April 23, 2018

FOUNDATION INVESTIGATION REPORT

Thorold Tunnel Rehabilitation, Site No. 34-177/T
Highway 58, City of Thorold,
Ministry of Transportation, Ontario
G.W.P. 2370-16-00

Submitted to:
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REPORT

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Golder Associates

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1.0 INTRODUCTION

Golder Associates Ltd. (Golder) has been retained by Morrison Hershfield Limited (MH) on behalf of the Ministry of Transportation, Ontario (MTO) to provide foundation, hydrogeological and tunnelling engineering services for the proposed rehabilitation of the Thorold Tunnel (Highway 58), in the City of Thorold, Regional Municipality of Niagara, Ontario.

The purpose of this study is to carry out an assessment of the water seepage/leakage into the tunnel and to assist the MH team in developing mitigation measures to minimize the amount of future seepage into the tunnel and along the exposed rock face on the north and south sides of Highway 58, east of the east portal of the Thorold Tunnel. The field investigation consisted of an inspection of the rock faces on the north and south sides of Highway 58, an inspection of the interior walls of the Thorold Tunnel, and a field investigation comprising one borehole advanced west of the West Service building to the north of the Thorold Tunnel.

As part of this assignment, Golder initially completed a desktop study to summarize existing information, and this is presented in the following report:

- "Foundation Desktop Study Report, Thorold Tunnel Rehabilitation, Site No. 34-177/T, Highway 58, Thorold, Ontario Assignment No 2016-E-0001, G.W.P. 2370-16-00", Geocres No 30M3-300, dated October 13, 2017.

The desktop study, referenced above, summarizes the background/site history of the tunnel investigations and construction/performance issues, a reconnaissance/site visit, and development of context for the hydrogeological setting of the tunnel based on both existing information and site reconnaissance. The desktop study also summarizes the subsurface conditions from the previous investigation reports prepared between 1964 and 1982.

The Terms of Reference and the scope of work for the foundation engineering services are outlined in MTO's Request for Proposal, dated October 2016, which forms part of the Consultant's Assignment No. 2016-E-0001 for this project. Due to legal/insurance challenges related to working on the St. Lawrence Seaway Authority property, the field investigation program was reduced as outlined in Golder's Revised Scope letter dated April 12, 2018. The work has been carried out in accordance with Golder's Project Specific Supplementary Specialty Plan for foundation engineering services for this project, dated May 9, 2017.

2.0 SITE DESCRIPTION

2.1 Thorold Tunnel

The Thorold Tunnel consists of two separate tube structures, each accommodating two lanes that carry the eastbound (EB) and westbound (WB) traffic of Highway 58 beneath the Welland Canal. The EB and WB tubes are separated by a service tunnel accommodating a walkway and utilities. A public sidewalk runs along the north side of the WB tube. The Thorold Tunnel extends from Ormond Street on the west side of the Welland Canal (West Portal) to just east of Seaway Haulage Road on the east side of the Welland Canal (East Portal), and is approximately 700 m long (see Drawing 1). The Highway 58 grade at the West Portal is at about Elevation 164.6 m, sloping downwards to the low point of the tunnel located approximately below the east side of the Welland Canal at Elevation 150.8 m, and then sloping upward toward the East Portal to about Elevation 163.6 m. The vertical outside height of the tunnel is about 9.6 m, and the inside height of the tunnel is about 6.0 m. The exterior concrete walls of the tunnel are about 1.8 m thick and are covered with a waterproofing zone consisting of 5 mm thick bentonite panels in turn protected by fibreboard. The base slab and top slab are about 2 m thick and 1.4 m thick, respectively; it is understood that the base slab contains a waterproofing steel membrane between the concrete and the bedrock, whereas the top slab is covered with a four-ply fibreglass waterproof membrane in turn covered by a 25 mm thick fibreboard and 127 mm concrete slab.

At the West and East Portals, service buildings contain the ventilation shafts and electrical controls. The West Service Building contains the pump controls and security cameras, in addition to the ventilation and electrical controls.

The land area between the west bank of the Welland Canal and the East Portal is owned by the St. Lawrence Seaway Authority (SLSA). The Welland Canal is about 107 m wide and is positioned such that its west bank is about 70 m west of the midpoint of the tunnel. The water level in the Canal is at about Elevation 171.3 m. A gravel road runs along the west side of the Canal, with a City of Thorold multi-use path located west of the gravel road. About 10 m west of the multi-use path, Trillium Railway owns and operates a single rail track. The gravel road, multi-use path and rail track are at about Elevation 176 m; further west, the ground surface is covered by low shrub and grass vegetation and slopes up to Elevation 179.5 m in the vicinity of the Tunnel's West Service Building. A double-set of railway tracks is present east of the West Service Building.

Between the east side of the Canal and the East Portal, the land north and south of the tunnel is used by the SLSA as a dredgate disposal area, and therefore the ground surface contours are variable. It is understood from SLSA that this dredgate disposal area is unlined. The tunnel's East Service Building is bounded by Seaway Haulage Road to the west. The ground surface at the East Service Building is at about Elevation 179.8 m.

The cover over the roof of the tunnel is about 7.5 m thick at the West Portal, then decreases to about 4.5 m below the Welland Canal, and about 13.5 m thick at the East Portal. The cover material above the roof of the tunnel and below the Welland Canal is comprised of rock fill.

2.2 Approach Side Slopes East and West of the Tunnel

At the West Portal, the north and south cut slopes of the Highway 58 approach embankment are inclined at about 2 horizontal to 1 vertical (2H:1V) and are vegetated with trees which are standing vertically (i.e., no evidence of curvature on the tree trunks).

At the East Portal there are vertical rock face cuts on the north side of the WB tube and on the south side of the EB tube, and the rock face is about 7.3 m high at the portal. The Highway 58 pavement surface gradually rises to the east to Davis Road where it is about coincident with the surrounding ground surface. At a distance of about 130 m east of the east portal, the surface of Highway 58 is approximately coincident with the near-horizontal bedrock surface. There is evidence of seepage between the bedding planes on the rock faces, and vegetation growth is present at locations of seepage. The seepage amount is greater on the north rock face compared to the south rock face. There is also rock debris present at the base of the rock faces, suggesting that rock has fallen from the face.

On the north side of Highway 58, the rock face extends a distance of about 75 m from the east portal. Rock bolts installed into the north rock cut face close to the east portal are evident, and there is also evidence of a formed concrete cap on the bedrock surface, although the concrete cap is not continuous. At a distance of about 28 m from the east portal, a more substantial concrete wall that is about 2 m wide extends from the sidewalk level to the full height of the rock face. East of the 2 m wide concrete wall, the rock face/concrete wall steps back by about 1 m (see Photograph 1 below). From this location to a distance of about 43 m easterly a concrete wall extends from the bedrock surface and downwards (partially covering the rock face) over a distance of about 1.5 m. A light pole is located on the north side of Highway 58, in close proximity to the rock face. At the base of the light pole, fallen rocks have accumulated. The distance from the rock face to the light pole varies vertically from about 1 m to 1.2 m (see Photograph 1), and the light pole is located about 1.9 m east of the full-height concrete wall (see Photograph 2).

Photograph 1: Looking west at the light pole (north side)

Photograph 2: Looking north at the light pole (north side)

On the south side of Highway 58, the rock face extends a distance of about 132 m east of the east portal. At a distance of about 85 m from the east portal, a concrete cap/wall extends from the bedrock surface and mostly covers the rock face but has an irregular shape. Near the east portal, the rock face is undercut and it is understood that pieces of rock occasionally fall from the face onto the curb.

The 1967 construction drawings indicate that 250 mm diameter subdrains are present at the base of the south and north rock faces, at a depth of about 1.2 m below the grade shown on the drawing.

3.0 SITE RECONNAISSANCE AND ROCK FACE INSPECTION

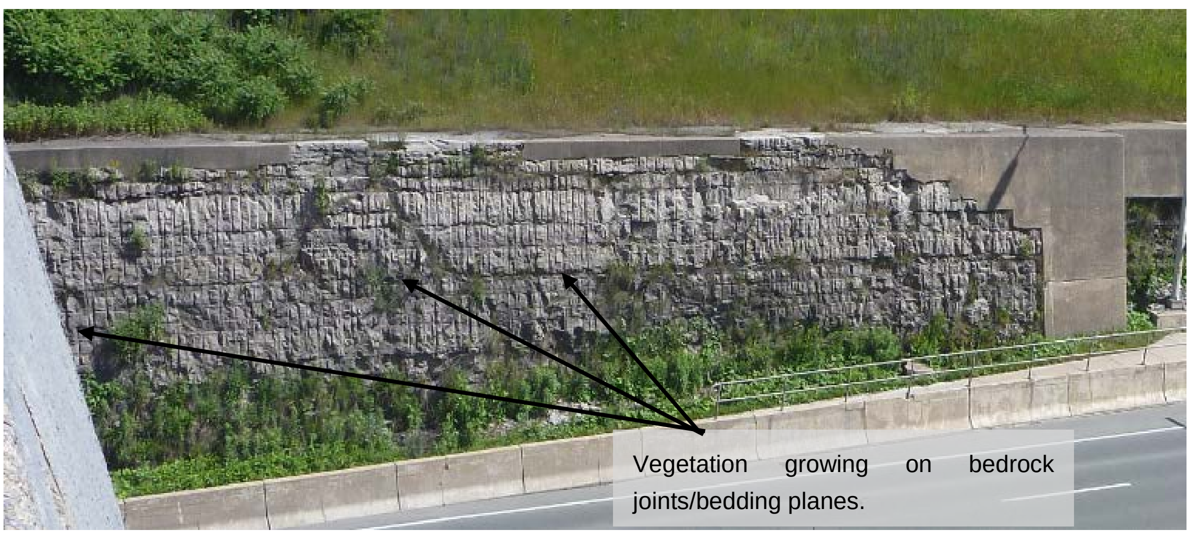
3.1 Inspection of Thorold Tunnel

On December 20, 2016 and May 11, 2017, Golder's foundation engineer inspected the north tunnel wall from the sidewalk, examining the vertical cracks in the tunnel wall, and the cracking through both the original and patched concrete where the tunnel wall meets the roof. Icicles (representing frozen seepage water) were observed on the vertical cracks and some of the joints in the south tunnel wall in the winter 2016 inspection. At the contraction joint at Station 13+002 in the south tunnel (located about 70 m west of the east portal in the area of the Pondage Canal), it is understood that several years ago MTO Maintenance placed a rubber mat over the joint from the curb to the corbel, in order to minimize the potential for ice adhering to the wall. Small, conical or flattened piles of soil were observed on the sidewalk at three of the existing crack locations (at approximately 55 m, 120 m and 175 m from the West Portal) in the north (WB) tube, and some fine soil particles were also observed on the sidewalk below cracks at about 390 m and 530 m from the West Portal; these observations may indicate that fine soil particles are being carried with the water seepage through the cracks. Wet pavement areas were also observed, and these areas are believed to be due to water emanating from beneath the pavement.

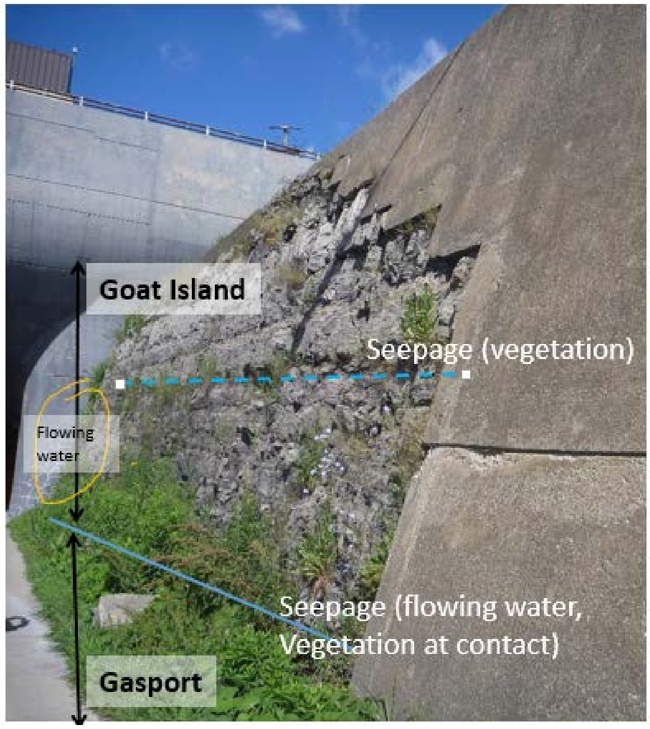
3.2 Rock Face Inspection

A senior hydrogeologist and rock mechanics engineer conducted a site reconnaissance of the north and south bedrock cut faces adjacent to the East Portal on June 22, 2017 to evaluate the local site conditions.

An area of exposed bedrock along the rock cut immediately east of the East Portal on the northern side of Highway 58 was examined. Based on bedrock mapping, the bedrock at the exposed rock face consists of dolomitic limestone of the Goat Island Member overlying the Gasport Member, both of which are part of the Lockport Formation. The rock face was observed to be damp with diffuse seepage occurring along the bedrock surface, and from a horizon midway up the rock cut. Vegetation (grass and small shrubs) was noted to be present along the bedding partings suggesting that seepage commonly occurs at this location. In addition, a damp rock surface and emanation of a low rate of seepage were observed at the interface of the bedrock cut and the northeast edge of the East Portal. During the winter the water seepage on the rock face freezes and forms icicles and water also seeps onto the sidewalk and freezes. There are wet swampy areas present behind the rock cut as well as standing water further north, which are inferred to be the source of the seepage water observed on the rock cut face. Rock bolts installed into the north rock cut face close to the East Portal are evident and there is also evidence of formed concrete near the crest of the slope. Rock debris has accumulated at the base of the rock face indicating that rock has fallen from the face. Selected photographs of these observed conditions are presented in Photographs 3 and 4.



Photograph 3: Looking north at rock face east of the East Portal.



Photograph 4: Looking westward at rock face on north side of Highway 58 east of the East Portal.

A bedrock cut is also exposed along the south side of Highway 58 east of the East Portal. This face was observed to be dry to damp, but no groundwater seepage was noted at the time of the site visit. Vegetation growth (grass) was also observed to be present along a bedrock bedding plane about halfway up the rock cut face. There is evidence of some undercutting of the rock face leaving an overhang, and rock debris has accumulated at the base of the rock face indicating that rock has fallen from the face. It is understood that historically, water seepage from the face sometimes seeps out onto the road surface and has the potential to freeze during winter conditions. The conditions on the south face east of the East Portal are shown in Photograph 5.

Photograph 5: Looking south at south rock cut face east of the East Portal.

4.0 INVESTIGATION PROCEDURES

4.1 1964 Investigation

In 1964 H.G. Acres & Company Limited, Consulting Engineers (Acres) completed a geotechnical field investigation for the Thorold Tunnel and the results are presented in a report titled "Thorold Tunnel, Feasibility Report Appendices, Appendix A – Field and Laboratory Investigations and Geotechnical Design Considerations, Tunnel and East Approach," dated October 30, 1964. Several horizontal tunnel alignments were under consideration during the field investigation:

- four boreholes (1001, 1002, 1004 and 1005) were advanced for Scheme 6 alignment, located 300 m to the north of the existing alignment;
- one borehole (1003) was advanced for Scheme 4 alignment, located 1,525 m to the south of the existing alignment; and
- twenty-seven boreholes and three test pits were advanced for the recommended location of the tunnel which was designated as the Scheme 3 alignment (see Drawing 1).

The locations of the boreholes from the 1964 investigation are shown on Plates A1 to A4 of the Acres (1964) report, copies of which are included in Appendix A; the locations of the boreholes from the 1964 investigation specifically for the recommended Scheme 3 alignment are also shown on Drawing 1, following the text of this report. It is understood that the bedrock contours shown on Plate A1 were developed using data from the SLSA.

The boreholes for the Scheme 3 alignment were advanced with diamond drills, supplied and operated by F.E. Johnston Drilling Co. Ltd. The test pits were excavated to the west of the current location of the West Portal with a tractor-mounted backhoe supplied and operated by W. Duffin Construction to a depth of about 2.7 m to expose the bedrock surface. In a total of twelve boreholes, samples of the overburden were obtained using a 50 mm diameter Shelby tube, or a 50 mm diameter split spoon, at approximately 1.5 m intervals of depth. The Acres (1964) report indicates that when attempting to obtain Shelby tube samples from the very stiff portions of the overburden, it was typically not possible to push the Shelby tube more than 150 mm and it was often necessary to drive the Shelby tubes using the 63.5 kg weight hammer. Bedrock core in NX-size was obtained from sixteen boreholes, of which twelve boreholes were drilled vertically and four boreholes were drilled inclined at 45 degrees. Several boreholes were advanced without sampling for the purpose of determining the bedrock surface; at these locations 3 m of bedrock cored was obtained.

The Acres (1964) report notes that, in every borehole advanced, drilling water was lost over a short depth below the bedrock surface, and that the static water level was typically above the bedrock surface and usually at an elevation equal to or higher that the water level in the Welland Canal at the time of the investigation.

In boreholes where the bedrock was cored for greater than a 3 m length, a packer test was carried out after each 1.5 m length of bedrock coring. The tests were carried out by lowering a 1.5 m long perforated pipe to the bottom of the borehole (at each test) with a single packer positioned at the top of the pipe. The tests were carried out by applying water pressure to the test section equal to 23 kPa per metre (1 psi/ft) of depth to the section being tested. Water level readings were taken at one minute intervals until steady state rate of flow was achieved, which typically took between 5 minutes and 10 minutes. Standpipes were installed in five of the boreholes (1001, 1009, 1014, 1016 and 1022).

The Acres (1964) report indicates that pockets of gas were encountered while coring the bedrock; the gas pressure was typically relieved fairly rapidly, with the exception of Boreholes 1016 and 1018, located near the East Portal, and in Borehole 1025 where "considerable volumes of gas were released."

A summary of the soil sampling, bedrock coring procedures, bedrock coring depths, packer testing and piezometer installations at each borehole advanced for the Scheme 3 alignment is presented below.

Borehole No.	Overburden Sampling	Bedrock Coring Depth/Elevation ** (m)	Packer Testing Carried Out	Standpipe Piezometer Installed
1006	Split-spoon and Shelby to bedrock surface	6.3 - 34.2 (172.5 - 144.6)	Yes	No
1007	Split-spoon to bedrock surface	3.0 - 29.4 (171.6 - 145.2)	Yes	No
1008	Drill to bedrock surface	None	No	No
1009	Shelby to bedrock surface	7.1 - 33.9 (171.8 - 144.9)	Yes	Yes
1010	Split-spoon, Shelby and Core Barrel to bedrock surface	11.6 - 13.4 (167.43 - 165.66)	No	No
1011	Split-spoon, Shelby and Core Barrel to bedrock surface	11.8 - 34.0 (167.3 - 145.1)	Yes	No
1012	Split-spoon and Shelby to bedrock surface	10.5 - 34.8 (170.4 - 146.0)	Yes	No
1013	Shelby to bedrock surface	6.4 - 31.7 (171.02 - 145.72)	Yes	No
1014	Shelby to bedrock surface	7.8 - 39.4 (172.1 - 140.5)	Yes	Yes
1015	Shelby to bedrock surface	7.0 - 32.0 (171.8 - 146.8)	Yes	No
1016	Shelby to bedrock surface	5.9 - 31.5 (171.3 - 145.8)	Yes	Yes
1017	Split-spoon to bedrock surface	6.7 - 10.6 (171.15 - 167.27)	No	No
1018	Shelby to bedrock surface	6.6 - 30.5 (170.81 - 146.88)	Yes	No
1019	Drill to bedrock surface	8.8 - 11.9 (169.9 - 166.8)	No	No
1020	Split-spoon and Shelby to bedrock surface	8.2 - 11.5 (170.44 - 167.15)	No	No
1021	Shelby to bedrock surface	8.0 - 24.7 (169.6 - 152.9)	Yes	No
1022	No sampling; advance casing to bedrock surface	7.9 - 25.8 (168.8 - 150.8)	No	Yes
1023	Split-spoon and Shelby to bedrock surface	None	No	No

Borehole No.	Overburden Sampling	Bedrock Coring Depth/Elevation ** (m)	Packer Testing Carried Out	Standpipe Piezometer Installed
1024	Split-spoon and Shelby to bedrock surface	None	No	No
1025*	No sampling; advance casing to bedrock surface	4.0 - 42.9* (170.7 - 131.8)*	Yes	No
1026*	No sampling; advance casing to bedrock surface	9.8 - 44.0* (168.8 - 134.6)*	Yes	No
1027*	No sampling; advance casing to bedrock surface	4.3 - 42.7* (170.5 - 132.1)*	Yes	No
1028*	No sampling; advance casing to bedrock surface	9.1 - 43.1* (168.8 - 134.8)*	Yes	No
1029	Drill to bedrock surface	8.9 - 11.7 (170.3 - 167.5)	No	No
1037	Drill to bedrock surface	8.2 - 11.0 (171.15 - 168.37)	No	No
1045	No sampling; advance casing to bedrock surface	None	No	No
1046	No sampling; advance casing to bedrock surface	None	No	No

* Depth to / Elevation of bedrock surface is not consistent with the bedrock surface elevation in the adjacent boreholes in the general area (as shown on Plate A4 in Appendix A of the Acres (1964) report).

** Elevations given in this table are consistent with those shown on the boreholes records and are referenced to SLSA datum. The SLSA datum is 0.35 m higher than Geodetic datum.

The ground surface and bedrock surface contour elevations presented in the Acres (1964) report are referenced to the SLSA datum using Benchmark 210A (Elevation 573.03 ft.). The borehole locations were tied-in to stations on the Canal using then-existing Canal survey baselines; the borehole locations shown in Drawing 1 have been established relative to various streets / identifiable features on Plate 1 of the Acres (1964) report and transposed into the MTM NAD 83 (Zone 10) locations/coordinates presented on Drawing 1. The ground surface elevations as depicted on Drawing 1 have been adjusted from the SLSA datum to be consistent with Geodetic datum. This adjustment is -0.35 m relative to the SLSA datum as referenced on the borehole records from the Acres 1964 report.

4.2 Current Investigation

The field work for the current foundation investigation was carried out between October 17 and November 7, 2017, during which time Borehole GT17-01 was advanced at the location shown on Drawing 1. The borehole records and the lists of abbreviations and symbols to assist in the interpretation of the borehole and records are provided in Appendix A.

The borehole investigation was carried out using a truck-mounted CME 75 drill rig, supplied and operated by Aardvark Drilling of Guelph, Ontario. The borehole was advanced through the overburden using 210 mm outside diameter hollow-stem augers and HW casing. Soil samples were obtained at 0.75 m and 1.5 m intervals of depth, using a 50 mm outer diameter split-spoon sampler driven by an automatic hammer in accordance with Standard Penetration Test (SPT) procedures (ASTM D1586-08)[1]. Samples of the bedrock were obtained using an 'HQ' size rock core barrel and coring techniques. The borehole was advanced to auger refusal (i.e. inferred bedrock) then further advanced to a depth of 36.2 m (Elevation 142.5 m) below existing ground surface, including coring of bedrock for core lengths of 29.1 m. Photographs of the recovered bedrock core samples are provided in Appendix B.

Blow-Out Prevention Procedures

Due to the naturally occurring gas that was previously encountered in the 1964 boreholes, and the known potential for naturally occurring gas in these bedrock formations, a well licence was required from the Ministry of Natural Resources and Forestry (MNRF). Golder submitted the well licence application and Well Licence 12542 was issued by the MNRF (see Appendix A for a copy of the well licence). In order to seal the rock formation where the gas was expected, the borehole was advanced to a depth of about 7 m below the bedrock surface (14 m below ground surface) and a 114 mm diameter conductor casing was cemented inside a 159 mm diameter cored borehole. Figure 1, following the text of this report, presents the installation and size details for the conductor casings. After the casings were grouted, the blow-out prevention (BOP) system was installed.

Photographs 6 and 7 illustrate the BOP system setup. The annular BOP, which is attached to the borehole casings, is connected to the degasser and the control unit. In the event of a blowout when drilling, the drill was immediately stopped and the annular BOP was initiated. This would seal the space around the drill rods and force the gas and water to come up around the drill rods and towards the degasser. Once separated, the gas vented out through a 7 m stack and the water accumulated in a holding basin.

Photograph 6: Blow-out prevention system showing the degasser and venting stack (left) and drill (right)

[1] ASTM D1586-08a – Standard Test Method for Standard Penetration Tests and Split Barrel Sampling of the soil.

Photograph 7: Blow-out prevention system on the borehole

Packer Testing

In situ hydrogeological testing, in general accordance with procedures defined in ASTM D4630, was conducted at six depths in Borehole GT17-01 using a dual pneumatic packer setup connection to an on-surface nitrogen tank through an inflation line. Upon completion of drilling, the packer assembly was lowered into the borehole to isolate a select depth interval within the rock and a constant pressure head (CH) test was performed. The test results were then used to evaluate the hydraulic conductivity within the isolated packer interval. A pressure gauge data logger, manufactured by In Situ Inc., was used to monitor water pressure responses in the isolated interval during the tests. Flow rates and test pressures in the isolated interval were recorded during CH tests as well as being recorded by the data logger. The water pressure profiles obtained were used to calculate estimates of hydraulic conductivity using standard steady-state analysis methods.

The groundwater conditions and water levels in the open borehole were observed during the drilling operations. Two vibrating wire piezometers were installed at depths of 16.1 m and 23.2 m below ground surface. The borehole was backfilled with wither grout or bentonite upon completion in accordance with Ontario Regulation 903, Wells (as amended).

The field work was observed by members of Golder's engineering and technical staff, who located the boreholes, arranged for the clearance of underground services including both public and privates locates, observed the drilling, sampling and in situ testing operations, and logged the boreholes. The samples were identified in the field, placed in appropriate containers, labelled and transported to Golder's Mississauga geotechnical laboratory where the samples underwent further visual examination and laboratory testing. All of the laboratory tests were carried out to MTO and/or ASTM Standards, as appropriate. Classification testing (water content, Atterberg limits and grain size distribution) was carried out on selected soil samples. Unconfined compression (UC) tests were carried out on selected specimens of the bedrock core samples by Golder's Mississauga Laboratory. Two rock core samples were submitted to the University of Western Ontario for free swell testing. The results of the geotechnical laboratory testing on soil and rock samples from the current investigation are included in Appendix B.

The borehole location and the ground surface elevation were obtained using a GPS (Trimble XH 3.5G), having an accuracy of 0.1 m in the vertical and horizontal directions. The location provided on the borehole and drillhole records and shown on Drawing 1 are positioned relative to MTM NAD 83 (Zone 10) coordinates system, and the ground surface elevations are referenced to Geodetic datum. The borehole location and ground surface elevation are summarized below.

Borehole No.	Location (MTM NAD 83)		Ground Surface Elevation (m)	Borehole Depth (m)
	Northing (Latitude, °)	Easting (Longitude, °)		
GT17-1	4,775,177.9 (43.11604)	329,361.1 (-79.19819)	178.7	36.2*

* includes 29.1 m of bedrock core

5.0 SITE GEOLOGY AND SUBSURFACE CONDITIONS

5.1 Regional Geology

This section of Highway 58 is located within the Iroquois Plain physiographic region, as delineated in the *Physiography of Southern Ontario* (Chapman and Putnam, 1984). The Iroquois Plain extends around the western shores of Lake Ontario and is comprised of the flat to undulating lakebed and beaches of the former glacial Lake Iroquois, which occupied this area during the last glacial recession. This site is bound to the north by shoreline beach deposits from Glacial lake Iroquois such as the Homer Bar on which downtown St. Catharines is located, and the Niagara Escarpment located some 3 km to the south.

Surficial sediments are typically comprised of silty and clayey till of the Halton Till sheet according to the *Quaternary Geology of the Niagara-Welland Area* (Ontario Geological Survey Map 2496; Feenstra, 1984). The Halton Till sheet is underlain by an older, red, sandy and silty till, possibly the Wentworth Till sheet (OGS Preliminary Map 764, Feenstra 1972). Shallow depressions on the surface of the clay plain upslope of the Homer Bar are infilled with bog sediments, while fill materials comprised of earth and rock fill associated with the canal construction occur in the vicinity of the former Welland Canal (OGS Preliminary Map 764, Feenstra 1972).

The Niagara Escarpment is the major topographic feature in the region (Karrow and White, 1998). The bedrock escarpment runs in an east-to-west direction along the southern shore of Lake Ontario and extends northward towards the Bruce Peninsula. The Niagara Escarpment is located approximately 2 km north of the Site, and rises up to 120 m above the lake plain to the north (Menzies and Taylor, 1998). The escarpment is discontinuous north of the site as it has a few re-entrant features which could possibly mark the sites of ancient tunnel valleys that have been infilled by glacial sediments (Menzies and Taylor, 1998). Immediately south of the Niagara Escarpment are a series of linear ridges that have been interpreted as terminal moraines (Chapman and Putnam, 1984).

The Niagara peninsula south of the Niagara Escarpment consists of Palaeozoic sedimentary strata bedrock of the Silurian and Devonian age. The beds dip to the south under Lake Erie with a shallow inclination of approximately

5.7 m/km. The massive dolomitic limestone is from the Salina Formation in the Welland area and is comprised of siltstone and calcareous shaly interbeds with occasional limestone layers and inclusions of gypsum within the dolomite. These strata occur within the middle part of the Salina formation and are of Silurian age. Two escarpments, the Niagara Escarpment and Onondaga Escarpment, run east-west in the northern area of Port Colborne and south of the Thorold Tunnel under the Welland Canal, respectively. The bedrock depression between the Onondaga Escarpment and Niagara Escarpment is infilled with overburden with elevations ranging between 460 m and 500 m.

Near the Thorold Tunnel, beneath the glacial till lies the Goat Island member of the Lockport Formation, which is comprised of massive to thickly bedded dolomite and is approximately 6 m thick at the site. The Gasport member lies below the Goat Island member and is a similar dolomitic limestone with occasional gypsum pockets. However, within this member there is a 3 m thick, black shaly zone that has been interpreted to have contributed to distress at the tunnel alignment due to the weak rock mass. The thickness of the Gasport member varies but is approximately 10 m thick at the tunnel site and is underlain by the Decew Formation which is typically thin to thickly bedded dolomite and has a thickness of about 2 m to 4 m. The Decew Formation is underlain by the Rochester Formation which consists of dark grey shale.

Throughout the Welland area, the surface topography of the overburden overlying the bedrock contact is characterized by low relief and poor drainage (Menzies and Taylor, 1998). Due to the presence of the weathered and fractured overburden-bedrock interface, a major source of groundwater is found in an aquifer contained within this upper zone and within pervious zones that occur locally at the overburden-bedrock interface. There is no known faulting in the immediate vicinity of the site; however a significant thrust fault is present in the region approximately 100 km east of the tunnel location.

5.2 Subsurface Conditions

The detailed subsurface soil, bedrock and groundwater conditions as encountered in the borehole advanced during the current investigation are presented on the borehole and drillhole records provided in Appendix A. The results of the geotechnical laboratory tests carried out on selected soil and bedrock core samples from the current investigation are contained in Appendix B. The results of the in-situ field tests (i.e. SPT "N" values) as presented on the borehole records and in subsections of Section 5.2 are uncorrected.

The stratigraphic boundaries in the overburden, shown on the borehole records and on the stratigraphic profile on Drawing 1, are inferred from non-continuous sampling, observations of drilling progress and the results of Standard Penetration Tests. These boundaries, therefore, represent transitions between soil types rather than exact planes of geological change. The bedrock formation contacts as presented on the drillhole records are based on visual examination of the bedrock core samples. Furthermore, subsurface conditions will vary between and beyond the borehole location. It should be noted that the interpreted stratigraphy shown on Drawing 1 is a simplification of the subsurface conditions from the current investigation and the investigation carried out by Acres in 1964.

In summary, the subsurface conditions in the borehole advanced during the current investigation consists of sandy gravel fill material with layers of silty clay fill. The fill material is underlain by the Goat Island member and Gasport member dolomitic limestone of the Lockport Formation. The Lockport Formation is underlain by dolomitic limestone of the Decew Formation which in turn is underlain by shale of the Rochester Formation. A more detailed description of the subsurface conditions encountered in the borehole advanced during the current investigation is provided in the following sections.

Golder's Foundation Desktop Study Report, referenced in Section 4.1, presents a detailed description of the subsurface conditions encountered in the boreholes advanced by Acres (1964). Information on the bedrock conditions, details about the gas encountered and the results of the packer testing from the Acres (1964) report are also presented in sections below.

All elevations given in the following sections as it relates to the Acres (1964) report are referenced to the SLSA datum, obtained relative to Benchmark 210A (Elevation 573.03 feet). The SLSA datum is 0.35 m higher than Geodetic datum.

5.2.1 Fill

In Borehole GT17-01, fill consisting primarily of gravelly sand to sandy gravel was encountered and extended to a depth of 7.1 m (Elevation 171.6 m) below ground surface. Within the granular fill, layers of silty clay fill were encountered at depths of 0.7 m (Elevation 178.0 m) and 1.5 m (Elevation 177.2 m) and were 0.5 m and 0.7 m thick, respectively.

The SPT "N" values within the granular fill range from 13 blows to 47 blows per 0.3 m of penetration with two samples having an SPT "N" value of 50 blows per 30 mm and 80 mm penetration, indicating that the granular fill generally has a compact to dense compactness condition. The two higher SPT "N" values may be more reflective of the split-spoon sampler encountering gravel. Two SPT "N" values measured within the cohesive fill were 12 blows and 17 blows per 0.3 m of penetration, indicating that the cohesive fill has a stiff to very stiff consistency.

The result of a grain size distribution test completed on one sample of the granular fill is presented on Figure B1 in Appendix B. The sandy gravel fill contains trace to some sand and trace clay. The water content measured on a sample of the granular fill material was about 3 per cent.

The result of a grain size distribution test completed on one sample of the cohesive fill is presented on Figure B2 in Appendix B. The silty clay fill contains trace to some sand and trace gravel. An Atterberg limits test was carried out on the fines portion of one sample of the cohesive fill, and measured a liquid limit of about 38 per cent, a plastic limit of about 19 per cent, and a plasticity index of about 19 per cent; as shown on the plasticity chart on Figure B3 in Appendix B, this result indicates that the fines portion of the cohesive fill can be classified as a silty clay of medium plasticity. The water content measured on a sample of the cohesive fill was 18 per cent, near the plastic limit of the material.

5.2.2 Bedrock

In Borehole GT17-01, bedrock was encountered at a depth of about 7.1 m (Elevation 171.6 m) below ground surface and core samples of the bedrock were recovered. The contacts between the formations and their respective members were selected based on visual examination of the core. Summarized below are the bedrock surface elevations for the major bedrock formations and members encountered in the current investigation, and their relative thickness.

Formation	Member	Depth to Surface of Formation (m)	Elevation of Surface of Formation (m)	Approximate Thickness of Formation (m)
Dolomitic limestone of Lockport Formation	Goat Island Member	7.1	171.6	8.7
	Gasport Member	15.8	162.9	6.3
Dolomitic limestone of Decew Formation	--	22.1	156.6	3.6
Shale of Rochester Formation	--	25.7	153.0	>10.5*

* Borehole GT17-01 terminated in the Rochester Formation at a depth of 36.2 m (Elevation 142.5 m) below ground surface.

Summarized below are the bedrock surface elevations for the major bedrock formations and members encountered during the Acres (1964) borehole drilling investigation, and their relative thickness.

Formation	Member	Approximate Range of Elevation* of the Surface of the Formation (m)	Range of Thickness (m)
Lockport	Goat Island	172.5 – 167.3	5.2 – 7.6
	Gasport	165.0 – 159.5	6.4 – 8.5
Decew	-	158.2 – 148.5	2.1 – 4.0
Rochester	-	154.5 – 142.3	13.4+

* Elevations given in this table are consistent with those shown on the boreholes records and are referenced to SLSA datum. The SLSA datum is 0.35 m higher than Geodetic datum.

As presented above, the elevation of the surface of the formations encountered in the borehole advanced for the current investigation is within the range of elevation from the Acres (1964) report.

In general, the dolomitic limestone bedrock core samples of the Lockport and Decew Formations are described as fresh, medium to thickly bedded, fine to medium grained, slightly to moderately porous, medium strong to strong, grey, and containing limestone and shale partings or thin interbeds at varying intervals. In general, the shale bedrock core samples of the Rochester Formation are described as fresh, thickly bedded, fine grained, slightly porous, medium strong, grey to black, shale to dolomitic shale. The drillhole records are presented in Appendix A, and photographs of the recovered bedrock core samples are shown on Figure B4 in Appendix B. The degree of weathering of the bedrock core samples (i.e. fresh – W1), and the strength classification of the intact rock mass based on field identification (i.e. medium strong to strong – R3 to R4) are described in accordance with the International Society for Rock Mechanics (ISRM[2]) standard classification system.

The Rock Quality Designation (RQD) measured on the bedrock core samples generally ranges from about 94 per cent to 100 per cent, indicating a rock mass of excellent quality as per Table 3.10 of CFEM (2006)[3]. The Total

[2] International Society for Rock Mechanics Commission on Test Methods, 1985. Int. J. Rock Mech. Min. Sci. & Geomech. Abstr. Vol 22, No. 2, pp. 51-60.

[3] Canadian Geotechnical Society, 2006. Canadian Foundation Engineering Manual (CFEM), 4th Edition. The Canadian Geotechnical Society, BiTech Published Ltd., British Columbia.

Core Recovery (TCR) and Solid Core Recovery (SCR) of samples recovered are between 96 per cent and 100 per cent and between 68 per cent and 100 per cent, respectively.

Two Unconfined Compression (UC) tests (ASTM D7012)[4] were carried out on selected core samples of the Goat Island bedrock obtained in Borehole GT17-01 and measured uniaxial compressive strengths of about 71 MPa and 101 MPa, as summarized on Figures B5 and B6 in Appendix B. Based on the laboratory UC tests, in accordance with Table 3.5 in CFEM (2006)[4], the limestone bedrock is classified as medium strong to strong (R3, 50 MPa < UCS < 75 MPa to R4, 75 MPa < UCS < 100 MPa).

Free Swell Test Results

Two rock core samples from Borehole GT17-01 were submitted to the University of Western in London, Ontario for free swell testing to provide information on the swelling potential of the shale of the Gasport Member of the Lockport Formation and the Rochester Formation. The following provides the depth, elevation and Formation for the two bedrock core samples tested:

Borehole	Depth (m)	Elevation (m)	Bedrock	Member/Formation
GT17-01	17.2	161.5	Shale	Gasport Member, Lockport Formation
	28.3	150.4	Shale	Rochester Formation

For the free swell tests, the bedrock core samples are tested without any applied pressure and are allowed to swell freely in all directions. Free swelling was tested on rock samples in vertical and horizontal direction (sample axis perpendicular to the bedding planes). The testing also included the determination of the moisture content, salinity of the pore fluid in the test specimen, and calcite content of the samples. The swell testing results for the free swell tests are given as swelling strains (in %) versus time (in log scale to base 10) curves. The results are presented in Appendix B.

Golder's analysis of the test results from horizontal and vertical free swell tests indicates the following free swelling potential of the shale bedrock. The results indicate that the free swelling potential of the Rochester shale is much greater than the Gasport shale and for both shales the free swell potential in the vertical direction is higher than in the horizontal direction.

	HSP[1] (X)	HSP[1] (Y)	Average HSP[1] (X+Y)/2	VSP[2] (Z)	Calcite Content
	[% per log cycle]	[% per log cycle]	[% per log cycle]	[% per log cycle]	[%]
Range	0.02 - 0.1	0.07 – 0.1	0.05 - 0.1	0.05 – 0.32	--
Average	--	--	0.07	0.19	--

1 HSP Horizontal Swelling Potential
2 VSP Vertical Swelling Potential

[4] ASTM D7012 – Standard Test Method for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens

5.2.3 Bedrock Hydraulic Conductivity

Six packer tests were carried out during the current investigation, in accordance with the procedures presented in Section 4.2. The following summarizes the depth and elevation of the interval of the test, the bedrock formation and the estimated hydraulic conductivity. The results confirm the tight nature of the rock mass, with intermediate hydraulic conductivities in the range of 10^{-6} to 10^{-8} m/s for the lower rock mass of the Gasport, Decew, and Rochester formations. The upper rock mass in the Goat Island formation shows high hydraulic conductivities in the range of 10^{-4} m/s.

Borehole	Packer Test Interval Depth (Elevation)		Rock Member and Formation	Water Level (mbgs)	Estimated Hydraulic Conductivity (m/s)
	From (m)	To (m)			
GT17-01	7.72 (170.98)	11.02 (167.68)	Goat Island member, Lockport Formation	N/A[1]	1×10^{-4}
	9.72 (168.98)	13.02 (165.68)	Goat Island Member, Lockport Formation	N/A[1]	N/A[1]
	16.75 (161.95)	20.05 (158.65)	Gasport	9.90	9×10^{-6}
	19.75 (158.95)	23.05 (155.65)	Gasport-Decew	9.95	2×10^{-7}
	22.78 (155.92)	26.08 (152.65)	Decew and Rochester Formation	10.96	3×10^{-6}
	25.75 (152.95)	29.05 (149.65)	Rochester Formation	9.20	8×10^{-8}

1. Packer test was conducted above the water table in a dry condition. Water level did not rise above the instrumentation for the duration of the testing phase; therefore, the test results are not valid.

Summary of Packer Testing from the Acres (1964) Report

Packer testing was carried out in 17 of the 32 boreholes advanced by Acres for the recommended alignment. After each 1.5 m of bedrock coring, a packer test was carried out in the boreholes where the bedrock was cored greater than a 3 m length. The test was carried out by lowering a 1.5 m long perforated pipe to the bottom of the borehole (at each test) with a single packer above it. The tests were carried out using gauge pressures equal to about 23 kPa/m (1 psi/ft) of depth to the section being tested. Water level readings were taken at one minute intervals until a steady state rate of flow was achieved, which typically took between 5 minutes and 10 minutes.

Borehole No.	Number of Tested Intervals	Top Interval (m)	Bottom Interval (m)	Average Bedrock Hydraulic Conductivity (m/sec)
1001	12	14.0	32.2	4.0×10^{-7}
1003	10	15.8	31.4	3.1×10^{-6}
1006	10	9.4	34.2	6.2×10^{-6}
1007	17	5.4	29.4	4.1×10^{-6}

Borehole No.	Number of Tested Intervals	Top Interval (m)	Bottom Interval (m)	Average Bedrock Hydraulic Conductivity (m/sec)
1009	17	7.1	33.9	4.6×10^{-6}
1011	13	13.2	34.0	3.0×10^{-6}
1012	15	11.0	34.8	3.8×10^{-6}
1013	16	7.1	31.7	4.5×10^{-6}
1014	18	8.3	37.5	2.1×10^{-6}
1015	15	7.1	32.0	2.0×10^{-6}
1016	17	5.9	31.5	1.3×10^{-6}
1018	15	7.7	30.5	1.9×10^{-6}
1021	10	8.2	24.7	2.9×10^{-6}
1025	23	4.6	43.0	5.5×10^{-6}
1026	17	10.4	44.0	1.8×10^{-6}
1027	16	5.3	42.7	6.5×10^{-6}
1028	14	10.1	43.1	1.8×10^{-6}

Coefficients of permeability were established from the test results in each borehole such that maximum and average coefficients were produced for each formation member. A summary of the bedrock permeability of the four bedrock formations as derived from the 255 individual packer tests is presented below:

Formation	Member	Co-efficient of Permeability of 10^{-6} (m/sec)		
		Maximum	Minimum	Average
Lockport	Goat Island	9.9	0	5.2
	Gasport	6.8	0	1.8
Decew	-	3.6	0	0.9
Rochester	-	3.0	0	0.5

5.2.4 Gas

During drilling of Borehole GT17-01, concentrations of methane and hydrogen sulphide were measured at the drill head using a RKI GX-2015 4 sensor gas monitor (CH_4/O_2/H_2S/CO). During the drilling program, gas was encountered while advancing the borehole within the Rochester Formation, between a depth of 27.8 m (Elevation 150.9 m) and 29.4 m (Elevation 149.3 m) below ground surface and a methane concentration of 29 per cent of the Lower Explosive Limit and a CO concentration of 150 ppm was measured within this interval.

Summary of Gas Encountered from the Acres (1964) Report

The Acres (1964) report indicates that pockets of gas were encountered while coring the bedrock and that the pressure was typically relieved fairly rapidly, with the exception of Boreholes 1016 and 1018, located near the East Portal and in Borehole 1025 where "considerable volumes of gas were released." The Acres (1964) report further indicates that the pressure at some depths was sufficient to blow the drilling water inside the casing about 8 m above the ground surface, that the gas had an odour similar to that of hydrogen sulphide and that it "burned with a blue flame and deposited a black coating on the drill rods." A summary of the measured back pressure (which is the residual gauge pressure remaining after packer testing) is provided in Table A4 of the Acres (1964) Feasibility Report – Appendices, included in Appendix A to the desktop report.

5.2.5 Groundwater

During the drilling operations for Borehole GT17-01, the water level inside the casing was measured at the start and end of each day and ranged from depths of between 9.8 m and 11.5 m (between Elevation 168.9 m and 167.2 m) below ground surface. Because water was required to advance the drill bit, the water levels are not considered to represent the stabilized groundwater level at the site. It is noted that during bedrock coring operations, water used to advance the core barrel did not recirculate back to ground surface, indicating that the water was dissipating into the bedrock formation.

Two vibrating wire piezometers (VWP) were installed in Borehole GT17-01 and details of the VWP installations and measured groundwater levels are shown on the borehole records in Appendix A. The following summarizes the VWP tip depth and elevation and the water levels recorded in the VWPs.

VWP No.	Bedrock Member, Formation	VWP Tip Depth	VWP Tip Elevation	Depth to Water Level (Groundwater Elevation)
1	Goat and Gasport Island Member, Lockport Formation	16.1 m	162.6 m	12.6 m (Elev 166.1 m) (February 1, 2018)
2	Decew Formation	23.2 m	155.5 m	12.0 m (Elev.166.7 m) (February 1, 2018)

It should be noted that the groundwater level in the area is subject to seasonal fluctuations and precipitation events, and should be expected to be higher during wet periods of the year. The shallow groundwater conditions in the immediate vicinity of the Welland canal may be influenced by seasonal draining of the canal, which occurs between January and March.

6.0 CLOSURE

This Foundation Investigation Report was prepared by Mr. Alex Champigny, E.I.T. who also supervised the drilling operations. Ms. Sandra McGaghran, M.Eng., P.Eng., a geotechnical engineer and Associate with Golder reviewed the report and Mr. Mark Telesnicki, P.Eng. a rock mechanics engineer and Principal with Golder provided Technical Input. Ms. Lisa Coyne, P.Eng., Golder's Designated MTO Foundation Contact for this project and Principal with Golder, conducted an independent technical and quality control review of the report.

GOLDER ASSOCIATES LTD.

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Lisa Coyne, P.Eng.
Principal, Designated MTO Foundations Contact

SMM/BL/MJT/LCC/sm

https://golderassociates.sharepoint.com/sites/12086g/shared documents/06 - deliverables/fnds/5 - final fidr/1668652 final fidr 2018apr19 thorold tunnel.docx

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

International Society for Rock Mechanics Commission on Test Methods, 1985. Int. J. Rock Mech. Min. Sci. & Geomech. Abstr. Vol 22, No. 2, pp. 51-60

ASTM International:

ASTM D1586 Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils

ASTM D4630-96 (2008) Standard Test Method for Determining Transmissivity and Storage Coefficient of Low-Permeability Rocks by In Situ Measurements Using the Constant Head Injection Test

ASTM D7012 Standard Test Method for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Ontario Water Resources Act:

Ontario Regulation 903 Wells (as amended)

Ontario Occupational Health and Safety Act:

Ontario Regulation 213/91 Construction Projects (as amended)

METRIC

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

CONT No. 2018–2007
GWP No. 2370–15–00

SHEET

HIGHWAY 58

THOROLD TUNNEL

BOREHOLE LOCATIONS AND SOIL STRATA

Golder Associates

LINETYPES LEGEND

- Limit of Excavation in Soil for Tunnel Construction
- MTO Right–of–Way
- Limits of Rock Excavation for Tunnel Construction
- Inner Concrete Tunnel Walls
- Approximate Ground Surface (Plate A2, Acres 1964)
- Road Surface Profile Along Tunnel

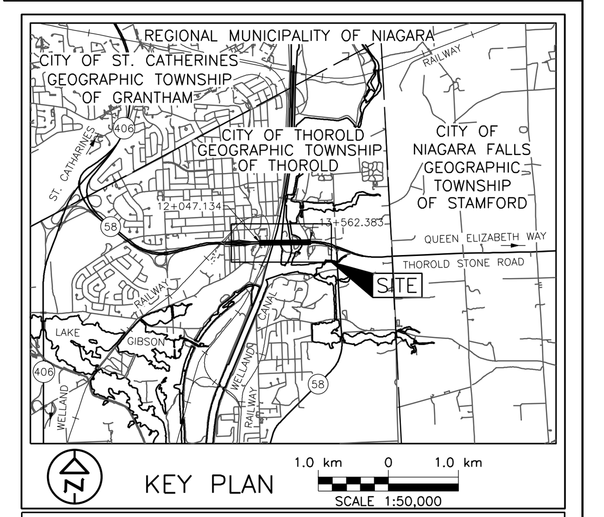
BOREHOLE CO–ORDINATES			
No.	ELEVATION	NORTHING	EASTING
1006	178.4	4775219.0	329418.8
1007	174.3	4775160.7	329512.5
1009	178.5	4775135.8	329335.8
1010	178.7	4775191.9	329306.2
1011	178.8	4775199.3	329304.7
1012	180.5	4775150.3	329262.5
1013	177.0	4775137.2	329170.2
1014	179.6	4775149.1	329719.3
1015	178.5	4775164.1	329854.0
1016	177.1	4775122.0	330049.6
1017	177.5	4775105.7	329942.5
1018	176.9	4775133.4	330147.7
1023	178.8	4775157.3	329937.5
1024	179.2	4775135.6	329385.6
1025	174.4	4775156.7	329501.4
1026	178.2	4775153.0	329855.4
1027	174.4	4775116.7	329485.8
1028	177.6	4775112.8	329853.6
1029	178.9	4775087.3	329285.6
1037	179.0	4775137.3	329297.1
1045	177.0	4775117.1	329187.7
1046	177.2	4775178.3	329196.2
GT17–01	178.7	4775177.9	329361.1

NOTES

1. The boreholes locations as provided on Plate A1 in Appendix A of the Thorold Tunnel Feasibility Report were plotted using available imagery of the site and the borehole coordinates were interpreted from the coordinate system superimposed on the imagery. The boreholes locations and northing and easting are therefore approximate.
2. BH1025 to BH1028 are not shown as they are not consistent with stratigraphy in adjacent boreholes nor as shown on plates A2 and A3 in Appendix A in Thorold Tunnel Feasibility Report, October 1964, H.G. Acres and Company Limited.
3. The ground surface elevations as depicted on this drawing have been adjusted from the SLSA datum to be consistent with Geodetic datum. This adjustment is −0.35 m relative to the SLSA datum as referenced on the Borehole Records from the Acres 1964 report.

REFERENCE

1. D.H.O Thorold Tunnel Feasibility Report Appendix A, prepared by H.G. Acres and Company Limited, dated October 1964, GEOCRES 30M–153
2. Road labels – MNRF LIO, obtained 2017.
3. Imagery – Region of Niagara, 2013.
4. Base plan, key plan and road surface in profile obtained from Morrison Hershfield, drawing file no. BC133581.dwg by Tulloch within file no. 2016–E–0001 Deliverables 2017–08–14.zip, downloaded August 15, 2017.



KEY PLAN

1.0 km 0 1.0 km
SCALE 1:50,000

LEGEND

- Borehole – Previous Investigation (Geocres No. 30M3–153)
- Borehole – Current Investigation
- Seal
- VWP Installation
- N — Standard Penetration Test Value
- 16 — Blows/0.3m unless otherwise stated (Std. Pen. Test, 475 j/blow)
- 100% — Rock Quality Designation (RQD)
- WL upon completion of drilling
- WL in piezometer, measured on February 01, 2018

STRATIGRAPHY LEGEND

- Fill
- Weathered Stratified Silty Clay Crust
- Relatively Unweathered Stratified Silty Clay
- Silty Till
- Limestone
- Shale

GENERAL 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.

LICENSED PROFESSIONAL ENGINEER — S. McGaghran — Mar. 07, 2018 — PROVINCE OF ONTARIO

LICENSED PROFESSIONAL ENGINEER — L.C. COYNE — Mar. 07, 2018 — PROVINCE OF ONTARIO

NO.	DATE	BY	REVISION
.	.	.	.

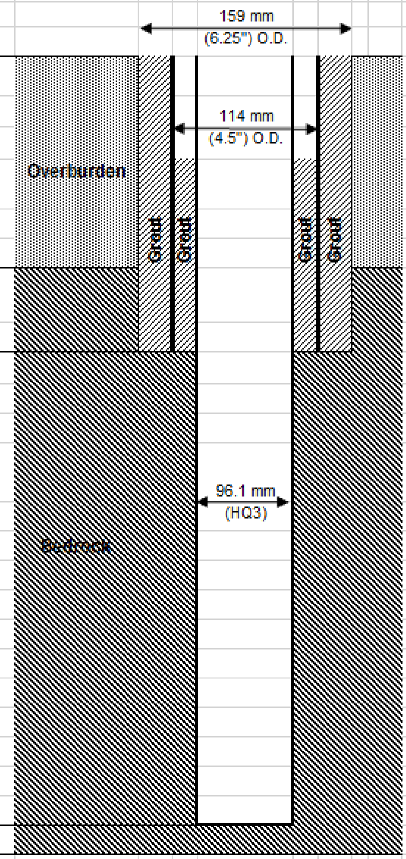
Geocres No. 30M3–302

HWY. 58		PROJECT NO. 1668652	DIST. CENTRAL
SUBM'D. KN	CHKD. DH	DATE: 2/27/2018	SITE: 34–177/T
DRAWN: MR	CHKD. SMM	APPD. LCC	DWG. 1

Borehole GT-17-01 Well Schematic

HWY 58 THOROLD TUNNEL

Geology	Depth below ground surface (m)	Notes
	0 m (Ground Surface)	Outer Borehole Size: outer diameter = 159 mm (6.25")
Overburden		Inner Casing: outer diameter = 114 mm (4.5")
		Grout was tagged at 6.7 m inside and was observed coming out to surface around the 114mm casing
	8 m (Top of Bedrock)	Casing was run in 7m into bedrock, minimum 2m competent, sound rock
Lockport and Decew Formation underlain by Clinton Group	13.97 m	Annulus between inner and outer casing grouted with HS Cement
		Borehole Size = 96.1 mm (HQ3) from top of rock to final depth
	36.2 (Final Depth)	**NOTE:** For complete details refer to the Supporting Document for pGT-17-01



Golder Associates

CLIENT
MTO

PROJECT
THOROLD TUNNEL
HIGHWAY 58
PARTIAL WALL GROUTING

TITLE
BOREHOLE SCHEMATIC FOR GT17-01

CONSULTANT
Golder Associates

YYYY-MM-DD	2018-03-23
DESIGNED	
PREPARED	DD/AS
REVIEWED	SMM
APPROVED	LCC

PROJECT NO.	CONTROL	REV.	FIGURE
1668652		A	1

APPENDIX A

Borehole and Drillhole Records

LIST OF SYMBOLS

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

I. GENERAL

π	3.1416
ln x,	natural logarithm of x
$\log_{10}$	x or log x, logarithm of x to base 10
g	acceleration due to gravity
t	time
FoS	factor of safety

II. STRESS AND STRAIN

γ	shear strain
Δ	change in, e.g. in stress: $\Delta\sigma$
ε	linear strain
ε_v	volumetric strain
η	coefficient of viscosity
υ	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 multiplied by acceleration due to gravity)

(a) Index Properties (continued)

w	water content
w_l or LL	liquid limit
w_p or PL	plastic limit
I_p or PI	plasticity index = ($w_l - w_p$)
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_α	secondary compression index
m_v	coefficient of volume change
c_v	coefficient of consolidation (vertical direction)
c_h	coefficient of consolidation (horizontal direction)
T_v	time factor (vertical direction)
U	degree of consolidation
σ'_p	pre-consolidation stress
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

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
DS	Denison type sample
FS	Foil sample
RC	Rock core
SC	Soil core
SS	Split-spoon
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, 60º 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) Non-Cohesive (Cohesionless) Soils

Compactness Condition	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	c_u, s_u 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.

V. MINOR SOIL CONSTITUENTS

Per cent by Weight	Modifier	Example
0 to 5	Trace	Trace sand
5 to 12	Trace to Some (or Little)	Trace to some sand
12 to 20	Some	Some sand
20 to 30	(ey) or (y)	Sandy
over 30	And (non-cohesive (cohesionless)) or	Sand and Gravel
	With (cohesive)	Silty Clay with sand / Clayey Silt with sand

WEATHERINGS 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 and structure are preserved.

BEDDING THICKNESS

Description	Bedding Plane Spacing
Very thickly bedded	Greater than 2 m
Thickly bedded	0.6 m to 2 m
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	Less than 6 mm

JOINT OR FOLIATION SPACING

Description	Spacing
Very wide	Greater than 3 m
Wide	1 m to 3 m
Moderately close	0.3 m to 1 m
Close	50 mm to 300 mm
Very close	Less than 50 mm

GRAIN SIZE

Term	Size*
Very Coarse Grained	Greater than 60 mm
Coarse Grained	2 mm to 60 mm
Medium Grained	60 microns to 2 mm
Fine Grained	2 microns to 60 microns
Very Fine Grained	Less than 2 microns

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

CORE CONDITION

Total Core Recovery (TCR)

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 varied 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 Core Axis

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

Description and Notes

An abbreviation 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

JN	Joint	PL	Planar
FLT	Fault	CU	Curved
SH	Shear	UN	Undulating
VN	Vein	IR	Irregular
FR	Fracture	K	Slickensided
SY	Stylolite	PO	Polished
BD	Bedding	SM	Smooth
FO	Foliation	SR	Slightly Rough
CO	Contact	RO	Rough
AXJ	Axial Joint	VR	Very Rough
KV	Karstic Void		
MB	Mechanical Break		

GOLDER

Foundation Design

RECORD OF BOREHOLE No GT17-01

SHEET 1 OF 3 **METRIC**

PROJECT 1668652

G.W.P. 2370-16-00 LOCATION N 4775177.9; E 329361.1 MTM NAD ZONE 10 (LAT. 43.116049; LONG. -79.198193) ORIGINATED BY AC

DIST Central HWY 58 BOREHOLE TYPE CME 75 - 210 mm O.D Hollow Stem Augers COMPILED BY AC

DATUM Geodetic DATE October 17 to November 7, 2017 CHECKED BY SMM

ELEV / DEPTH	SOIL PROFILE DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	WATER CONTENT (%)	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
178.7	GROUND SURFACE					
0.0	Gravelly sand (FILL)	1A	SS	12		
0.2	Silty clay (FILL), Compact, Brown, Moist	1B			Plastic limit – liquid limit plotted	2 11 48 39
178.0 / 0.7	Silty clay, trace to some sand, trace gravel (FILL), Stiff, Brown, Moist	2	SS	13		
177.3 / 1.5	Gravelly sand (FILL), Compact, Brown, Moist	3	SS	17		
176.5 / 2.2	Silty clay, trace to some sand and gravel (FILL), Very stiff, Brown, Moist	4	SS	50/0.08		
	Sandy gravel, trace to some silt, trace clay (FILL), Compact to very dense, Brown, Moist	5	SS	14		
		6	SS	91/0.18		
		7	SS	47	~7	66 23 9 2
		8	SS	17		
171.6 / 7.1	AUGER REFUSAL DOLOSTONE (BEDROCK) (Goat Island Member, Lockport Formation) Bedrock cored from a depth of 7.1 m to 36.2 m. For bedrock coring details refer to Record of Drillhole GT17-01.	1	HQ	REC 100%		RQD = 100%
		2	HQ	REC 96%		RQD = 96%
		3	HQ	REC 100%		RQD = 97%
		4	HQ	REC 100%		RQD = 94%
		5	HQ	REC 100%		RQD = 100%
		6	HQ	REC 100%		RQD = 100%
		7	HQ	REC 100%		RQD = 100%

Elevation scale: 178, 177, 176, 175, 174, 173, 172, 171, 170, 169, 168, 167, 166, 165, 164. Groundwater level symbol shown at approx. elevation 166.8.

DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100; SHEAR STRENGTH kPa: ○ 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

Continued Next Page

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

RECORD OF BOREHOLE No GT17-01

SHEET 2 OF 3

METRIC

PROJECT 1668652

G.W.P. 2370-16-00

LOCATION N 4775177.9; E 329361.1 MTM NAD ZONE 10 (LAT. 43.116049; LONG. -79.198193)

ORIGINATED BY AC

DIST Central HWY 58

BOREHOLE TYPE CME 75 - 210 mm O.D Hollow Stem Augers

COMPILED BY AC

DATUM Geodetic

DATE October 17 to November 7, 2017

CHECKED BY SMM

--- CONTINUED FROM PREVIOUS PAGE ---

ELEV DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	REMARKS & GRAIN SIZE DISTRIBUTION (%)
		7	HQ	REC 100%	RQD = 100%
163.0 15.8	DOLOSTONE (BEDROCK) with shale partings (Gasport Member, Lockport Formation)	8	HQ	REC 100%	RQD = 100%
		9	HQ	REC 100%	RQD = 100%
		10	HQ	REC 100%	RQD = 98%
		11	HQ	REC 100%	RQD = 100%
156.6 22.1	DOLOSTONE (BEDROCK) (Decew Formation)	12	HQ	REC 100%	RQD = 100%
		13	HQ	REC 100%	RQD = 94%
		14	HQ	REC 100%	RQD = 100%
153.0 25.7	SHALE (BEDROCK) (Rochester Formation)	15	HQ	REC 100%	RQD = 100%
		16	HQ	REC 100%	RQD = 100%
		17	HQ	REC 100%	RQD = 100%
		18	HQ	REC 100%	RQD = 100%

Elevation scale: 163, 162, 161, 160, 159, 158, 157, 156, 155, 154, 153, 152, 151, 150, 149

Column headings: SOIL PROFILE; STRAT PLOT; SAMPLES; GROUND WATER CONDITIONS; ELEVATION SCALE; DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100; SHEAR STRENGTH kPa ○ 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; GR SA SI CL

Continued Next Page

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

GOLDER

RECORD OF BOREHOLE No GT17-01

SHEET 3 OF 3 **METRIC**

PROJECT 1668652

G.W.P. 2370-16-00

DIST Central HWY 58

DATUM Geodetic

LOCATION N 4775177.9; E 329361.1 MTM NAD ZONE 10 (LAT. 43.116049; LONG. -79.198193)

BOREHOLE TYPE CME 75 - 210 mm O.D Hollow Stem Augers

DATE October 17 to November 7, 2017

ORIGINATED BY AC

COMPILED BY AC

CHECKED BY SMM

ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	REMARKS & GRAIN SIZE DISTRIBUTION (%)
	--- CONTINUED FROM PREVIOUS PAGE ---							
	SHALE (BEDROCK) (Rochester Formation)		18	HQ	REC 100%		148	RQD = 100%
			19	HQ	REC 100%		147	RQD = 97%
			20	HQ	REC 100%		146	RQD = 100%
							145	
			21	HQ	REC 100%		144	RQD = 100%
			22	HQ	REC 100%		143	RQD = 100%
142.5 36.2	END OF BOREHOLE							

Column headings: DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100; SHEAR STRENGTH kPa ○ 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; GR SA SI CL

NOTES:

1. For groundwater observations see page 4 of Record of Drillhole GT17-01.

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

RECORD OF DRILLHOLE: GT17-01

PROJECT: 1668652
LOCATION: N 4775177.9 ;E 329361.1
INCLINATION: -90° AZIMUTH: ---
DRILLING DATE: October 17 to November 7, 2017
DRILL RIG: CME 75
DRILLING CONTRACTOR: Aardvark
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	DRILLING RECORD	DESCRIPTION	ELEV. / DEPTH (m)	RUN No.	TYPE AND SURFACE DESCRIPTION	Jr	Ja	NOTES WATER LEVELS INSTRUMENTATION
		Continued from Record of Borehole GT 17-01	171.59					
	HQ3 Coring	Fresh, medium bedded, grey, fine to medium grained, slightly porous, strong DOLOSTONE [Goat Island]	7.09	1	BD,IR,RO	3	3	
					BD,IR,RO	3	3	
8				2	BD,IR,RO	3	3	
					BD,IR,RO	3	1	
					BD,IR,RO	3	1	
9								
				3	BD,IR,RO	3	1	November 1, 2017
					BD,IR,RO	3	1	
10					BD,IR,RO Ca	3	4	October 30, 2017
					JN,UN,RO	3	1	
					BD,UN,RO	3	3	October 31, 2017 Grout
					BD,IR,RO Cl	3	3	October 25, 2017
11				4	BD,CU,RO	3	2	
					BD,IR,SM	2	1	October 16, 2017
					BD,PL,SM	1	3	October 20, 2017
12					BD,UN,SM	2	3	January 2, 2018
				5	BD,UN,RO Cl	3	4	January 2, 2018
13								
					BD,UN,RO Cl	3	4	
14				6				
				7	BD,UN,RO	3	1	
15								Bentonite pelle
			162.93 / 15.75	8				
16								

CONTINUED NEXT PAGE

FEATURES LEGEND

BROKEN CORE | CLAY SEAM | LIMESTONE | LOST CORE

DEPTH SCALE 1 : 50

GOLDER

LOGGED: AC
CHECKED: MT

LOCATION: N 4775177.9 ;E 329361.1
DRILLING DATE: October 17 to November 7, 2017
DATUM: Geodetic
INCLINATION: -90° AZIMUTH: ---
DRILL RIG: CME 75
DRILLING CONTRACTOR: Aardvark

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.

DRILLING RECORD: HQ3 Coring

--- CONTINUED FROM PREVIOUS PAGE ---

DEPTH SCALE METRES	DESCRIPTION	ELEV. DEPTH (m)	RUN No.	DISCONTINUITY DATA TYPE AND SURFACE DESCRIPTION	Jr	Ja	NOTES WATER LEVELS INSTRUMENTATION
	Fresh, thickly bedded, grey, fine grained, moderatly porous, medium strong DOLOSTONE with shale partings [Gasport]						Sand and Vibrating Wire Piezo at 16.09 m
			8	BD,PL,SM	1	1	
				BD,PL,SM	1	1	
17				BD,UN,SM	2	1	
18			9				
				BD,UN,SM	2	1	
19				BD,PL,RO	1.5	1	
			10				Bentonite pelle
20				BD,PL,SM	1	1	
				BD,IR,SM	2	1	
21			11				
				BD,UN,RO	3	4	
22		156.56 22.12					
	Fresh, thickly bedded, grey, fine grained, slightly porous, strong DOLOSTONE [Decew Formation]		12	BD,CU,RO	3	1	
23							Sand and Vibrating Wire Piezo at 23.22 m
							Bentonite pelle
24			13				
				BD,UN,VR Ca	3	3	Sand
				BD,UN,RO Ca	3	3	
25			14				

CONTINUED NEXT PAGE

FEATURES LEGEND

BROKEN CORE | CLAY SEAM | LIMESTONE | LOST CORE

PROJECT: 1668652

RECORD OF DRILLHOLE: GT17-01

LOCATION: N 4775177.9 ;E 329361.1

INCLINATION: -90° AZIMUTH: ---

DRILLING DATE: October 17 to November 7, 2017

DRILL RIG: CME 75

DRILLING CONTRACTOR: Aardvark

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.

Columns: DEPTH SCALE METRES | DRILLING RECORD | DESCRIPTION | SYMBOLIC LOG | ELEV. DEPTH (m) | RUN No. | RECOVERY (TOTAL CORE %, SOLID CORE %) 80 60 40 20 | R.Q.D. % 80 60 40 20 | FRACT. INDEX PER Meter 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; Jr; Ja) | ROCK STRENGTH INDEX R4 R3 R2 R1 | WEATHERING INDEX W1 W2 W3 W4 W5 W6 | FEATURES | R0/R1 ZONES | NOTES WATER LEVELS INSTRUMENTATION

--- CONTINUED FROM PREVIOUS PAGE ---

Drilling record: HQ3 Coring

Elev. / Depth (m)	Description
	Fresh, thickly bedded, grey, fine grained, slightly porous, strong DOLOSTONE [Decew Formation]
153.02 / 25.66	Fresh, thickly bedded, grey to black, fine grained, slightly porous, medium strong SHALE with frequent DOLOSTONE partings [Rochester Formation]

Run Nos.: 14, 15, 16, 17, 18, 19, 20, 21

Depth scale: 26, 27, 28, 29, 30, 31, 32, 33, 34

Approx. Depth (m)	Type and Surface Description	Jr	Ja
25.1	BD,UN,RO	3	1
25.5	BD,CU,RO	3	1
26.5	BD,UN,RO	3	1
31.0	BD,UN,SM Ca	2	3
31.3	BD,UN,SM Ca	2	3
31.4	BD,UN,SM	2	1
32.2	BD,UN,SM Ca	2	3
32.9	BD,UN,SM Ca	2	3
33.1	BD,UN,SM	2	1

Notes: Sand

CONTINUED NEXT PAGE

FEATURES LEGEND

BROKEN CORE | CLAY SEAM | LIMESTONE | LOST CORE

DEPTH SCALE
1 : 50

GOLDER

LOGGED: AC
CHECKED: MT

PROJECT: 1668652

RECORD OF DRILLHOLE: GT17-01

LOCATION: N 4775177.9 ;E 329361.1

DRILLING DATE: October 17 to November 7, 2017

DATUM: Geodetic

DRILL RIG: CME 75

INCLINATION: -90° AZIMUTH: ---

DRILLING CONTRACTOR: Aardvark

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	DRILLING RECORD	DESCRIPTION	ELEV. DEPTH (m)	RUN No.	ROCK STRENGTH INDEX	WEATHERING INDEX	NOTES WATER LEVELS INSTRUMENTATION
		--- CONTINUED FROM PREVIOUS PAGE ---					
35–36	HQ3 Coring	Fresh, thickly bedded, grey to black, fine grained, slightly porous, medium strong SHALE with frequent DOLOSTONE partings [Rochester Formation]	142.50 36.18	21, 22			Sand
		END OF DRILLHOLE					

Columns also printed: SYMBOLIC LOG; RECOVERY (TOTAL CORE %, SOLID CORE %); R.Q.D. %; FRACT. INDEX PER Meter; DISCONTINUITY DATA (B Angle, DIP w.r.t. CORE AXIS, TYPE AND SURFACE DESCRIPTION, Jr, Ja); FEATURES; R0/R1 ZONES.

NOTE:

1. Groundwater observations:

Date	Depth (m)	Elev. (m)
10/19/17	11.5	167.2
10/25/17	10.7	168.0
10/30/17	10.1	168.6
10/31/17	10.5	168.2
11/01/17	9.8	168.9

2. Water level in vibrating wire piezometers (VWP):

VWP tip at Elev 162.6 m

Date	Depth (m)	Elev. (m)
02/01/18	12.6	166.1

VWP tip at Elev 155.5 m

Date	Depth (m)	Elev. (m)
02/01/18	12.0	166.7

Depth scale: 35, 36, 37, 38, 39, 40, 41, 42, 43

FEATURES LEGEND

BROKEN CORE | CLAY SEAM | LIMESTONE | LOST CORE

DEPTH SCALE 1 : 50

GOLDER

LOGGED: AC
CHECKED: MT

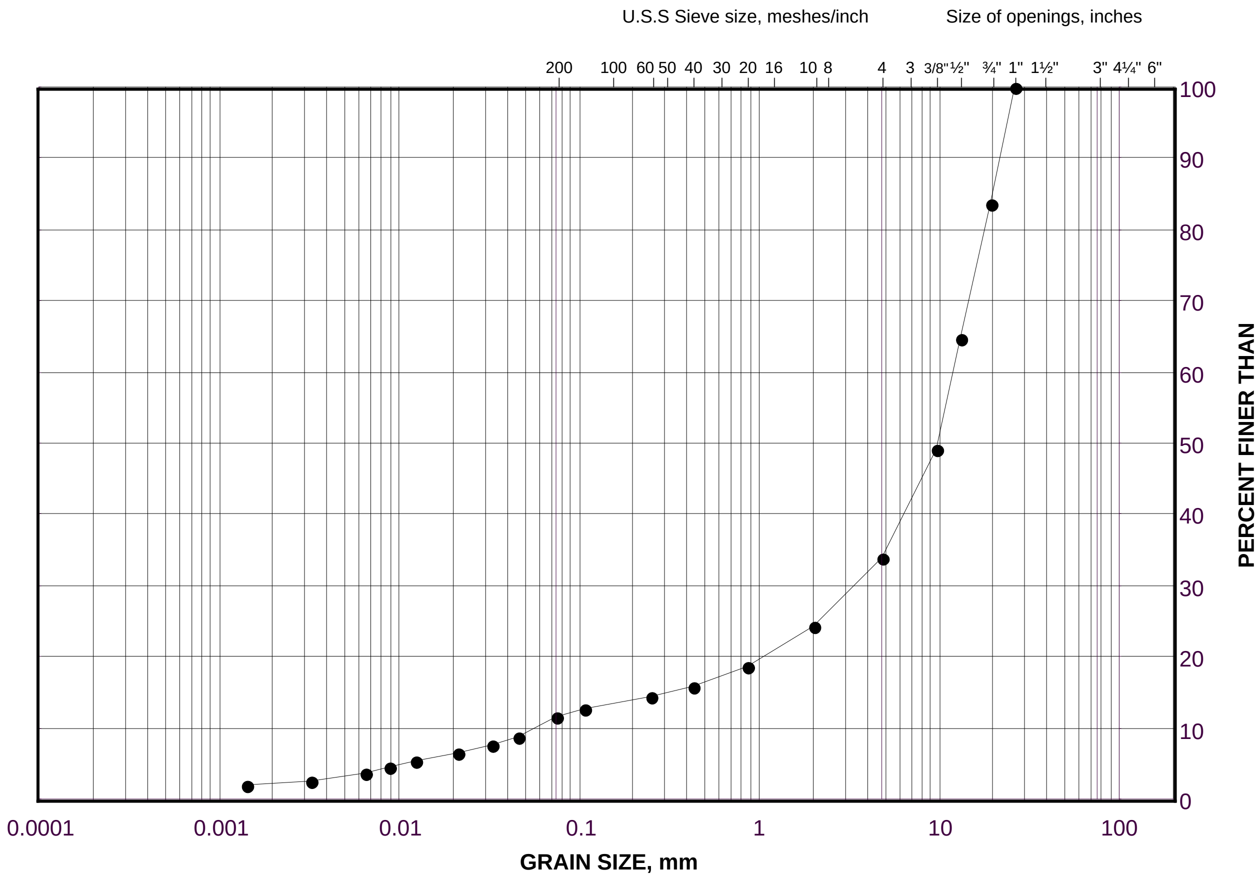
APPENDIX B

Geotechnical Laboratory Test Results

GRAIN SIZE DISTRIBUTION

Sandy Gravel Fill

FIGURE B1



SILT AND CLAY SIZES	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED	SAND SIZE			GRAVEL SIZE		SIZE

LEGEND

SYMBOL	Borehole	SAMPLE	ELEVATION(m)
●	GT17-01	7	173.8

Project Number: 1668652

Checked By: SMM

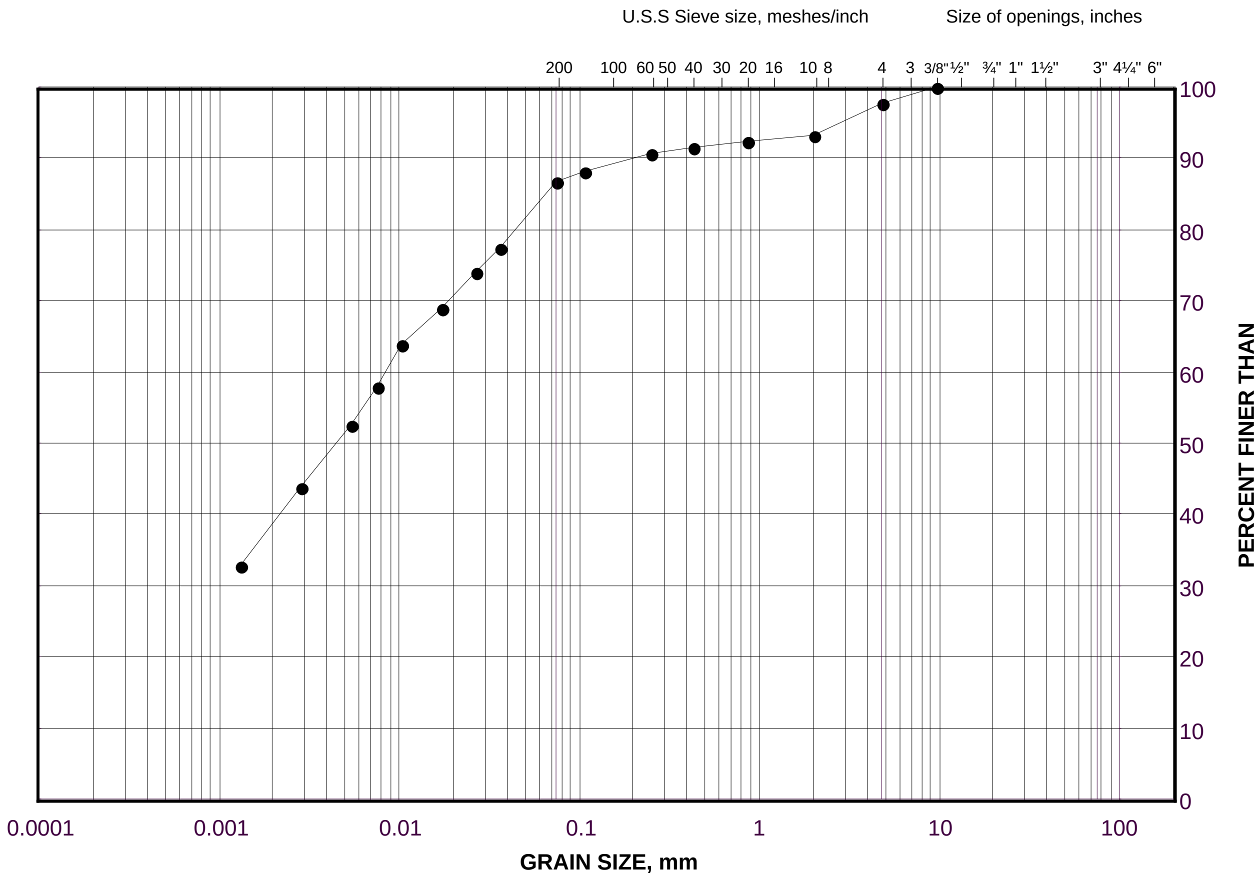
Golder Associates

Date: 21-Feb-18

GRAIN SIZE DISTRIBUTION

Silty Clay Fill

FIGURE B2



SILT AND CLAY SIZES	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED	**SAND SIZE**			**GRAVEL SIZE**		**SIZE**

LEGEND

SYMBOL	Borehole	SAMPLE	ELEVATION(m)
●	GT17-01	1B	178.4

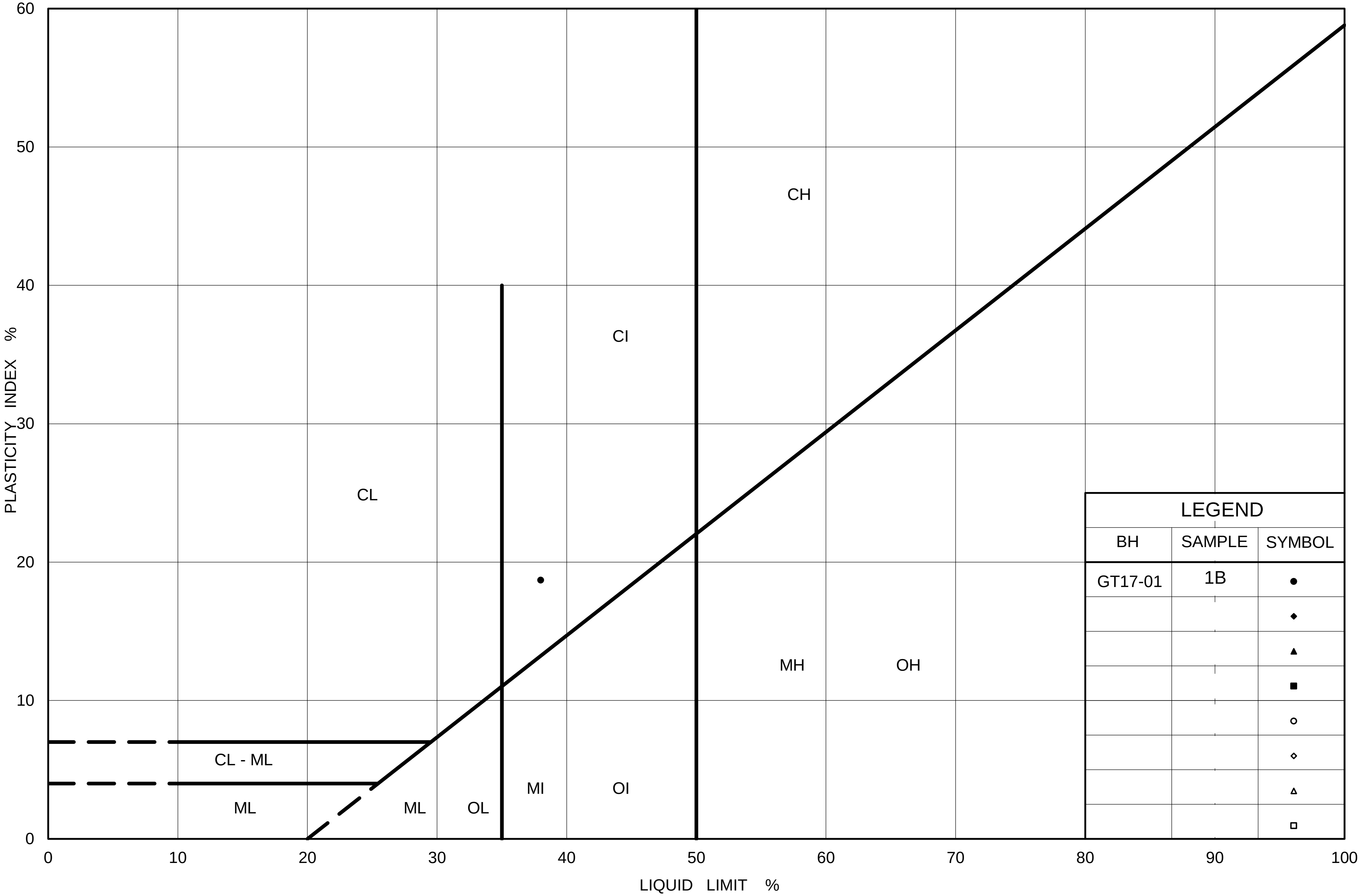
Project Number: 1668652

Checked By: SMM

Golder Associates

Date: 21-Feb-18

Oct 75, FF-S-21



Ministry of Transportation

Ontario

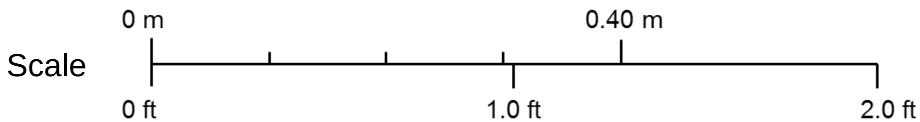
PLASTICITY CHART
Silty Clay Fill

Figure No. B3

Project No. 1668652

Checked By: SMM

Box 1-3: 7.09 m to 13.97 m



PROJECT	Thorold Highway 58 Tunnel Improvements				
TITLE	Bedrock Core Photographs Borehole GT17-01 (7.09 m to 13.97 m)				
PROJECT No. 1668652			FILE No. ----		
DESIGN	AC	171117	SCALE	NTS	REV.
CADD	--		FIGURE B4- A		
CHECK	SMM	20170208			
REVIEW		20170208			

Golder Associates

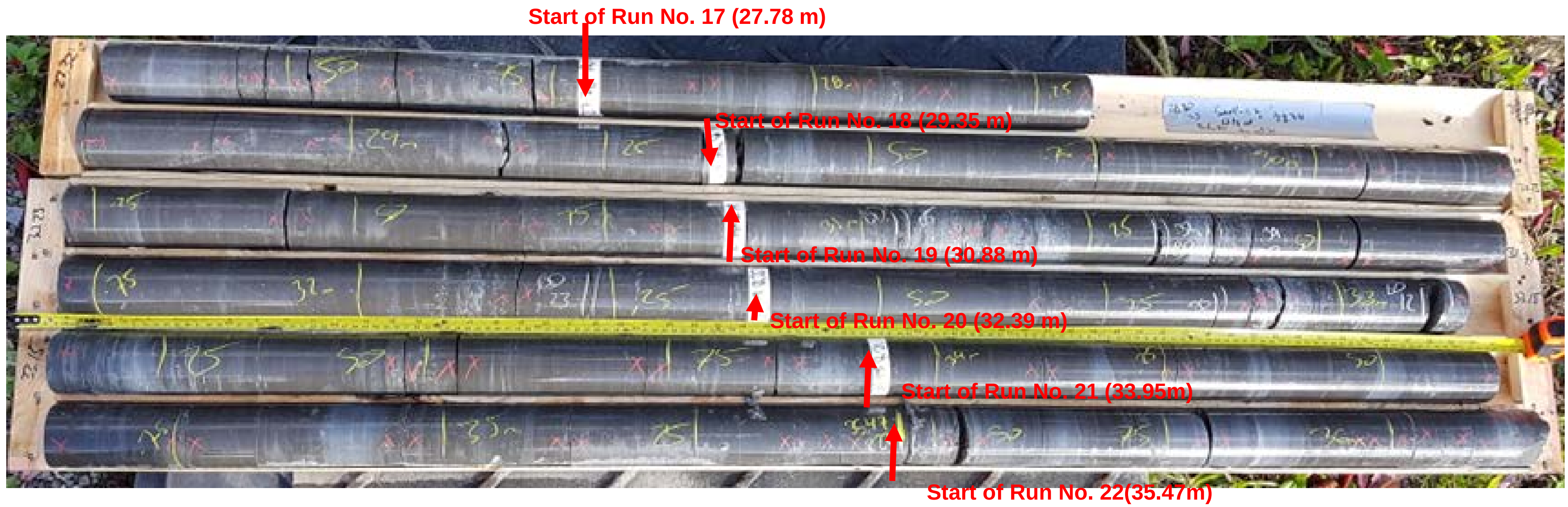
REVISION DATE November 17, 2017 BY: AC Project: 1668652

Box 4-8: 13.97 m to 27.32 m

Scale: 0 m — 0.40 m; 0 ft — 1.0 ft — 2.0 ft

PROJECT	**Thorold Highway 58 Tunnel Improvements**				
TITLE	**Bedrock Core Photographs Borehole GT17-01 (13.97 m to 27.32 m)**				
Golder Associates	PROJECT No. 1668652			FILE No. ----	
	DESIGN	AC	171117	SCALE NTS	REV.
	CADD	--		**FIGURE B4- B**	
	CHECK	SMM	20170208		
	REVIEW		20170208		

REVISION DATE November 17, 2017 BY: AC Project: 1668652



Box 9-11: 27.32 m to 36.18 m

Scale: 0 m — 0.40 m; 0 ft — 1.0 ft — 2.0 ft

PROJECT	**Thorold Highway 58 Tunnel Improvements**				
TITLE	**Bedrock Core Photographs Borehole GT17-01 (27.32 m to 36.18 m)**				
Golder Associates	PROJECT No. 1668652			FILE No. ----	
	DESIGN	AC	171117	SCALE NTS	REV.
	CADD	--		**FIGURE B4- C**	
	CHECK	SMM	20170208		
	REVIEW		20170208		

REVISION DATE November 17, 2017 BY: AC Project: 1668652

Golder Associates

UNCONFINED COMPRESSION TEST (UC) OF INTACT ROCK CORE SPECIMENS

ASTM D7012

SAMPLE IDENTIFICATION

PROJECT NUMBER	1668652 (1008)	SAMPLE NUMBER	SA-1-1
PROJECT NAME	MTO/2016-E-0001/Thorold Tunnel	SAMPLE DEPTH, m	8.64-8.87
BOREHOLE NUMBER	GT17-01	DATE:	2018-01-17

TEST CONDITIONS

MACHINE SPEED, mm/min	N/A	TYPE OF SPECIMEN	Rock Core
DURATION OF TEST,min	>2 <15	L/D	2.43

SPECIMEN INFORMATION

SAMPLE HEIGHT, cm	14.81	WATER CONTENT, (specimen) %	0.30
SAMPLE DIAMETER, cm	6.10	UNIT WEIGHT, kN/m^3	26.78
SAMPLE AREA, cm^2	29.18	DRY UNIT WT., kN/m^3	26.70
SAMPLE VOLUME, cm^3	432.02	SPECIFIC GRAVITY	-
WET WEIGHT, g	1180.12	VOID RATIO	-
DRY WEIGHT, g	1176.59		

VISUAL INSPECTION

FAILURE SKETCH

TEST RESULTS

STRAIN AT FAILURE, %	N/A	COMPRESSIVE STRENGTH, MPa	101.4

REMARKS:

Checked By: SMM

Golder Associates

UNCONFINED COMPRESSION TEST (UC) OF INTACT ROCK CORE SPECIMENS ASTM D7012	FIGURE B5 Sheet 2 of 2

BEFORE COMPRESSION

AFTER COMPRESSION

Date Jan. 17, 2018
Project 1668652/1008

Golder Associates

Drawn Frank
Chkd. SMM

Golder Associates

UNCONFINED COMPRESSION TEST (UC) OF INTACT ROCK CORE SPECIMENS

ASTM D7012

SAMPLE IDENTIFICATION

PROJECT NUMBER	1668652 (1008)	SAMPLE NUMBER	SA-1-4
PROJECT NAME	MTO/2016-E-0001/Thorold Tunnel	SAMPLE DEPTH, m	11.78-12.07
BOREHOLE NUMBER	GT17-01	DATE:	2018-01-17

TEST CONDITIONS

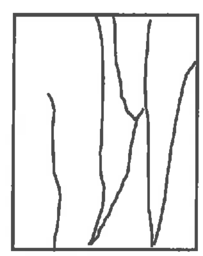
MACHINE SPEED, mm/min	N/A	TYPE OF SPECIMEN	Rock Core
DURATION OF TEST,min	>2 <15	L/D	2.49

SPECIMEN INFORMATION

SAMPLE HEIGHT, cm	15.20	WATER CONTENT, (specimen) %	0.60
SAMPLE DIAMETER, cm	6.10	UNIT WEIGHT, kN/m^3	26.63
SAMPLE AREA, cm^2	29.19	DRY UNIT WT., kN/m^3	26.47
SAMPLE VOLUME, cm^3	443.72	SPECIFIC GRAVITY	-
WET WEIGHT, g	1205.41	VOID RATIO	-
DRY WEIGHT, g	1198.22		

VISUAL INSPECTION

FAILURE SKETCH



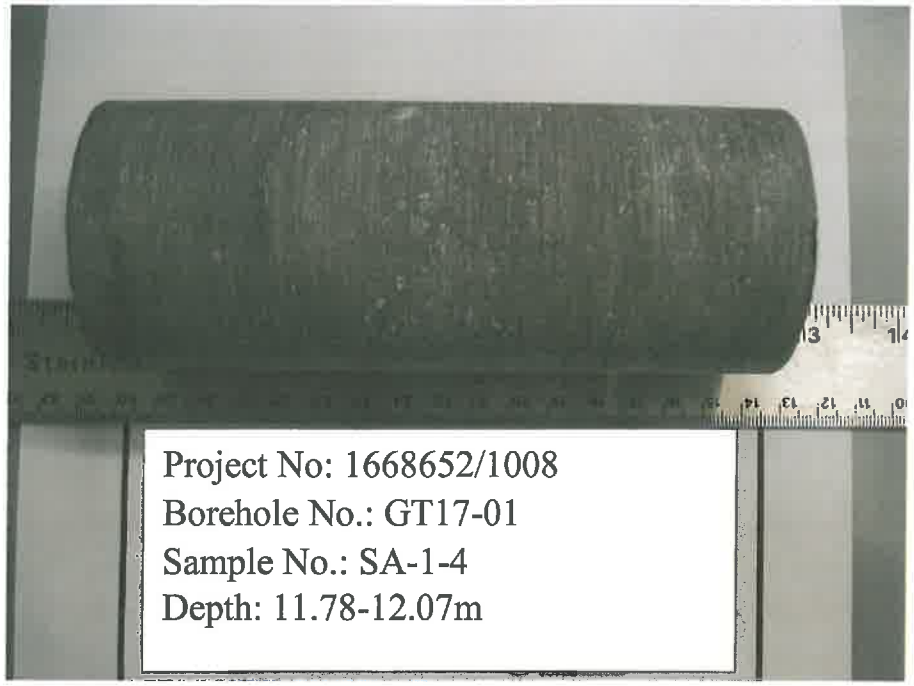
TEST RESULTS

STRAIN AT FAILURE, %	N/A	COMPRESSIVE STRENGTH, MPa	70.9

REMARKS:

Checked By: SMM

UNCONFINED COMPRESSION TEST (UC) OF INTACT ROCK CORE SPECIMENS ASTM D7012	FIGURE B6 Sheet 2 of 2



BEFORE COMPRESSION

AFTER COMPRESSION

Date Jan. 17, 2018
Project 1668652/1008

Golder Associates

Drawn Frank
Chkd. SMM

K.Y. Lo Inc.

FACTUAL REPORT

Factual Results of Laboratory Swell Tests
on Rock Samples

Thorold Tunnel

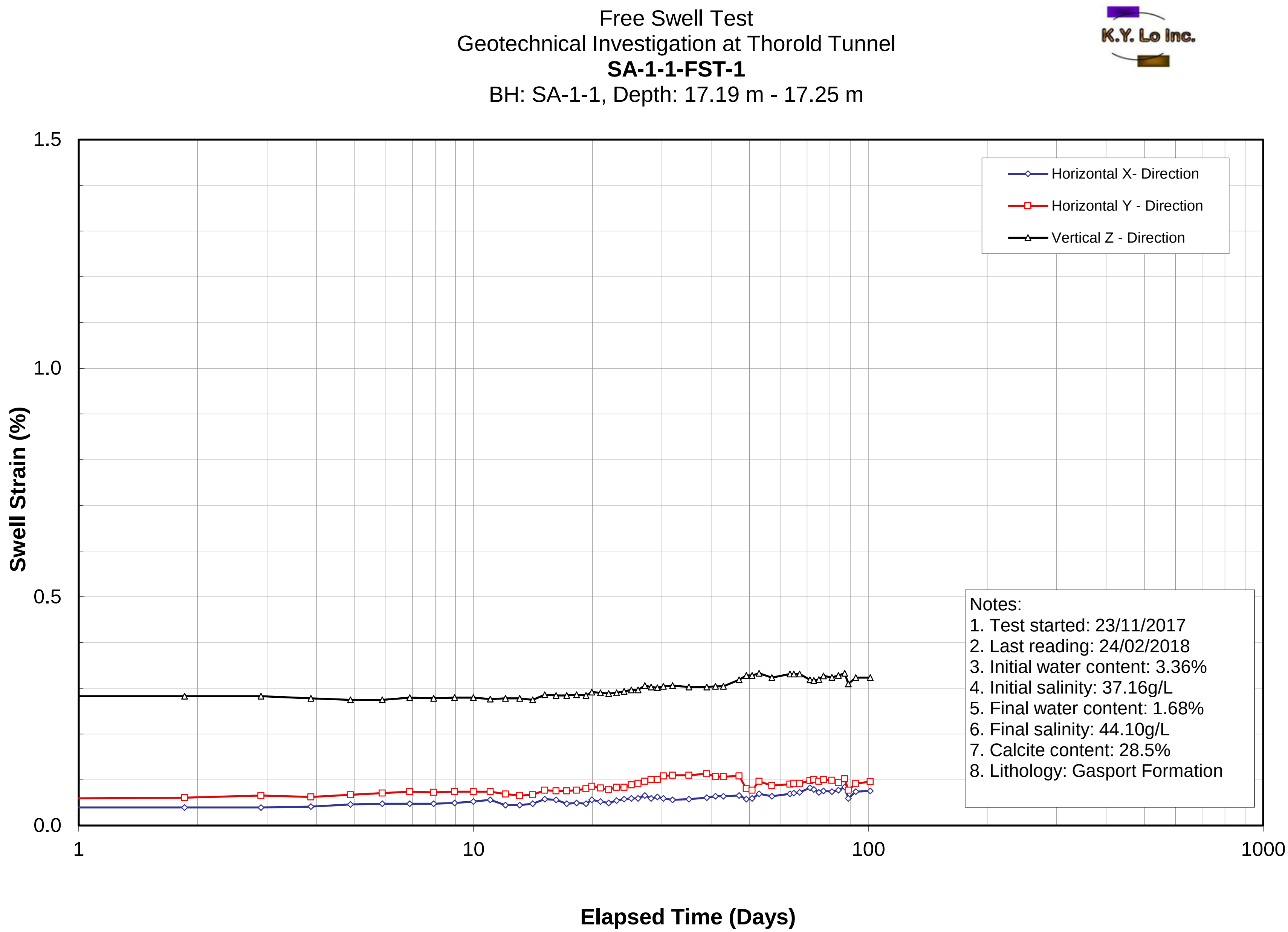
Prepared for:

Golder Associates Ltd.

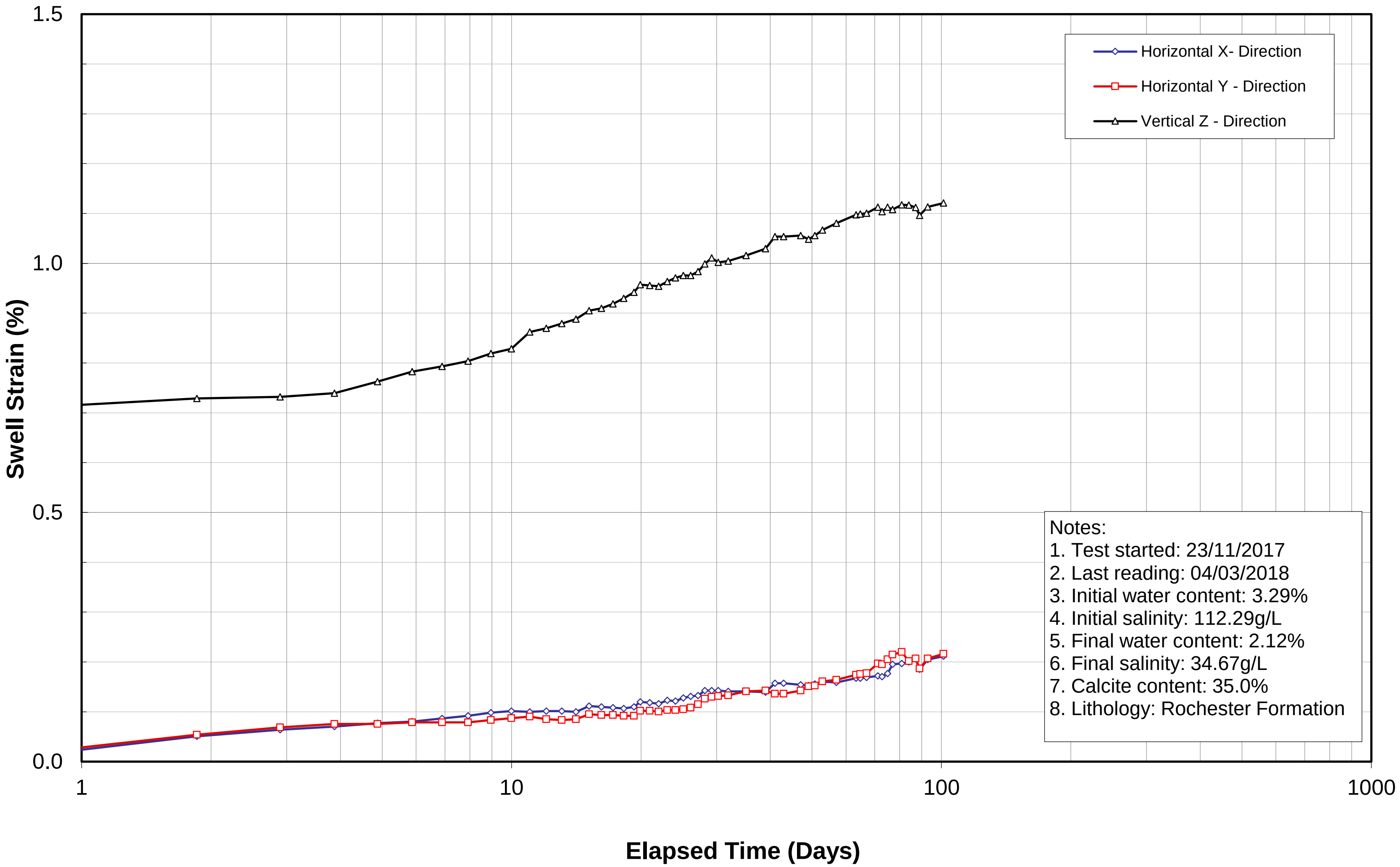
K. Y. Lo Inc.

March 9, 2018

Free Swell Test
Geotechnical Investigation at Thorold Tunnel
SA-1-1-FST-1
BH: SA-1-1, Depth: 17.19 m - 17.25 m



Free Swell Test
Geotechnical Investigation at Thorold Tunnel
SA-1-2-FST-2
BH: SA-1-2, Depth: 28.33 m - 28.39 m



As a global, employee-owned organisation with over 50 years of experience, Golder Associates is driven by our purpose to engineer earth's development while preserving earth's integrity. We deliver solutions that help our clients achieve their sustainable development goals by providing a wide range of independent consulting, design and construction services in our specialist areas of earth, environment and energy.

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