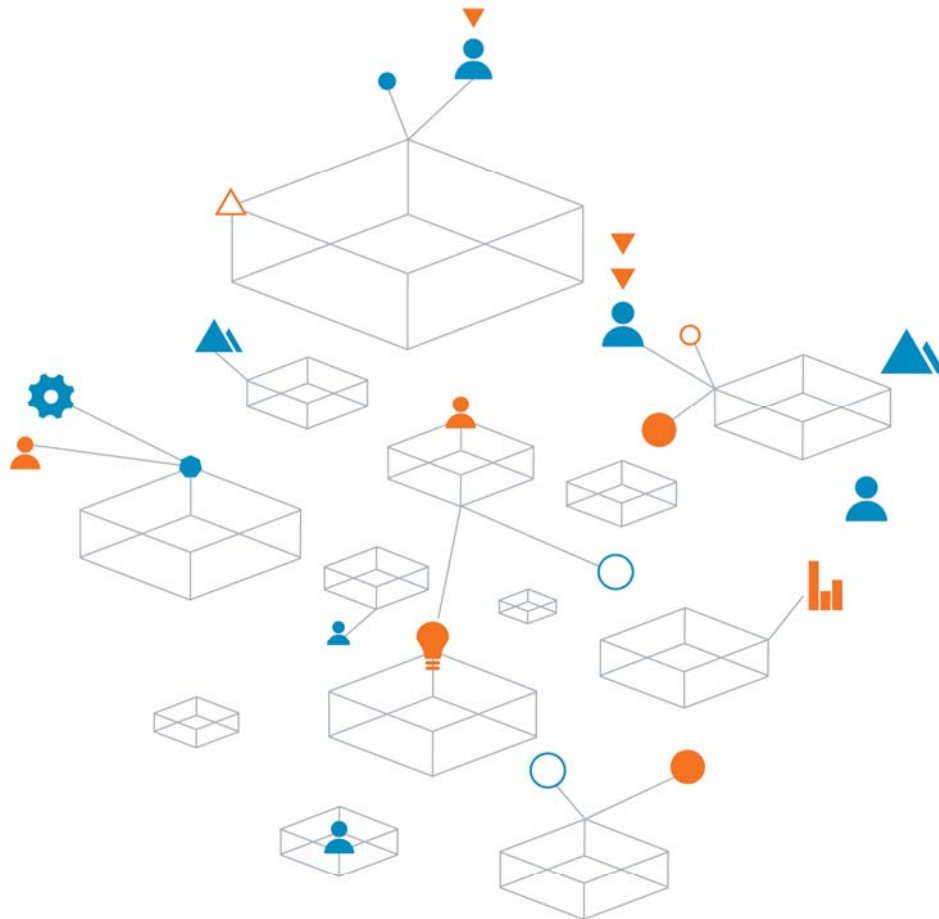


Highway 400 Culverts - Extension/Replacement-CSP, South of BCR  
and RFOF, North of Tiffin Street, G.W.P. 2074-11-00,  
Design-Build Ready Package, GEOCREC No. 31D-589  
GEOTETOB22161AA  
11 February, 2015



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projects



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11 February, 2015

**Attention: Bruce Dickey, P. Eng., AVS**

**RE: Preliminary Foundation Investigation and Design Reports  
Highway 400 Culverts - Extension/Replacement-CSP, South of BCR and RFOF, North of Tiffin  
Street, G.W.P. 2074-11-00, Design-Build Ready Package, GEOCRE No. 31D-589**

Coffey is pleased to present our Foundation Investigation and Design Reports (for a Design-Build Ready Package) relating to the above-noted culverts.

Should you require clarification on any aspect of the reports, please contact the undersigned at (416) 213-5357.

For and on behalf of Coffey

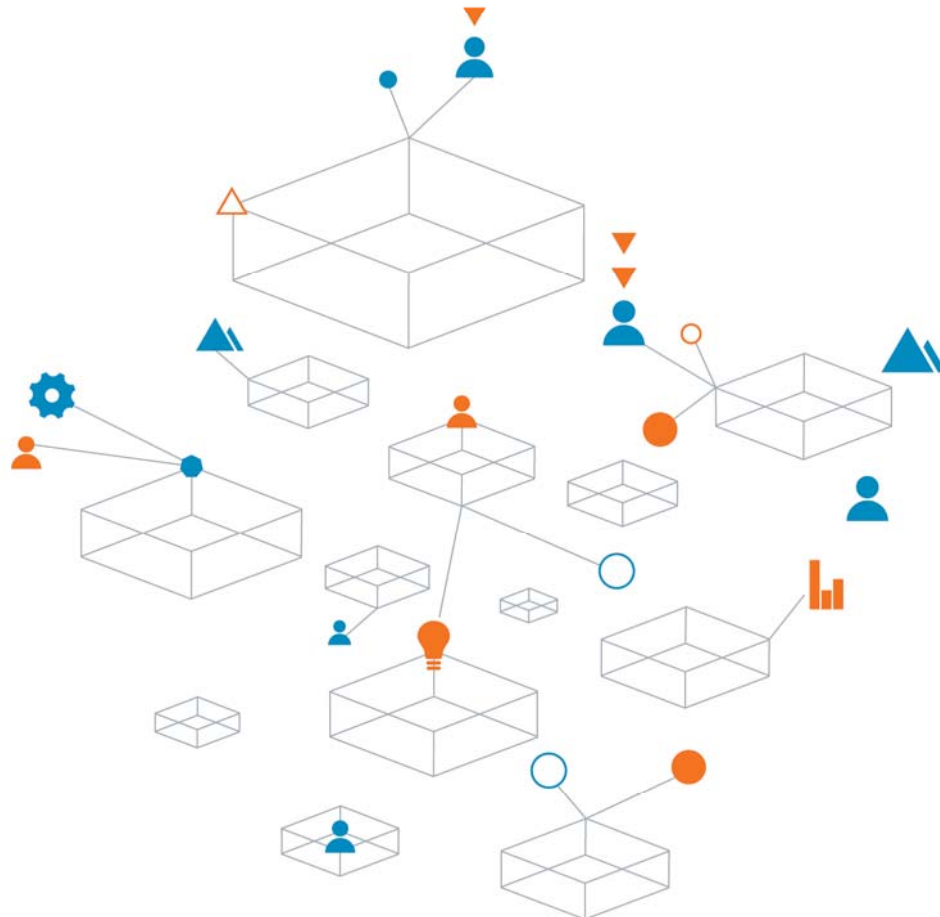
A handwritten signature in blue ink, appearing to read "Sanket Shah".

**Sanket Shah, P. Eng.**  
Project Manager, Geotechnical Engineer



## **Preliminary Foundation Investigation Report**

Highway 400 Culverts - Extension/Replacement-CSP, South of BCR  
and RFOF, North of Tiffin Street, G.W.P. 2074-11-00,  
Design-Build Ready Package, GEOCRES No. 31D-589  
GEOTETOB22161AA - DRAFT  
11 February, 2015



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**PRELIMINARY FOUNDATION INVESTIGATION REPORT  
HIGHWAY 400 CULVERTS EXTENSION/REPLACEMENT  
CSP, SOUTH OF BCR AND RFOF, NORTH OF TIFFIN STREET,  
G.W.P. 2074-11-00, DESIGN-BUILD READY PACKAGE**

## **1 Introduction**

Coffey was retained by Morrison Hershfield (herein “MH”) on behalf of the Ministry of Transportation Ontario (herein “MTO”) to provide preliminary foundation investigation and engineering services for the proposed Design-Build (DB) ready package for MTO G.W.P. 2074-11-00, *Highway 400/Tiffin Street Overpass Structure Replacements and Highway 400/Barrie-Collingwood Railway (BCR) Overhead Structure Rehabilitation and Addition*. The project extends from just north of the existing Essa Road – Highway 400 Interchange to just south of the Dunlop Street – Highway 400 Interchange. This investigation report is prepared for proposed culvert extensions or replacements at Stations 29+280 and 10+120 (Highway 400 centreline chainage).

The purpose of the investigation was to obtain information about the subsurface conditions at the two culvert sites by means of boreholes and to assess the engineering characteristics of the subsurface soils by means of field and laboratory tests. The findings of the investigation are presented in this report. It provides factual information on subsurface soil and groundwater conditions, in-situ testing, and laboratory test results. Owing to known TCE (trichloroethylene) contamination in the project area and the design-build nature of the project, the subsurface investigation scope was limited to a reduced number of boreholes and a requirement not to investigate the subsurface conditions below certain pre-specified depths/elevations.

## **2 Site Description and Physiography**

### **2.1 Site and Structure Description**

The overall project is located in the City of Barrie (Townships of Innisfil and Vespra). The existing culvert at Station 29+280 is a 1775 mm diameter 70 m long Corrugated Steel Pipe (CSP) with its invert at elev. 230 m. The other culvert, located at Station 10+120, is a Rigid Frame Open Footing (RFOF) concrete structure with a span of 1220 mm, rise of 1200 mm and a length of 61 m. The existing stream bed at the RFOF culvert location is at elev. 232 m. The areas on the east and west sides of Highway 400 have been developed and include both residential and mixed commercial and industrial land uses.

Photographs of the site are presented in **Appendix C**.

### **2.2 Physiography**

The project site is located in the Simcoe Lowlands Physiographic Region of Southern Ontario. The soil deposits are either deltaic or lacustrine in origin. They consist of fine grained non-cohesive silts and fine sands intermixed with thin (< 1 m thickness) stringers of clayey silt deposited during quieter periods of sedimentation.

Due to the depositional environment and lack of adequate drainage that encouraged in-situ decay of growing vegetation, peat and muck lenses and layers are present in depressed areas in the upper horizons of deltaic and lacustrine silt and sand deposits.

## 3 Method of Investigation

### 3.1 Field Investigation

The borehole locations were discussed with MH to maximize borehole coverage for a design-build ready package. Due to the known TCE contamination within the project limits, borehole depths/elevations were restricted to minimize potential environmental disturbance.

Six (6) boreholes were advanced in the vicinity of the two culverts - five (5) for culvert foundation and one (1) for a retaining wall. The borehole locations were laid out by Coffey personnel on the basis of chainage painted by MH along Highway 400. Underground services were cleared using Ontario One Call and private locators. The field work was conducted from October 6 to 27, 2014 under Coffey supervision. Boreholes C5 and RW12 were drilled from the existing Highway 400 grade during nightly lane closures as directed by MTO COMPASS. Boreholes C1, C2, C3 and C4 were drilled at the existing embankment toe areas without traffic control. An MH representative was also present during the drilling and sampling of boreholes C3 and C5.

Table 3.1.1 below provides a summary of the field work.

**Table 3.1.1: Summary of Boreholes**

| Structure                         | BH No. | Borehole Locations<br>(Station and Offset from the centerline) | Ground Elevation (m) | Borehole Depth (m) | Borehole Bottom Elevation (m) | Piezometer/<br>Monitoring Well |
|-----------------------------------|--------|--|----------------------|--------------------|-------------------------------|--------------------------------|
| CSP culvert<br>Station<br>29+280  | C1     | 29+292, 40 m Rt  | 232.0                | 3.1                | 229.0                         | Piezometer                     |
|                                   | C3     | 29+274, 34.3 m Lt  | 233.0                | 8.2                | 224.8                         | Piezometer                     |
|                                   | C5     | 29+288, 2.6 m Lt   | 238.7                | 14.3               | 224.4                         |                                |
| RFOF Culvert<br>Station<br>10+120 | C2     | 10+124, 38 m Rt  | 233.3                | 8.2                | 225.1                         | Piezometer                     |
|                                   | C4     | 10+150, 33.1 m Lt  | 233.7                | 8.2                | 225.5                         | Piezometer                     |
| Temporary<br>Retaining<br>Walls   | RW12   | 10+120, 4 m Lt   | 237.7                | 9.8                | 228.0                         |                                |

Four (4) piezometers were installed for long term groundwater monitoring. Boreholes C5 and RW12 were backfilled and sealed in accordance with MOE Reg. 903.

The boreholes were drilled with truck mounted CME-75 machines (owned and operated by Davis Drilling of Milton, Ontario) equipped with solid stem and hollow stem augers. Soil samples were obtained in the Standard Penetration Test (ASTM D-1586), with N values noted in blows/0.3m. All samples were placed in moisture proof bags after field classification. They were subsequently re-examined under controlled laboratory conditions prior to assigning laboratory tests.

The borehole locations were tied in to NAD83 coordinates and the geodetic elevations at the borehole locations were determined by MH surveyors.

## 3.2 Laboratory Testing

The following tests were performed on selected soil samples:

- Natural moisture content;
- Grain size analyses (sieve and hydrometer); and
- Atterberg Limits Test.

Laboratory test results are presented in **Appendix B**. The results of laboratory tests are also presented on the Record of Borehole Sheets in **Appendix A**.

## 4 Subsurface Conditions

The major native soil deposits at the project site below and around the Highway 400 embankment fill are silty sand to sandy silt, silt and sand and silt. Localized peat was encountered at the Borehole C1 location.

Detailed descriptions of the materials encountered in the boreholes are presented on the Record of Borehole Sheets presented in **Appendix A**, which includes Explanation of Terms Used in the Report.

Borehole Location Plan and the generalized subsurface stratigraphy are presented on **Drawings 1 and 2**.

### 4.1 CSP at Station 29+280

Boreholes C1, C3 and C5 were advanced for the proposed CSP culvert extension or replacement. The soil and groundwater conditions at the borehole locations are described in the following sections.

#### 4.1.1 Topsoil and Peat

About 0.1 m to 0.2 m thick topsoil was presented at the ground surface at the location of Boreholes C1 and C3. A 0.9 m thickness of fibrous peat was encountered at the location of Borehole C1 beneath topsoil and fill. Retrieved split spoon samples (major component was fine sand) were coated with peat. The moisture contents of the peat coated sand samples were 42% and 61%.

#### 4.1.2 Pavement Structure

On the Highway 400 pavement 150 mm thick asphaltic concrete was underlain by 0.45 m of sand and gravel base and subbase. The granular base/subbase is dense, based on one N value of 38 blows/0.3 m.

#### 4.1.3 Embankment Fill

Under the pavement structure in Borehole C5 and topsoil in Boreholes C1 and C3, a fill layer consisting of silty sand, trace to some gravel and silt with occasional silty clay layers was found down to about elev. 233 m to 230 m.

The grain size distribution for one (1) sample from the embankment fill is included in **Figure B-1** with the following grain size distribution: 0% gravel, 56% sand and 44% silt and clay size particles (6% clay sized particles).



The grain size distribution for one (1) sample from a discontinuous silty clay layer within the embankment fill (Borehole C1) is presented in **Figure B-2**. It shows the following grain size distribution: 1% gravel, 22% sand, 50% silt and 27% clay sized particles.

Atterberg Limits tests on the clayey silt gave the following results (see **Figure B-3**);

|                           |     |
|---------------------------|-----|
| Liquid Limit:             | 23% |
| Plastic Limit:            | 13% |
| Plasticity Index:         | 10% |
| Natural Moisture Content: | 20% |

These results are characteristic of clayey soils of low plasticity (CL).

In the non-cohesive fill N values ranged from 1 to 32 blows/0.3 m, indicating a very loose to dense condition (typically loose in the embankment toe areas, and compact under the highway pavement).

The natural moisture content of samples from the embankment fill ranged from 5% to 23% (average 16%).

Cobbles, boulders and rock fill were not encountered in boreholes drilled through the fill, but their likely presence elsewhere within the Highway 400 embankment fill should not be discounted.

#### **4.1.4 Sandy Silt to Silty Sand, Silt, and Sand and Silt**

The native soils beneath and adjacent to the Highway 400 embankment are sandy silt to silty sand, silt, and sand and silt. This stratified deposit contains trace gravel and clay. All boreholes were terminated within this deposit at depths ranging from 3.1 m to 14.3 m below the existing grade (at elev. 228.9 m to 224.8 m).

Gradation analysis on four (4) samples from this stratified deposit (see **Figure B-4**) gave the following results.

|                |                                       |
|----------------|---------------------------------------|
| Gravel:        | 0 - 1%                                |
| Sand:          | 8 - 76%                               |
| Silt and Clay: | 23 - 92% (5 - 7% clay size particles) |

An Atterberg Limits test was attempted on a sample from Borehole C3. It was non-plastic.

The natural moisture content of samples from this deposit ranged from 6% to 24% (average 20%).

N values of 4 to 44 blows/0.3 m indicate the deposit is very loose to dense, being generally loose to compact in the embankment toe area and compact to dense under the highway paved surface.

#### **4.1.5 Groundwater Conditions**

The groundwater levels observed during and after the investigation are summarized in **Table 4.1.5.1** and are also presented on the Record of Borehole Sheets in **Appendix A**.

**Table 4.1.5.1: Groundwater Observations**

| Borehole No. | Ground Elevation (m) | Date   | Depth to Water Level (m) | Groundwater Elevation (m) |
|--------------|----------------------|--|--------------------------|---------------------------|
| C1           | 232.0                | October 31, 2014<br>(about 4 weeks after installation) | 1.8                      | 230.2                     |
| C3           | 233.0                | October 31, 2014<br>(about 2 weeks after installation) | 1.5                      | 231.5                     |

Based on these observations, the groundwater table is located between elev. 232 m and 230 m.

It should be noted that groundwater levels are subject to variation due to the influence of rainfall, seasons and water level in the water course.

## **4.2 RFOF at Station 10+120**

Boreholes C2 and C4 were advanced to determine the subsurface conditions for the proposed CSP culvert extension. Borehole RW12 was advanced in the highway median adjacent to the existing culvert alignment, for a proposed grade raise related retaining wall. A borehole location plan and generalized subsurface conditions are shown on **Drawing 2**. The soil and groundwater conditions are described in the following sections.

### **4.2.1 Topsoil**

About 0.1 m thick topsoil was presented at the ground surface at the location of Boreholes C2 and C4 advanced at the embankment toe areas. It may be thicker (200-300 mm) elsewhere within the culvert extension area.

### **4.2.2 Pavement Structure**

The pavement consists of 220 mm of asphaltic concrete underlain by 0.6 m sand and gravel base and sub-base courses. The granular materials are compact (N = 16 blows/0.3 m).

### **4.2.3 Embankment Fill**

Under the pavement structure in Borehole RW12 and topsoil in Boreholes C2 and C4, a fill layer consisting of silty sand, trace to some gravel, was encountered to elev. 234 m to 232 m.

A grain size distribution of one (1) sample from the embankment fill is included in **Figure B-5**. It shows the following grain size distribution: 3% gravel, 70% sand and 27% clay sized particles.

N values of 6-32 blows/0.3 m indicate the fill is loose to dense, being typically loose in the embankment toe areas and compact under the highway pavement.

The natural moisture content of the embankment fill was 8-13%.

Cobbles, boulders and rock fill were not encountered in boreholes drilled through the fill, but their likely presence elsewhere within the Highway 400 embankment fill should not be discounted.

#### 4.2.4 Sandy Silt to Silty Sand and Silt

The native soils beneath and adjacent to the Highway 400 embankment consists of sandy silt to silty sand and silt. This stratified deposit contains clayey silt layers and lenses. A thin gravelly sand layer was found in Borehole C4, in which the soil backed up approximately 0.6 m when the hole depth reached elev. 230 m.

All boreholes were terminated within this deposit at depths ranging from 8.2 m to 9.8 m below the existing grade (elev. 227.9 m to 225.1 m).

The gradation of two (2) samples (see **Figure B-6**) gave the following results:

|                |                                    |
|----------------|------------------------------------|
| Gravel:        | 0 - 1%                             |
| Sand:          | 45 - 69%                           |
| Silt and Clay: | 31 - 54% (8% clay sized particles) |

The grain size distribution of one (1) sample from a discontinuous silty clay layer within the deposit (Borehole C2) is presented in **Figure B-7**. It has the following grain size distribution: 0% gravel, 1% sand, 63% silt and 36% clay sized particles.

An Atterberg Limits test on the same sample (see **Figure B-8**) gave the following results:

|                           |     |
|---------------------------|-----|
| Liquid Limit:             | 29% |
| Plastic Limit:            | 12% |
| Plasticity Index:         | 17% |
| Natural Moisture Content: | 30% |

These results are characteristic of clayey soils of low plasticity (CL).

A grain size analysis on the gravelly sand layer (Borehole C4) gave the following: 32% gravel, 59% sand and 9% silt and clay sized particles (**Figure B-6**).

The natural moisture content of the stratified deposit ranged from 5% to 24% (average 16%)

N values of 3 to 44 blows/0.3 m indicate the deposit is very loose to dense, being typically compact (N average = 16 blows/0.3 m).

#### 4.2.5 Groundwater Conditions

Groundwater levels were observed in the open boreholes while drilling and upon completion of each borehole. Piezometers were installed in Boreholes C2 and C4 for long term groundwater monitoring. The groundwater levels observed during and after the investigation are summarized in **Table 4.2.5.1** and are also presented on the Record of Borehole Sheets in **Appendix A**.


**Table 4.2.5.1: Groundwater Observations**

| Borehole No. | Ground Elevation (m) | Date   | Depth to Water Level (m) | Groundwater Elevation (m) |
|--------------|----------------------|--|--------------------------|---------------------------|
| C2           | 233.3                | October 31, 2014<br>(about 4 weeks after installation) | 3.6                      | 229.7                     |
| C4           | 233.7                | October 31, 2014<br>(about 4 days after installation)  | 2.1                      | 231.6                     |

Based on above measurements, the groundwater table at the site is located between elev. 232 m and 230 m.

It should be noted that groundwater levels are subject to variation due to the influence of rainfall, seasons and water level in the water course.

For and on behalf of Coffey

  
**Gwangha Roh**, P. Eng., Ph.D.  
 Associate Geotechnical Engineer



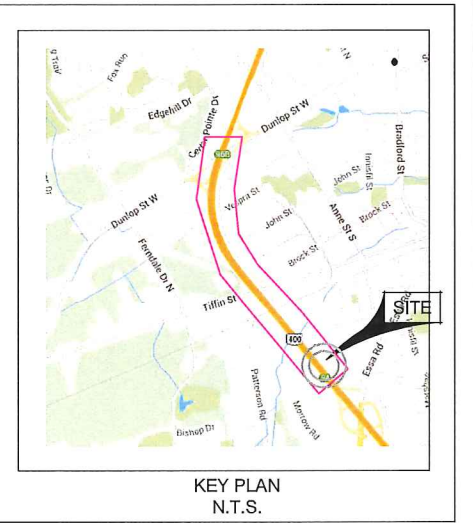
  
**Sanket Shah**, P. Eng.  
 Project Manager, Geotechnical Engineer







  
**Cam Mirza**, P. Eng.  
 MTO Designated Contact, Principal



Drawings



| LEGEND  |   |  |  |
|---|---|--|--|
|   | Borehole                                |  |  |
| N   | Blows/0.3m (Std. Pen. Test, 475 J/blow) |  |  |
|  | Water Level at Time of Investigation    |  |  |
|  | Water Level in Piezometer               |  |  |
|  | Piezometer                              |  |  |

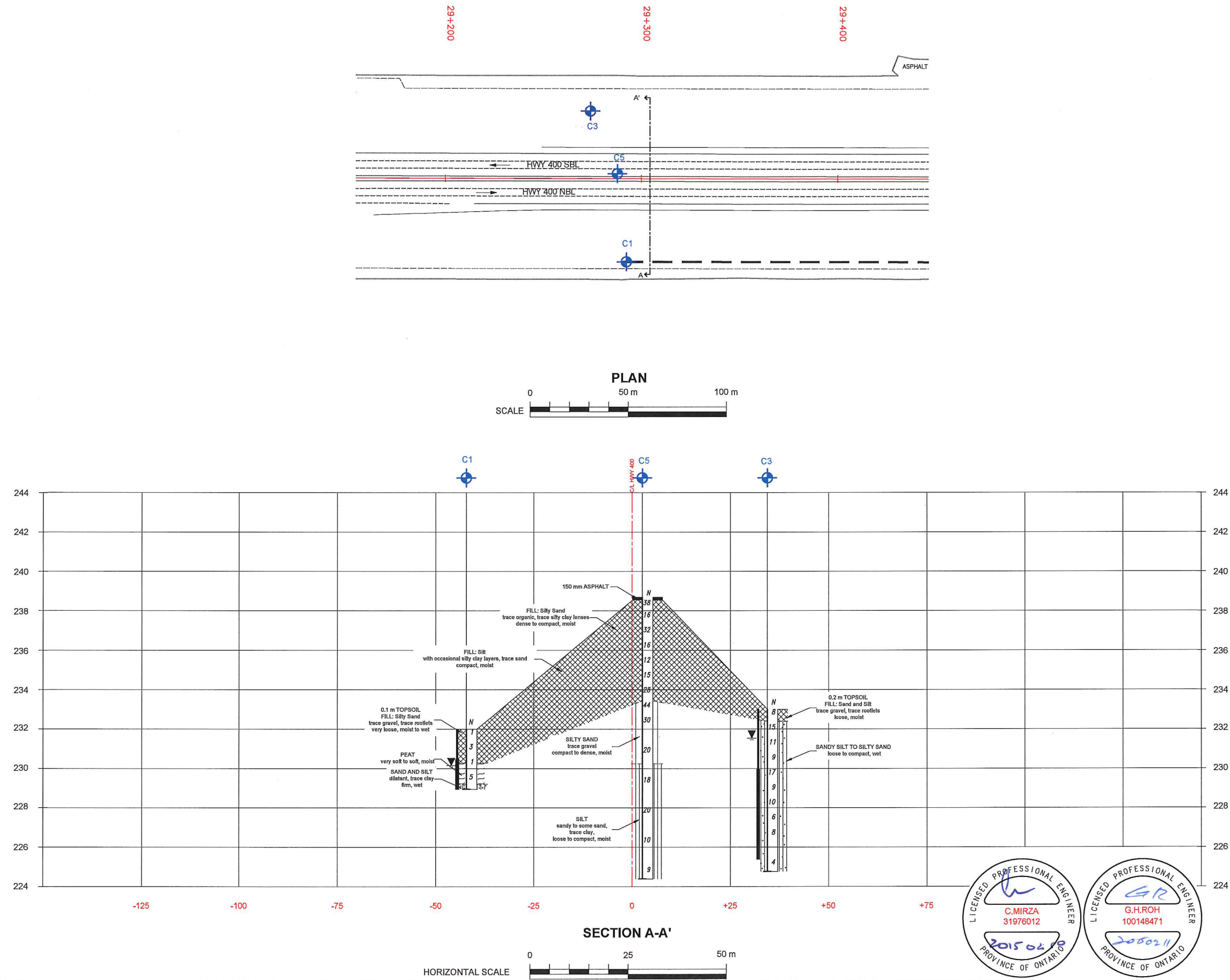
| No. | ELEVATION | NORTHING | EASTING   |
|-----|-----------|----------|-----------|
| C1  | 232.0     | 288578.9 | 4914237.9 |
| C3  | 233.0     | 288531.9 | 4914174.7 |
| C5  | 238.7     | 288547.5 | 4914205.6 |

-NOTE-

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

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

GEOCRES No. 31D-589PROJECT No. GEOTETO22161AA

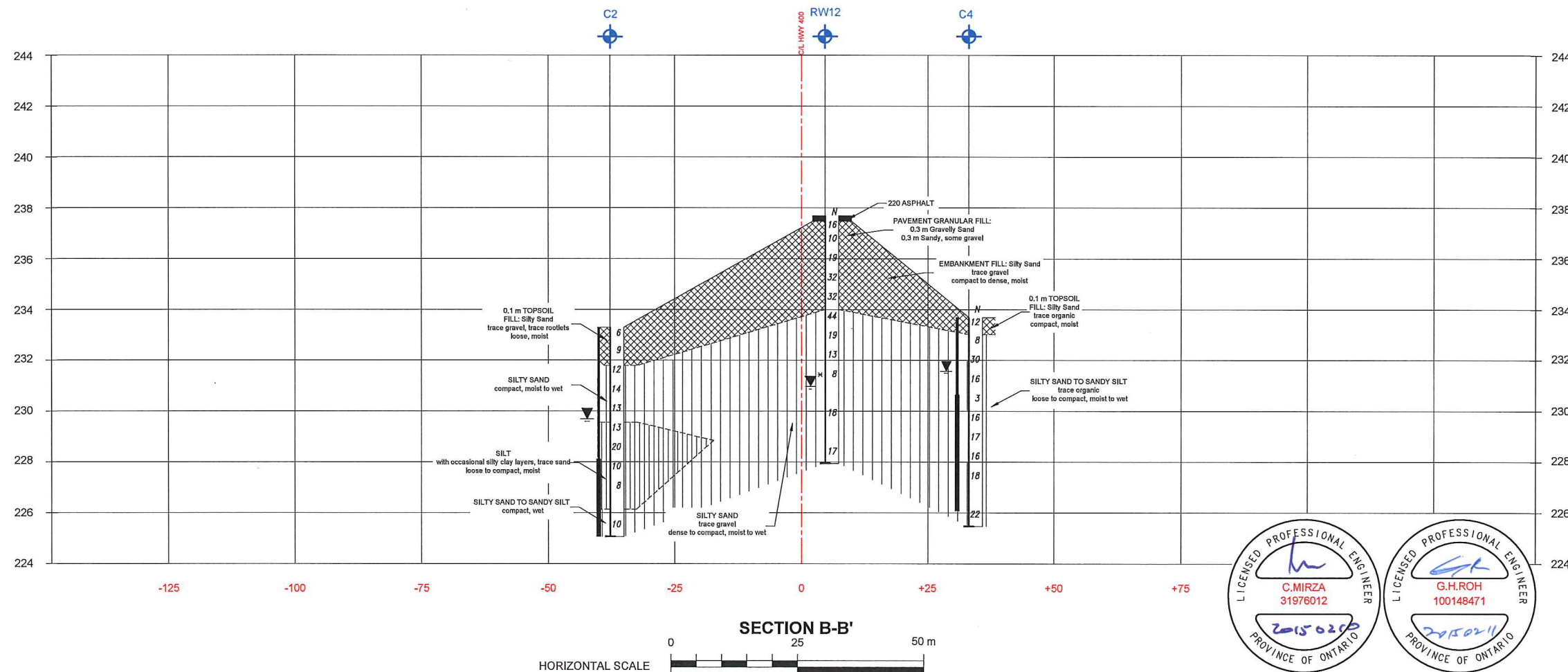
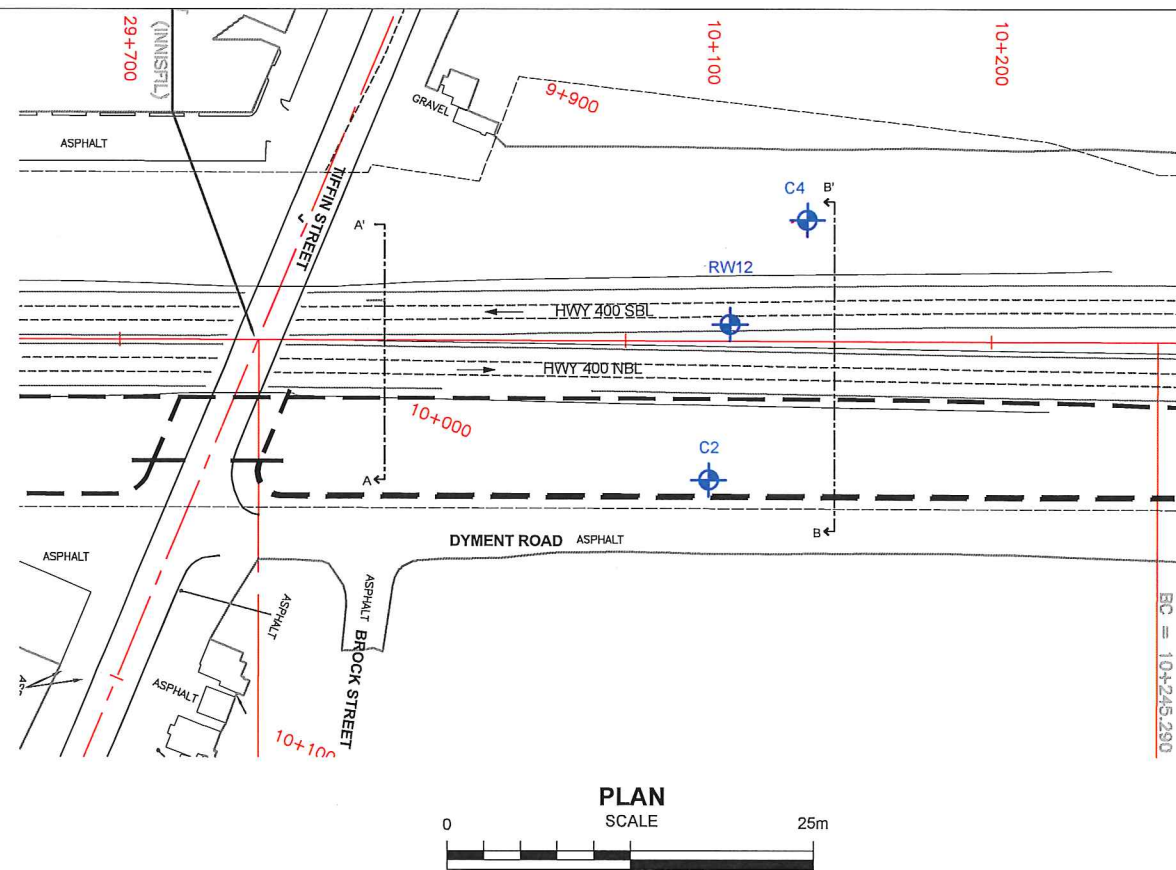


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| REVISIONS |     | DESCRIPTION |    |      |         |
|-----------|-----|-------------|----|------|---------|
| DESIGN    | GR  | CHK         | SH | CODE | LOAD    |
| DESIGN    | SSH | CHK         | CM | SITE | STRUCT  |
|           |     |             |    | DATE | Dec /14 |
|           |     |             |    | DWG  | DWG 1   |





DISTRICT  
CONT. No.  
WP No. -

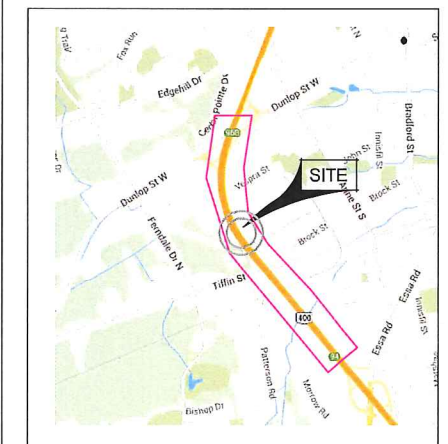


Highway 400 Culverts  
Extension/Replacement-RFOF,  
North of Tiffin Street  
Borehole Location Plan  
and Soil Strata

SHEET



METRIC



KEY PLAN  
N.T.S.

LEGEND

- Borehole
- Blows/0.3m (Std. Pen. Test, 475 J/blow)
- Water Level at Time of Investigation
- Water Level in Piezometer
- Piezometer

| No.  | ELEVATION | NORTHING | EASTING   |
|------|-----------|----------|-----------|
| C2   | 233.3     | 288212.1 | 4914672.0 |
| C4   | 233.7     | 288140.5 | 4914647.2 |
| RW12 | 237.7     | 288175.8 | 4914649.3 |

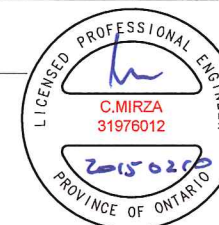
-NOTE-

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

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

GEOCRES No. 31D-589 PROJECT No. GEOTETO22161AA

| REVISIONS |     | DESCRIPTION |    |      |         |
|-----------|-----|-------------|----|------|---------|
| DESIGN    | GR  | CHK         | SH | CODE | LOAD    |
| DESIGN    | SSH | CHK         | CM | SITE | STRUCT  |
|           |     |             |    | DWG  | DWG 2   |
|           |     |             |    | DATE | Dec /14 |



# Appendix A

**Explanation of Terms Used in Report and  
Record of Borehole Sheets**



## EXPLANATION OF TERMS USED IN REPORT

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

**DYNAMIC CONE PENETRATION TEST:** CONTINUOUS PENETRATION OF A CONICAL STEEL POINT (51mm O.D. 60° CONE ANGLE) DRIVEN BY 475J IMPACT ENERGY ON 'A' SIZE DRILL RODS. THE RESISTANCE TO CONE PENETRATION IS MEASURED AS THE NUMBER OF BLOWS FOR EACH 0.3m ADVANCE OF THE CONICAL POINT INTO THE UNDISTURBED GROUND.

SOILS ARE DESCRIBED BY THEIR COMPOSITION AND CONSISTENCY OR DENSENESS.

**CONSISTENCY:** COHESIVE SOILS ARE DESCRIBED ON THE BASIS OF THEIR UNDRAINED SHEAR STRENGTH ( $c_u$ ) AS FOLLOWS:

| $C_u$ (kPa) | 0 – 12    | 12 – 25 | 25 – 50 | 50 – 100 | 100 – 200  | >200 |
|-------------|-----------|---------|---------|----------|------------|------|
|             | VERY SOFT | SOFT    | FIRM    | STIFF    | VERY STIFF | HARD |

**DENSENESS:** COHESIONLESS SOILS ARE DESCRIBED ON THE BASIS OF DENSENESS AS INDICATED BY SPT N VALUES AS FOLLOWS:

| N (BLOWS/0.3m) | 0 – 5      | 5 – 10 | 10 – 30 | 30 – 50 | >50        |
|----------------|------------|--------|---------|---------|------------|
|                | VERY LOOSE | LOOSE  | COMPACT | DENSE   | VERY DENSE |

ROCKS ARE DESCRIBED BY THEIR COMPOSITION AND STRUCTURAL FEATURES AND/OR STRENGTH.

**RECOVERY:** SUM OF ALL RECOVERED ROCK CORE PIECES FROM A CORING RUN EXPRESSED AS A PERCENT OF THE TOTAL LENGTH OF THE CORING RUN.

**MODIFIED RECOVERY:** SUM OF THOSE INTACT CORE PIECES, 100mm+ IN LENGTH EXPRESSED AS A PERCENT OF THE LENGTH OF THE CORING RUN. THE ROCK QUALITY DESIGNATION (RQD), FOR MODIFIED RECOVERY IS:

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

**JOINT AND BEDDING:**

| SPACING  | 50mm       | 50 – 300mm | 0.3m – 1m  | 1m – 3m | >3m        |
|----------|------------|------------|------------|---------|------------|
| JOINTING | VERY CLOSE | CLOSE      | MOD. CLOSE | WIDE    | VERY WIDE  |
| BEDDING  | VERY THIN  | THIN       | MEDIUM     | THICK   | VERY THICK |

## ABBREVIATIONS AND SYMBOLS

### FIELD SAMPLING

|    |                     |    |                           |
|----|---------------------|----|---------------------------|
| SS | SPLIT SPOON         | TP | THINWALL PISTON           |
| WS | WASH SAMPLE         | OS | OSTERBERG SAMPLE          |
| ST | SLOTTED TUBE SAMPLE | RC | ROCK CORE                 |
| BS | BLOCK SAMPLE        | PH | TW ADVANCED HYDRAULICALLY |
| CS | CHUNK SAMPLE        | PM | TW ADVANCED MANUALLY      |
| TW | THINWALL OPEN       | FS | FOIL SAMPLE               |

### STRESS AND STRAIN

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

### MECHANICAL PROPERTIES OF SOIL

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

## PHYSICAL PROPERTIES OF SOIL

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

GEOTETOB22161AA: Hwy 400/ Tiffin Street

# RECORD OF BOREHOLE No BH C1

1 OF 1

METRIC

GWP 2074-11-00 LOCATION 29+288, 42.4 m Rt C/L (N 4914237.9, E 288578.9) ORIGINATED BY JD  
DIST HWY 400 BOREHOLE TYPE Hollow Stem Auger COMPILED BY MP  
DATUM Geodetic DATE 06/10/2014 CHECKED BY SH

| SOIL PROFILE   |  |            | SAMPLES |      |            | GROUND WATER<br>CONDITIONS | ELEVATION SCALE | DYNAMIC CONE PENETRATION<br>RESISTANCE PLOT |    |    |    |     | UNIT<br>WEIGHT<br>$\gamma$<br>kN/m <sup>3</sup> | REMARKS<br>&<br>GRAIN SIZE<br>DISTRIBUTION<br>(%) |
|--|--|------------|---------|------|------------|----------------------------|-----------------|---|----|----|----|-----|---|---|
| ELEV<br>DEPTH  | DESCRIPTION  | STRAT PLOT | NUMBER  | TYPE | "N" VALUES |                            |                 | 20  | 40 | 60 | 80 | 100 |   |   |
| 232.0<br>0.0   | GROUND SURFACE   |            |         |      |            |                            | 232             |   |    |    |    |     |   |   |
|  | 0.1 m TOPSOIL<br>FILL: Silty Sand<br>trace gravel, trace rootlets<br>brown, very loose, moist to wet |            | 1       | SS   | 1          |                            | 232             |   |    |    |    |     |   |   |
|  |  |            | 2       | SS   | 3          |                            | 231             |   |    |    |    |     |   |   |
| 230.3<br>1.7   | PEAT   |            | 3       | SS   | 1          |                            | 230             |   |    |    |    |     |   |   |
|  | dark grey to dark brown, very soft to soft, moist  |            | 4       | SS   | 5          |                            | 229             |   |    |    |    |     |   |   |
| 229.2<br>2.8   | SAND AND SILT  |            |         |      |            |                            |                 |   |    |    |    |     |   |   |
| 229.0<br>3.1   | dilatant, trace clay<br>grey, firm, wet  |            |         |      |            |                            |                 |   |    |    |    |     |   |   |
| End of Borehole<br>Piezometer installed to 3.1 m.<br>Piezometer water level records :<br>Oct. 31, 2014 1.8 m (El. 230.2 m) |  |            |         |      |            |                            |                 |   |    |    |    |     |   |   |

GEOTETO22161AA: Hwy 400/ Tiffin Street

# RECORD OF BOREHOLE No BH C2

1 OF 1

METRIC

GWP 2074-11-00 LOCATION 10+123, 37.8 Rt C/L (N 4914672.0, E 288212.1) ORIGINATED BY JD  
DIST HWY 400 BOREHOLE TYPE Hollow Stem Auger COMPILED BY MP  
DATUM Geodetic DATE 06/10/2014 CHECKED BY SH

| SOIL PROFILE   |  |            | SAMPLES |      |            | GROUND WATER<br>CONDITIONS | ELEVATION SCALE | DYNAMIC CONE PENETRATION<br>RESISTANCE PLOT |                 |                 |                 |                 | UNIT<br>WEIGHT<br>$\gamma$<br>kN/m <sup>3</sup> | REMARKS<br>&<br>GRAIN SIZE<br>DISTRIBUTION<br>(%) |
|----------------|--|------------|---------|------|------------|----------------------------|-----------------|---|-----------------|-----------------|-----------------|-----------------|---|---|
| ELEV.<br>DEPTH | DESCRIPTION  | STRAT PLOT | NUMBER  | TYPE | "N" VALUES |                            |                 | 20 40 60 80 100                             | 20 40 60 80 100 | 20 40 60 80 100 | 20 40 60 80 100 | 20 40 60 80 100 |   |   |
| 233.3<br>0.0   | GROUND SURFACE   |            | 1       | SS   | 6          |                            | 233             |   |                 |                 |                 |                 |   |   |
|                | 0.1 m TOPSOIL<br>FILL: Silty Sand<br>trace gravel, trace rootlets<br>brown, loose, moist                                   |            | 2       | SS   | 9          |                            | 232             |   |                 |                 |                 |                 |   |   |
| 231.8<br>1.5   | SILTY SAND<br>grey, compact, moist to wet  |            | 3       | SS   | 12         |                            | 231             |   |                 |                 |                 |                 |   |   |
|                |  |            | 4       | SS   | 14         |                            | 230             |   |                 |                 |                 |                 |   |   |
|                |  |            | 5       | SS   | 13         |                            | 229             |   |                 |                 |                 |                 |   |   |
| 229.6<br>3.7   | SILT<br>with occasional silty clay layers, trace sand<br>moist, loose to compact   |            | 6       | SS   | 13         |                            | 228             |   |                 |                 |                 |                 |   |   |
|                |  |            | 7       | SS   | 20         |                            | 227             |   |                 |                 |                 |                 |   |   |
|                |  |            | 8       | SS   | 10         |                            | 226             |   |                 |                 |                 |                 |   |   |
|                |  |            | 9       | SS   | 8          |                            |                 |   |                 |                 |                 |                 |   |   |
| 226.1<br>7.2   | SILTY SAND TO SANDY SILT<br>grey, compact, wet   |            | 10      | SS   | 10         |                            |                 |   |                 |                 |                 |                 |   |   |
| 225.1<br>8.2   | End of Borehole<br>Piezometer installed to 8.2 m.<br>Piezometer water level records :<br>Oct. 31, 2014 3.6 m (El. 229.7 m) |            |         |      |            |                            |                 |   |                 |                 |                 |                 |   |   |

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to  
Sensitivity

20  
15  
10  
(%) STRAIN AT FAILURE

GEOTETO22161AA: Hwy 400/ Tiffin Street

# RECORD OF BOREHOLE No BH C3

1 OF 1

METRIC

GWP 2074-11-00 LOCATION 29+274, 34.3 m Lt C/L (N 4914174.7, E 288531.9) ORIGINATED BY LG  
DIST HWY 400 BOREHOLE TYPE Hollow Stem Auger COMPILED BY MP  
DATUM Geodetic DATE 16/10/2014 CHECKED BY SH

| SOIL PROFILE   |   |            | SAMPLES |      |            | GROUND WATER<br>CONDITIONS | ELEVATION SCALE | DYNAMIC CONE PENETRATION<br>RESISTANCE PLOT  |  |  | UNIT<br>WEIGHT<br><br>$\gamma$<br>kN/m <sup>3</sup> | REMARKS<br>&<br>GRAIN SIZE<br>DISTRIBUTION<br>(%)<br><br>GR SA SI CL |
|----------------|---|------------|---------|------|------------|----------------------------|-----------------|--|--|--|---|--|
| ELEV.<br>DEPTH | DESCRIPTION   | STRAT PLOT | NUMBER  | TYPE | "N" VALUES |                            |                 | SHEAR STRENGTH (kPa)<br>○ UNCONFINED    + FIELD VANE<br>● POCKET PENETR.    × LAB VANE |  |  |   |  |
| 233.0          | GROUND SURFACE  |            |         |      |            |                            |                 | 20 40 60 80 100  |  |  |   |  |
| 0.0            | 0.2 m TOPSOIL<br>FILL: Sand and Silt<br>trace gravel, trace rootlets<br>brown to grey, loose, moist   |            | 1       | SS   | 8          |                            | 233             |  |  |  |   |  |
| 232.4          |   |            |         |      |            |                            |                 |  |  |  |   |  |
| 0.6            | SANDY SILT TO SILTY SAND<br>brown to grey, loose to compact, wet  |            | 2       | SS   | 15         |                            | 232             |  |  |  |   |  |
|                |   |            |         |      |            |                            |                 |  |  |  |   |  |
|                |   |            | 3       | SS   | 11         |                            | 231             |  |  |  |   | wet spoon<br>0 57 38 5   |
|                |   |            |         |      |            |                            |                 |  |  |  |   |  |
|                |   |            | 4       | SS   | 9          |                            | 230             |  |  |  |   |  |
|                |   |            |         |      |            |                            |                 |  |  |  |   |  |
|                | silt<br>trace to some sand, trace clay<br>brown, compact to loose, wet  |            | 5       | SS   | 17         |                            | 229             |  |  |  |   | 0 8 86 6   |
|                |   |            |         |      |            |                            |                 |  |  |  |   |  |
|                |   |            | 6       | SS   | 9          |                            | 228             |  |  |  |   |  |
|                |   |            |         |      |            |                            |                 |  |  |  |   |  |
|                |   |            | 7       | SS   | 10         |                            | 227             |  |  |  |   |  |
|                |   |            |         |      |            |                            |                 |  |  |  |   |  |
|                |   |            | 8       | SS   | 6          |                            | 226             |  |  |  |   |  |
|                |   |            |         |      |            |                            |                 |  |  |  |   |  |
|                |   |            | 9       | SS   | 8          |                            | 225             |  |  |  |   |  |
|                |   |            |         |      |            |                            |                 |  |  |  |   |  |
|                | silt<br>some sand, trace clay<br>grey, very loose, wet  |            | 10      | SS   | 4          |                            |                 |  |  |  |   |  |
| 224.8          |   |            |         |      |            |                            |                 |  |  |  |   |  |
| 8.2            | End of Borehole<br>cave-in @ 1.8 m<br>Piezometer installed to 7.6 m.<br>Piezometer water level records :<br>Oct. 31, 2014    1.5 m    (El. 231.5 m) |            |         |      |            |                            |                 |  |  |  |   |  |

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to Sensitivity 20 15 10 5 (%) STRAIN AT FAILURE

GEOTETOB22161AA: Hwy 400/ Tiffin Street

## 1 OF 1

METRIC

|       |            |               |  |               |    |
|-------|------------|---------------|--|---------------|----|
| GWP   | 2074-11-00 | LOCATION      | 10+150, 33.1 m Lt C/L (N 4914647.2, E288140.5) | ORIGINATED BY | LG |
| DIST  | HWY 400    | BOREHOLE TYPE | Hollow Stem Auger                              | COMPILED BY   | MP |
| DATUM | Geodetic   | DATE          | 27/10/2014                                     | CHECKED BY    | SH |

[illegible]

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to Sensitivity

GEOTETOB22161AA: Hwy 400/ Tiffin Street

# RECORD OF BOREHOLE No BH C5

1 OF 1

METRIC

GWP 2074-11-00 LOCATION 29+288, 2.6 m Lt C/L (N 4914205.6, E 288547.5) ORIGINATED BY JD  
DIST HWY 400 BOREHOLE TYPE Hollow Stem Auger COMPILED BY MP  
DATUM Geodetic DATE 16/10/2014 CHECKED BY SH

| SOIL PROFILE   |  |            | SAMPLES |      |            | GROUND WATER<br>CONDITIONS | ELEVATION SCALE | DYNAMIC CONE PENETRATION<br>RESISTANCE PLOT |                 |                                    |                                     | UNIT<br>WEIGHT<br>$\gamma$<br>kN/m <sup>3</sup> | REMARKS<br>&<br>GRAIN SIZE<br>DISTRIBUTION<br>(%) |
|----------------|--|------------|---------|------|------------|----------------------------|-----------------|---|-----------------|------------------------------------|-------------------------------------|---|---|
| ELEV.<br>DEPTH | DESCRIPTION  | STRAT PLOT | NUMBER  | TYPE | "N" VALUES |                            |                 | 20 40 60 80 100                             | 20 40 60 80 100 | PLASTIC<br>LIMIT<br>W <sub>P</sub> | NATURAL<br>MOISTURE<br>CONTENT<br>W | LIQUID<br>LIMIT<br>W <sub>L</sub>               |   |
| 238.7          | GROUND SURFACE   |            |         |      |            |                            |                 |   |                 |                                    |                                     |   |   |
| 238.6          | 150 mm ASPHALT   |            |         |      |            |                            |                 |   |                 |                                    |                                     |   |   |
| 0.2            | 0.5 m gravelly sand  |            | 1       | SS   | 38         |                            | 238             |   |                 |                                    |                                     |   |   |
|                | FILL: Silty Sand<br>trace organic, trace silty clay lenses<br>brown, dense to compact, moist |            | 2       | SS   | 16         |                            |                 |   |                 |                                    |                                     |   |   |
|                |  |            | 3       | SS   | 32         |                            | 237             |   |                 |                                    |                                     |   |   |
| 236.1          | 2.6  |            | 4       | SS   | 16         |                            | 236             |   |                 |                                    |                                     |   |   |
|                | silty clay, very stiff   |            | 5       | SS   | 12         |                            |                 |   |                 |                                    |                                     |   |   |
|                | FILL: Silt<br>with occasional silty clay layers, trace sand<br>grey to brown, compact, moist |            | 6       | SS   | 15         |                            | 235             |   |                 |                                    |                                     |   |   |
|                |  |            | 7       | SS   | 28         |                            | 234             |   |                 |                                    |                                     |   |   |
| 233.4          | 5.3  |            | 8       | SS   | 44         |                            | 233             |   |                 |                                    |                                     |   |   |
|                | SILTY SAND<br>trace gravel<br>brown to grey, compact to dense, moist                         |            | 9       | SS   | 30         |                            | 232             |   |                 |                                    |                                     |   |   |
|                |  |            | 10      | SS   | 20         |                            | 231             |   |                 |                                    |                                     |   |   |
| 230.2          | 8.5  |            | 11      | SS   | 18         |                            | 230             |   |                 |                                    |                                     |   |   |
|                | SILT<br>sandy to some sand, trace clay<br>grey, loose to compact, moist                      |            | 12      | SS   | 20         |                            | 229             |   |                 |                                    |                                     |   |   |
|                |  |            | 13      | SS   | 10         |                            | 228             |   |                 |                                    |                                     |   |   |
|                |  |            | 14      | SS   | 9          |                            | 227             |   |                 |                                    |                                     |   |   |
| 224.4          | 14.3   |            |         |      |            |                            | 226             |   |                 |                                    |                                     |   |   |
|                | End of Borehole  |            |         |      |            |                            | 225             |   |                 |                                    |                                     |   |   |

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to Sensitivity 20 15 10 5 (%) STRAIN AT FAILURE

GEOTETO22161AA: Hwy 400/ Tiffin Street

# RECORD OF BOREHOLE No BH RW12

1 OF 1

METRIC

GWP 2074-11-00 LOCATION 10+129, 4.5 m Lt C/L (N 4914649.3, E 288175.8) ORIGINATED BY LG  
 DIST HWY 400 BOREHOLE TYPE Hollow Stem Auger COMPILED BY MP  
 DATUM Geodetic DATE 14/10/2014 CHECKED BY SH

| SOIL PROFILE   |   |            | SAMPLES |      |            | GROUND WATER<br>CONDITIONS | ELEVATION SCALE | DYNAMIC CONE PENETRATION<br>RESISTANCE PLOT |    |    |    |     | UNIT<br>WEIGHT<br>$\gamma$<br>kN/m <sup>3</sup> | REMARKS<br>&<br>GRAIN SIZE<br>DISTRIBUTION<br>(%) |
|----------------|---|------------|---------|------|------------|----------------------------|-----------------|---|----|----|----|-----|---|---|
| FLEV.<br>DEPTH | DESCRIPTION   | STRAT PLOT | NUMBER  | TYPE | "N" VALUES |                            |                 | 20  | 40 | 60 | 80 | 100 |   |   |
| 237.7          | GROUND SURFACE  |            |         |      |            |                            |                 |   |    |    |    |     |   |   |
| 230.9<br>0.2   | 220 mm ASPHALT  |            |         |      |            |                            |                 |   |    |    |    |     |   |   |
|                | PAVEMENT GRANULAR FILL:<br>0.3 m Gravelly Sand<br>0.3 m Sandy, some gravel    |            | 1       | SS   | 16         |                            | 237             |   |    |    |    |     |   |   |
|                | EMBANKMENT FILL: Silty Sand<br>trace gravel<br>brown, compact to dense, moist |            | 2       | SS   | 10         |                            |                 |   |    |    |    |     |   |   |
|                |   |            | 3       | SS   | 19         |                            | 236             |   |    |    |    |     |   |   |
|                |   |            | 4       | SS   | 32         |                            | 235             |   |    |    |    |     |   |   |
|                |   |            | 5       | SS   | 32         |                            |                 |   |    |    |    |     |   |   |
| 234.0<br>3.7   | SILTY SAND<br>trace gravel<br>brown to grey, dense to compact<br>moist to wet |            | 6       | SS   | 44         |                            | 234             |   |    |    |    |     |   |   |
|                |   |            | 7       | SS   | 19         |                            | 233             |   |    |    |    |     |   |   |
|                |   |            | 8       | SS   | 13         |                            | 232             |   |    |    |    |     |   |   |
|                |   |            | 9       | SS   | 8          |                            | 231             |   |    |    |    |     |   |   |
|                |   |            | 11      | SS   | 18         |                            | 230             |   |    |    |    |     |   |   |
|                |   |            | 12      | SS   | 17         |                            | 229             |   |    |    |    |     |   |   |
| 228.0<br>9.8   | End of Borehole<br>Water level @ 6.7 m (not stabilized)* upon<br>completion.  |            |         |      |            |                            | 228             |   |    |    |    |     |   |   |

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to  
Sensitivity

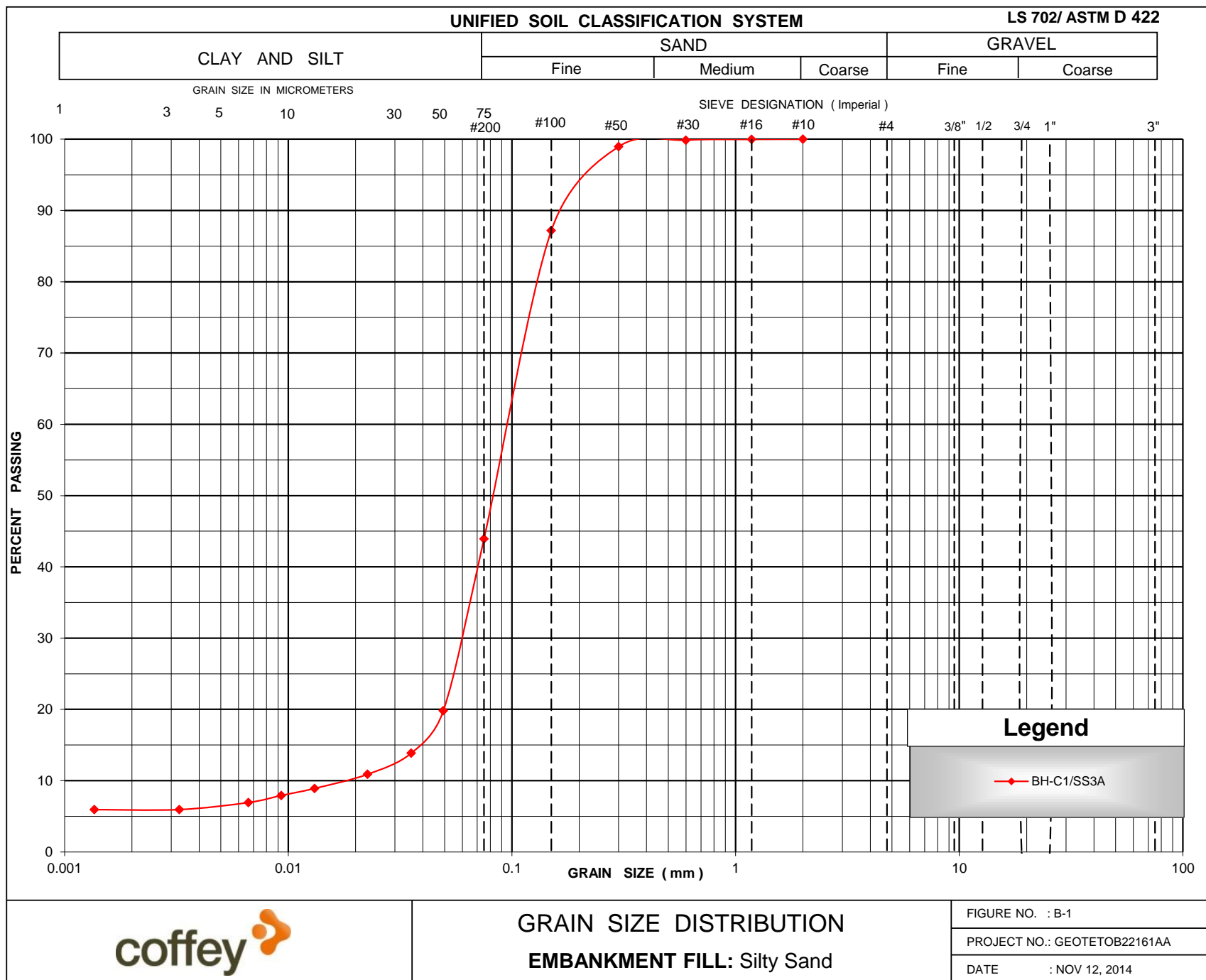
20  
15  
10

(%) STRAIN AT FAILURE

# Appendix B

## Laboratory Test Results

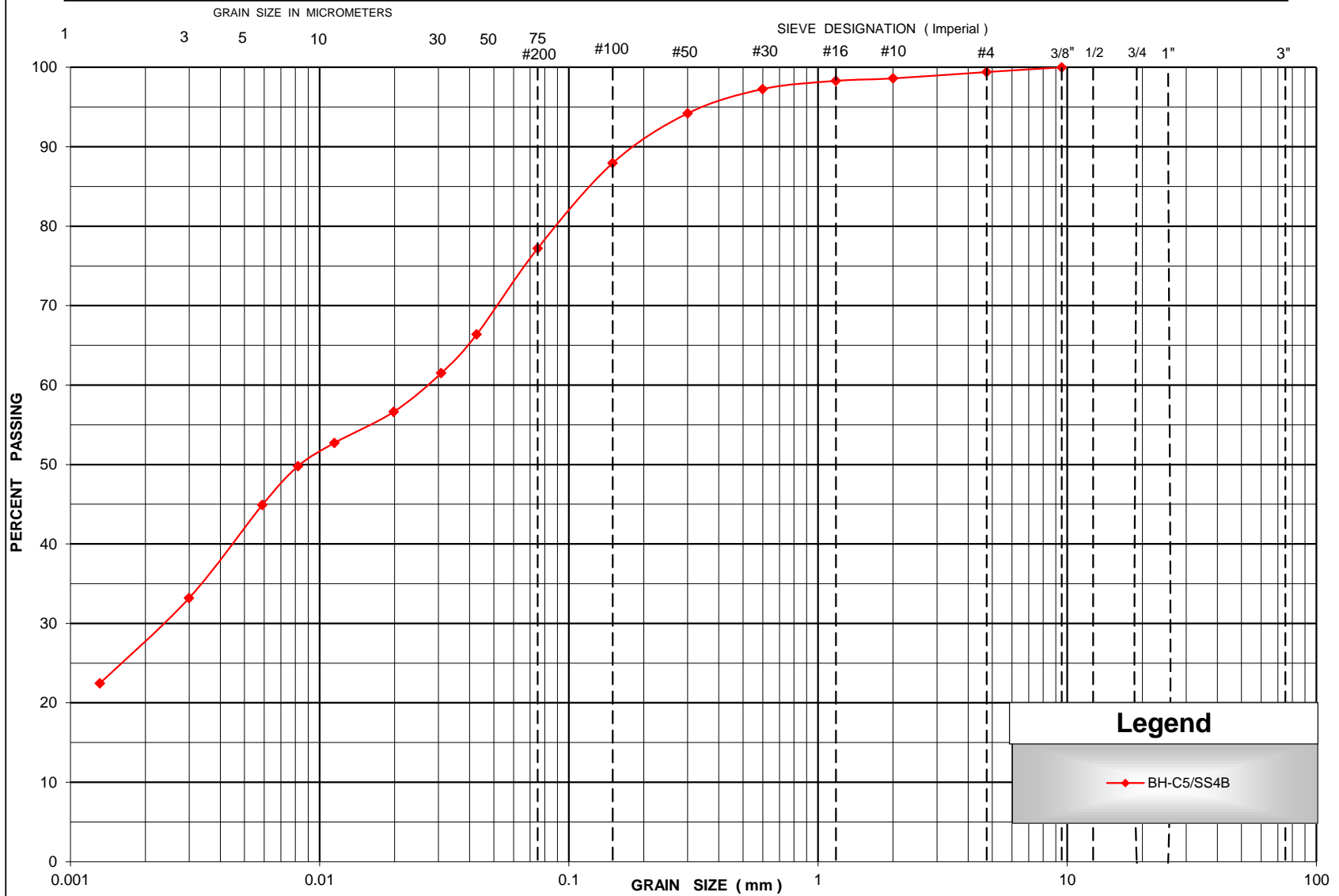




# UNIFIED SOIL CLASSIFICATION SYSTEM

LS 702/ ASTM D 422

| CLAY AND SILT | SAND |        |        | GRAVEL |        |
|---------------|------|--------|--------|--------|--------|
|               | Fine | Medium | Coarse | Fine   | Coarse |

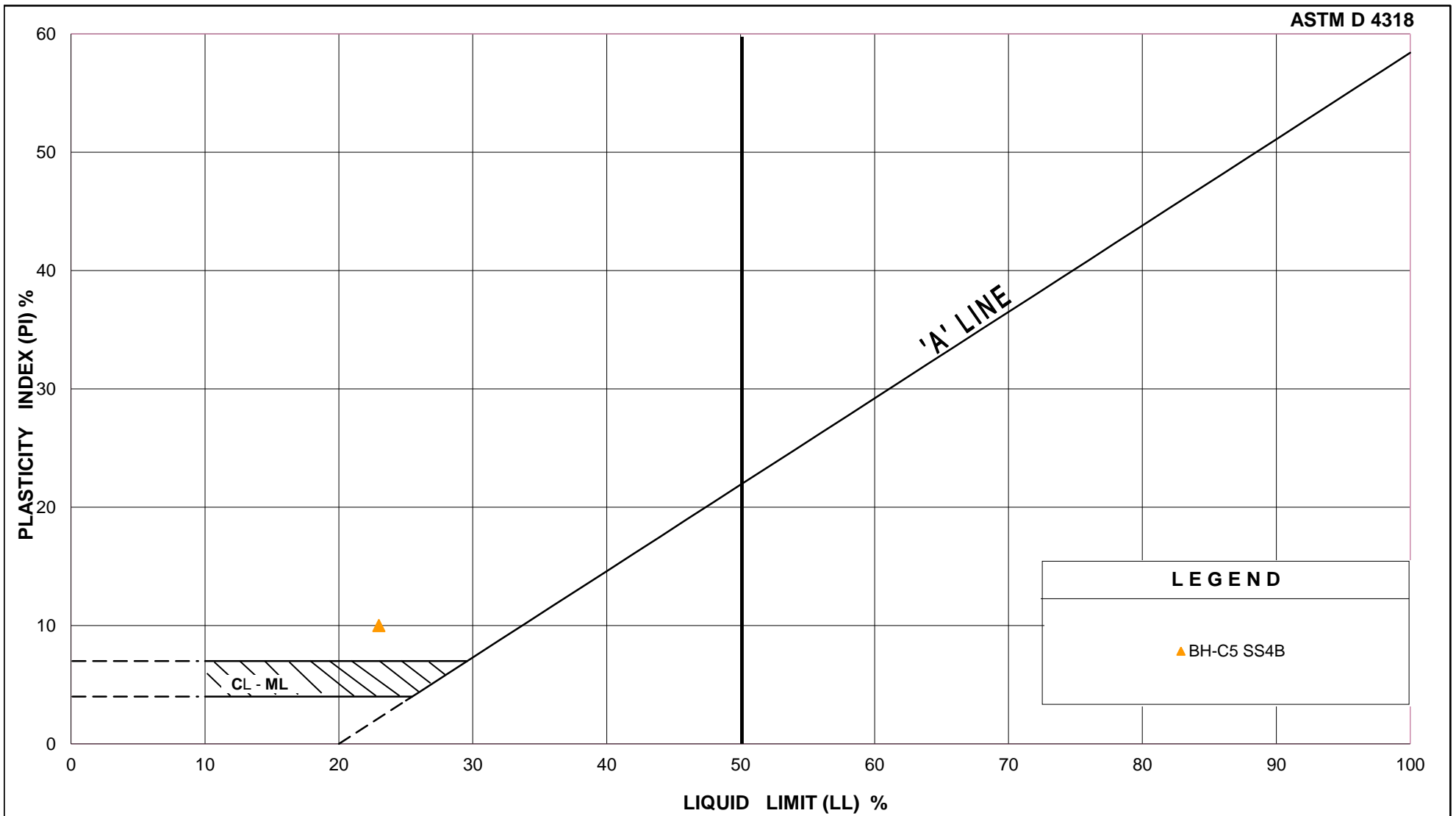


GRAIN SIZE DISTRIBUTION  
EMBANKMENT FILL: Silty Clay

FIGURE NO. : B-2

PROJECT NO.: GEOTETO22161AA

DATE : NOV 17, 2014



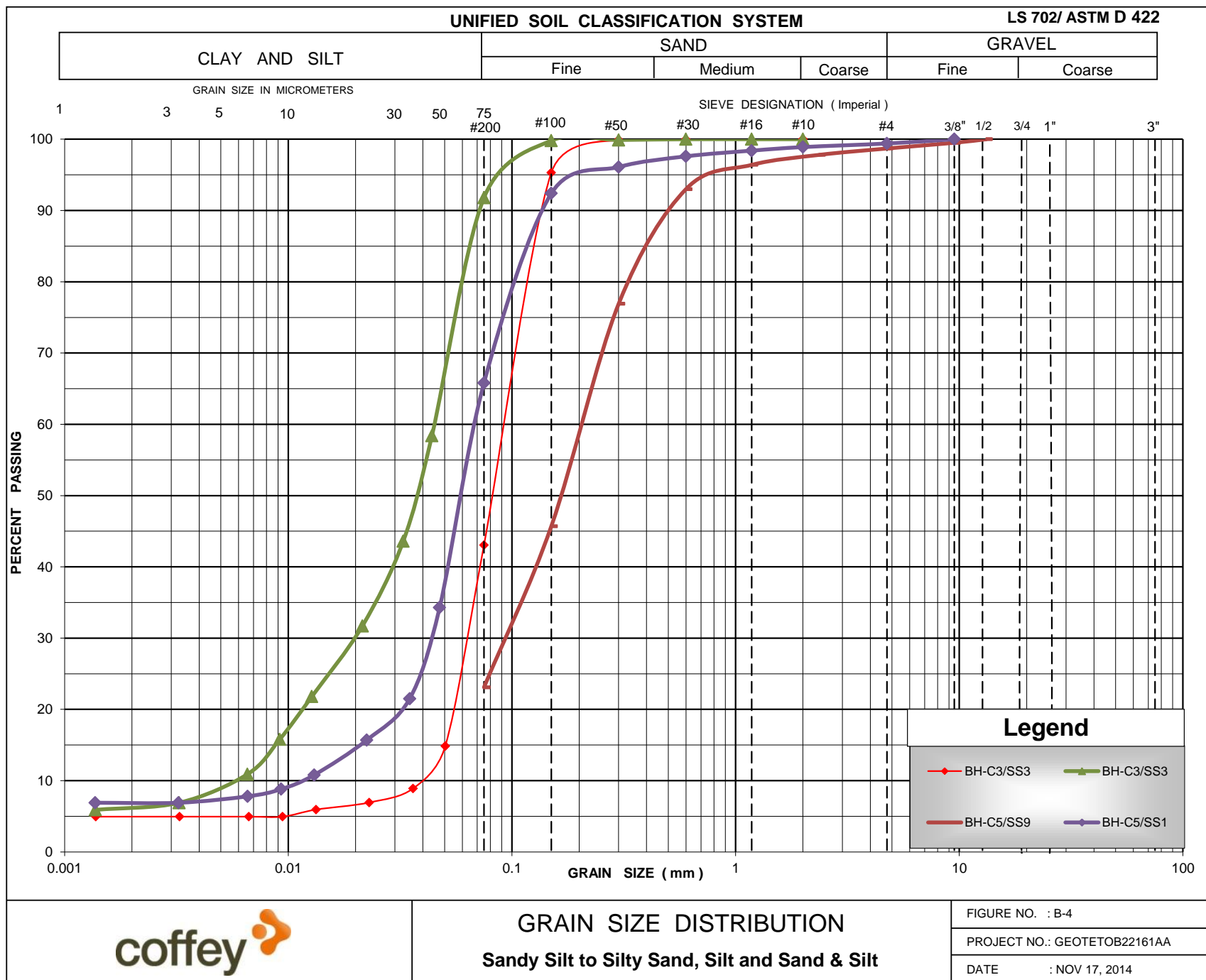
**PLASTICITY CHART**

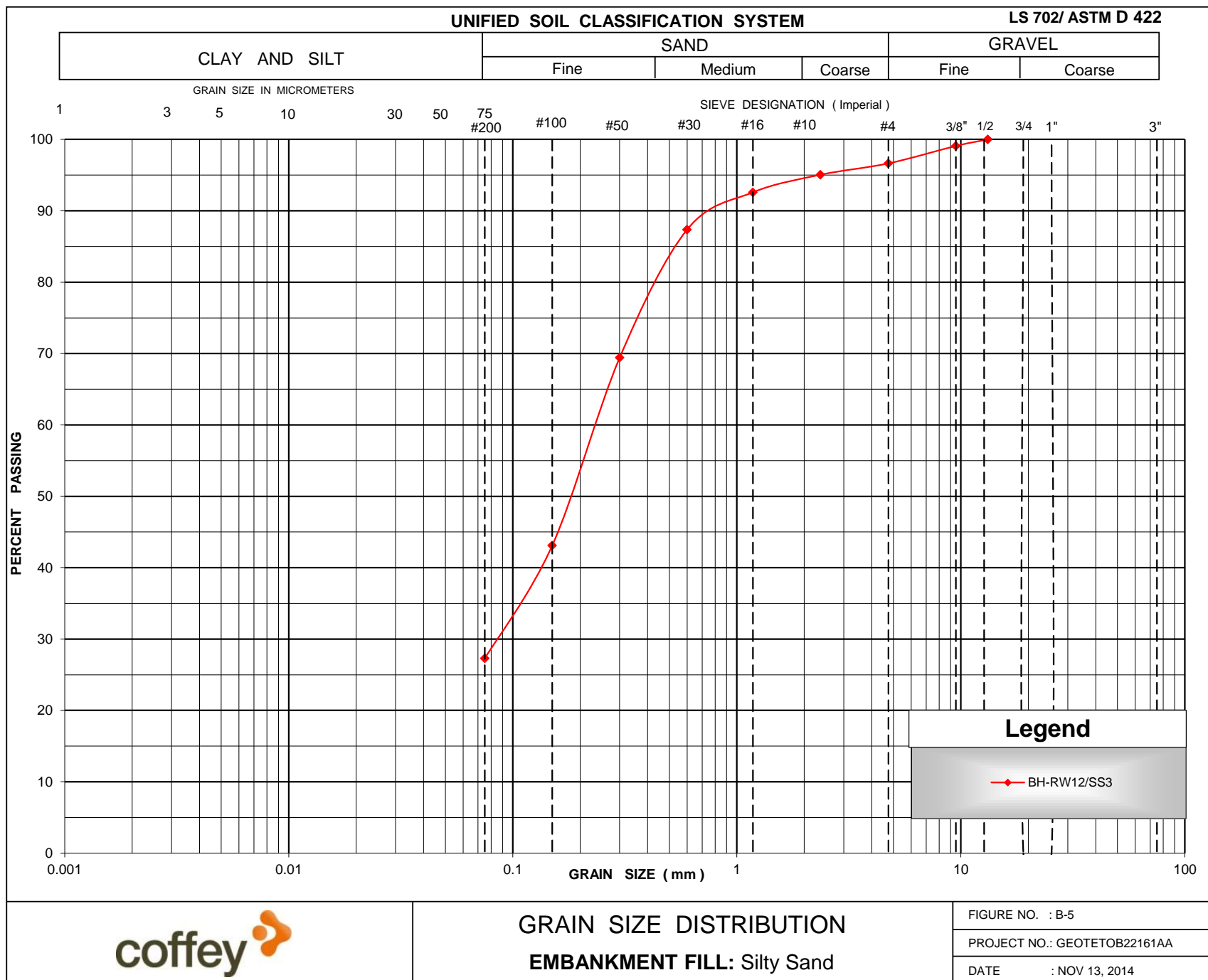
**EMBANKMENT FILL: Silty Clay**

Figure No. : B-3

Project No.: GEOTETOB22161AA

Date : NOV 19, 2014



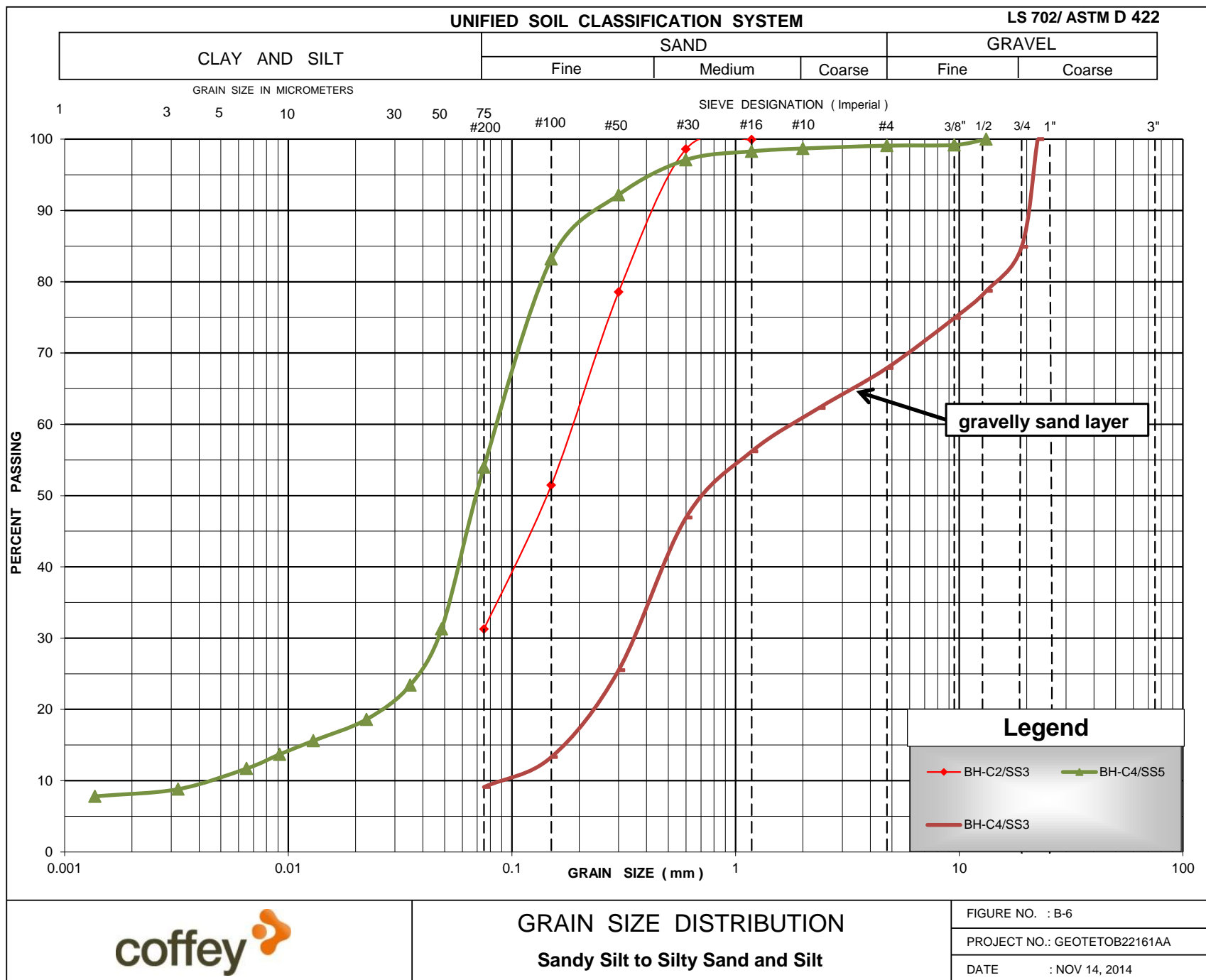


**GRAIN SIZE DISTRIBUTION**  
**EMBANKMENT FILL: Silty Sand**

FIGURE NO. : B-5

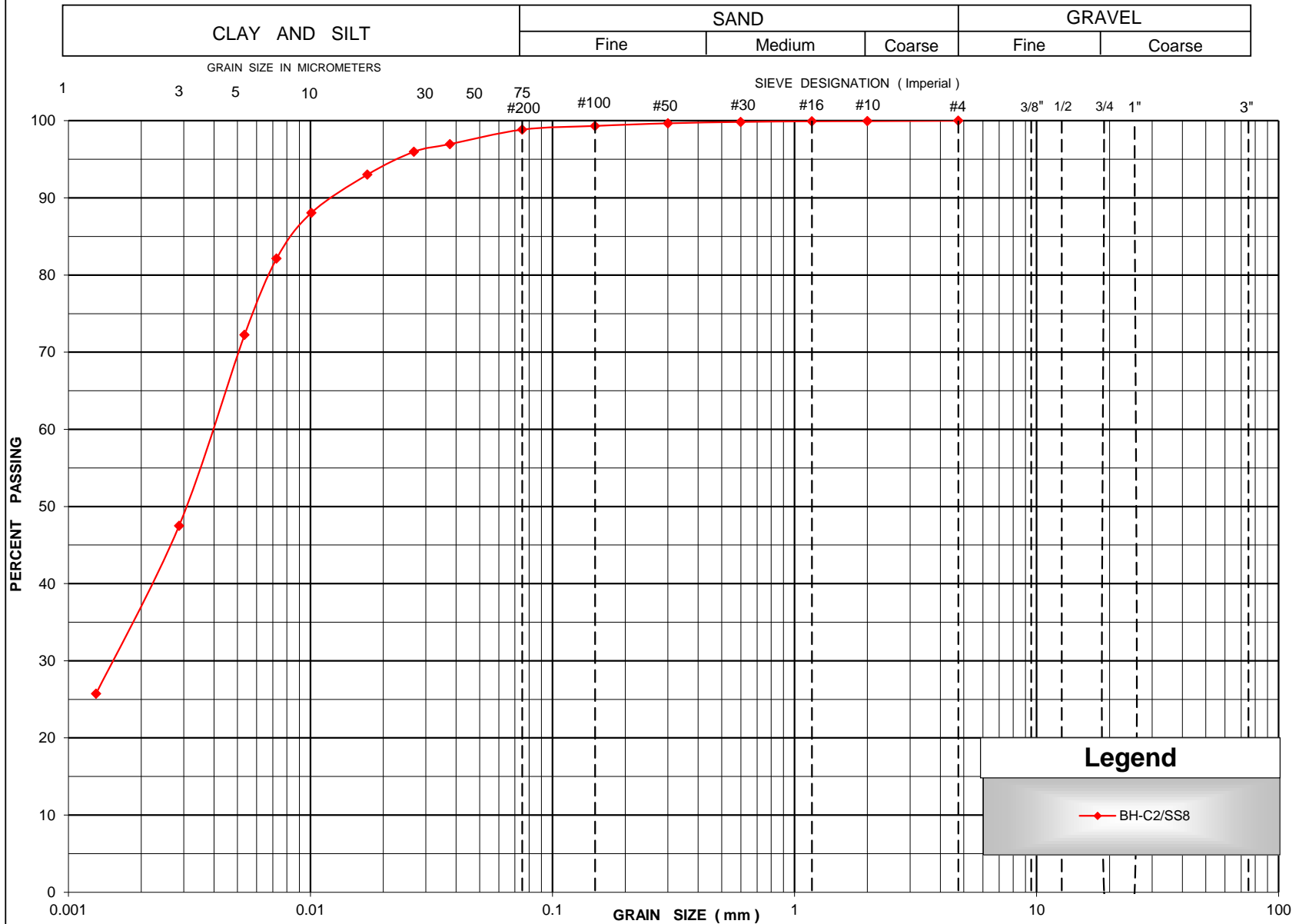
PROJECT NO.: GEOTETO22161AA

DATE : NOV 13, 2014



# UNIFIED SOIL CLASSIFICATION SYSTEM

LS 702/ ASTM D 422



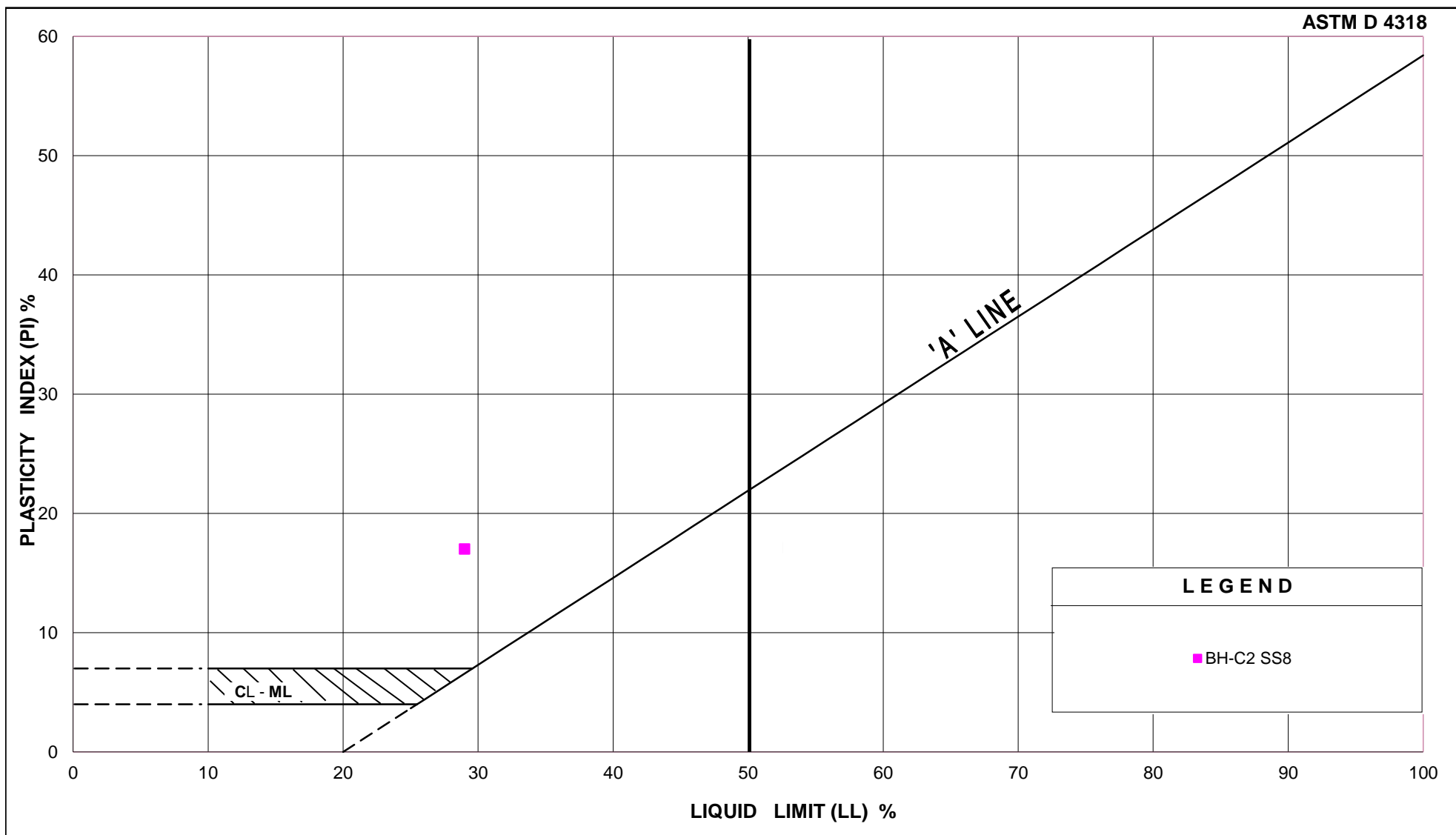
## GRAIN SIZE DISTRIBUTION

### Silty Clay

FIGURE NO. : B-7

PROJECT NO.: GEOTETO22161AA

DATE : NOV 17, 2014



## PLASTICITY CHART

**Silty Clay**

Figure No. : B-8

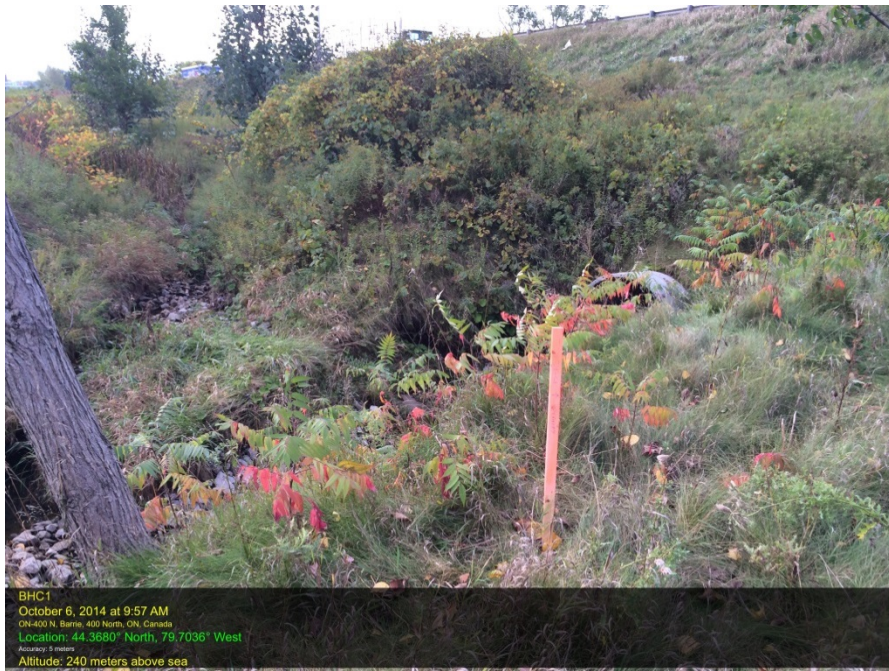
Project No.: GEOTETOB22161AA

Date : NOV 19, 2014



# Appendix C

## Site Photographs



**Photograph 1: Borehole C1 @ Station 29+288, Looking South-West**



**Photograph 2: Borehole C2 @ Station 10+123, Looking North-East**

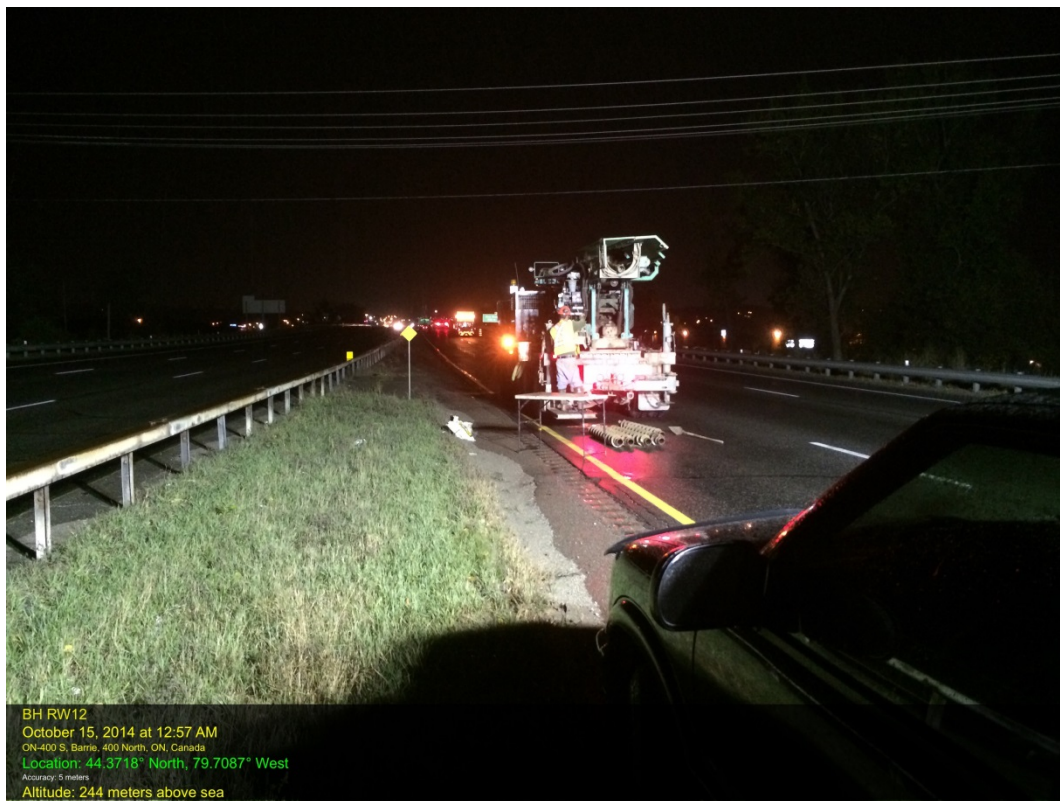




**Photograph 3: Borehole C3 @ Station 29+274, Looking South-West**



**Photograph 4: Borehole C4 @ Station 10+150, Looking South-East**



BH RW12  
October 15, 2014 at 12:57 AM  
ON-400 S, Barrie, 400 North, ON, Canada  
Location: 44.3718° North, 79.7087° West  
Accuracy: 5 meters  
Altitude: 244 meters above sea

**Photograph 5: Borehole RW12 @ Station 10+129, Looking South**





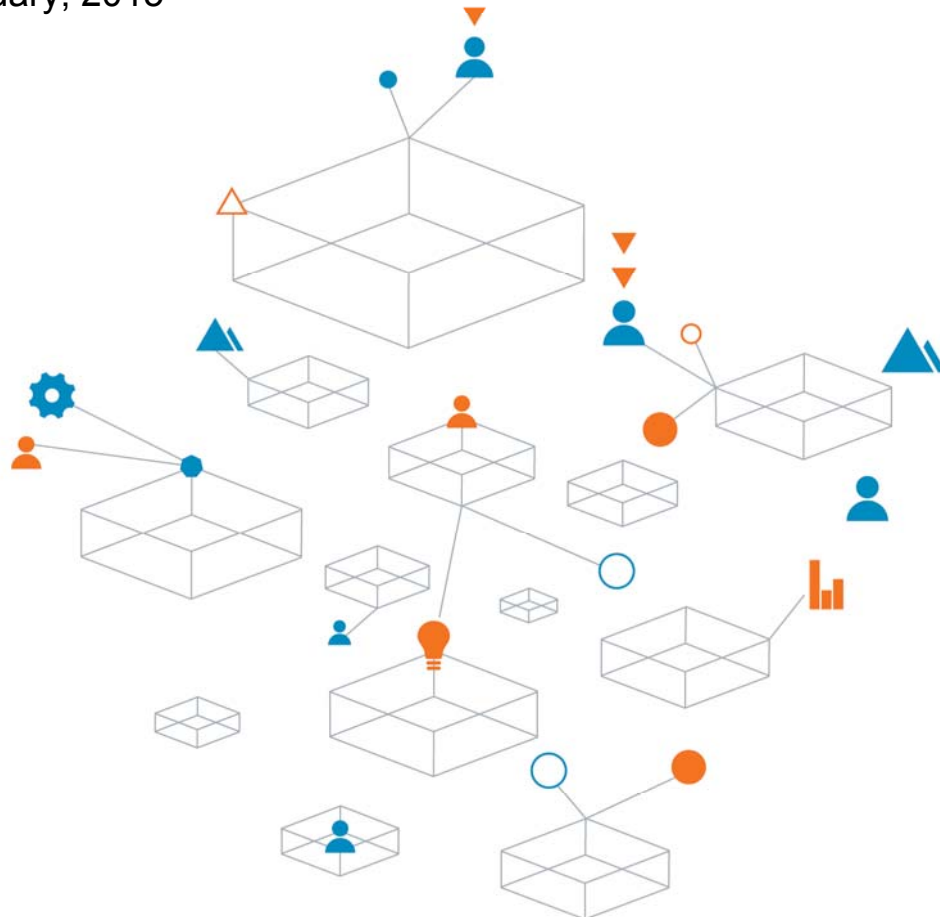
## **Preliminary Foundation Design Report**

Highway 400 Culverts - Extension/Replacement - CSP, South of BCR  
and RFOF, North of Tiffin Street, G.W.P. 2074-11-00

Design-Build Ready Package, GEOCRES No. 31D-589

GEOTETOB22161AA

11 February, 2015



Trust is the  
cornerstone  
of all our  
projects

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## Appendices

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**PRELIMINARY FOUNDATION DESIGN REPORT  
HIGHWAY 400 CULVERT EXTENSION/REPLACEMENT  
CSP, SOUTH OF BCR AND RFOF, NORTH OF TIFFIN STREET  
G.W.P. 2074-11-00, DESIGN-BUILD READY PACKAGE**

## 5 Discussions and Recommendations

### 5.1 General

As part of *Highway 400/Tiffin Street Overpass Structure Replacement and Highway 400/Barrie-Collingwood Railway Overhead Structure Rehabilitation*, it is proposed to extend two existing culverts: a corrugated steel pipe (CSP) culvert at Station 29+280 and a rigid frame open footing (RFOF) culvert at Station 10+120. Recently, a full culvert replacement option was also added to the project.

Existing culverts details (MTO Central Region culvert information system) are summarized in Table 5.1.1.

**Table 5.1.1 Details of Existing Culverts (from MTO data base)**

| Culvert type | Station | Existing Earth cover (m) | Span (mm) | Rise (mm) | Length (m) | Approximate Invert elevation (m) |
|--------------|---------|--------------------------|-----------|-----------|------------|----------------------------------|
| CSP          | 29+280  | 7                        | 1770      | 1775      | 70         | 230                              |
| RFOF         | 10+120  | 5                        | 1220      | 1200      | 61         | 232                              |

Both culverts are said to be in fair to good condition. No major pavement cracks and subsidence were noted atop of the culverts on the Highway 400 pavement

Details on culvert relining, replacement, extension or resizing and installation of additional culverts were not available at the time of submission of this report.

### 5.2 Culvert Extension

The Highway 400 proposed embankment widening to provide a 10-12 lane platform will entail lengthening of the existing culverts, the major extension being towards the east, with only minor extension towards the west.

#### 5.2.1 CSP at Station 29+280

Peat is present within the upper 2-3 m of ground surface at the CSP culvert location, on the east side of Highway 400. Its extent parallel to the highway is not known, but it may be less than 50 m on either side of the culvert. The peat should be removed to natural mineral soil and the sub-excavation backfilled with compacted local sandy soil to the invert level of the culvert extension. Various culvert extension options are shown in Table 5.2.1.1.

**Table 5.2.1.1. Culvert Extension Options (CSP at Station 29+280)**

| Culvert Type                             | Advantages/Disadvantages  | Risks/Consequences/Relative Cost                         | Preferred Alternative |
|--|---|--|-----------------------|
| Corrugated Steel Pipe (CSP) type culvert | Flexible, easy to construct, durable (when galvanized), can be easily re-lined. | May need MTO approval for 400-series highway application | Recommended           |
| Precast                                  | Less flexible than CSP.   | Sectional difference (circular to                        | May be                |

| Culvert Type                            | Advantages/Disadvantages  | Risks/Consequences/Relative Cost   | Preferred Alternative         |
|---|---|--|-------------------------------|
| Concrete Box Culvert                    | Prone to cracking owing to differential settlement.   | rectangular); relatively higher cost than CSP  | considered as an alternative. |
| Rigid Frame Open Footing Culvert (RFOF) | Requires relatively competent soil conditions. Requires considerable construction time (foundation construction). | Sectional difference (circular to rectangular); cannot withstand high differential settlements. Relatively higher cost than CSP. | Not recommended.              |

### 5.2.2 RFOF at Station 10+120

The poor soil support conditions and a relatively high groundwater table suggest that a continuation of the RFOF for the extension may not be advisable. The extension options are shown in Table 5.2.2.1.

**Table 5.2.2.1. Culvert Extension-Options (RFOF at Station 10+120)**

| Culvert Type                            | Advantages/Disadvantages   | Risks/Consequences/Relative Cost  | Preferred Alternative   |
|---|--|---|---|
| Rigid Frame Open Footing Culvert (RFOF) | <ul style="list-style-type: none"> <li>Requires relatively competent soil conditions.</li> <li>Requires considerable construction time and as such is not frequently used under existing highway embankments.</li> </ul> | <ul style="list-style-type: none"> <li>Cannot withstand high differential settlements.</li> <li>High cost.</li> </ul> | May not be a favourable option due to variable earth cover thickness along its length and settlement sensitivity. |
| Precast Concrete Box Culvert            | <ul style="list-style-type: none"> <li>Greater flexibility when added in small lengths</li> <li>Less foundation contact pressure than RFOF</li> </ul>  | <ul style="list-style-type: none"> <li>High cost.</li> </ul>  | Recommended   |
| Corrugated Steel Pipe (CSP)             | <ul style="list-style-type: none"> <li>Flexible and can withstand relatively high differential settlements</li> <li>Can be placed very rapidly.</li> </ul>   | <ul style="list-style-type: none"> <li>Needs MTO approval for use in 400 series highways.</li> </ul>                  | May be considered as an alternative   |

For a precast box culvert extension, a factored geotechnical resistance of 200 kPa at ULS and a geotechnical reaction of 120 kPa at SLS (for 25 mm total settlement and 20 mm differential settlement) may be used for preliminary design. The ULS and SLS values are valid for support of the extension on soil not underlain by peat.

The unfactored horizontal resistance against sliding between concrete culvert and the native silty sand to sandy silt can be estimated using a friction angle of 28 degrees. Culvert Replacement

A full culvert replacement option was recently added to the project. The existing culverts can be replaced using open cut construction or tunnelling. Table 5.2.2.2 shows replacement options.



**Table 5.2.2.2. Culvert Replacement Options**

| Construction Method   | Comments   | Recommendation   |
|-----------------------|--|--|
| Open Cut Construction | <ul style="list-style-type: none"> <li>Due to the observed shallow TCE contamination at the culvert location temporary roadway protection for open cut construction may not be feasible.</li> <li>Complete staging plan with detours will be required to facilitate open cut construction.</li> <li>Potential exists for traffic disruptions during construction,</li> </ul> | Feasible, depending on staging and construction scheduling.                      |
| Tunneling             | <ul style="list-style-type: none"> <li>The culvert alignments will go through fine grained non-cohesive soil.</li> <li>A high water table renders this option very risky due to running ground conditions, especially if the obvert is at or below the water table</li> <li>Will not cause traffic disruptions.</li> </ul>   | Risky compared with open cut installation. The soils are “running” to “flowing”. |

New pipes can also be installed by pipe ramming and pipe jacking. The large diameter of the CSP is not conducive to “jack and bore” methods. Pipe culvert installation using trenchless technologies under the highway should be carried out in accordance with the latest MTO NSSP, *Pipe Installation by Trenchless method*. If twinning of the culvert is proposed, minimum clearance between multiple conduits should be maintained as per *CAN/CSA-S6-06, Chapter 7 Buried Structures*. The Design-Build Contractor is responsible to maintain the stability of existing CSP culvert and embankment during the installation of new culvert using trenchless methods.

The RFOF at Station 10+120 may be replaced with a precast concrete box culvert using open cut construction methods. A significant grade raise and new embankment construction need to be considered in designing the open cut installation. For a preliminary design of culvert replacement, the same geotechnical resistance and reaction values given in section 5.2.2 may be used.

### 5.3 Culvert Bedding

RFOF and precast box culvert bedding should be provided in accordance with *OPSD803.010 Backfill and Cover for Concrete Culvert Span Less than or Equal to 3.0 m* and *OPSS 422*. For the CSP culvert, bedding should be provided as per *OPSD 802.010, Flexible Pipe Embedment and Backfill Earth Excavation*.

### 5.4 Culvert Camber

The CSP extension should be provided with a camber to allow for an anticipated post construction settlement at the east extension end of 25-50 mm. The anticipated settlement at the west extremity of the culvert is 20-35 mm. These post-construction settlement estimates are drawn from past experience with similar loose-compact fine grained non-cohesive soils and case histories. Such estimates could be in error as much as 50%, given lack of data below the depths drilled at the two culvert sites.

The estimated settlements could be much greater if undiscovered peat exists beneath new embankment fills.

### 5.5 Backfilling Structures

Backfill materials and compaction should comply with *OPSD 803.010* for RFOF and precast box culverts and *OPSD 802.010* and *OPSS 421* for CSP culverts. The backfill should consist of well-graded, non-frost susceptible granular materials such as Granular ‘A’ or ‘B’ (*OPSS-1010*). Backfill should be placed in 200 mm lifts, compacted in accordance with *OPSS 501*. For the CSP culverts, both sides should be backfilled

equally, the levels on each side not differing by more than 400 mm as per OPSS 422. Covers should be placed in layers not exceeding 200 mm, each layer compacted according to OPSS 501.

Backfilling behind retaining (wing) walls should consist of free-draining granular materials such as Granular 'O' or Granular B, Type 1 with fines restricted to less than 5-7%. Weep holes and backfill drains should be provided to prevent hydrostatic pressure build-up. Computation of static earth pressures ( $K_A$  and  $K_O$  are coefficients of active and at-rest earth pressure coefficients respectively) may be based on the following design parameters:

#### Compacted Granular 'A' or Granular 'B' Type II

Angle of Internal Friction  $\phi = 35^\circ$  (unfactored)

Unit weight = 22 kN/m<sup>3</sup>

Coefficient of Lateral Earth Pressure:

| Level Backfill | Backfill Sloping at 3H:1V | Backfill Sloping at 2H:1V |
|----------------|---------------------------|---------------------------|
| $K_A = 0.27$   | $K_A = 0.34$              | $K_A = 0.40$              |
| $K_O = 0.43$   | $K_O = 0.56$              | $K_O = 0.62$              |

#### Compacted Granular 'B' Type I

Angle of Internal Friction  $\phi = 30^\circ$  (unfactored)

Unit Weight = 21 kN/m<sup>3</sup>

Coefficient of Lateral Earth Pressure:

| Level Backfill | Backfill Sloping at 3H:1V | Backfill Sloping at 2H:1V |
|----------------|---------------------------|---------------------------|
| $K_A = 0.33$   | $K_A = 0.42$              | $K_A = 0.54$              |
| $K_O = 0.50$   | $K_O = 0.66$              | $K_O = 0.76$              |

The earth pressure coefficient used in design should consider the restraint provided for wall movement. Allowance should be made for compaction induced stresses in the selection of the appropriate earth pressure coefficients. The use of vibratory compaction equipment behind the culvert and the retaining walls (if any), and above culvert roof or obvert should be restricted in size as per current MTO policy.

## **5.6 New NB Embankment at Culvert Locations**

A new north bound embankment will be constructed with support of the permanent retaining wall on the east ROW and temporary retaining walls near to the existing NB edge of pavement. Sectional drawings provided by MHL show the proposed wall height will be about 3 m at the existing CSP culvert location (station 29+300) and about 7 m at the existing RFOF culvert location (station 10+125). Actual embankment height over the existing grade is about 6 m at the CSP culvert location and 9 m at the RFOF culvert location.

Due to the loose to compact soil conditions observed in the retaining wall boreholes drilled along the east side of the existing highway and anticipated height of new embankment, the proposed embankment should be constructed in stages to allow the fine sand and silt to consolidate. This will reduce the magnitude of any residual post-construction settlement, anticipated to be in the order of 25-50 mm (barring uncertainties with respect to soil conditions at depths below those drilled).

The existing soil conditions preclude consideration of conventional concrete retaining walls as they would need to be supported on a deep foundation for which subsurface information is lacking owing to environmental constraints. RSS walls are recommended as they are better suited to the site subsurface conditions and tolerate differential settlement without causing structural distress.

Typically, RSS wall facing is supported on a granular bearing pad placed below the frost depth (1.5 m). A geotechnical resistance and reaction at each site should be evaluated during a detail investigation and design phase with consideration of MTO “*Embankment Settlement Criteria for Design*” issued on July 2010.

For proper abutting between new and existing embankment fill, *OPSD208.010 Benching of Earth Slopes* should be applied.

The RSS supplier and wall designer are responsible for internal wall stability. Highway traffic loads should be considered in design. Global stability analysis should be performed once detailed design drawings are made available.

A temporary retaining wall is not required at the CSP location. The maximum height of a temporary retaining wall will be about 4 m at the RFOF culvert location. An RSS wall is recommended.

## 5.7 SB Embankment Reconfiguration

The existing SB bound embankment slope will be widened towards the west. A temporary retaining wall will be placed close to the existing highway centreline. Minimal embankment widening is proposed at the existing CSP culvert location. More than 10 m embankment widening is proposed at the existing RFOF culvert location. However, this widening will be accomplished using standard 2:1 side slopes. Embankments more than 8 m in height should be provided with mid-height benches as per *OPSD 202.010 slope flattening using surplus excavated material on earth and rock embankment*. Embankment new side slopes should be protected using sodding or seed and cover (*OPSS 571 and 572*).

## 5.8 Construction Considerations

All excavations, shoring and backfilling should be carried out in conformance with the *Occupational Health and Safety Act (OHSA), Regulation 213/91*, as well as the following specifications.

*OPSS 539 – Construction Specification for Temporary Protection Systems*

*OPSS 902 – Construction Specification for Excavating and Backfilling-Structures.*

Excavations can be expected to extend through embankment fill and native granular soil deposits. These soils can be classified as follows:

|                       |                               |
|-----------------------|-------------------------------|
| Fill                  | Type 3 soil above water level |
| Native Granular Soils | Type 3 soil above water level |
|                       | Type 4 soil below water level |

Temporary shoring may be required to retain the existing embankment during new culvert construction, if installation by open cut methods is proposed. The shoring system should be designed so that the lateral movement of any portion of the roadway protection system will not exceed the established criterion for the structural performance level. In this case, the required Performance Level is 2. The shoring system should be designed by a Professional Engineer, experienced in this type of work. Design parameters are given in Table 5.9.1.

**Table 5.9.1 Recommended Unfactored Parameters for Temporary Shoring Design**

| Soil Type                                     | $K_A$ | $K_O$ | $K_P$ | Unit weight $\gamma$<br>(kN/m <sup>3</sup> ) |
|---|-------|-------|-------|--|
| Embankment Fill                               | 0.36  | 0.53  | 2.77  | 19.5   |
| Silty Sand to Sandy Silt, Silt to Sand & Silt | 0.36  | 0.53  | 2.77  | 19.5   |

It should be pointed out that cobbles and random boulders may be present within the embankment fill that may cause problems with the installation of interlocking steel piling.

Dewatering will be required where excavation bases penetrate the prevailing groundwater table. The groundwater level should be depressed sufficiently below the deepest part of the excavation to maintain excavation basal stability and side slope stability. The Design-Build Contractor should be made aware of his responsibilities which include the following:

- Engaging a dewatering specialist to provide advice on the most appropriate method for dewatering
- Ensuring that dewatering by the method chosen does not disturb the TCE plume below the phreatic surface
- Obtaining the necessary dewatering permits
- Testing of pumped water for disposal in accordance with prevailing regulations for surface disposal
- Municipal approval and testing of pumped water for discharge into a storm sewer system.

## 5.9 Seismic Design

The subsurface conditions are represented by Soil Profile Type II (see Clause 4.4.6.2 of CHBDC CAN/CSA-S6-06). In accordance with Clause 4.4.6.1, the site coefficient,  $S$ , is 1.2. The Zonal Acceleration Ratio = 0.05 and Velocity Related Seismic Zone ( $Z_v$ ) = 0. The design zonal acceleration ratio for the site,  $A$  = 0.06. The culvert sites are in Seismic Performance Zone 2, and are subject to independent review by a structural engineer.

## 5.10 Culvert Erosion Protection

The native sandy and silty soils are considered highly erodible. Geotextile separation should be provided at interfaces between the sandy embankment fill and the silty natural soils when in contact with processed or natural coarser soils. For erosion protection, consideration may be given to a low permeability clay seal (*OPSS 1205*) at the upstream and downstream ends. Toe walls will help control loss of soil through under-seepage.

## 5.11 Frost Depth

The design frost protection depth for the two culvert sites is 1.5 m.

## 5.12 Instrumentation and Monitoring

Culvert replacement by means of tunnelling or trenchless technologies should be accompanied by appropriate instrumentation to monitor ground movements and pavement surface deflections on existing Highway 400.

## 6 Scope of Work Required for Detailed Design

Due to environmental constraints and the Design-Build nature of the project, this investigation falls short of MTO requirements for both lateral coverage with boreholes and depth of borings for the existing and proposed structure. It may become necessary to drill additional and deeper boreholes to comply with *RFP, Appendix 6.8, Minimum Requirements for Foundations Engineering Applications*, unless waived by the MTO.

## 7 Closure

The "Limitations of Report", as presented in **Appendix G**, are integral part of the report.

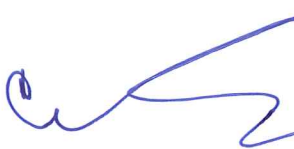
For and on behalf of Coffey.



**Gwangha Roh**, P. Eng., Ph.D.  
Associate Geotechnical Engineer



**Sanket Shah**, P. Eng.  
Project Manager, Geotechnical Engineer



**Cam Mirza**, P. Eng.  
MTO Designated Contact, Principal



# Appendix D

## **Embankment Profile and Cross-sectional Drawings at Culvert Locations**

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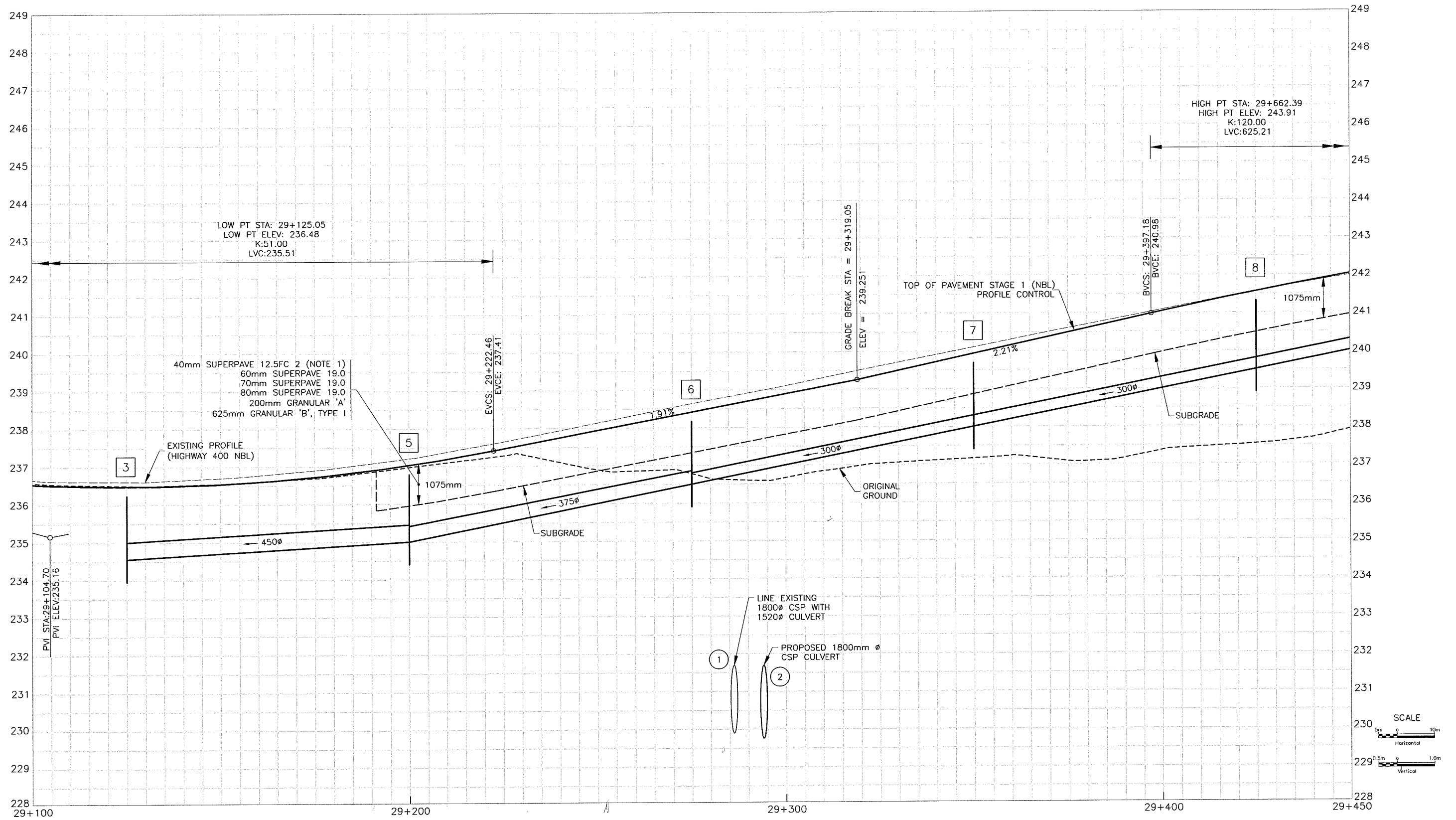
MINISTRY OF TRANSPORTATION, ONTARIO

PR-0-707 88-05

- NOTES:
1. SURFACE COURSE ASPHALT TO BE DEFERRED UNTIL END OF CONSTRUCTION.

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

|   |            |       |
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| PLATE No  |            |       |
| CONT  | 201X-XXXX  |       |
| WP  | 2159-11-00 |       |
| HWY 400/TIFFIN STREET<br>PROFILE (NBL)  |            | SHEET |
| STA 29+100 TO STA 29+450  |            | 36    |
|  MORRISON HERSHFIELD |            |       |





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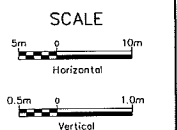
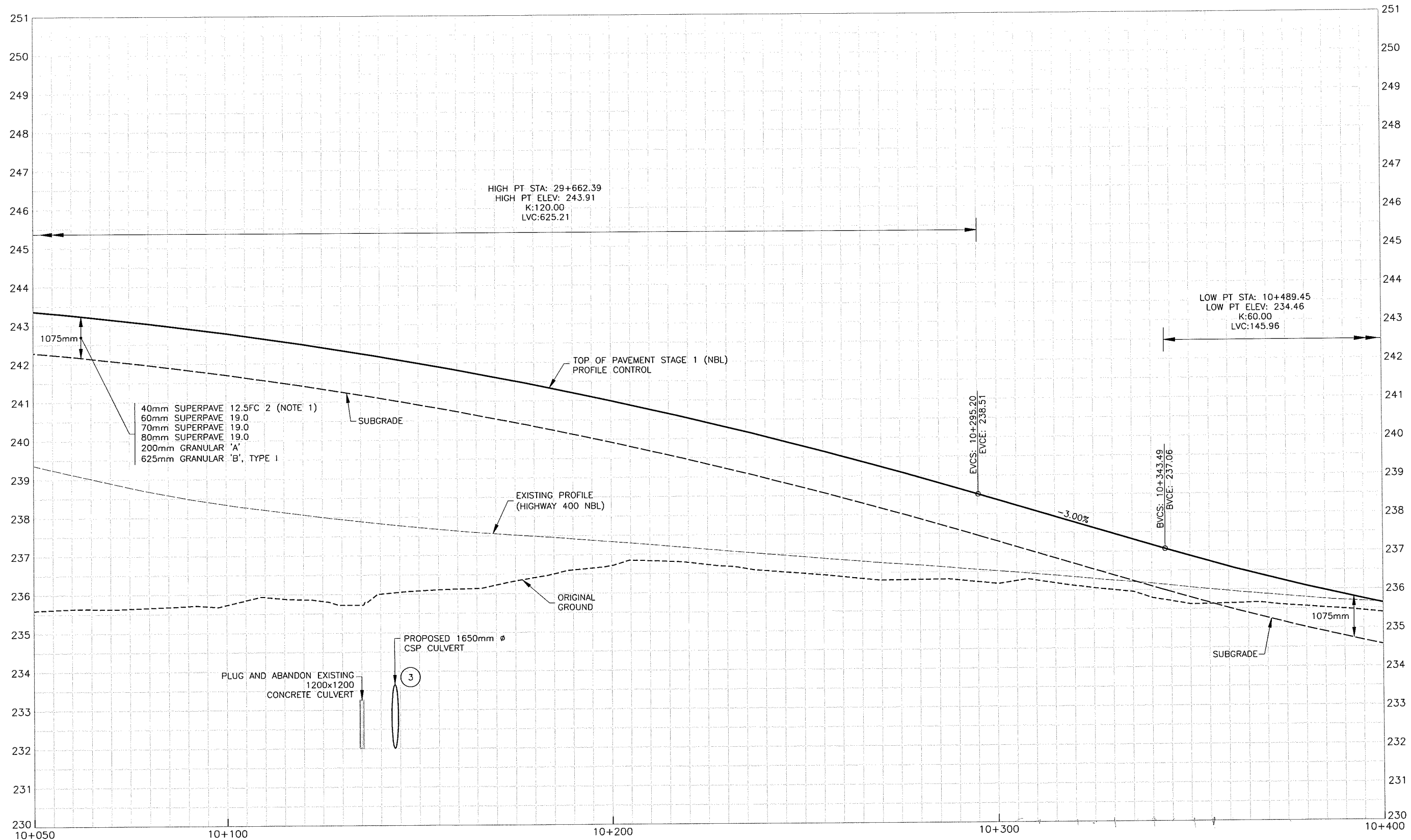
MINISTRY OF TRANSPORTATION, ONTARIO

PR-D-707 BR-05

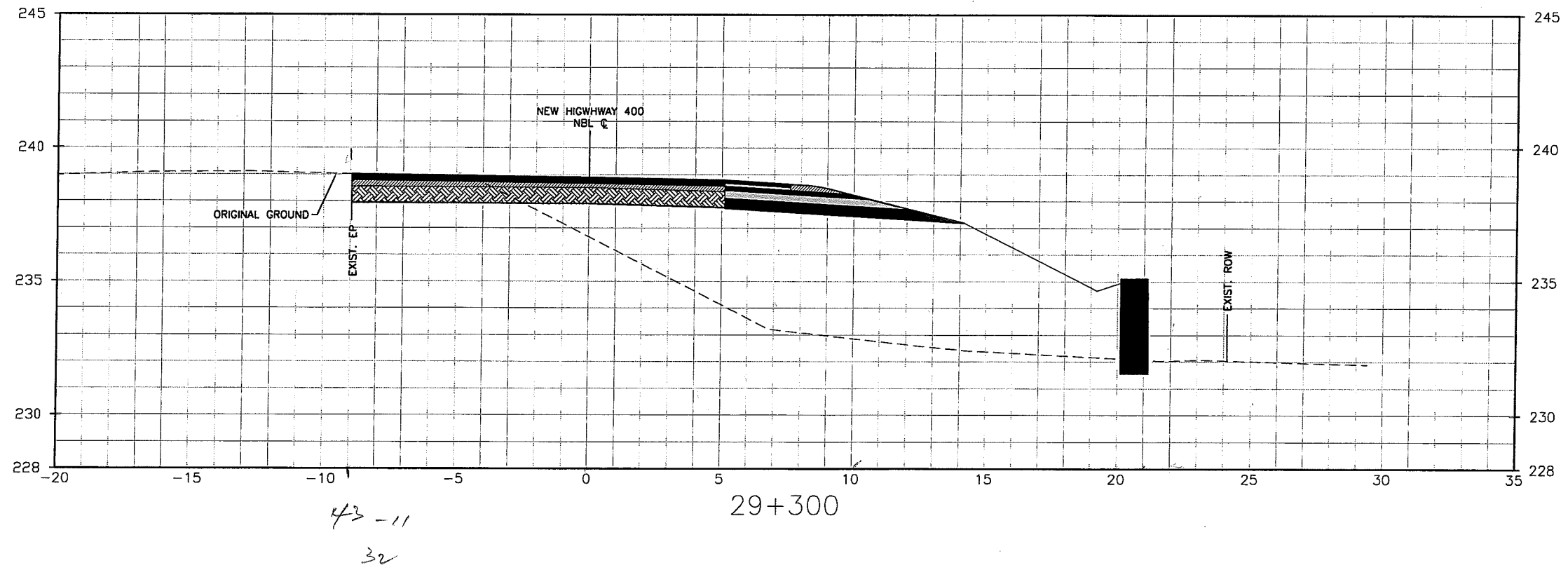
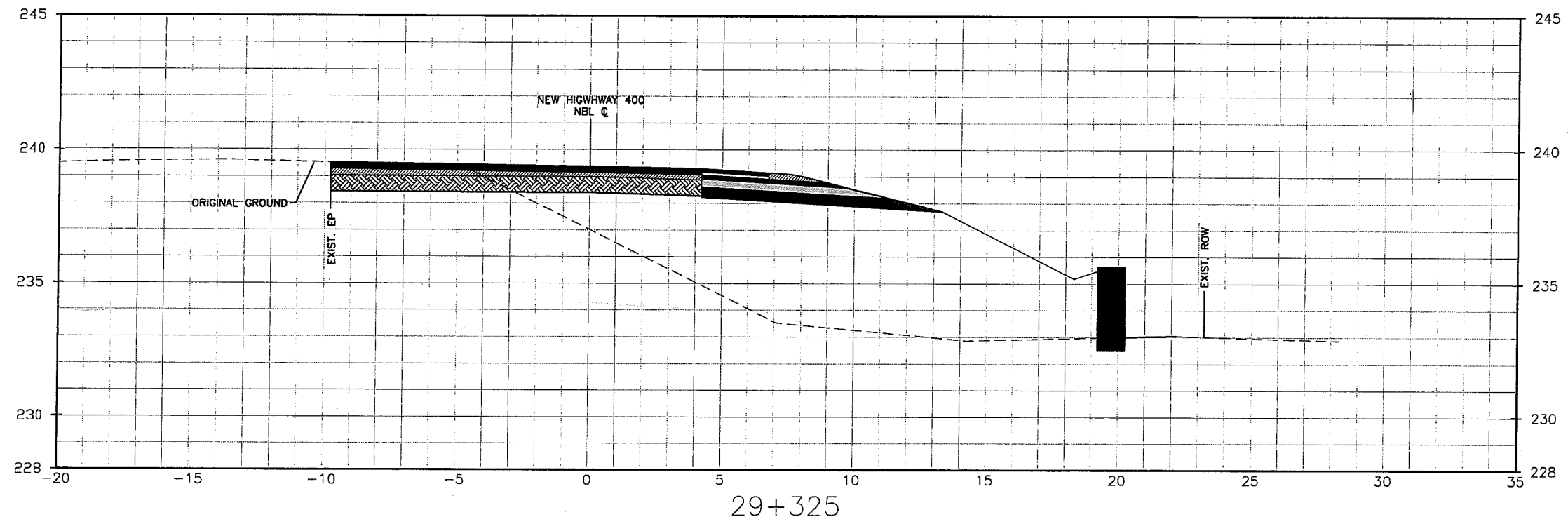
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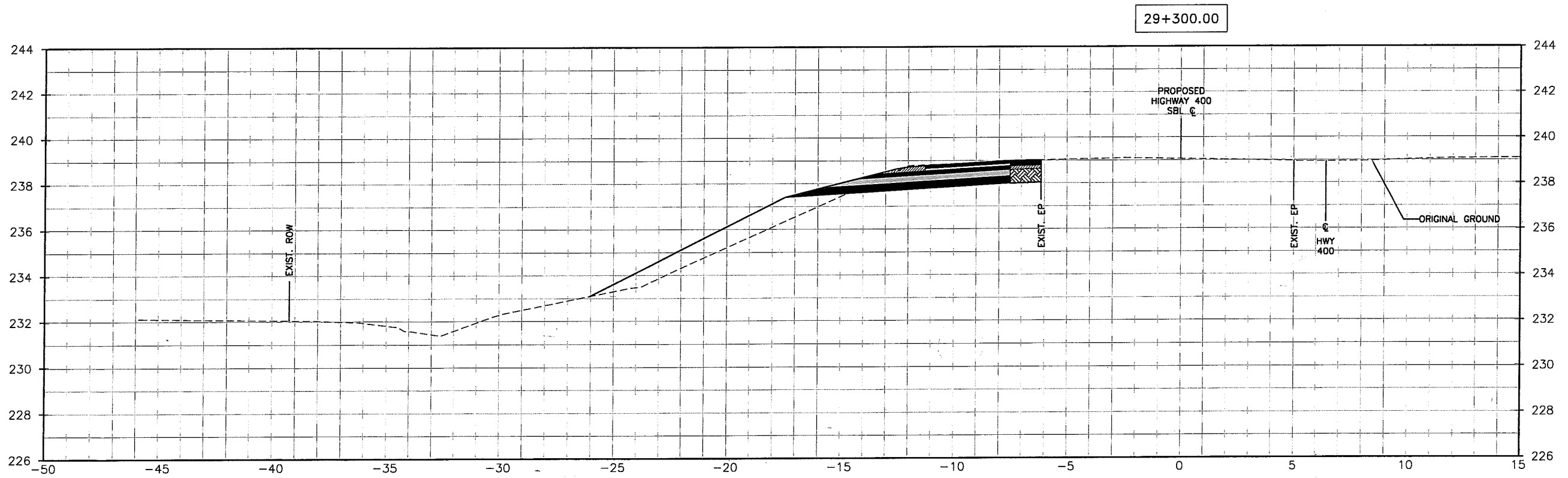
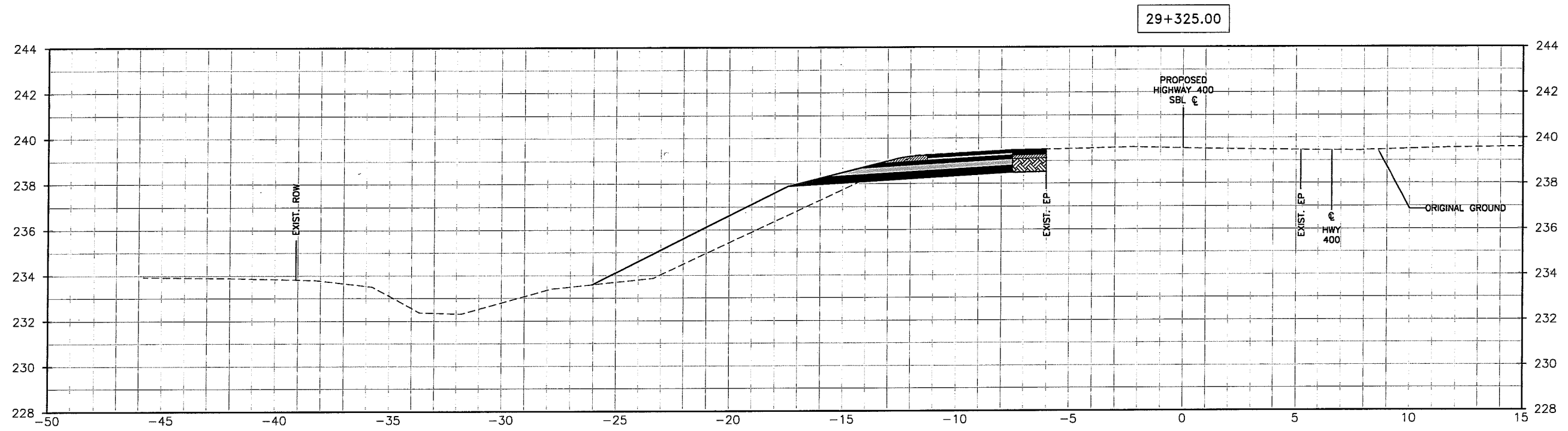
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AND/OR MILLIMETRES  
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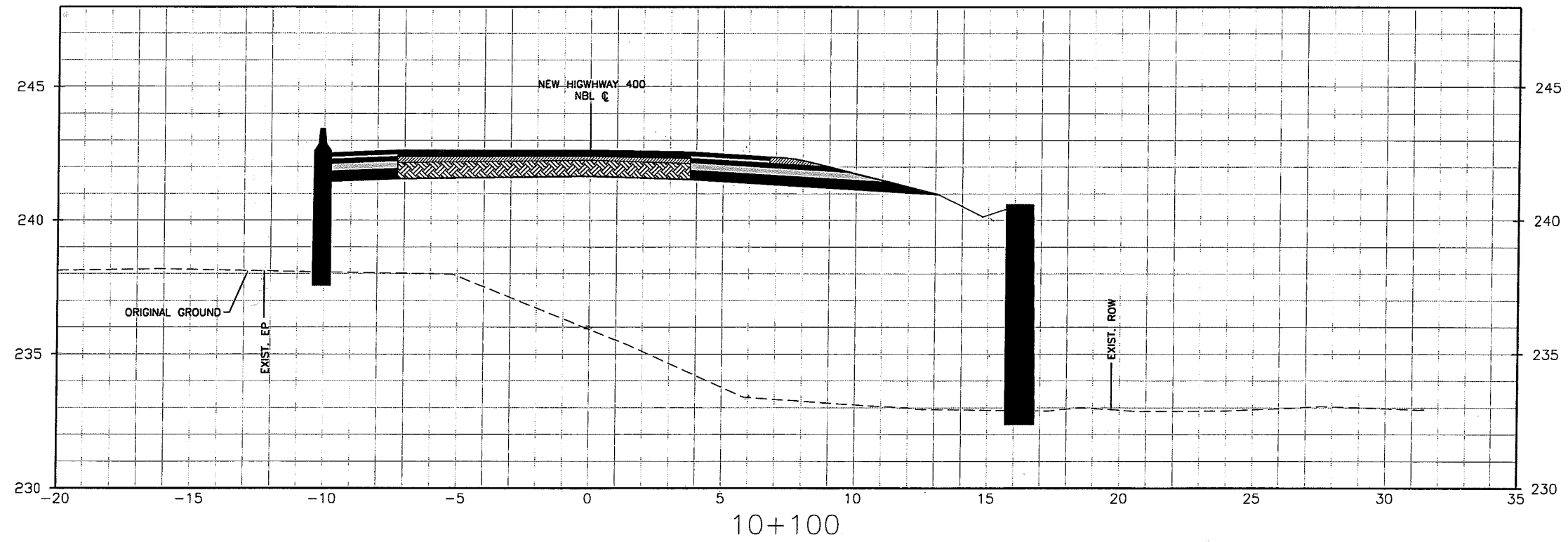
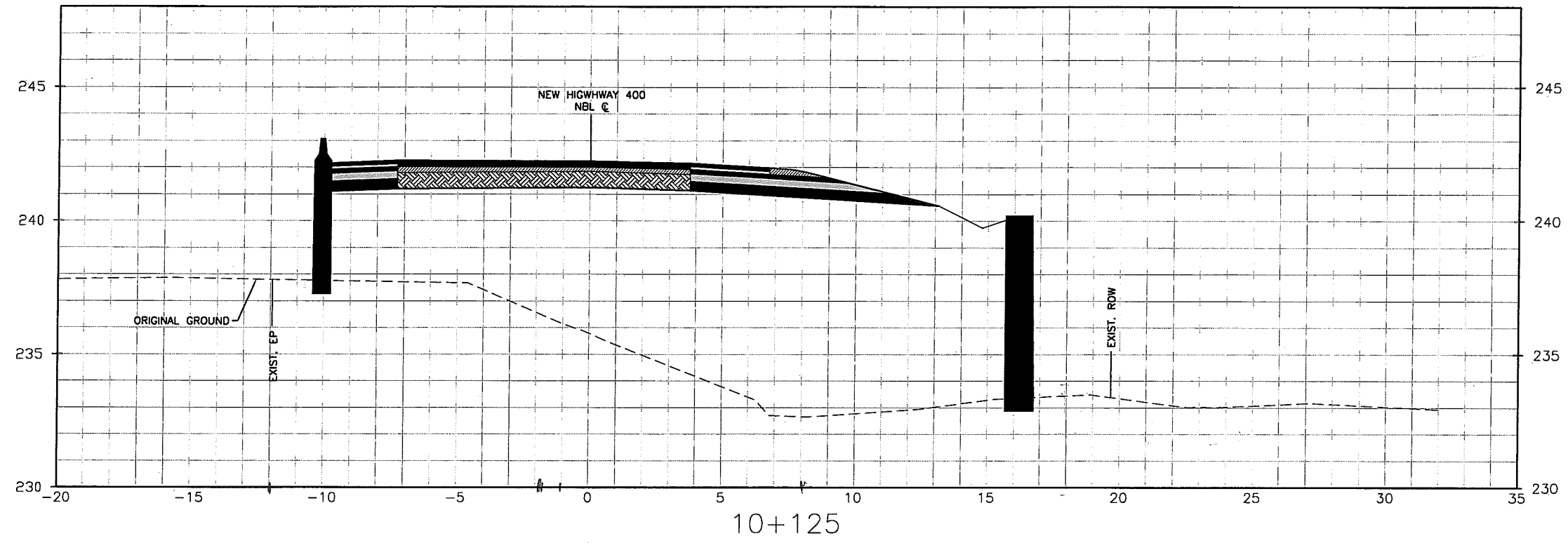
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|  MORRISON HERSHFIELD |                |             |

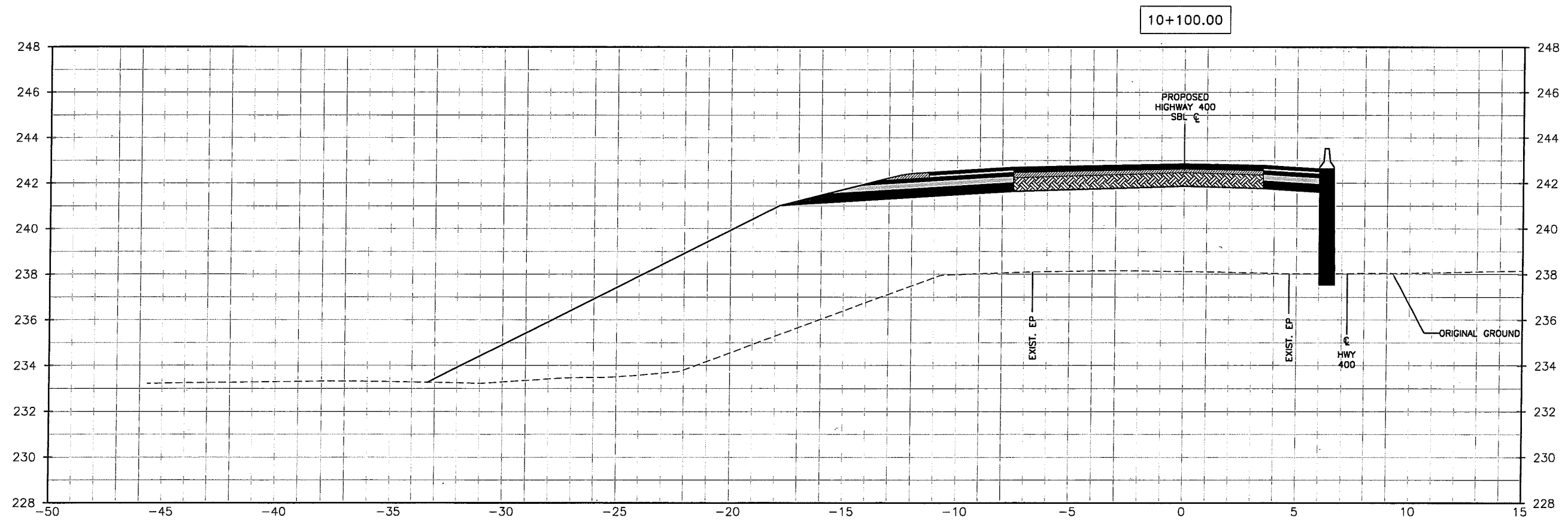
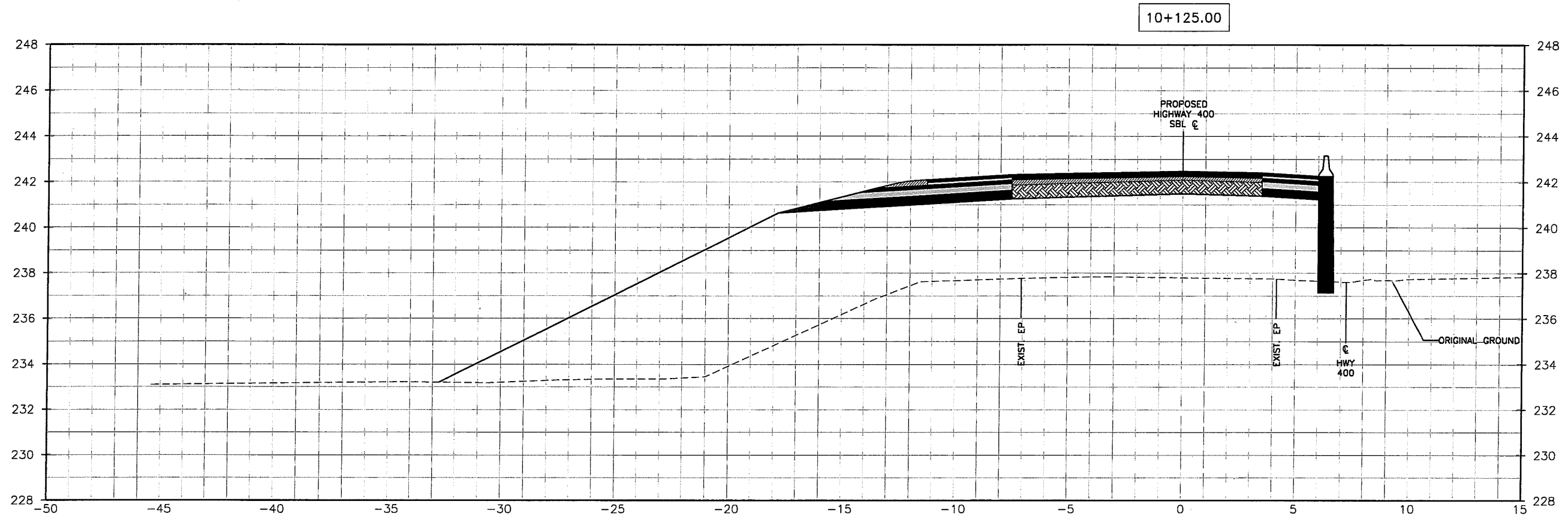












# Appendix E

## List of Standard Specifications

**OPSSs**

OPSS 209 Construction Specification for Embankment over Swamps and Compressible Soils.

OPSS 501 Construction Specification for Compacting.

OPSS 539 Construction Specification for Temporary Protection Systems

OPSS 571 Construction Specification for Sodding

OPSS 572 Construction Specification for Seed and Cover

OPSS 1010 Material Specification for Aggregates – Base, Subbase, Select Subgrade and Backfill Material

OPSS 1205 Material Specification for Clay Seal

OPSS 421 Construction Specification for Pipe Culver Installation in Open Cut

OPSS 422 Construction Specification for Precast Reinforced Concrete Box Culverts and Box Sewers in Open Cut

**OPSDs**

OPSD202.010 Slope Flattening using Surplus Excavated Material on Earth and Rock Embankment.

OPSD208.010 Benching of Earth Slopes

OPSD 802.010 Flexible Pipe Embedment and Backfill Earth Excavation

OPSD803.010 Backfill and Cover for Concrete Culvert span less than or Equal to 3.0 m

# Appendix F

**NSSPs**

**MTO NSSP**- PIPE INSTALLATION BY TRENCHLESS METHOD, 2009

**Additional NSSP wording**

**Vibration Monitoring**

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Special Provision

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The vibration monitoring equipment shall be placed on the existing structure such that it will not be disturbed. The location should be as close as possible to the tunnelling site (trenchless construction).

The vibrations at the existing structure shall not exceed 100 mm/s (peak particle velocity).

The monitoring results shall be certified by the Quality Verification Engineer as being accurate and meeting the requirements of the specification. The results shall be submitted to the Contract Administrator.



# Appendix G

## **Limitations of Report**

## **LIMITATIONS OF REPORT**

This report is intended solely for the Client named. The material in it reflects our best judgment in light of the information available to Coffey at the time of preparation. Unless otherwise agreed in writing by Coffey it shall not be used to express or imply warranty as to the fitness of the property for a particular purpose. No portion of this report may be used as a separate entity, it is written to be read in its entirety.

The conclusions and recommendations given in this report are based on information determined at the test hole locations. The information contained herein in no way reflects on the environment aspects of the project, unless otherwise stated. Subsurface and groundwater conditions between and beyond the test holes may differ from those encountered at the test hole locations, and conditions may become apparent during construction, which could not be detected or anticipated at the time of the site investigation. The benchmark and elevations used in this report are primarily to establish relative elevation differences between the test hole locations and should not be used for other purposes, such as grading, excavating, planning, development, etc.

The design recommendations given in this report are applicable only to the project described in the text and then only if constructed substantially in accordance with the details stated in this report.

The comments made in this report on potential construction problems and possible methods are intended only for the guidance of the designer. The number of test holes may not be sufficient to determine all the factors that may affect construction methods and costs. For example, the thickness of surficial topsoil or fill layers may vary markedly and unpredictably. The contractors bidding on this project or undertaking the construction should, therefore, make their own interpretation of the factual information presented and draw their own conclusions as to how the subsurface conditions may affect their work. This work has been undertaken in accordance with normally accepted geotechnical engineering practices.

Any use which a third party makes of this report, or any reliance on or decisions to be made based on it, are the responsibility of such third parties. Coffey accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report.

We accept no responsibility for any decisions made or actions taken as a result of this report unless we are specifically advised of and participate in such action, in which case our responsibility will be as agreed to at that time. Any user of this report specifically denies any right to claims against the Consultant, Sub-Consultants, their officers, agents and employees in excess of the fee paid for professional services.