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FOUNDATION INVESTIGATION AND DESIGN REPORT

Highway 400 Culvert 97 Rehabilitation Inlet End Gabion Basket Wall Barrie, Ontario G.W.P. 2184-10-00 Agreement No.: 4014-E-0012 Assignment No. 10

Submitted to:

Ministry of Transportation Ontario
Foundation Engineering Section
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REPORT





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HIGHWAY 400 CULVERT 97 GABION BASKET WALL**

PART A

**FOUNDATION INVESTIGATION REPORT
HIGHWAY 400 CULVERT 97 GABION BASKET WALL
BARRIE, ONTARIO
AGREEMENT NO. 4014-E-0012 – ASSIGNMENT NO. 10
G.W.P. 2184-10-00**



1.0 INTRODUCTION

Golder Associates Ltd. (Golder) has been retained by the Ministry of Transportation, Ontario (MTO) under MTO's Eastern Region Foundation Engineering Retainer (Agreement No. 4014-E-0012) to provide foundation engineering services for a proposed gabion basket retaining wall / head wall at the inlet (west side of the SBL embankment) of Culvert 97 crossing under Highway 400 at approximately Station 24+327, which is located approximately 920 m south of Maplevue Drive in the City of Barrie, Ontario. The general location of the culvert is shown on the Key Plan on Drawing 1.

The Terms of Reference and Scope of Work for the foundation investigation are outlined in MTO Work Item Form No. 10 of Agreement No. 4014-E-0012, which was sent to Golder via email on August 2, 2016 and the detailed scope of work is presented in Golder's Understanding of the Scope letter dated August 6, 2016. Authorization to proceed was received from MTO via an email on August 12, 2016.

2.0 SITE AND PROJECT DESCRIPTION

Culvert 97 crossing under Highway 400 is located at STA 24+327, approximately 920 m south of Maplevue Drive in the City of Barrie, Ontario. The existing culvert is oriented east to west, with the inlet on the west side of the highway embankment and the outlet on the east side of the embankment. The invert of the inlet and outlet of the existing culvert are at approximately Elevation 289 m and 288 m, respectively. The existing culvert is a 1220 x 900 mm reinforced concrete open footing culvert and is approximately 50 m in length. The Highway 400 road surface is at between approximately Elevation 293.4 m and 294 m sloping downward from west to east and the highway embankment is approximately 4.5 m high relative to the ground surface at the toe adjacent to the culvert.

3.0 INVESTIGATION PROCEDURES

The field work was carried out on September 26 and 27, 2016, during which time a total of two boreholes (Boreholes C97-1 and C97-2) were advanced on the west side of Highway 400: one borehole at the crest of the embankment through the Highway 400 southbound lane right shoulder; and one borehole near the inlet of Culvert 97 on the west side of the Highway 400 embankment. Boreholes C97-1 and C97-2 were advanced to depths of 11.1 m and 6.6 m below ground surface, respectively. The borehole locations are shown in plan on Drawing 1.

The borehole investigation was carried out using a D-50 track-mounted drill rig supplied and operated by Walker Drilling of Utopia, Ontario. The boreholes were advanced through the overburden using 210 mm outside diameter (O.D.) continuous flight hollow-stem augers. Soil samples were obtained at intervals of depth of about 0.75 m and 1.5 m, using a 50 mm outside diameter split-spoon sampler driven by an automatic hammer in accordance with Standard Penetration Test (SPT) procedures (ASTM D1586 – Standard Test Method for Standard Penetration Test).

The groundwater conditions were noted in open boreholes during and upon completion of drilling. All boreholes were backfilled to the ground surface upon completion of the drilling operations using bentonite pellets, in accordance with Ontario Regulation 903, as amended. The borehole located on the shoulder of Highway 400 was patched at the surface with cold mix asphalt.



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The field work for this investigation was observed by a member of our engineering staff who arranged for underground service locates, observed the drilling and sampling operations, and logged the boreholes. The soil samples were identified in the field, placed in appropriate containers, labelled and transported to Golder's Mississauga geotechnical laboratory where samples underwent further visual examination and laboratory testing including natural water content testing and selected classification testing (i.e. sieve and hydrometer and Atterberg limits).

The as-drilled boreholes were located in the field by Golder, relative to existing site features on the site plan and profile drawings titled "New Construction, STA 24+300 to STA 25+000", dated July 13, 2016, provided by MTO on August 2, 2016. The ground surface elevations and coordinates of the boreholes were obtained by Golder from a Global Positioning System (GPS). The borehole locations in MTM NAD83 Zone 17 northing and easting coordinates, the ground surface elevations referenced to Geodetic datum and the borehole drilled depths are summarized in the table below. The MTM NAD83 coordinates and ground surface elevations are also presented on the borehole records.

Borehole Number	Location (MTM NAD 83)		Ground Surface Elevation (m)	Borehole Depth (m)
	Northing (m)	Easting (m)		
C97-1	4909673.1	290209.8	293.3	11.1
C97-2	4909681.7	290198.2	290.8	6.6

4.0 SITE GEOLOGY AND SUBSURFACE CONDITIONS

4.1 Regional Geology

As delineated in *The Physiography of Southern Ontario*¹, this section of Highway 400 lies within the Peterborough Drumlin Field physiographic region which consists primarily of sandy till deposits and sand to sand and gravel deposits. Deposits of silt, clay or peat may also be found in the low-lying areas between drumlins and eskers.

4.2 Subsurface Conditions

The detailed subsurface soil and groundwater conditions encountered in the boreholes advanced as part of the investigation, together with the results of in situ and laboratory testing are presented on the Record of Borehole sheets and laboratory test summary figures provided in Appendices A and B, respectively. The results of the in situ field tests (i.e. SPT 'N'-values) as presented on the Record of Borehole sheets and in Section 4.2 are uncorrected.

The stratigraphic boundaries shown on the Record of Borehole sheets are inferred from observations of drilling progress and non-continuous sampling and, therefore, represent transitions between soil types rather than exact planes of geological change. The subsoil conditions will vary between and beyond the borehole locations.

¹ 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. Ontario Ministry of Natural Resources.



In general, the subsurface conditions on the west side of the Highway 400 southbound lanes at Culvert 97 consist of asphalt or topsoil underlain by gravelly sand and/or silty sand fill. The fill layers are underlain by a deposit of silty sand at one borehole location and by a deposit of silty clay. The silty clay deposit in turn is underlain by a deposit of sand. A detailed description of the subsurface conditions encountered in the boreholes is provided in the following sections.

4.2.1 Asphalt

A 230 mm thick layer of asphalt was encountered at ground surface in Borehole C97-1.

4.2.2 Topsoil

An approximately 100 mm thick layer of topsoil was encountered at ground surface of Borehole C97-2.

4.2.3 Gravelly Sand Fill

A 0.5 m thick layer of gravelly sand fill was encountered below the asphalt in Borehole C97-1 at a depth of 0.2 m below ground surface (Elevation 293.1 m). The gravelly sand fill contains some silt and trace clay.

One SPT 'N'-value of 16 blows per 0.3 m of penetration was measured within the gravelly sand fill layer, indicating a compact relative density.

4.2.4 Silty Sand Fill

A 3.7 m and 2.0 m thick deposit of silty sand fill was encountered below the gravelly sand fill deposit in Borehole C97-1 and below the topsoil in Borehole C97-2 at depths of 0.7 m and 0.1 m (Elevation 292.6 m and 290.7 m), respectively. The silty sand fill contains trace to some clay and trace gravel. Trace organics and pockets of clayey silt were noted to be present within the silty sand fill in Borehole C97-2.

The measured SPT "N"-values within the silty sand fill deposit range from 4 blows to 26 blows per 0.3 m of penetration indicating a loose to compact relative density.

The water content measured on two samples of the silty sand fill material were 8 per cent and 9 per cent.

The result of a grain size distribution test completed on one sample of the silty sand fill deposit is shown on Figure B1 in Appendix B.

4.2.5 Silty Sand containing organics

A deposit of silty sand containing trace organics, trace gravel and trace clay was encountered below the silty sand fill deposit in Borehole C97-1 at a depth of 4.4 m below ground surface (Elevation 288.9 m) and the deposit is 1.2 m thick.

One SPT 'N' value of 6 blows per 0.3 m of penetration was measured within the silty sand deposit, indicating a compact relative density.

4.2.6 Silty Clay

A 1.5 m and 2.2 m thick deposit of silty clay was encountered below the silty sand deposit in Borehole C97-1 and below the silty sand fill deposit in Borehole C97-2 at depths of 5.6 m and 2.1 m (Elevation 287.7 m and 288.7 m), respectively. The silty clay deposit contains trace sand and is laminated.



The measured SPT “N”-values within the silty clay deposit range from 12 blows to 39 blows per 0.3 m of penetration, suggesting a stiff to hard consistency.

The water content measured on three samples of the silty clay range from 22 per cent to 28 per cent.

Atterberg limits testing was carried out on two samples of the silty clay and measured liquid limits of 32 per cent and 38 per cent, plastic limits of 17 per cent and 18 per cent and plasticity indices of 15 per cent and 20 per cent. The test results, which are plotted on a plasticity chart on Figure B2 in Appendix B, indicate that the material is a silty clay of intermediate plasticity.

The result of a grain size distribution test completed on one sample of the silty clay deposit is shown on Figure B3 in Appendix B.

4.2.7 Sand

A deposit of sand was encountered below the silty clay deposit in Boreholes C97-1 and C97-2 at depths of 7.1 m and 4.3 m (Elevation 286.2 m and 286.5 m), respectively. Boreholes C97-1 and C97-2 were terminated within the sand deposit at depths of 11.1 m and 6.6 m (Elevation 282.2 m and 284.2 m) after penetrating 4.0 m and 2.3 m into the deposit, respectively. The sand deposit contains trace to some gravel, trace to some silt and trace clay.

The measured SPT “N”-values within the sand deposit range from 41 blows to 82 blows per 0.3 m of penetration, with on SPT “N”-value of 86 blows per 0.25 m of penetration, indicating a dense to very dense relative density.

The water content measured on three samples of sand ranges from 2 per cent to 3 per cent.

The result of a grain size distribution test completed on one sample of the sand deposit is shown on Figure B4 in Appendix B.

4.2.8 Groundwater Conditions

Boreholes C97-1 and C97-2 were noted to be dry upon completion of drilling, however, the base of the fill and silty sand containing organics material encountered in the boreholes was noted to be wet, which is attributed to ground water “perched” on the underlying, less permeable layers. The groundwater level at the site is expected to fluctuate seasonally in response to changes in precipitation and snow melt, and is expected to be higher during the spring and periods of precipitation.

5.0 CLOSURE

This Foundation Investigation Report was prepared by Ted Beadle and Al Varshoi from Golder Geotechnical Group. Jorge M. A. Costa, P.Eng., a Designated MTO Foundation Contact and Senior Consultant of Golder, conducted an independent quality review of the report.



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Report Signature Page

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TWB/ARV/JMAC/sm/arv

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PART B

**FOUNDATION DESIGN REPORT
HIGHWAY 400 CULVERT 97 GABION BASKET WALL
BARRIE, ONTARIO
AGREEMENT NO. 4014-E-0012 – ASSIGNMENT NO. 10
G.W.P. 2184-10-00**



6.0 DISCUSSION AND FOUNDATION ENGINEERING RECOMMENDATIONS

6.1 General

This section of the report provides discussion and foundation engineering recommendations for the proposed gabion basket retaining wall / head wall located on the west side of Highway 400 southbound lanes (SBL) at the inlet of Culvert 97 at Station 24+327. The proposed gabion basket wall is located approximately 920 m south of Maplevue Drive in the City of Barrie, Ontario. These recommendations are based on interpretation of the factual data obtained from the boreholes advanced during the investigation. The discussion and recommendations presented are intended to provide the designer with sufficient information to assess the feasible foundation alternatives and carry out the design of the culvert foundations. The foundation investigation report, discussion and recommendations are intended for the use of the Ministry of Transportation, Ontario (MTO) and shall not be used or relied upon for any other purpose or by any other parties, including the construction or design-build contractor. The contractor must make their own interpretation based on the factual data in Part A (Foundation Investigation) of the report. Where comments are made on construction, they are provided to highlight those aspects that could affect the design of the project and for which special provisions may be required in the Contract Documents. Those requiring information on the aspects of construction must make their own interpretation of the factual information provided as such interpretation may affect equipment selection, proposed construction methods, scheduling and the like.

It is understood that the gabion basket wall is the preferred alternative by MTO. Based on the plan, profile and details drawings for the new construction (culvert rehabilitation) at STA 24+300 to STA 25+000 provided to Golder by MTO, it is understood that the proposed gabion basket retaining wall / head wall is located at the inlet of Culvert 97 and will extend to approximately 1.5 m above the top of the existing concrete culvert resulting in an approximately 2 m high wall adjacent to the culvert edge; the wall will be stepped-up as it extends laterally away from the culvert. The Highway 400 embankment slope will be graded from the back of the top of the wall to the embankment shoulder at an inclination of 4 Horizontal to 1 Vertical (4H:1V), resulting in an additional 1 m of fill on top of the existing culvert at the back of the gabion basket wall. The gabion wall will extend 4 m north and 4 m south of the sides of the culvert. The proposed gabion basket wall is to be founded at or just below the top of the existing culvert strip footing on a 150 mm thick OPSS.PROV 1010 Granular 'A' bedding / levelling layer.

6.2 Consequence and Site Understanding Classification

In accordance with Section 6.5 of the 2014 Canadian Highway Bridge Design Code and its Commentary (CHBDC, S6-14), the proposed gabion basket wall and its foundation system is considered to be classified as having a "typical consequence level" associated with exceeding limits states design. In addition, given the level of foundation investigation completed to date in comparison to the degree of site understanding in Section 6.5 of CHBDC (2014), the level of confidence for design is considered to be a "typical degree of site and prediction model understanding." Accordingly, the appropriate corresponding ULS and SLS consequence factor, Ψ , from Table 6.1 and geotechnical resistance factors, ϕ_{gu} and ϕ_{gs} , from Table 6.2 of the CHBDC have been used for design.

6.3 Founding Elevation and Geotechnical Resistances

The gabion baskets and mats should meet the requirements of OPSS 1403 (Gabion Baskets and Mats) and the gabion basket retaining wall should be constructed in accordance with OPSS.PROV 512 (Installation of Gabions). The gradation requirements of the gabion stone [G-3 or G-10 as per OPSS.PROV 1004 (Aggregates –



Miscellaneous)] should be specified by the overall design engineer in consultation with the hydraulics engineer. The lower course of gabion baskets should be founded below the existing ground surface, following removal of any unsuitable surficial materials such as topsoil and organic materials or loose silty sand soils. The gabion retaining wall should be founded on a minimum 150 mm thick compacted levelling pad comprising of OPSS.PROV 1010 (Aggregates) Granular 'A' material.

Based on the cross-section drawing provided to us by MTO Foundations on November 4, 2016, the gabion baskets will be stepped-up extending laterally from both sides of the culvert. The lowest portion of the gabion basket wall is proposed to be placed at about Elevation 289 m. The subsoils as encountered in boreholes at or below about Elevation 289 m generally consist of stiff to hard silty clay underlain by a deposit of dense to very dense sand. Borehole C97-1 penetrated a 1.2 m thick layer of loose silty sand underlain by the stiff silty clay deposit.

The proposed lowest founding level for the gabion basket wall at approximately Elevation 289 m is at or just below the top of the existing culvert footing. The loose silty sand stratum encountered in Borehole C97-1 is considered not suitable for supporting the gabion basket wall and, where encountered, it should be subexcavated from the full width of the gabion basket bottom row to a depth of not greater than one-half of the footing thickness such as to not undermine the footing, and the excavation should be backfilled with Granular B Type II material or unshrinkable fill as per OPSS 1359 (Unshrinkable Fill). It is recommended that a Class II non-woven geotextile meeting the requirements of OPSS 1860 (Geotextiles), be placed to extend fully against the back of the gabion basket wall as a separator to the back fill to reconstruct the highway embankment.

Due to the proximity to the creek, it is anticipated that the excavation for the installation of the bottom coarse of the gabion retaining wall and granular pad will be required below the groundwater / creek water level. Further, to complete the subexcavation for removal of the loose silty sand deposit, if present, the Granular 'B' Type II material can be placed sub-aqueously to the underside of the Granular 'A' levelling pad, in accordance with OPSS 209 (Excavation over Compressible Soils). It is likely that dewatering will be required to allow for subexcavation of unsuitable (loose) silty sand and to place the levelling pad and bottom row of gabion baskets. Backfilling behind the gabion basket wall should be carried out consistent with OPSS 902 (Excavating and Backfilling Structures).

The minimum toe embedment for internal stability of the gabion basket wall and scour protection should be considered by the proprietary designer and hydraulics engineer, respectively.

For a 1.5 m or 2.0 m wide gabion basket footing (bottom layer) constructed on a compacted Granular 'A' bedding layer overlying the stiff to hard silty clay deposit of overlying the Granular 'B' Type II subexcavation backfill or unshrinkable fill factored geotechnical resistances at Ultimate Limit States (ULS) of 200 kPa and Serviceability Limit States (SLS) of 150 kPa (for 25 mm of settlement) may be used for the support of the gabion basket retaining wall / head wall.

6.4 Global Stability

Global stability analyses have been performed for the proposed gabion basket retaining wall using the commercially available program SLIDE, produced by Rocscience Inc. employing the Morgenstern-Price method of analysis. The Factor of Safety (FoS) is defined as the ratio of the forces tending to resist failure to the driving forces tending to cause failure. For the purpose of the stability analysis, the FoS is equal to the inverse of the product of the consequence factor, Ψ , and the geotechnical resistance factor, ϕ_{gu} . (i.e. $FoS = 1/(\Psi \cdot \phi_{gu})$). Accordingly, target minimum FoS of 1.3 and 1.5 have been used for the design of the gabion basket wall/embankment slopes for temporary and permanent conditions, respectively, as per Table 6.2 of CHBDC (2014).



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This minimum factor of safety is considered appropriate for the proposed wall on this site considering the design requirements and the available field and laboratory data.

The following parameters have been used in the global stability analyses for the 2 m high gabion basket wall section for the soil conditions encountered in Boreholes C97-1 and C97-2, based on field and laboratory test data as well as accepted correlations (Bowles, 1984 and Kulhawy and Mayne, 1990):

Soil Deposit	Short-Term (Undrained) Analysis			Long-Term (Drained) Analysis		
	Bulk Unit Weight (kN/m ³)	Effective Friction Angle, ϕ' (degrees)	Undrained Shear Strength (kPa)	Unit Weight (kN/m ³)	Effective Friction Angle, ϕ' (degrees)	Cohesion (kPa)
Existing Embankment Fill	20	30	0	20	30	0
New Embankment Fill	21	32	0	21	32	0
Loose Silty Sand	21	30	0	21	30	0
Stiff to Hard Silty Clay	21	0	75	21	30	0
Dense to Very Dense Sand	21	35	0	21	35	0

*Apparent cohesion for the gabion baskets interconnected with each other

The analyses assume that all existing topsoil / organic materials are completely removed and the loose silty sand, if present, is removed from under the footing footprint and replaced with Granular 'B' Type II fill prior to constructing the Granular 'A' bedding levelling layer. The results of the static global stability analyses indicate that a minimum factor of safety of 1.5 is achieved for both short-term (undrained) and long-term (effective stress) conditions for the 2.0 m high (retained soil) gabion basket wall as presented on Figures 1 and 2, respectively.

6.5 Settlement

The proposed gabion basket retaining wall located on the west side of the Highway 400 SBL will require a grade raise of approximately 1 m above the top of the existing culvert and on the north and south sides of the culvert to accommodate a proposed slope flattening of 4H:1V extending from the top of the proposed retaining wall to the Highway 400 shoulder. The proposed fill embankment will extend from approximately Elevation 293.3 m at the Highway 400 SBL shoulder to approximately Elevation 291 m at the top of the proposed retaining wall. The grade raise and slope flattening will induce some settlement in the foundation soils beneath the existing culvert and the proposed gabion basket retaining wall. Given that the existing fill at the toe of the Highway 400 SBL embankment slope is at approximately the top of the existing concrete culvert, the subsoils underlying the base of the proposed gabion basket wall will encounter an additional 1 m (approximately 21 kPa) of soil load after construction of the embankment.

The following presents the simplified stratigraphy and the associated elastic modulus and unit weights employed for the existing fill material as well as the native overburden deposits encountered within the boreholes at the proposed retaining wall as input to Settle 3D, produced by Rocscience Inc. to estimate the total factored settlement of the subgrade / gabion basket wall due to the 1 m grade raise on the embankment side slope:



Soil Deposit	Bulk Unit Weight (kN/m ³)	Elastic Modulus (MPa)
New embankment fill	21	-
Existing embankment fill	20	-
Stiff to hard silty clay	21	12.5
Dense to very dense sand	21	60

Based on the analyses, the estimated total settlement (immediate and consolidation) of the soils under the additional 1 m of fill on top of the embankment toe at the back of the gabion basket wall over the culvert and on the north and south sides of the culvert is estimated to be less than 10 mm. The majority of settlement is expected to occur during and immediately following placement of the embankment fill at and immediately behind the gabion basket wall.

6.6 Resistance to Lateral Loads/Sliding Resistance

Resistance to lateral forces / sliding resistance between the compacted fill (Granular 'A') of the gabion basket wall material (assumed to be cobble size fill) and the subgrade should be calculated in accordance with Section 6.10.5 of the *CHBDC (2014)*. The coefficient of friction, $\tan \phi'$, between the compacted granular bedding / levelling pad and the gabion basket wall may be taken as 0.6. This represents an unfactored value. The actual values used should be reviewed and revised, if necessary, by the proprietary gabion basket wall designer as part of the detail design of this structure.

6.7 Lateral Earth Pressures for Design

The lateral pressure acting on the gabion basket retaining wall will depend on the type and method of placement of backfill materials, the nature of the soils behind the backfill, the magnitude of surcharge including construction loadings, the freedom of lateral movement of the wall and the drainage conditions behind the wall.

The following recommendations are made concerning the design of the gabion basket wall:

- A minimum compaction surcharge of 12 kPa should be included in the lateral earth pressures for the structural design of the wall, in accordance with CHBDC (2014) Section 6.12. Other surcharge loadings should be accounted for in the design as required.
- The granular fill may be placed either in a zone with the width equal to at least 1.4 m behind the back of the walls (Case I - Figure C6.20 (a) of the Commentary to the CHBDC), or within the wedge shaped zone defined by a line drawn at 1.5 horizontal to 1 vertical (1.5H:1V) extending up and back from the rear face of the bottom layer (footing) of the gabion basket wall (Case II - Figure C6.20 (b) of the Commentary to the CHBDC) using OPSS.PROV 1010 Granular 'A' or Granular 'B' Type II fill.
- For Case I, the pressures are based on the new embankment fill materials and the reuse of silty sand fill compacting the existing embankment and the following parameters (unfactored) may be used assuming the use of approved earth fill for embankment construction:



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Lateral Earth Pressures (Case I)

	Earth Fill (Existing Fill)
Soil unit weight	20 kN/m ³
Coefficients of static lateral earth pressure	
Active, k_a	0.33
At rest, k_o	0.50

- For Case II, the pressures are based on the granular fill as placed, and the following parameters (unfactored) may be assumed:

Lateral Earth Pressure (Case II)

	Granular A	Granular B, Type II
Soil unit weight:	22 kN/m ³	21 kN/m ³
Coefficients of static lateral earth pressure:		
Active, k_a	0.27	0.27
At rest, k_o	0.43	0.43

If the gabion basket wall allows lateral yielding, active earth pressures may be used in the geotechnical design of the wall. The movement required to allow active pressures to develop within the backfill, and thereby assume an unrestrained structure for design, should be calculated in accordance with Section C6.12.1 and Table C6.6 of the Commentary to the CHBDC (2014). The gabion basket wall design should consider the need for a batter on the wall and the width / thickness of the gabion baskets per row of baskets to adequately resist the lateral earth pressure.

The earth pressure coefficients noted above are based on a horizontal surface adjacent to the top of the excavation. If sloped surfaces are present, the coefficient of earth pressure should be adjusted according to Figures C6.17 and C6.18 of the Commentary to CHBDC (2014).

7.0 CONSTRUCTION CONSIDERATIONS

The following sections identify construction considerations for the construction of the gabion basket retaining wall.

7.1 Excavation

The foundation excavations for the gabion basket wall bottom row (footing) should be constructed above the water table as the boreholes advanced at Culvert 97 were dry on completion of drilling, however, seepage of creek water through the silty sand layer, if present, or other permeable layers should be expected. The open cut excavations for the footing of the gabion basket retaining wall will extend through the existing fill material to the underlying



native stiff to hard silty clay material. The excavation for the retaining wall footing should be carried out in accordance with the guidelines outlined in the Occupational Health and Safety Act (OHSA) for Construction Activities. The existing embankment fill and any surficial deposits (i.e. topsoil) are classified as Type 3 soil and the native silty clay and sand deposits are classified as Type 2 soils. Temporary excavations (i.e. those open for a relatively short time period) should be sloped no steeper than 1H:1V.

7.2 Groundwater Control

The foundation excavations for the granular bedding / levelling pad and bottom row of the proposed gabion basket retaining wall will likely be constructed above the water table as the boreholes advanced at Culvert 97 were dry on completion of drilling. However, wet soil was encountered at the base of the existing fill material over the native less permeable silty clay deposit. Seepage from the overlying silty sand fill material is expected to be minimal and can be controlled using a sump if necessary. If the loose silty sand deposit penetrated in Borehole C97-2, or similar material, is encountered at subgrade level of the gabion basket footing, then subexcavation of this material may extend below the groundwater level and the adjacent creek water level. Such excavations should be made in short sections and backfilled with Granular 'B' Type II or unshrinkable fill simultaneously, or the excavation strips maintained unwatered by pumping from strategically placed sumps. Given that the gabion basket wall will be constructed in the immediate vicinity of an existing culvert and stream, temporary construction dewatering in conjunction with a cofferdam may be required to maintain the integrity of the excavation and subgrade during construction.

7.3 Temporary Protection Systems

It is understood that temporary protection systems may be required on either side of Culvert 97 during the construction of the proposed gabion basket wall. The temporary protection systems should be designed and constructed in accordance with OPSS.PROV 539 (*Temporary Protection Systems*) to meet Performance Level 2.

Temporary protection systems typically consist of either driven steel sheet piling, or soldier piles and lagging where the H-piles would be installed and concreted into a pre-augered hole to a suitable depth and horizontal lagging installed as the excavation proceeds. Lateral support to the system could be in the form of struts and wales (if the protection systems are sufficiently close to one another), rakers or anchors. For this site, the presence of very dense soils (having Standard Penetration Test "N" values of greater than 50 blows per 0.3 m of penetration) may make the installation of driven steel sheet piles difficult, and therefore soldier pile and lagging systems is more likely to be adopted. Soldier pile and lagging systems do not provide a cut-off to groundwater, and groundwater control and/or other mitigative measures (e.g., geotextile filter fabric behind the lagging boards) will be required in conjunction with this type of protection system.

The design of the temporary protection system will be completed by the Contractor and their shoring designer. However, for planning and estimating purposes for the design team, the temporary protection system may be designed using the following parameters:



FOUNDATION INVESTIGATION AND DESIGN REPORT - HIGHWAY 400 CULVERT 97 GABION BASKET WALL

Soil Type	Unit Weight	Internal Angle of Friction	Coefficient of Earth Pressure		
	(γ , kN/m ³)	(ϕ , degrees)	Active K_a	At Rest K_o	Passive, K_p
New Granular A or Granular B Type II fill	22	35	0.27	0.43	3.69
Existing loose to compact silty sand fill	20	32	0.31	0.47	3.25
Loose silty sand	19	29	0.35	0.52	2.88
Stiff to hard silty clay	20	30	0.33	0.50	3.00
Dense to very dense sand	20	34	0.28	0.44	3.54

The earth pressure coefficients noted above are based on a horizontal surface adjacent to the top of the excavation. If sloped surfaces are present, the coefficient of earth pressure should be adjusted according to Figures C6.17 and C6.18 of the Commentary to CHBDC (2014).

For design purposes, the water table should be assumed to be at Elevation 286 m. Design of the temporary support system by the Contractor and their shoring designer should include an evaluation of base stability, soil squeezing stability and hydraulic uplift stability as defined in the Canadian Foundation Engineering Manual (CFEM, 2006).

8.0 CLOSURE

This Foundation Design Report was prepared by Ted Beadle and Al Varshoi from Golder Geotechnical Group. Jorge M. A. Costa, P.Eng., a Designated MTO Foundation Contact and Senior Consultant, conducted an independent quality review of the report.



FOUNDATION INVESTIGATION AND DESIGN REPORT - HIGHWAY 400 CULVERT 97 GABION BASKET WALL

Report Signature Page

GOLDER ASSOCIATES LTD.



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Geotechnical Engineer



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Designated MTO Foundations Contact, Senior Consultant

TWB/ARV/JMAC/sm/arv

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n:\active\2014\1111\1413191 mto - foundations eng retainer - east on\10 - hwy 400 culverts #97, #99\5 - report\culvert 97\1413191 rpt10-1 2016-12-20 - hwy 400 culvert 97.docx



REFERENCES

Canadian Geotechnical Society. 2006. *Canadian Foundation Engineering Manual*, 4th Edition. The Canadian Geotechnical Society, BiTech Publisher Ltd., British Columbia.

Canadian Standards Association (CSA). 2014. *Canadian Highway Bridge Design Code and Commentary on CAN/CSA-S6-06*. CSA Special Publication, S6.1 06.

Chapman, L.J., and Putnam, D.F. 1984. *The Physiography of Southern Ontario*. Ontario Geological Survey, Special Volume 2, 3rd Edition. Ontario Ministry of Natural Resources.

Kulhawy, F.H. and Mayne, P.W. 1990. *Manual on Estimating Soil Properties for Foundation Design*. EL 6800, Research Project 1493 6. Prepared for Electric Power Research Institute, Palo Alto, California.

Ontario Provincial Standard Specifications (OPSS)

OPSS 512	Construction Specification for Installation of Gabions
OPSS 1359	Material Specification for Unshrinkable Fill
OPSS 1403	Material Specification for Gabion Baskets and Mats
OPSS 1004	Material Specification for Aggregate - Miscellaneous
OPSS.PROV 1010	Material Specification for Aggregates – Base, Subbase, Select Subgrade, and Backfill Material
OPSS 1860	Material Specification for Geotextiles
OPSS.PROV 539	Construction Specification for Temporary Protection Systems

ASTM International

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

Ontario Water Resources Act

Ontario Regulation 903 Wells (as amended)

Ontario Occupational Health and Safety Act

Ontario Regulation 213 Construction Projects (as amended)

Commercial Software

Slide (Version 6.0) by Rocscience Inc.

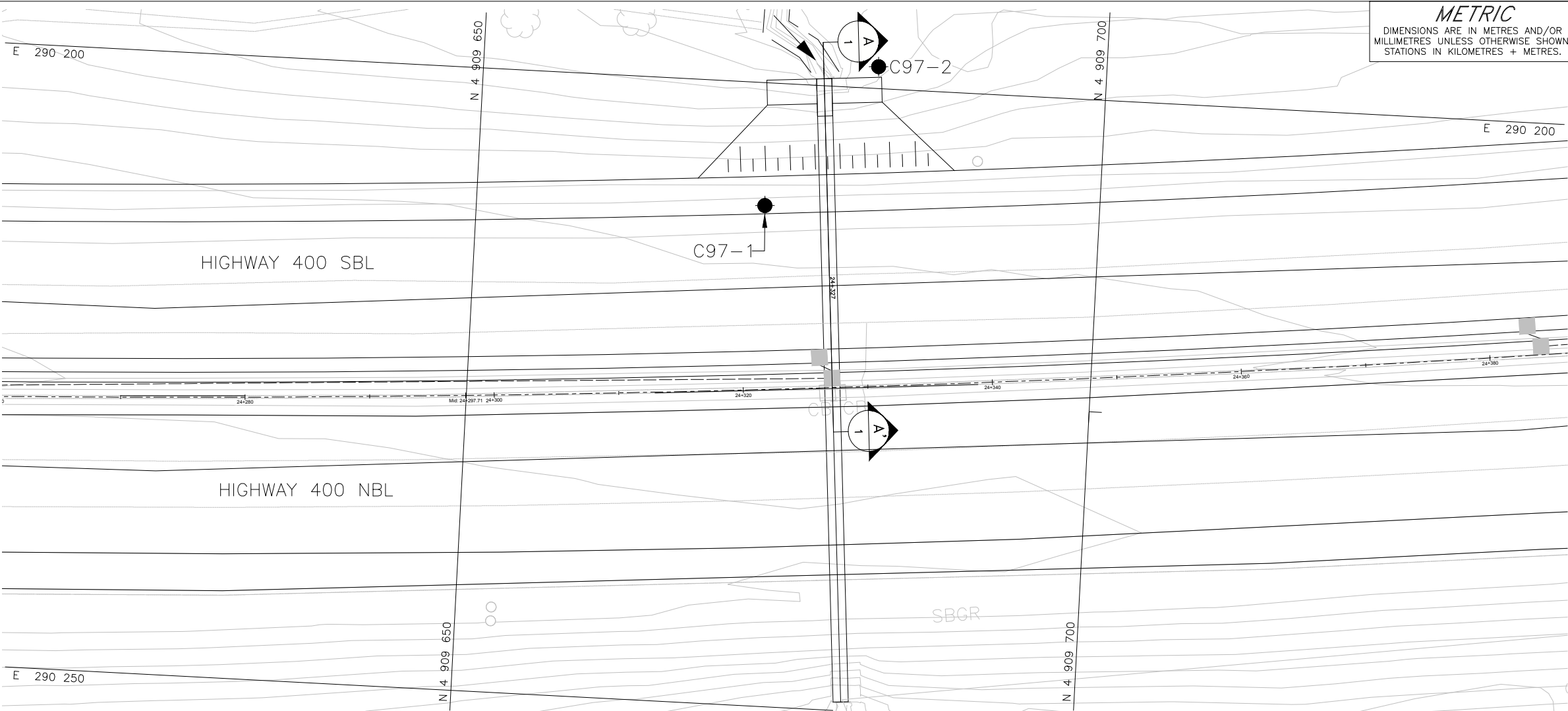
Settle3D (Version 4.0) by Rocscience Inc.



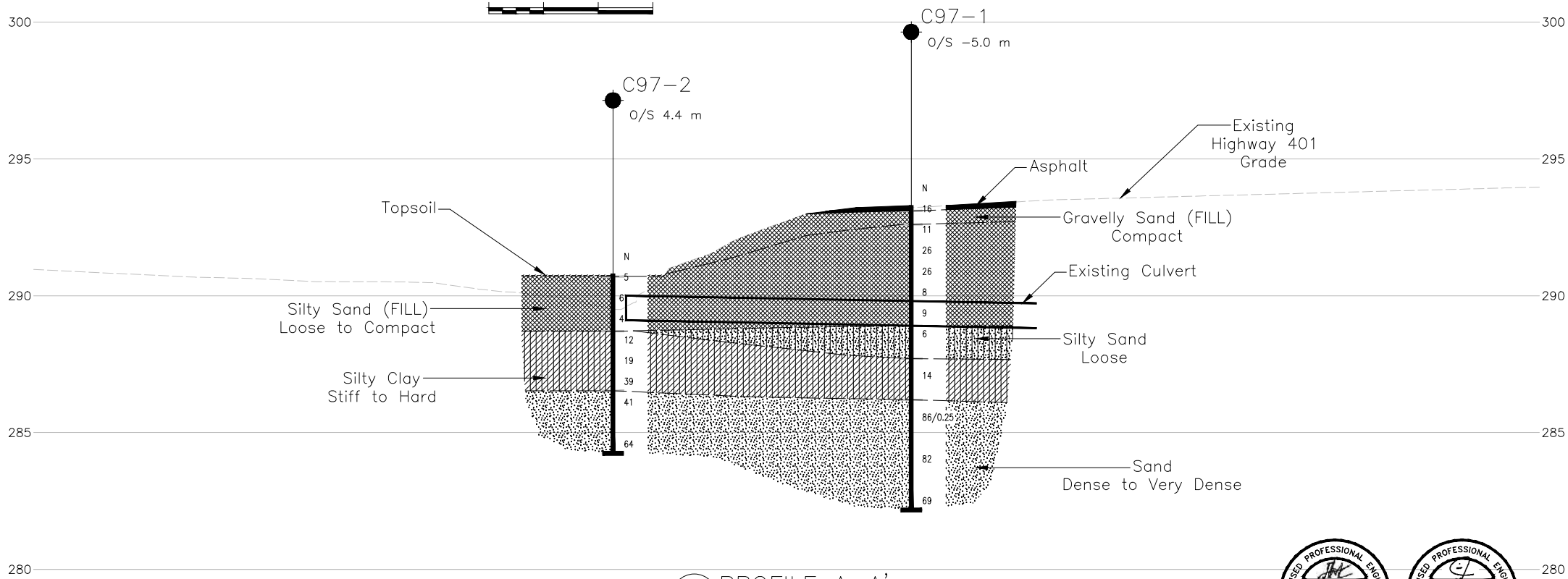
FOUNDATION INVESTIGATION AND DESIGN REPORT - HIGHWAY 400 CULVERT 97 GABION BASKET WALL

TABLE 1 – Summary Details of Existing Culvert

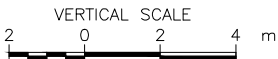
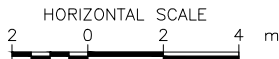
Culvert	Height of Embankment	Existing Culvert			Approximate Inlet / Outlet Invert
		Type	Span / Height	Length	
#97 STA 24+327	4.5 m	Open Footing	1220 mm x 900 mm	50 m	Elev. 289.0 m (west end) Elev. 288.0 m (east end)



PLAN



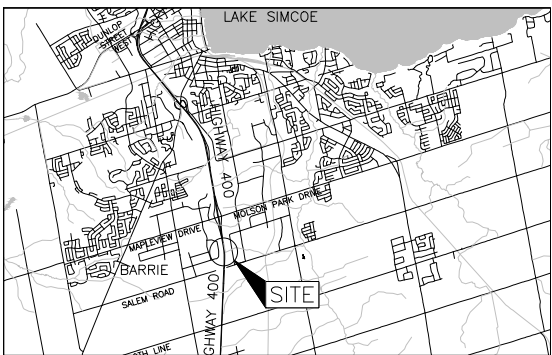
PROFILE A-A'
STA. 24+327



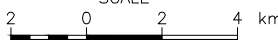
METRIC
DIMENSIONS ARE IN METRES AND/OR
MILLIMETRES UNLESS OTHERWISE SHOWN.
STATIONS IN KILOMETRES + METRES.

CONT No. _____
GWP No. 2184-10-00

CULVERT 97 STA. 24+327
HIGHWAY 400
BOREHOLE LOCATIONS
AND SOIL STRATA



KEY PLAN
SCALE



LEGEND

- Borehole - Golder (2016)
- N Standard Penetration Test Value
- 16 Blows/0.3m unless otherwise stated
(Std. Pen. Test, 475 j/blow)
- ≡ WL upon completion of drilling

BOREHOLE CO-ORDINATES			
No.	ELEVATION	NORTHING	EASTING
C97-1	293.3	4909673.1	290209.8
C97-2	290.8	4909681.7	290198.2

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, culvert plan and profile, and surface data provided in digital format by URS, drawing file nos. Culvert 97 & 99 Plan View.dwg, 1.Culvert 97 Profile (from 60% Dwgs).pdf, and HWY 400-BASE PLAN SURFACE.dwg, received Oct. 17, 2016.

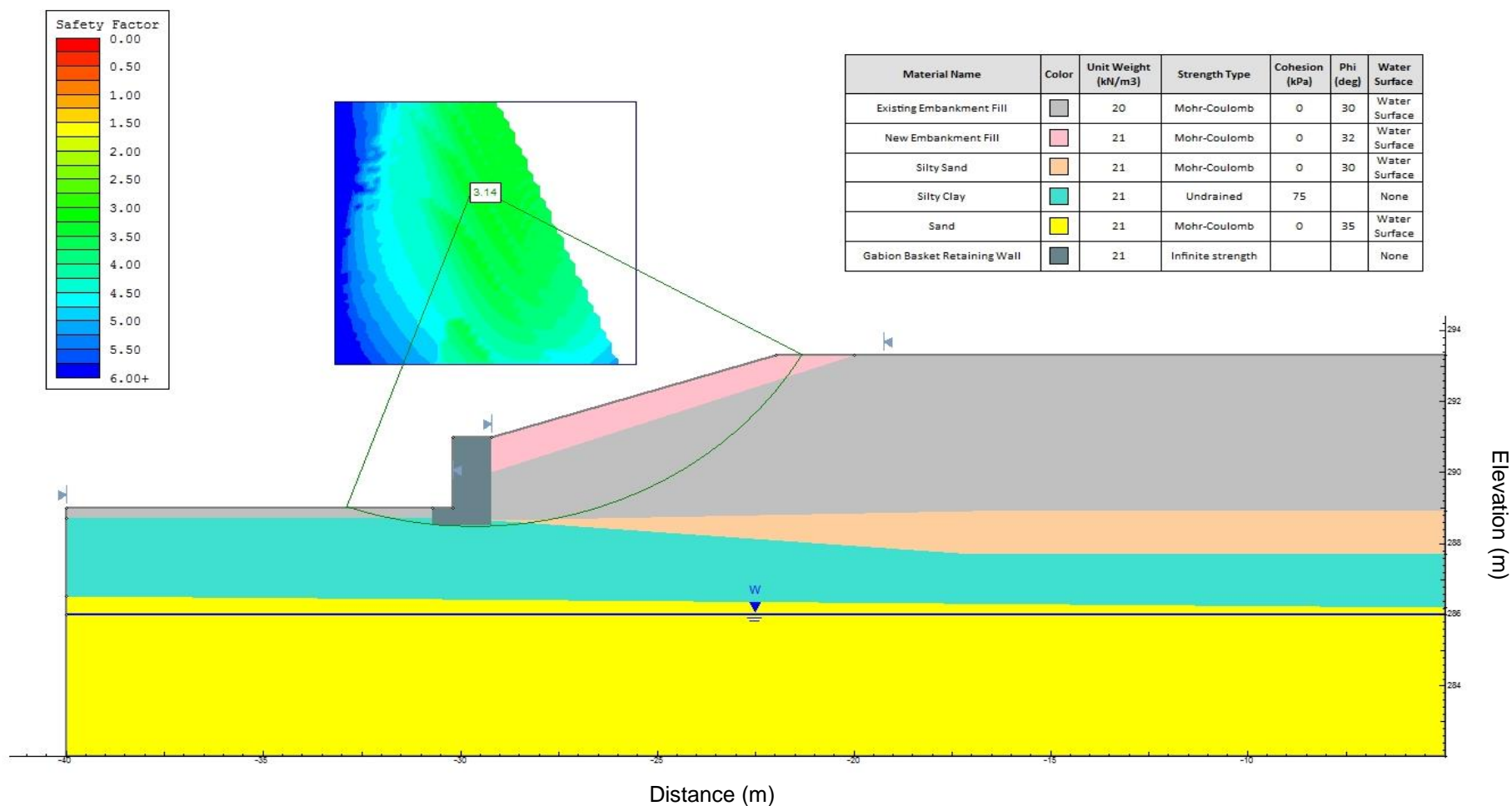
NO.	DATE	BY	REVISION
Geocres No. 31D-667			
HWY. 400	PROJECT NO. 1413191		DIST. CENTRAL
SUBM'D. TWB	CHKD. TWB	DATE: 10/25/2016	SITE: .
DRAWN: DD/MR	CHKD. JMAC	APPD. JMAC	DWG. 1





Static Global Stability – Culvert 97 Gabion Basket Retaining Wall Short-Term (Undrained) Condition

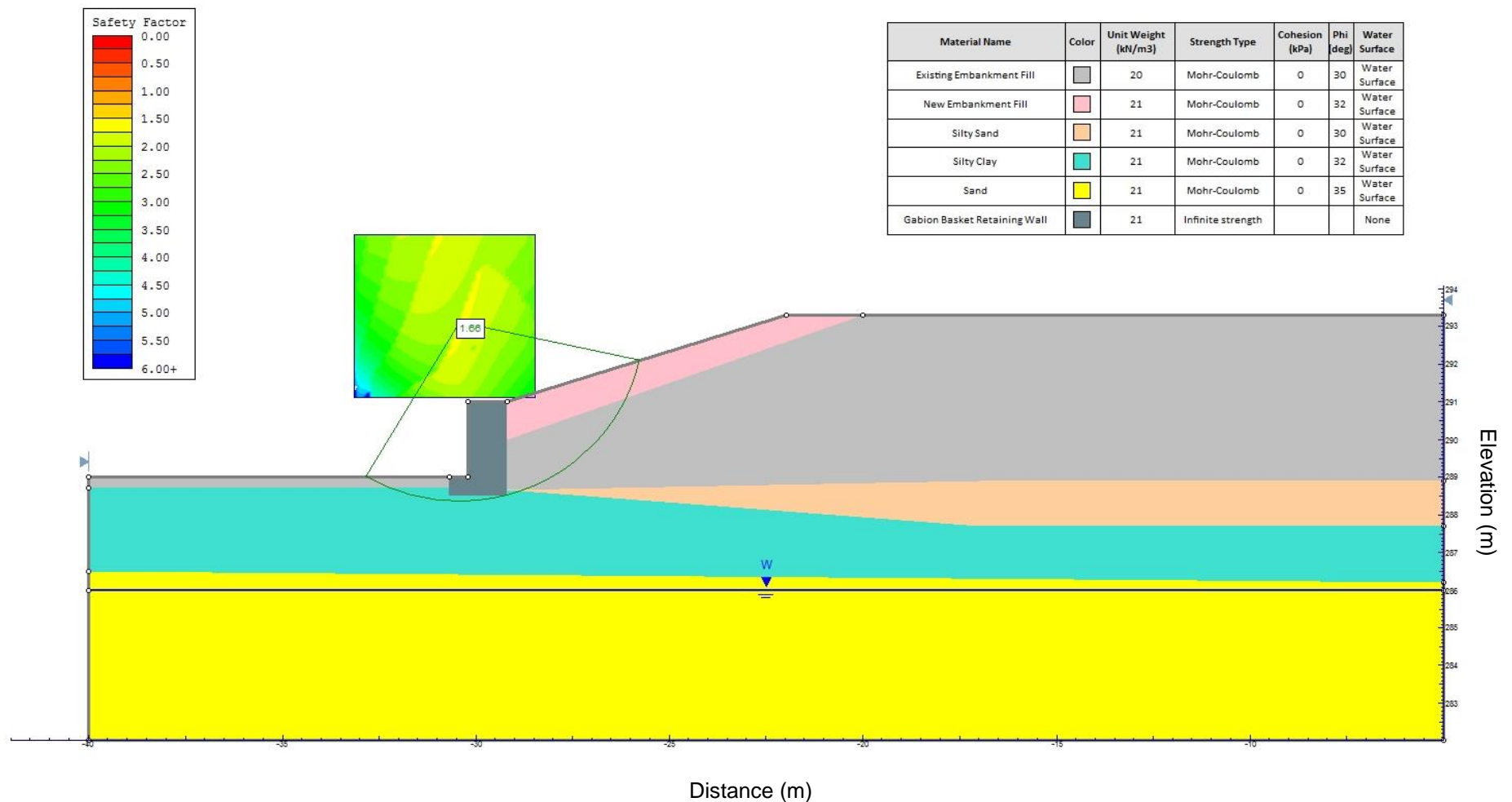
Figure 1





Static Global Stability Culvert 97 Gabion Basket Retaining Wall Long-Term (Drained) Condition

Figure 2





APPENDIX A

List of Symbols

List of Abbreviations

Record of Borehole C97-1 and C97-2



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
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

(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 = $\tan \delta$
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

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

Notes: 1
2

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



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, 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 cm² 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

Density Index	N
Relative Density	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




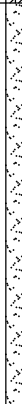
w	water content
w_p	plastic limit
w_l	liquid limit
C	consolidation (oedometer) test
CHEM	chemical analysis (refer to text)
CID	consolidated isotropically drained triaxial test ¹
CIU	consolidated isotropically undrained triaxial test with porewater pressure measurement ¹
D_R	relative density (specific 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.

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 With (cohesive)	Sand and Gravel Silty Clay with sand / Clayey Silt with sand

PROJECT 1413191 (1100)		RECORD OF BOREHOLE No 97-1		SHEET 1 OF 1		METRIC	
G.W.P. 2184-10-00		LOCATION N 4909673.1 ; E 290209.8		ORIGINATED BY IK			
DIST Central HWY 400		BOREHOLE TYPE D-50 Track Mount, 210 mm Outer Diameter Hollow Stem Augers, Auto Hammer		COMPILED BY PKS/AJS			
DATUM Geodetic		DATE September 26 and 27, 2016		CHECKED BY LCC			

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT NATURAL LIMIT MOISTURE LIQUID CONTENT LIMIT			UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa					WATER CONTENT (%)				
								20	40	60	80	100	W _p	W	W _L		
293.3	GROUND SURFACE																
0.0	ASPHALT (230 mm)																
0.2	Gravelly sand, some silt, trace clay (FILL)		1	SS	16		293										5 67 22 6
292.6	Compact Brown Moist						292										
0.7	Silty sand, trace to some clay, trace gravel (FILL)		2	SS	11		291										
	Loose to compact Brown Moist, becoming wet at base of stratum						290										
			3	SS	26												
			4	SS	26												
		5	SS	8													
		6	SS	9													
288.9							289										
4.4	Silty SAND, trace gravel, trace clay, trace organics		7	SS	6		288										
	Loose Dark grey Wet																
287.7	SILTY CLAY, trace sand		8	SS	14	287											
	Stiff Laminated dark grey to grey Moist																
286.2						286											
7.1	SAND, trace to some silt, trace clay, trace gravel		9	SS	86/0.25	285											
	Very dense Light brown Moist					284											
			10	SS	82	283											
282.2			11	SS	69												
11.1	END OF BOREHOLE																
	NOTE: 1. Borehole dry on completion of drilling.																

PROJECT		1413191 (1100)		RECORD OF BOREHOLE No 97-2		SHEET 1 OF 1		METRIC													
G.W.P.		2184-10-00		LOCATION		N 4909681.7 ; E 290198.2		ORIGINATED BY													
DIST		Central HWY 400		BOREHOLE TYPE		D-50 Track Mount, 210 mm Outer Diameter Hollow Stem Augers, Auto Hammer		COMPILED BY													
DATUM		Geodetic		DATE		September 27, 2016		CHECKED BY													
								LCC													
SOIL PROFILE			SAMPLES			DYNAMIC CONE PENETRATION RESISTANCE PLOT			PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT			REMARKS & GRAIN SIZE DISTRIBUTION (%)						
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	SHEAR STRENGTH kPa					WATER CONTENT (%)			γ					
290.8	GROUND SURFACE							20 40 60 80 100 ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × REMOULDED					W _p W W _L 10 20 30			kN/m ³			GR SA SI CL		
0.0	TOPSOIL		1	SS	5		290														
	Silty sand, trace gravel, trace clay, trace organics and rootlets, pockets of clayey silt (FILL)		2	SS	6																
	Loose Brown Moist, becoming wet at base of stratum		3	SS	4		289														
288.7	SILTY CLAY, trace sand		4	SS	12		288														
2.1	Stiff to hard Laminated dark grey to grey Moist		5	SS	19																
			6	SS	39		287														
286.5	SAND, some gravel, trace to some silt, trace clay		7	SS	41		286														
4.3	Dense to very dense Light brown Moist		8	SS	64		285														
284.2	END OF BOREHOLE																				
6.6	NOTE: 1. Borehole dry on completion of drilling.																				



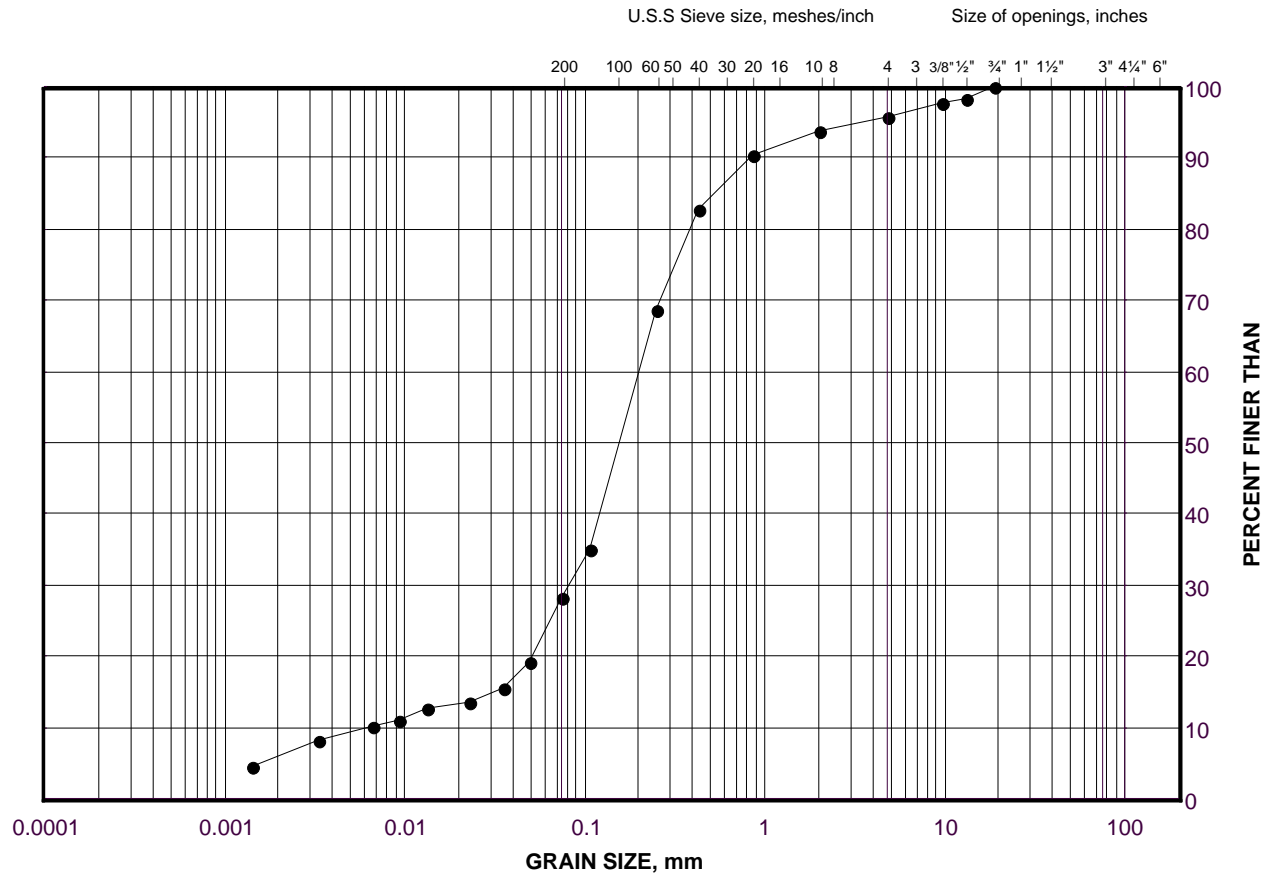
APPENDIX B

Laboratory Test Results

GRAIN SIZE DISTRIBUTION

Silty Sand (Fill)

FIGURE B1



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

LEGEND

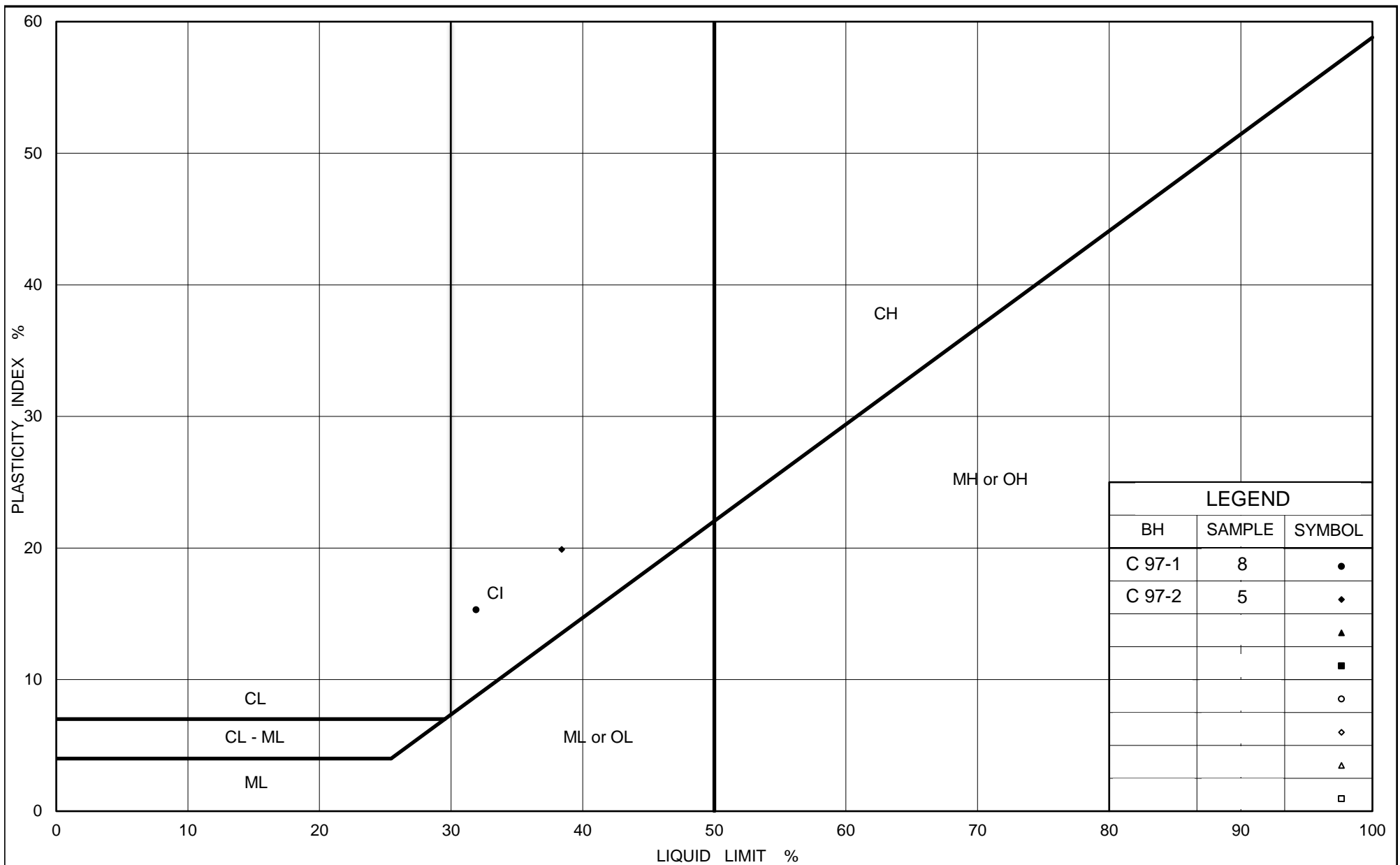
SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
•	C 97-1	3	291.5

Project Number: 1413191

Checked By: TWB

Golder Associates

Date: 24-Oct-16



PLASTICITY CHART Silty Clay

Figure No. B2

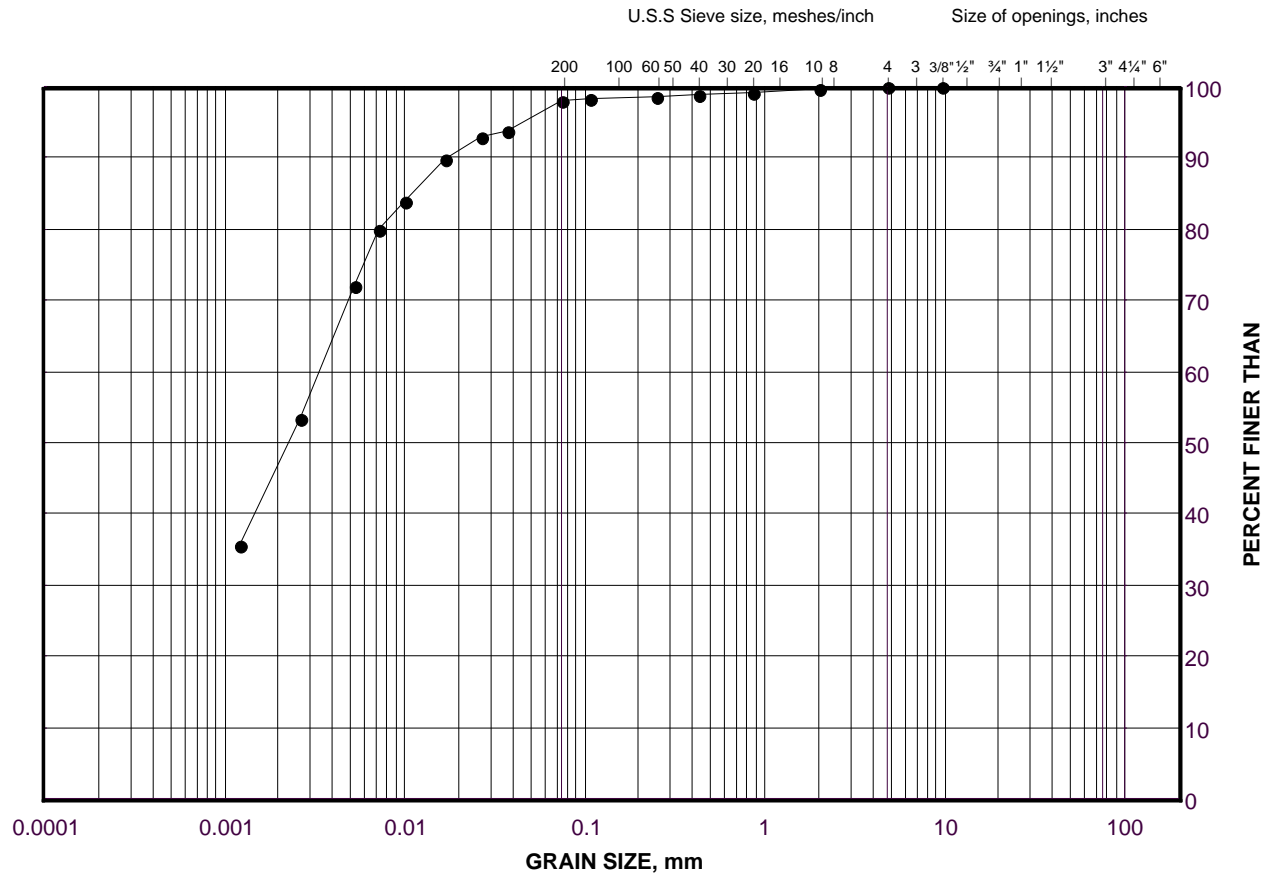
Project No. 1413191 (1100)

Checked By: TWB

GRAIN SIZE DISTRIBUTION

Silty Clay

FIGURE B3



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

LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
•	C 97-2	5	287.5

Project Number: 1413191

Checked By: TWB

Golder Associates

Date: 24-Oct-16

Sand

FIGURE B4



SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	C 97-2	8	284.5
■	C 97-1	9	285.4

Date: 24-Oct-16

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