEY AVENUE
HIGHWAY 405 REHABILITATION FROM QEW TO
QUEENSTON–LEWISTON BORDER CROSSING
G.W.P. 2445-04-00

6.0 ENGINEERING RECOMMENDATIONS

6.1 General

This section of the report provides geotechnical design recommendations for the restoration of the portion of the eroded slope at about Station 15+718 on the south side of the Highway 405 W-N/S ramp, approximately 200 m west of Stanley Avenue. These recommendations are based on interpretation of the factual data obtained from the boreholes advanced during the subsurface investigation at this site. The interpretation and recommendations provided are intended to provide the designers with sufficient information to assess the feasible slope restoration alternatives and to carry out the design. Where comments are made on construction, they are provided in order to highlight those aspects which could affect the design and construction of the project, and for which special provisions or operational constraints may be required in the Contract Documents. Those requiring information on aspects of construction should make their own interpretation of the factual information provided as it may affect equipment selection, proposed construction methods, scheduling and the like.

The following sections present our assessment of the cause of slope distress, feasible remedial alternatives and design recommendations for the preferred alternative to restore the slope.

6.2 Cause of Slope Distress

Based on the observations during our site visit on September 7, 2006 and the results of the borehole investigation, the cause of distress of the slope (manifested as erosion gullying) is considered to be directly related to the existing clay drainage pipe discharging onto the slope. This clay pipe likely forms part of a tile system draining the large area of formerly farmed land immediately south of the slope. Water flowing from the pipe appears to have caused erosion of the soil surrounding the pipe. Over time, the discharge from the pipe caused loss of supporting soils below the pipe and sloughing of the soils above and around it, leading to the fracture of the pipe at the edge of the sloughed area. Erosion and widening of the existing gully appears to be on-going as water continues to discharge from the pipe (refer to Photographs 5 and 6 in Appendix A). The volume of water discharged from the pipe varies, and appears to increase following rainfall events.

Slope stability analyses of the existing embankment were carried out to assess the global stability of the slope for the condition where the groundwater level is at the depth measured in Borehole 2 on September 22, 2006, but without active discharge of water from the drainage tile. The analyses were based on the following effective stress parameters, derived from field and laboratory testing and accepted correlations, using the commercially available program SLOPE/W produced by Geo-Slope International Ltd., employing the Morgenstern-Price method of analysis:

Soil Type	*Bulk Unit Weight*	*Effective Angle of Friction*
Clayey Silt	19 kN/m^3	28°
Sandy Silt to Silt	20 kN/m^3	30°

The results of the slope stability analyses, presented on Figure 3, indicate that the approximately 6.5 m high embankment with a side slope inclination at about 2 horizontal to 1 vertical (2H:1V) has a factor of safety of 1.7 against deep-seated instability. Therefore, the analyses indicate that global slope instability is unlikely given the subsurface conditions present at the site, and confirms that the observed distress is related only to localized erosion of the embankment as a result of the drainage tile discharge.

6.3 Remedial Alternatives

Three alternative remedial options have been considered for the slope restoration at this site, as follows:

1- Cap off the clay drainage tile and backfill the slope with properly placed and compacted earth fill, then reseed the face of the slope;

2- Extend the drainage tile and re-shape the erosion gully down the slope with geotextile or half-pipe channel with rip-rap protection, or a slope drain, to channel the discharge water to the toe of the slope and into the drainage structure immediately west of the distressed area. The slope adjacent to the re-shaped channel would be backfilled with earth fill properly placed and compacted, and the face of the slope reseeded;

3- Completely or partially remove the clay drainage tile and reinstate the slope and ground at the top of the slope to its original condition. The distressed area would then be backfilled with earth fill properly placed and compacted and the face of the slope reseeded. However, the length of the drainage tile is not known, and thus the extent of excavation required to completely or partially remove the pipe can not be assessed at this time. This work would have to be carried out on the privately-owned land to the south of the ramp.

The feasibility, advantages, disadvantages, relative costs, risks and consequences for each of the above options are presented in Table 1 following the text of this report. The drainage pipe still carries water, and selection of either Options 1 or 3 (which would ultimately eliminate the flow of water at this location) would require further investigation of the current use, lateral extent of the drainage pipe system, and flows carried by the pipe system. Golder has contacted the current property owner who has no knowledge of the pipe distribution system.

Based on the available information and the existing site conditions, Option 2, which involves repair of the existing drainage tile and proper channelling of the discharge water from the pipe to the toe of the slope, is considered the most appropriate. This option is the least disruptive to the private property to the south, as it will maintain the flow of water in the pipe rather than cause the water to be distributed to other (unknown) areas of the drainage pipe system. Design recommendations for this option are provided in the following section.

6.4 Design Recommendations for the Preferred Slope Restoration Alternative

The preferred slope restoration option consists of extending the existing drainage tile and reinstating the slope with a rip-rap protected channel to direct the discharge water from the pipe to the toe of the slope and into the drainage structure immediately west of the distressed area.

The existing 200 mm diameter drainage tile can be extended using a high density polyethylene (HDPE) pipe (or a vitrified clay pipe) to be connected to the existing drainage tile with an appropriate banded rubber coupling and elastomeric bushing to ensure a self centering tight fit and full circumference seal. Typical pipe transitional connections are presented in Appendix B.

The discharge water from the drainage pipe should be directed down the slope through a rip-rap protected channel with a geotextile fabric or half pipe installed under the rip-rap; alternatively a pipe slope drain directly connected to the drainage tile may be used. The rip-rap protected channel should be about 300 mm deep and have a bottom width of 1.5 m with side slopes no steeper than 2 Horizontal to 1 vertical as illustrated in the typical cross sectional profile shown on Drawing 2. The channel should be worked into the erosion gully to achieve as flat a slope as practical. Rip-rap should consist of 100 mm to 300 mm angular stone with a minimal thickness of 350 mm, and should extend below the outlet of the drainage tile. A geotextile fabric, such as Terrafix 360R or equivalent, should be installed under all rip-rap to separate it from the native subgrade and should be keyed at least 300 mm into the ground at the edges of the channel and down the slope; the geotextile fabric should be installed according to the manufacturer's recommendations. An HDPE or vitrified clay half pipe may alternatively be used in lieu of the geotextile fabric. The half pipe should have a minimal diameter of 0.6 m and should be positioned such that it extends under the outlet of the existing drainage tile with excavation side slopes no steeper than 2 Horizontal:1 Vertical. The half pipe should be securely anchored to the slope according to the manufacturer's specifications.

Backfill to re-shape the slope along the down-slope channel should consist of Select Subgrade Materials (SSM) compacted in place as practical; where silt or sandy silt soils are encountered immediately below the drainage channel, these should be subexcavated and replaced with silty clay / clayey silt materials to prevent potential wash out of the sandy silt soils from below the rip-rap channel.

Alternatively, a slope drain consisting of a solid pipe placed down the slope may be used to convey the discharge water from the existing drainage tile to the toe of the slope and into the existing drainage structure, west of the distressed area. The drain may consist of a corrugated metal pipe or flexible plastic conduit connected to the existing clay pipe with an appropriate coupling, then securely anchored to the slope; the appropriate connections as well as the type and spacing of anchors should be in accordance with the manufacturer's recommendations. The slope drain should be at least of the same size as the discharge pipe (i.e. minimum of 200 mm in diameter) and may be either buried or placed at the surface of the slope.

The protected rip-rap channel should be provided with a rock pad at the toe of the slope and the discharge water directed to the drainage structure immediately west of the distressed area. If a pipe slope drain is used, then it may either outlet at the toe of the slope into a rock pad or be extended to discharge directly into the existing drainage structure.

Backfill placed to shape the slope should also consist of Select Subgrade Materials (SSM) placed in loose lifts and compacted as practical; the backfilled soil slope should be reseeded after completion of the restoration works.

7.0 CLOSURE

This Geotechnical Design Report was prepared by Mr. Brian Lapos, EIT, and reviewed by Ms. Houda Jadi, P.Eng., a Geotechnical Engineer with Golder, with technical input from Ms. Lisa Coyne, P.Eng. an Associate and Geotechnical Engineer with Golder. Mr. Jorge Costa, a Designated MTO Contact for Golder, conducted an independent review of the report.

GOLDER ASSOCIATES LTD.

Brian Lapos, M.Sc., EIT
Geotechnical Group

Houda Jadi, P.Eng.
Geotechnical Engineer

LICENSED PROFESSIONAL ENGINEER
H. JADI
100078753
PROVINCE OF ONTARIO

Jorge M. A. Costa, P.Eng.
Principal, Designated MTO Contact

LICENSED PROFESSIONAL ENGINEER
J. M. A. COSTA
PROVINCE OF ONTARIO

BML/HJ/LCC/JMAC/bml/hj

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Table 1
Comparison of Slope Restoration Alternatives
Highway 405 W - N/S Ramp at Stanley Avenue - Station 15+718
Highway 405 Rehabilitation from QEW to Queenston-Lewiston Border Crossing
W.P. 2445-04-00

Slope Remediation Option	Feasibility	Advantages	Disadvantages	Relative Costs	Risks/Consequences
Option 1. Cap off the clay drainage tile; backfill the slope with earth fill and reseed the face of the slope	• Feasible for stabilization of slope face	• Removes concentrated (point) source discharge from face of slope • Little excavation required to access the clay drainage tile	• The source of water for the drainage tile is unknown; capping the end of the drainage tile may introduce a new discharge point upstream of the outfall or elsewhere along the slope face	• Expected to be the least expensive option due to low excavation and material costs to cap tile end	• Capping the end of the drainage tile may result in a rise in the groundwater level upstream of the outfall • Quantity and source of discharge is unknown – the quantity of discharge likely varies depending on upstream drainage watershed and season • Potential for reoccurrence of point source discharge and slope erosion
Option 2. Extend drainage tile and reinstate the slope with geotextile or half-pipe channel with rip-rap protection or a slope drain	• Feasible for stabilization of slope face	• Will allow continued discharge of the drainage tile to a local catch basin immediately west of the distress area. • Relatively easy construction	• Requirement for more materials and construction time	• More expensive than Option 1 (e.g. pipe, rip-rap, geotextile and construction)	• The structural integrity of the existing clay drainage tile could be deteriorating with time; potentially causing discharge of water into the slope which in turn could lead to the reoccurrence of a similar failure event in the future

Table 1 - Continued
Comparison of Slope Restoration Alternatives
Highway 405 W - N/S Ramp at Stanley Avenue - Station 15+718
Highway 405 Rehabilitation from QEW to Queenston-Lewiston Border Crossing
W.P. 2445-04-00

Option 3. Completely or partially remove the clay drainage tile; backfill with earth fill and reseed the slope face	• May not be feasible if the drainage tile is still in use • Requires owner's approval / cooperation	• Removes concentrated (point) source discharge from the face of slope	• The extent of the clay drainage tile is unknown and may require extensive excavation works (pipe is about 1.5 m deep and lateral distribution is not known) • Could require an alternate or replacement drainage system for the water currently discharged through the clay pipe	• Expected to be the most expensive option due to the potential for large amounts of excavation, reinstating of private property and drainage system replacement	• Removing the drainage tile may result in a rise in groundwater level upstream of the slope face and potential ponding locally • Potential decrease in slope stability due to increases in groundwater levels

Note: If Options 1 or 3 are selected, it is important that further investigation of the use, extent and flows carried by the clay pipe be carried out in order to ensure proper design of the slope restoration works.

Prepared By: BML
Checked By: H.J.

n:\active\2006\1111\06-1111-036 mrc hwy 405 niagara\reporting\slope restoration station 15+718\table 1 -slope restoration sta 15+718 (alternatives).doc

LIST OF ABBREVIATIONS

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

I. SAMPLE TYPE

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

II. PENETRATION RESISTANCE

Standard Penetration Resistance (SPT), N:

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

Dynamic Cone Penetration Resistance; N_d:

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

PH: Sampler advanced by hydraulic pressure
PM: Sampler advanced by manual pressure
WH: Sampler advanced by static weight of hammer
WR: Sampler advanced by weight of sampler and rod

Piezo-Cone Penetration Test (CPT)

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

III. SOIL DESCRIPTION

(a) Cohesionless Soils

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

(b) Cohesive Soils

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

IV. SOIL TESTS

w	water content
w_p	plastic limit
w_l	liquid limit
C	consolidation (oedometer) test
CHEM	chemical analysis (refer to text)
CID	consolidated isotropically drained triaxial test[1]
CIU	consolidated isotropically undrained triaxial test with porewater pressure measurement[1]
D_R	relative density (specific gravity, G_s)
DS	direct shear test
M	sieve analysis for particle size
MH	combined sieve and hydrometer (H) analysis
MPC	Modified Proctor compaction test
SPC	Standard Proctor compaction test
OC	organic content test
SO_4	concentration of water-soluble sulphates
UC	unconfined compression test
UU	unconsolidated undrained triaxial test
V	field vane (LV-laboratory vane test)
γ	unit weight

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

S:\FINALDATA\ABBREV\2000\LOFA-D00.DOC

LIST OF SYMBOLS

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

I. General

π	3.1416
in x,	natural logarithm of x
$\log_{10}$	x or log x, logarithm of x to base 10
g	acceleration due to gravity
t	time
F	factor of safety
V	volume
W	weight

II. STRESS AND STRAIN

γ	shear strain
Δ	change in, e.g. in stress: $\Delta\sigma$
ε	linear strain
ε_v	volumetric strain
η	coefficient of viscosity
ν	Poisson's ratio
σ	total stress
σ'	effective stress ($\sigma' = \sigma$-u)
σ'_{vo}	initial effective overburden stress
$\sigma_1, \sigma_2, \sigma_3$	principal stress (major, intermediate, minor)
σ_{oct}	mean stress or octahedral stress $= (\sigma_1+\sigma_2+\sigma_3)/3$
τ	shear stress
u	porewater pressure
E	modulus of deformation
G	shear modulus of deformation
K	bulk modulus of compressibility

III. SOIL PROPERTIES

(a) Index Properties

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

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

(a) Index Properties (continued)

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

(b) Hydraulic Properties

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

(c) Consolidation (one-dimensional)

C_c	compression index (normally consolidated range)
C_r	recompression index (over-consolidated range)
C_s	swelling index
C_a	coefficient of secondary consolidation
m_v	coefficient of volume change
c_v	coefficient of consolidation
T_v	time factor (vertical direction)
U	degree of consolidation
σ'_p	pre-consolidation pressure
OCR	over-consolidation ratio = σ'_p/σ'_{vo}

(d) Shear Strength

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

Notes: 1 $\tau = c' + \sigma' \tan\phi'$
2 Shear strength = (Compressive strength)/2

LITHOLOGICAL AND GEOTECHNICAL ROCK DESCRIPTION TERMINOLOGY

WEATHERING STATE

Fresh: no visible sign of weathering.

Faintly weathered: weathering limited to the surface of major discontinuities.

Slightly weathered: penetrative weathering developed on open discontinuity surfaces but only slight weathering of rock material.

Moderately weathered: weathering extends throughout the rock mass but the rock material is not friable.

Highly weathered: weathering extends throughout rock mass and the rock material is partly friable.

Completely weathered: rock is wholly decomposed and in a friable condition but the rock texture and structure are preserved.

BEDDING THICKNESS

Description	Bedding Plane Spacing
Very thickly bedded	> 2 m
Thickly bedded	0.6 m to 2m
Medium bedded	0.2 m to 0.6 m
Thinly bedded	60 mm to 0.2 m
Very thinly bedded	20 mm to 60 mm
Laminated	6 mm to 20 mm
Thinly laminated	< 6 mm

JOINT OR FOLIATION SPACING

Description	Spacing
Very wide	> 3 m
Wide	1 - 3 m
Moderately close	0.3 - 1 m
Close	50 - 300 mm
Very close	< 50 mm

GRAIN SIZE

Term	Size*
Very Coarse Grained	> 60 mm
Coarse Grained	2 - 60 mm
Medium Grained	60 microns - 2 mm
Fine Grained	2 - 60 microns
Very Fine Grained	< 2 microns

Note: * Grains >60 microns diameter are visible to the naked eye.

CORE CONDITION

Total Core Recovery

The percentage of solid drill core recovered regardless of quality or length, measured relative to the length of the total core run.

Solid Core Recovery (SCR)

The percentage of solid drill core, regardless of length, recovered at full diameter, measured relative to the length of the total core run.

Rock Quality Designation (RQD)

The percentage of solid drill core, greater than 100 mm length, recovered at full diameter, measured relative to the length of the total core run. RQD varies from 0% for completely broken core to 100% for core in solid sticks.

DISCONTINUITY DATA

Fracture Index

A count of the number of discontinuities (physical separations) in the rock core, including both naturally occurring fractures and mechanically induced breaks caused by drilling.

Dip with Respect to (W.R.T.) Core Axis

The angle of the discontinuity relative to the axis (length) of the core. In a vertical borehole a discontinuity with a 90° angle is horizontal.

Description and Notes

An abbreviated description of the discontinuities, whether naturally occurring separations such as fractures, bedding planes and foliation planes or mechanically induced features caused by drilling such as ground or shattered core and mechanically separated bedding or foliation surfaces. Additional information concerning the nature of fracture surfaces and infillings are also noted.

Abbreviations

B - Bedding	P - Polished
FO - Foliation/Schistosity	S - Slickensided
CL - Cleavage	SM - Smooth
SH - Shear Plane/Zone	R - Ridged/Rough
VN - Vein	ST - Stepped
F - Fault	PL - Planar
CO - Contact	FL - Flexured
J - Joint	UE - Uneven
FR - Fracture	W - Wavy
MF - Mechanical Fracture	C - Curved
∥ - Parallel To	
⊥ - Perpendicular To	

RECORD OF BOREHOLE No 1

 METRIC

PROJECT 06-1111-036
W.P. 2445-04-00 LOCATION N 4778453.0 ;E 338192.0 ORIGINATED BY MSM
DIST Central HWY 405 BOREHOLE TYPE CONTINUOUS FLIGHT HOLLOW STEM AUGERS COMPILED BY SB
DATUM Geodetic DATE Sept. 21, 2006 CHECKED BY HJ

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT (20 40 60 80 100) / SHEAR STRENGTH kPa (O UNCONFINED, + FIELD VANE, ● QUICK TRIAXIAL, × REMOULDED) 20 40 60 80 100	PLASTIC LIMIT W_P / NATURAL MOISTURE CONTENT W / LIQUID LIMIT W_L — WATER CONTENT (%) 10 20 30	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES						
180.5	GROUND SURFACE										
0.0	100 mm to 150 mm size cobbles (RIP-RAP)										
180.1 0.5	Sandy SILT, some gravel, trace clay Dense to very dense Reddish brown Moist						180				
			1	SS	42				o		18 23 52 7
							179				
			2	SS	>100				o		
178.4 2.1	Dolostone (BEDROCK) Bedrock cored from 2.1 m to 4.6 m depth. For bedrock coring details refer to Record of Drillhole 1.						178				
							177				
175.9 4.6	END OF BOREHOLE NOTE: 1. Borehole dry upon completion of drilling.						176				

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

HJ

PROJECT: 06-1111-036

RECORD OF DRILLHOLE: 1

SHEET 1 OF 1

LOCATION: N 4778453.0 ;E 338192.0

INCLINATION: -90° AZIMUTH: ---

DRILLING DATE: Sept. 21, 2006

DRILL RIG: CME-55 Bombardier

DRILLING CONTRACTOR: DBW DRILLING

DATUM: Geodetic

JN - Joint	BD - Bedding	PL - Planar	PO - Polished	BR - Broken Rock
FLT - Fault	FO - Foliation	CU - Curved	K - Slickensided	NOTE: For additional abbreviations refer to list of abbreviations & symbols.
SHR - Shear	CO - Contact	UN - Undulating	SM - Smooth	
VN - Vein	OR - Orthogonal	ST - Stepped	Ro - Rough	
CJ - Conjugate	CL - Cleavage	IR - Irregular	MB - Mechanical Break	

DEPTH SCALE METRES	DRILLING RECORD	DESCRIPTION	SYMBOLIC LOG	ELEV. DEPTH (m)	RUN No.	PENETRATION RATE (m/min)	FLUSH COLOUR % RETURN	RECOVERY TOTAL CORE % (80 60 40 20)	RECOVERY SOLID CORE % (80 60 40 20)	R.Q.D. % (80 60 40 20)	FRACT. INDEX PER 0.3 m (5 10 15 20)	DISCONTINUITY DATA B Angle (0 90 180 270)	DIP w.r.t. CORE AXIS (0 30 60 90)	TYPE AND SURFACE DESCRIPTION	HYDRAULIC CONDUCTIVITY K, cm/sec (10^{-6} 10^{-5} 10^{-4} 10^{-3})	Diametral Point Load Index (MPa) (2 4 6)	RMC -Q' AVG.	NOTES WATER LEVELS INSTRUMENTATION
		CONTINUED FROM BOREHOLE LOG		178.45														
	NQ Coring	Dolostone containing interlayers of limestone and calcium carbonate mineral inclusion (BEDROCK - Clinton Group) Moderately to slightly weathered Thinly bedded Medium strong Grey		2.05	1	0.4	100											
3					2	0.1	100							,BD,IR,Ro ,JN,PL,SM				
4				175.91 4.59	3	0.4	100							... Ca				
		END OF DRILLHOLE																
5																		
6																		
7																		
8																		
9																		
10																		
11																		
12																		

MIS-RCK 004 06-1111-036.GPJ GAL-MISS.GDT 3/1/07 MSM

DEPTH SCALE

1 : 50

Golder Associates

LOGGED: MSM

CHECKED: HJ

HJ

Golder Associates

Foundation Design

RECORD OF BOREHOLE No 2

 METRIC

PROJECT 06-1111-036			
W.P. 2445-04-00	LOCATION N 4778438.0 ;E 338200.0		ORIGINATED BY MSM
DIST Central HWY 405	BOREHOLE TYPE CONTINUOUS FLIGHT HOLLOW STEM AUGERS		COMPILED BY SB
DATUM Geodetic	DATE Sept. 21, 2006		CHECKED BY HJ

SOIL PROFILE (ELEV / DEPTH, DESCRIPTION, STRAT PLOT) — SAMPLES (NUMBER, TYPE, "N" VALUES) — GROUND WATER CONDITIONS — ELEVATION SCALE — DYNAMIC CONE PENETRATION RESISTANCE PLOT (20, 40, 60, 80, 100) — SHEAR STRENGTH kPa (O UNCONFINED, + FIELD VANE, ● QUICK TRIAXIAL, × REMOULDED; 20, 40, 60, 80, 100) — PLASTIC LIMIT W_P, NATURAL MOISTURE CONTENT W, LIQUID LIMIT W_L; WATER CONTENT (%) 10, 20, 30 — UNIT WEIGHT γ kN/m³ — REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL

ELEV / DEPTH	DESCRIPTION
186.9	GROUND SURFACE
0.0	TOPSOIL
0.2	CLAYEY SILT, trace gravel, sand and clay Very stiff Reddish brown Moist
184.6 / 2.3	SILT, trace to some clay and trace sand Very dense to compact Brown Moist to wet
178.1 / 8.8	Dolostone (BEDROCK) Bedrock cored from 8.8 m to 11.7 m depth. For bedrock coring details refer to Record of Drillhole 2.
175.2 / 11.7	END OF BOREHOLE

NUMBER	TYPE	"N" VALUES	GR	SA	SI	CL
1	SS	26				
2	SS	20				
3	SS	58/0.22				
4	SS	94/0.18				
5	SS	68/0.15				
6	SS	55	1	4	86	9
7	SS	44				
8	SS	28				

Elevation scale: 186, 185, 184, 183, 182, 181, 180, 179, 178, 177, 176

NOTES:

1. Water level measured in Piezometer upon completion of installation at 7.6 m below ground surface (Elev. 178.9 m).

2. Water level measured in Piezometer on Sep. 22, 2006 at 7.8 m depth (Elev. 178.7 m).

3. Water level measured in Piezometer on Oct. 19, 2006 at 8.4 m depth (Elev. 178.1 m).

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

HJ

MIS-MTO 001 06-1111-036.GPJ GAL-MISS.GDT 3/1/07 MSM

RECORD OF DRILLHOLE: 2

PROJECT: 06-1111-036
LOCATION: N 4778438.0 ;E 338200.0
INCLINATION: -90° AZIMUTH: —

DRILLING DATE: Sept. 21, 2006
DRILL RIG: CME-55 Bombardier
DRILLING CONTRACTOR: DBW DRILLING

DATUM: Geodetic

JN - Joint, FLT - Fault, SHR - Shear, VN - Vein, CJ - Conjugate; BD - Bedding, FO - Foliation, CO - Contact, OR - Orthogonal, CL - Cleavage; PL - Planar, CU - Curved, UN - Undulating, ST - Stepped, IR - Irregular; PO - Polished, K - Slickensided, SM - Smooth, Ro - Rough, MB - Mechanical Break; BR - Broken Rock

NOTE: For additional abbreviations refer to list of abbreviations & symbols.

DEPTH SCALE METRES	DESCRIPTION	ELEV. DEPTH (m)	RUN No.	PENETRATION RATE (m/min)	FLUSH COLOUR % RETURN	TYPE AND SURFACE DESCRIPTION	NOTES WATER LEVELS INSTRUMENTATION
	CONTINUED FROM BOREHOLE LOG	178.06					
9	Dolostone containing interlayers of limestone and calcium carbonate mineral inclusion (BEDROCK - Clinton Group) Moderately to slightly weathered Thinly bedded Medium strong Grey	8.84					
			1	0.3	0	,BD,IR,Ro	
						,BD,IR,Ro	
10						,BD,IR,Ro	
						... BC	Grout
						... BC	
11			2	0.2	8	,BD,IR,Ro	
						,BD,IR,SM	
		175.17				,BD,IR,Ro	
	END OF DRILLHOLE	11.73				,BD,IR,Ro	
12							
13							
14							
15							
16							
17							
18							

DEPTH SCALE
1 : 50

Golder Associates

LOGGED: MSM
CHECKED: HJ

HJ

MIS-RCK 004 06-1111-036.GPJ GAL-MISS.GDT 3/1/07 MSM

MINISTRY OF TRANSPORTATION, ONTARIO

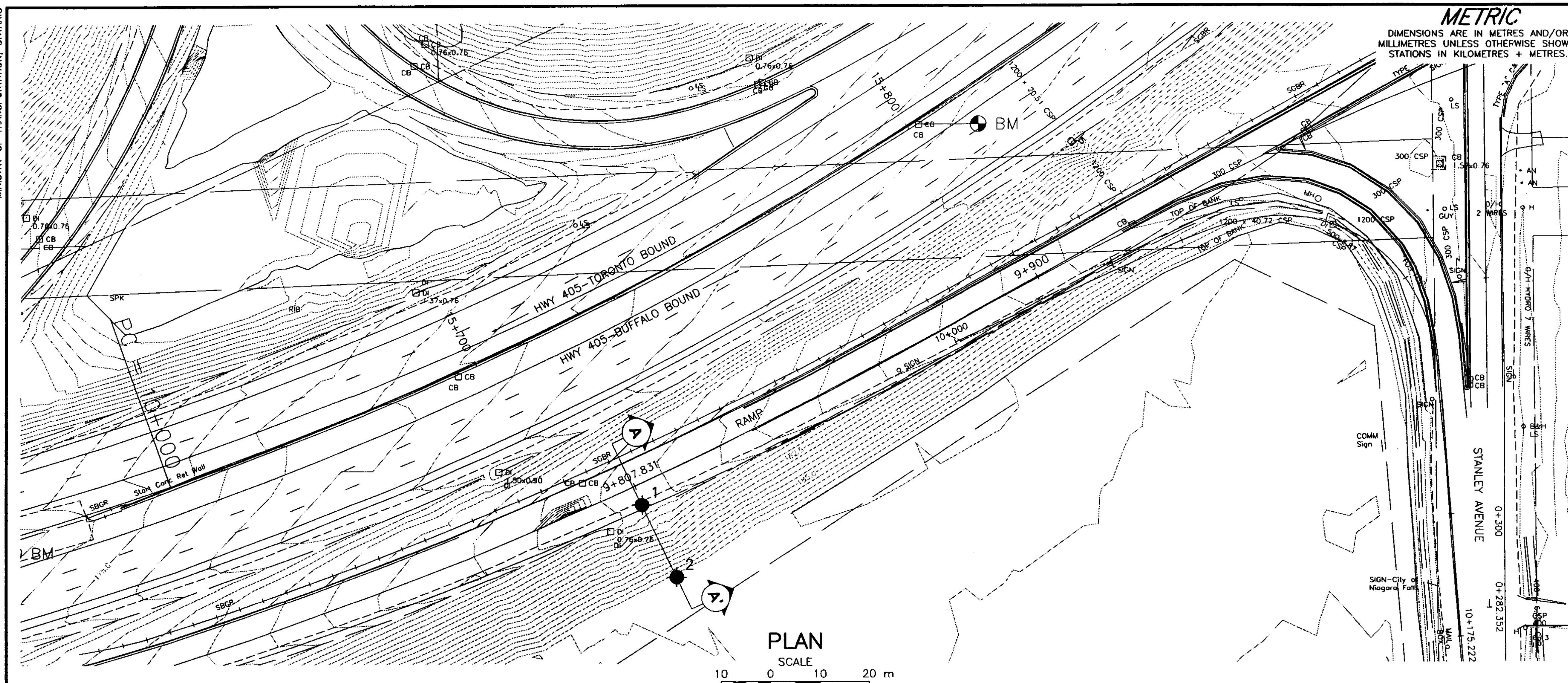
CONT No.
GWP No. 2445-04-00

SHEET

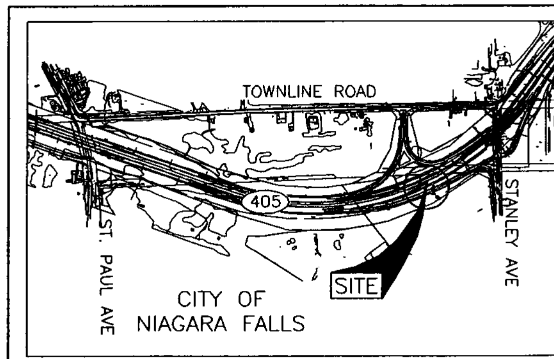
HIGHWAY 405
SLOPE RESTORATION AREA STA. 15+718
BOREHOLE LOCATIONS AND SOIL STRATA

Golder Associates Ltd.
MISSISSAUGA, ONTARIO, CANADA

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



PLAN



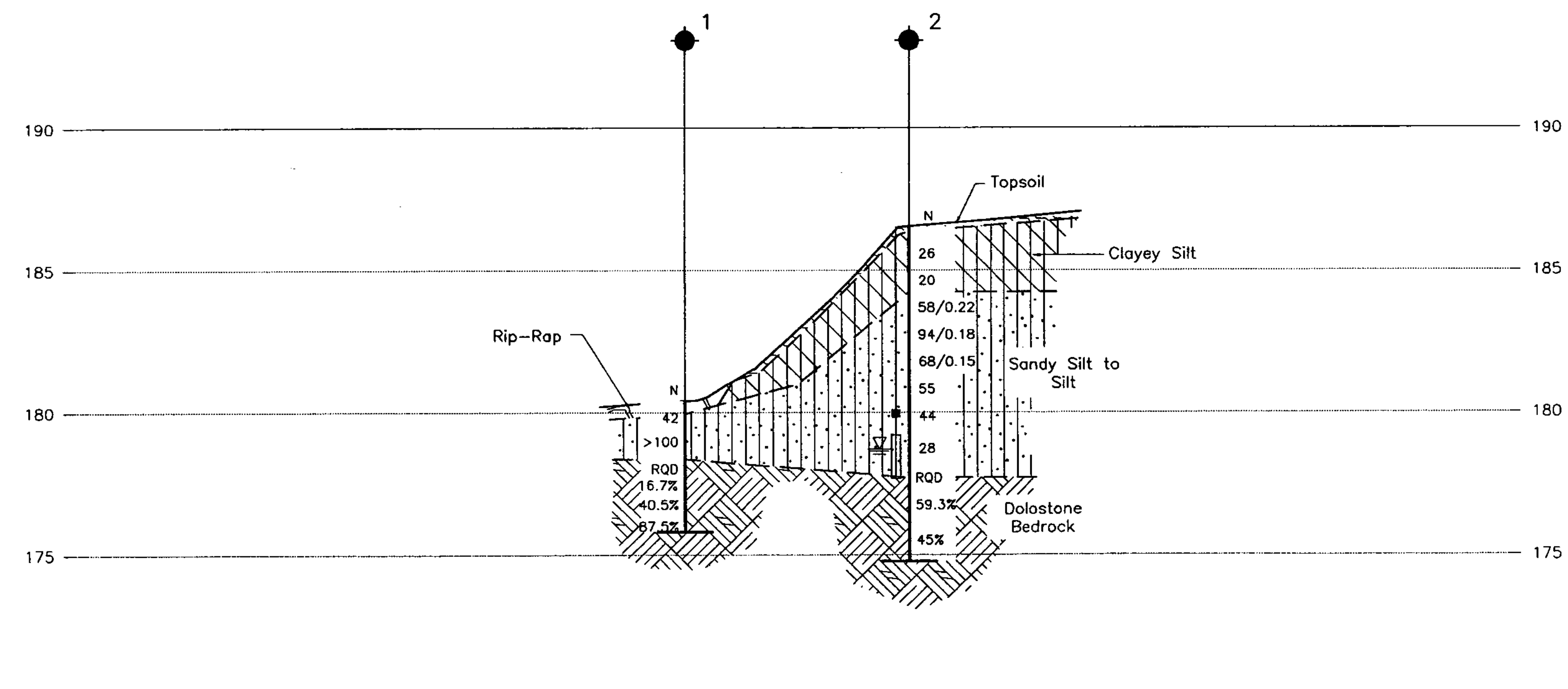
KEY PLAN

SCALE
200 0 200 400 m

LEGEND

● Borehole location

No.	ELEVATION	CO-ORDINATES	
		NORTHING	EASTING
1	180.5	4778453	338192
2	186.9	4778438	338200



PROFILE A-A'

SCALE
HORIZONTAL 5 0 5 10 m

SCALE
VERTICAL 2.5 0 2.5 5 m

NOTES

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

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

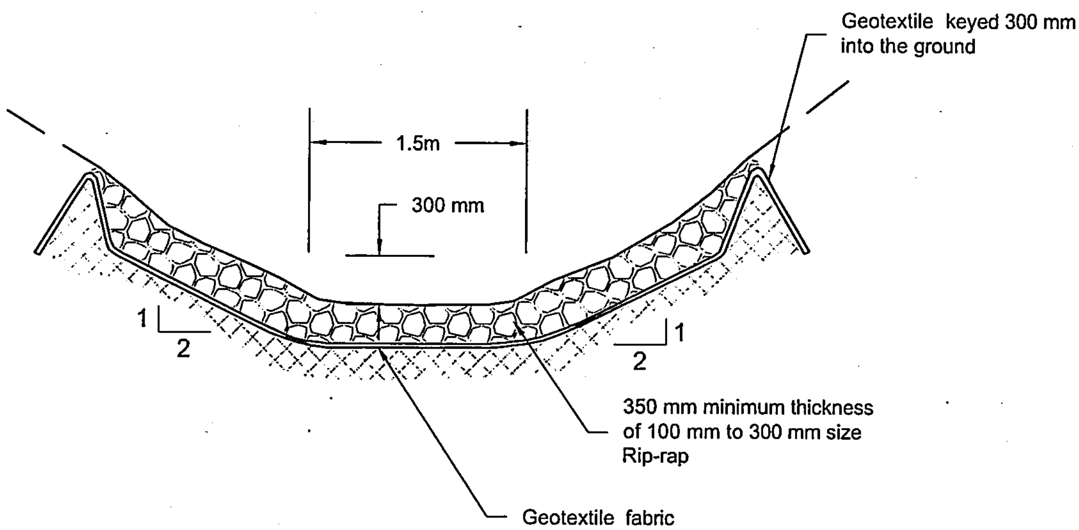
The complete foundation investigation and design report for this project and other related documents may be examined at the Materials Engineering and Research Office, Downsview. Information contained in this report and related documents is specifically excluded in accordance with Section GC 2.01 of OPS General Conditions.

REFERENCE

Base plans provided in digital format by Mc Cormick Rankin Corporation, drawing file nos. 6583 existing Hwy405 mapping.dwg and h5405xb2.dwg, received August 3, 2006.

NO.	DATE	BY	REVISION

Geocres No.			
HWY. 405		PROJECT NO. 06-1111-036	DIST. CENTRAL
SUBM'D. HJ	CHKD. HJ	DATE: OCT 2006	SITE:
DRAWN: MSM	CHKD. BML	APPD. LCC	DWG. 1

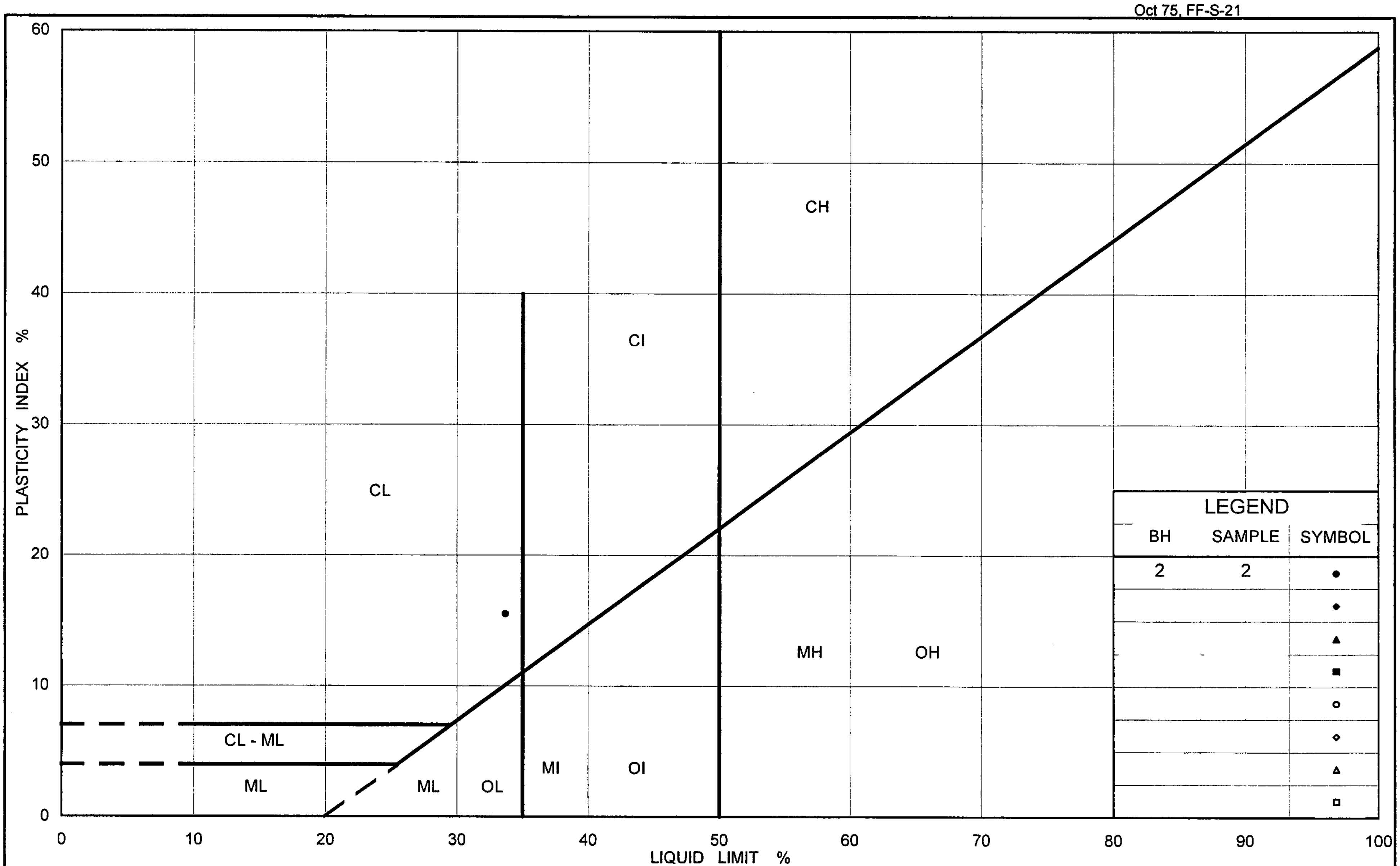


Notes:

- The rip-rap protected channel should be about 300 mm deep and have a bottom width of 1.5 m with 2H: 1V or flatter side slopes.
- Rip-rap should consist of 100 mm to 300 mm angular stone with a minimum thickness of 350 mm and should extend below the outlet of the drainage tile.
- The rip-rap channel should be worked into the erosion gully to obtain as flat a drainage slope as practical.
- Where silts and sandy silt soils are encountered immediately below the rip-rap channel, these should be subexcavated and replaced with silty clay/clayey silt materials compacted in place as practical
- A non-woven geotextile fabric (such as a Terrafix 360 R or equivalent) should be installed under all rip-rap and should be keyed 300 mm into the ground at the edges of the gully and along the slope.
- Rip-rap should blend into the existing ground.

Golder Associates Mississauga, Ontario, Canada	SCALE N.T.S. DATE DEC. 19, 2006 DESIGN CAD MSM	TITLE **RIP-RAP PROTECTED CHANNEL TYPICAL CROSS SECTION**	
FILE No. 061111036DA002.dwg	CHECK HJ	SLOPE RESTORATION - STATION 15+718 HIGHWAY 405 W-N/S Ramp AT STANLEY AVENUE	DRAWING 2
PROJECT No. 06-1111-036 REV.	REVIEW		

PLOT DATE: December 22, 2006
FILENAME: T:\Projects\2006\06-1111-036 (MRC, Niagara Falls)\-DA- Slope Restoration\061111036DA002.dwg



Ministry of Transportation

Ontario

PLASTICITY CHART
Clayey Silt

FIG No.1

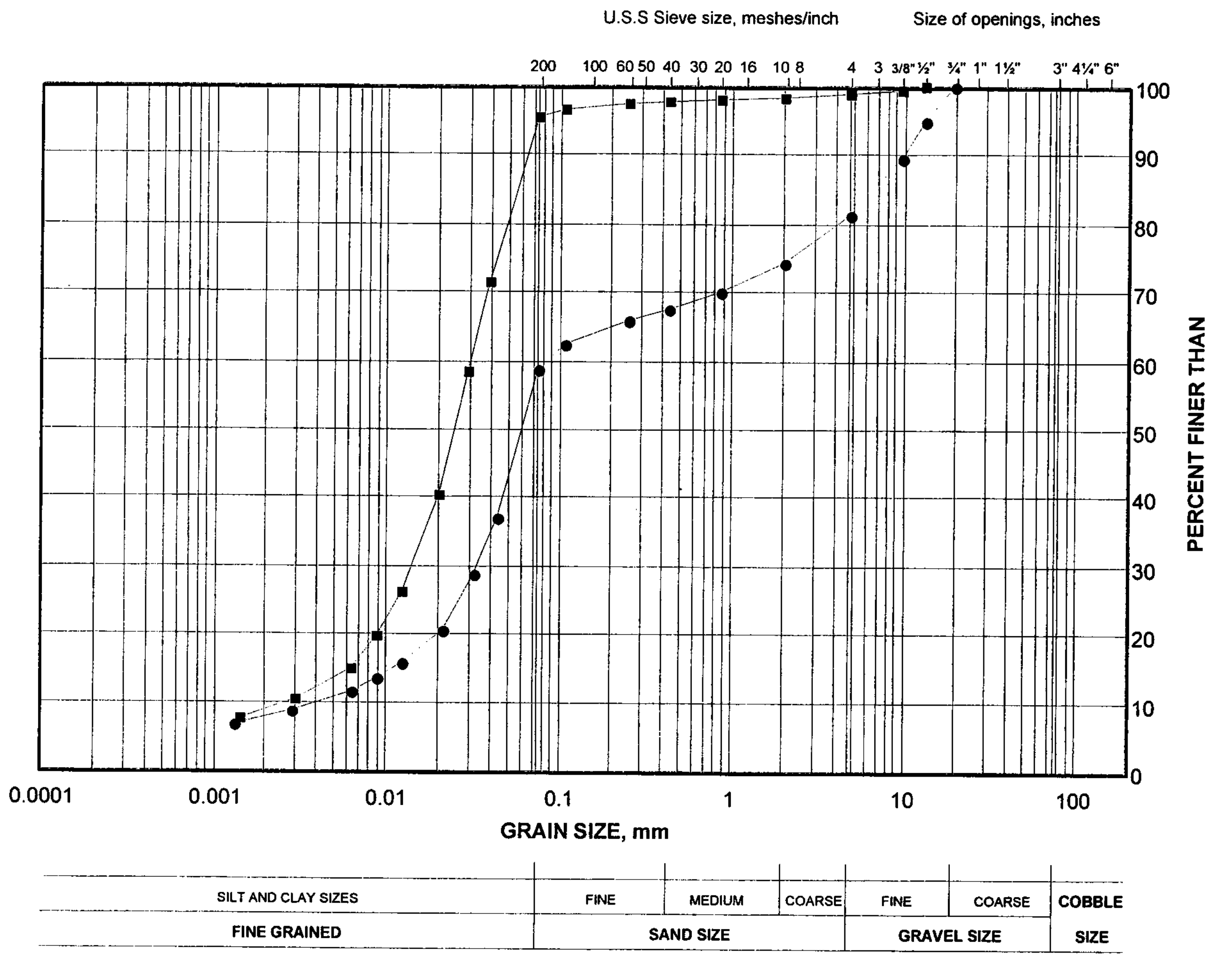
Project No. 06-1111-036

Date: October, 2006

GRAIN SIZE DISTRIBUTION TEST RESULTS

Sandy Silt to Silt

FIGURE 2



LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	1	1	179.3
■	2	6	181.6

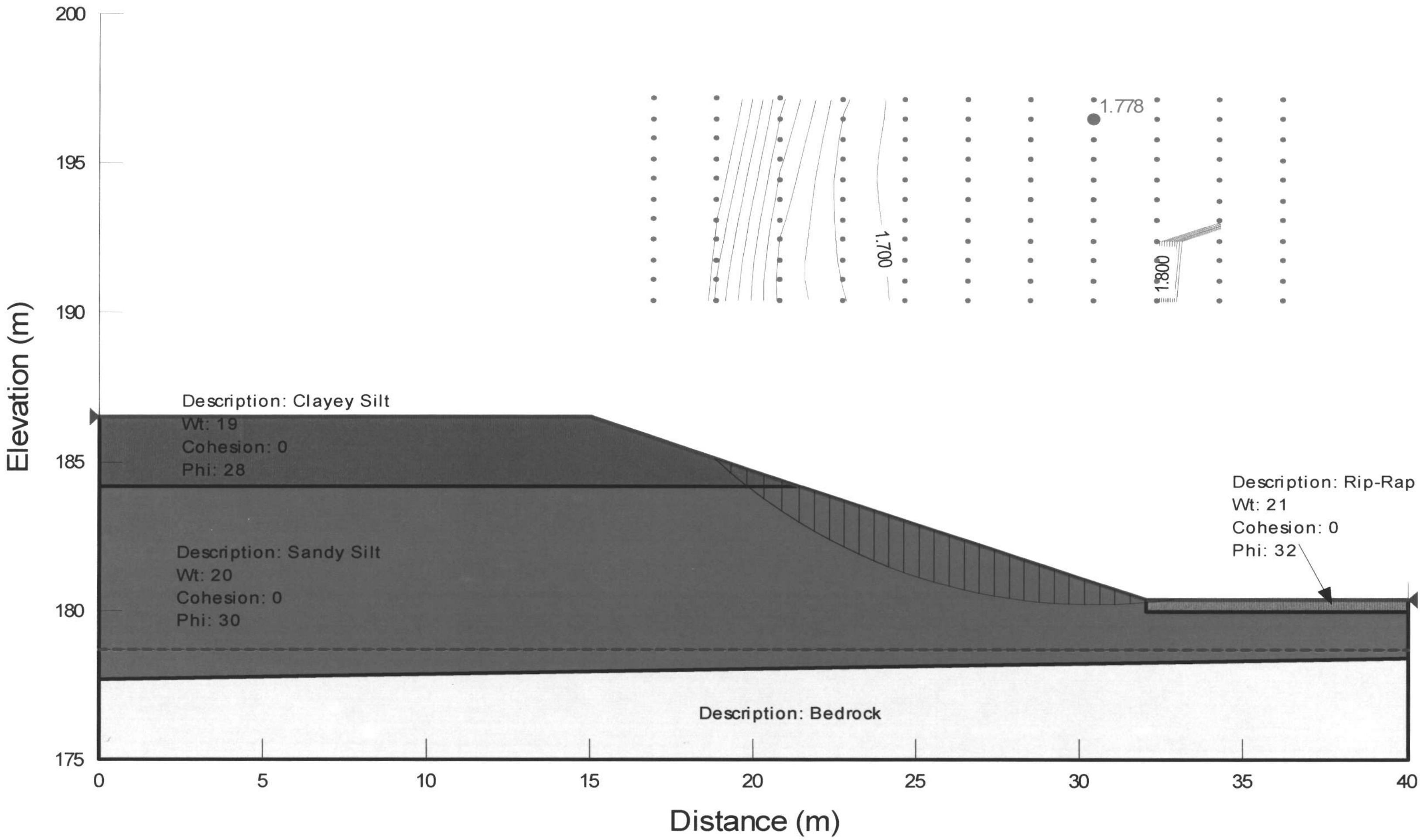
Project Number: 06-1111-036

Checked By: ________

Golder Associates

Date: 02-Nov-06

Results of Slope Stability Analysis	Figure 3



Date: October 2006
Project: 06-1111-036

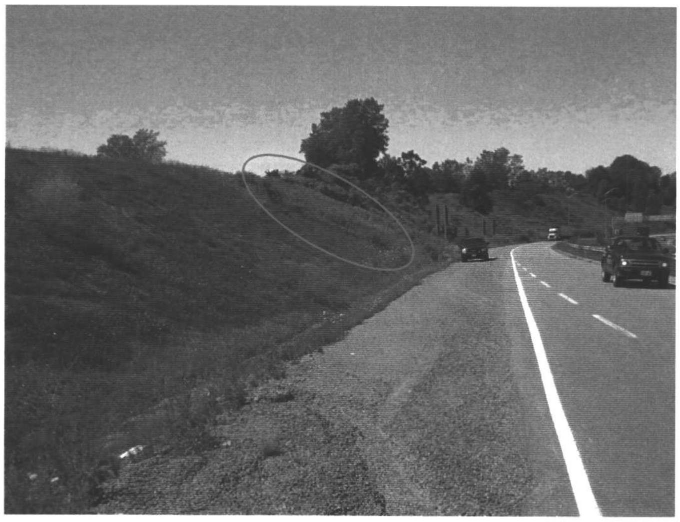
Golder Associates

Drawn: BML
Checked: HJ HJ

APPENDIX A

PHOTOGRAPHS

Slope Restoration at Station 15+718
Highway 405 W-N/S Ramp at Stanley Avenue



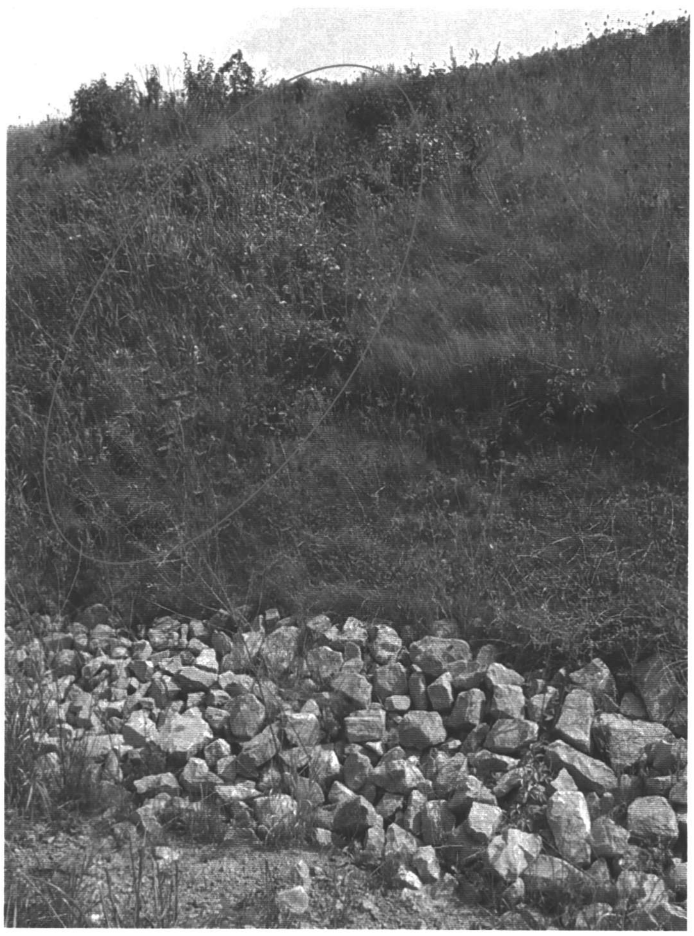


Photo Nos. 3 & 4 – Top of the Erosion Gully, September, 2006

Photo Nos. 1 & 2 - General View, September, 2006

Slope Restoration at Station 15+718
Highway 405 W-N/S Ramp at Stanley Avenue

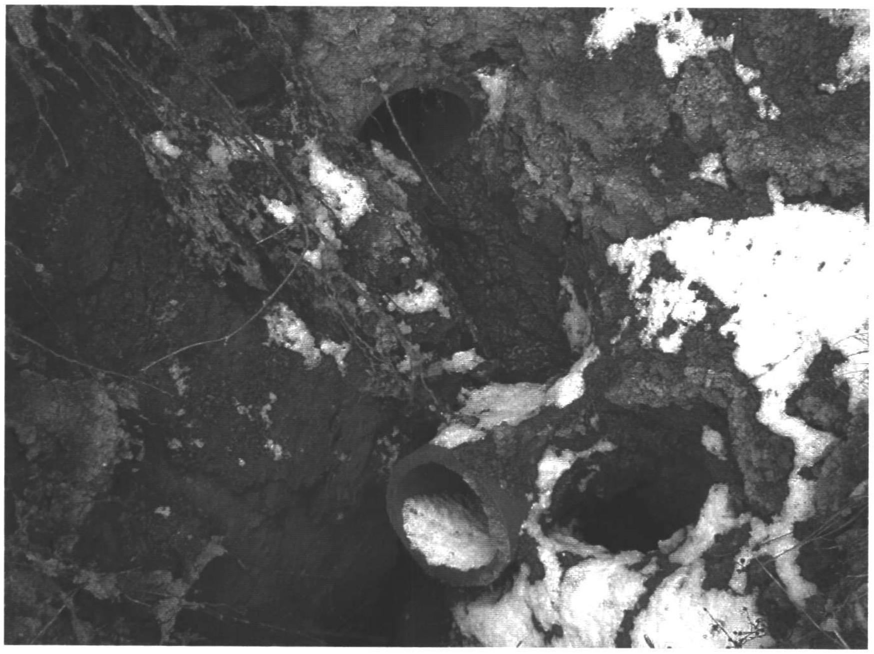


Photo No. 5 - Clay Drainage Tile- March, 2006 (Photo taken by MTO)

Photo No. 6: Erosion Gully- March, 2006 (Photo taken by MTO)

APPENDIX B

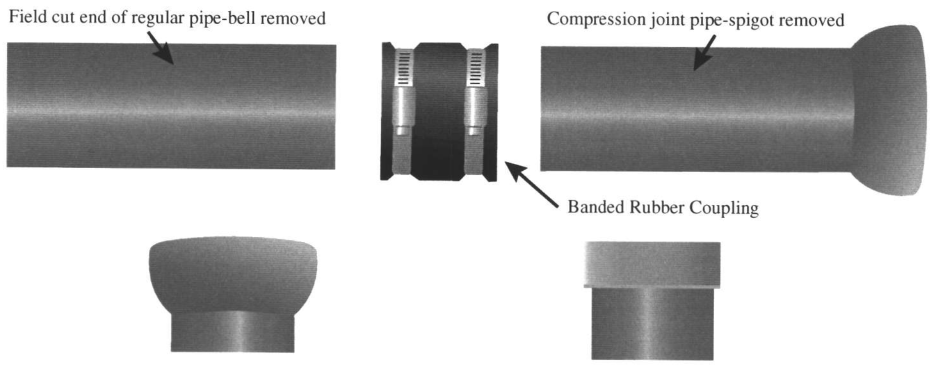
EXAMPLE CLAY PIPE TRANSITIONAL CONNECTIONS DETAIL

Source: http://gladdingmcbean.paccoast.com/gladdingmcbean/docs/csp_TransConn.pdf
(Supplier:Gladding McBean)

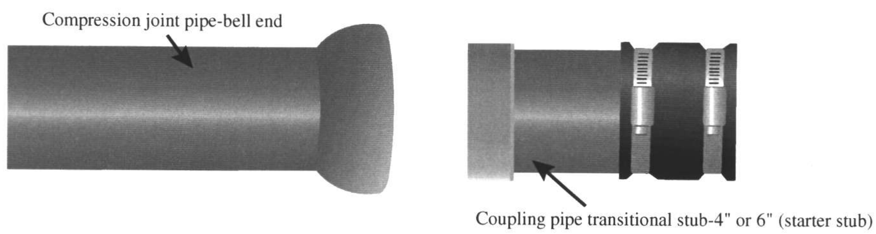
TRANSITIONAL CONNECTIONS

Joints for field cut sections and transitional requirements installed with ease, speed, and assured security performance to meet every Vit-Clay pipe job condition.

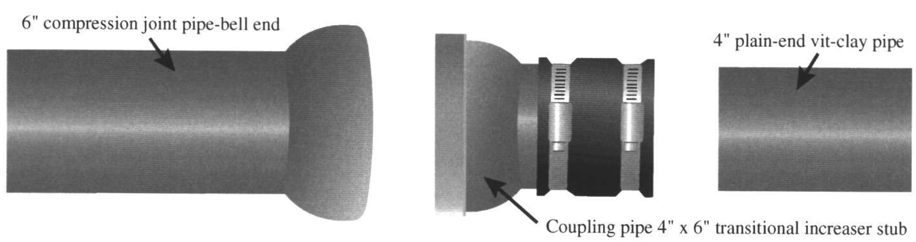
Connecting SPEED-SEAL Vit-Clay to Regular Bell and Spigot Vit-Clay Pipe.



Connecting Plain-End Vit-Clay to SPEED-SEAL Vit-Clay Pipe.



Connecting 4" Plain-End Vit-Clay to 6" SPEED-SEAL Vit-Clay Pipe.



Connecting Plain-End Vit-Clay to - Regular Plain-End or Field Cut Spigot End of Compression Joint Pipe - to P.V.C. Pipe.