



FINAL REPORT

FOUNDATION INVESTIGATION AND DESIGN REPORT

Trenchless Installation of Three Pipe Culverts, Highway 11

New Liskeard Area, Ontario

CV(11+595) - Latitude 48.696883; Longitude 80.790053

CV(20+603.5) - Latitude 48.564769; Longitude 80.587706

CV(20+832.5) - Latitude 48.564081; Longitude 80.586900

Agreement No. 5015-E-0007

Assignment No. 9

GWP 5205-10-00

MTO GEOCRES No. 42A-125

Prepared for:

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Provincial Highways Management

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September 17, 2018

Ontario Ministry of Transportation

Northeastern Region Geotechnical Section

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1 FOUNDATION INVESTIGATION REPORT

1.1 Introduction

This report presents the results of a geotechnical investigation completed by **exp** Services Inc. for trenchless installation of three pipe culverts on Highway 11, New Liskeard Area, Ontario. The work was undertaken under Agreement No. 5015-E-0007, Assignment No. 9. The terms of reference (TOR) were as presented in Ministry of Transportation Ontario (MTO) email dated April 20, 2018. The details of the three proposed culverts are as follows:

- 1) Culvert at Sta. 11+595 (Culvert #1), approximately 0.9 km south of Porquis junction, Highway 11, Clergue Township, (Latitude 48.696883, Longitude 80.790053);
- 2) Culvert at Sta. 20+603.5 (Culvert #2), approximately 3.9 km south of Porquis junction, Highway 11, Taylor Township, (Latitude 48.564769, Longitude 80.587706);
- 3) Culvert at Sta. 20+832.5 (Culvert #3), approximately 4.1 km south of Porquis junction, Highway 11, Taylor Township, (Latitude 48.564081, Longitude 80.586900).

The purpose of the investigation is to determine the subsurface conditions along the proposed new culverts alignments (next to existing culverts alignments) to permit detailed design and recommendations for their installation using a trenchless method, for stability of cut slopes including temporary and permanent, and temporary protection systems. The site specific geotechnical investigation consisted of a field investigation including visual inspections, drilling of boreholes, soil sampling, and laboratory testing.

This foundation investigation report has been prepared specifically and solely for the project described herein. It contains the factual results of the investigation and the laboratory testing completed for this project.

1.2 Site Descriptions and Geological Setting

1.2.1 Site Descriptions

1.2.1.1 General

The general site conditions were assessed during the drilling operations between May 29, 2018 and June 5, 2018. Photographs of the sites and existing culverts are presented in Appendix A. The surrounding terrain is generally rolling to gently undulating with some grass and shrubs and occasional stands of deciduous and coniferous trees along the banks of creeks.

The proposed replacement Culvert #1 is located on Highway 11, in the Township of Clergue and other two proposed replacement culverts, Culvert #2 and Culvert #3, are located on Highway 11, in the Township of Taylor. At the site locations, Highway 11 is a two-lane highway with a speed limit of 80 km/h and gravel shoulders. Highway 11 generally runs in a north-south direction. The locations of the proposed and existing culverts alignments are shown on Drawings No. 1 to 3 in Appendix B.

1.2.1.2 Culvert #1 (CV11+595)

The existing Culvert #1 is a corrugated steel pipe (CSP) culvert, approximately 1.2 m in diameter and 58.7 m long. The existing highway embankment at this culvert location is approximately 5.0 m high on both sides of roadway. The side slopes of embankment are approximately 2H:1V (inlet side) and 5H:1V (outlet side) from the top of the embankment to the toe of the embankment at west and east sides, respectively. It is understood that, the existing culvert will be replaced by a new culvert of 1.2 m in diameter and 43 m long, located south of the existing culvert.

The creek flows from the west to east direction at this culvert location. During the site visit, a sink hole of approximately 1.2 m diameter and 0.7 m deep was observed on the west side slope at the existing culvert location (see Photo 4 in Appendix A).

1.2.1.3 Culvert #2 (CV20+603.5)

The existing Culvert #2 is a CSP culvert, approximately 0.9 m in diameter and 36.8 m long. The existing highway embankment at this culvert location is approximately 4.0 m high on both sides of roadway. The side slopes of embankment are approximately 2H:1V from the top of the embankment to the toe of the embankment at both west and east sides. It is understood that, the existing culvert will be replaced by a new culvert of 0.9 m in diameter and 37 m long, located north of the existing culvert.

The creek flows from the west to east direction at this culvert location. During the site visit, sink hole of approximately 0.8 m diameter was observed on the west side slope at the existing culvert location (see Photo 8 in Appendix A).

1.2.1.4 Culvert #3 (CV20+832.5)

The existing Culvert #3 is also a CSP culvert, approximately 1.05 m in diameter and 39.9 m long. The existing highway embankment at this culvert location is approximately 4.0 m high on both sides of roadway. The side slopes of embankment are approximately 2H:1V and 4H:1V from the top of the embankment to the toe of the embankment at the west and east sides, respectively. It is understood that, the existing culvert will be replaced by a new culvert of 1.05 m in diameter and 39 m long, located south of the existing culvert.

The creek flows from the east to west direction at this culvert location. During the site visit, a sink hole of approximately 0.8 m diameter was observed on the west side slope at the existing culvert location. It is also observed that, the existing culvert at the sink hole location is disjointed forming a hole (see Photo 16 in Appendix A).

1.2.2 Geological Setting

According the Ministry of Northern Development and Mines, Map 2555 (Quaternary Geology of Ontario, East-Central Sheet, 1991) the surface conditions in the vicinity of the project area consists of undifferentiated igneous and metamorphic rock exposed at surface to glaciolacustrine deposits which

includes sand, gravelly sand and gravel. Glaciofluvial ice-contacts deposits, which includes gravel, sand and minor till includes esker, kame, end moraine, ice-marginal delta and subaqueous fan deposits and according to Map 2543 (Bedrock Geology of Ontario, East-Central Sheet, 1991. The bedrock geology of the site is of mafic to intermediate metavolcanics rocks of basaltic and andesitic flows, tuffs and breccias, chert, iron formation, minor metasedimentary and intrusive rocks.

1.3 Investigation Procedures

1.3.1 Site Investigation and Field Testing

The field investigation was performed between May 29, 2018 and June 5, 2018. The field program consisted of drilling four (4) sampled boreholes at each site. For each culvert, one borehole at the inlet side and one borehole at the outlet side, and two boreholes at the top of the embankment (one at each shoulder) were drilled during the field investigation. The borehole locations are shown on Drawings No. 1 to 3 in Appendix B.

All culvert boreholes (BH(11+595)-1 to 4, BH(20+603.5)-1 to 4 and BH(20+832.5)-1 to 4) were strategically located along the proposed culvert alignments to provide subsurface information for the trenchless installation of new culverts, stability analysis of cut slopes, including temporary and permanent, and construction of temporary protection systems.

All of the boreholes were advanced using a track mounted CME 55 drill rig, equipped with hollow stem augers and standard soil sampling equipment operated by a specialist drilling contractor, Landcore Drilling. The roadway boreholes (BH(11+595)-3, BH(20+603.5)-2 and BH(20+832.5)-2) located at proposed temporary protection system areas were advanced to depths of about 14 to 15 m below the ground surface, while all other boreholes were advanced to a depth of about 9 to 11 m.

The borehole locations (referenced to the MTM NAD83 coordinate system) and their ground surface elevations were surveyed by **exp** personnel. The ground surface elevations were referenced to temporary benchmarks set up at a central line of Highway 11 along existing culvert alignment for each proposed culvert site location. The elevations of the TBMs at Culvert #1 of Elev. 290.5 m, Culvert #2 of Elev. 269.0 m and Culvert #3 of Elev. 270.4 m are assumed based on the provided cross-section drawings. The temporary benchmark locations for each site location are shown on Drawings No. 1 to 3 in Appendix B.

During the drilling of all boreholes, soil samples were obtained using a 51 mm outside diameter (O.D.) split-spoon sampler in accordance with Standard Penetration Test (SPT) procedures (ASTM D1586) at intervals ranging from 0.75 m to 1.5 m in depth as shown on the attached borehole logs (Appendix C). The original field (uncorrected) SPT "N" values were recorded on the borehole logs as recommended in the Canadian Foundation Engineering Manual (CFEM, pg. 40) and used to provide an assessment of in-situ relative density of non-cohesive soils and/or consistency of cohesive soils. In addition, field vane testing was conducted in all boreholes to measure an in-situ undrained shear strength of cohesive soils.

Upon completion of the boreholes, groundwater level measurements were carried out in open boreholes in accordance with MTO guidelines. The recorded groundwater levels after completion of drilling boreholes

were presented in the borehole log sheets in Appendix C. The roadway boreholes were decommissioned by bentonite/cement mixtures in accordance with the Ministry of the Environment Regulation 903, as amended by Regulation 128/03 (the well regulation under the *Ontario Water Resources Act*).

The fieldwork was supervised by the **exp** geotechnical representative who directed the drilling and sampling operations, logged borehole data in accordance with MTO and/or ASTM Standards for Soils Classification, and retrieved soil samples for subsequent laboratory testing and identification.

All recovered soil samples were placed in labelled moisture-proof bags and returned to **exp**'s Brampton laboratory for additional visual, textual and olfactory examination and selective testing.

1.3.2 Previous Investigation

No foundation reports are available in the MTO GEOCREST library for these particular sites.

1.3.3 Laboratory Testing

All samples returned to the laboratory were subjected to visual examination and classification. The laboratory testing program included the determination of natural moisture content on all samples and particle size distribution and Atterberg Limit tests for approximately 25% of the collected soil samples. In addition, organic content tests on selected soil samples were performed. All of the laboratory tests were carried out according to MTO and/or ASTM Standards as appropriate.

The laboratory test results are provided on the attached borehole log sheets in Appendix C. The results of the grain size analyses tests and Atterberg Limit tests are presented graphically in Appendix D.

1.4 Subsurface Conditions

The detailed subsurface conditions encountered in the boreholes advanced during this investigation are presented on the borehole log sheets in Appendix C. Laboratory test results of grain size analyses and Atterberg Limit tests are also provided in Appendix D. The "Explanation of Terms Used in Report" preceding the borehole logs in Appendix C forms an integral part of and should be read in conjunction with this report.

Borehole location plans and cross section subsurface profiles for each culvert are provided in Appendix B. It should be noted that the stratigraphic boundaries indicated on the borehole logs and cross section stratigraphic profiles are inferred from semi-continuous sampling, observations of drilling progress and results of Standard Penetration Tests. These boundaries typically represent transitions from one soil type to another and should not be regarded as exact planes of geological change. Furthermore, subsurface conditions may vary between and beyond the borehole locations.

1.4.1 Culvert #1 (CV11+595)

In general, the subsurface conditions along the proposed Culvert #1 site consist of embankment fill layers (i.e. gravelly sand fill underlain by a layer of silty clay/clayey silt fill) followed by native deposit of clayey silt

with organics underlain by silty clay/clayey silt followed by silt. A detailed description of the subsurface conditions encountered along the proposed culvert location is discussed further in subsequent sections.

1.4.1.1 Fill: Gravelly Sand

Gravelly sand fill was encountered at the surface of BH(11+595)-2 and BH(11+595)-3. The fill layer extended to depths ranging from 1.5 m to 3.1 m below the ground surface with elevations ranging between Elev. 287.6 m and 288.5 m. Therefore, the explored thickness of this fill layer was between 1.5 m and 3.1 m.

A layer of this fill was also encountered below clayey silt fill in BH(11+595)-2 and BH(11+595)-3 from the depth of 4.6 m and 3.1 m, respectively. The layer extended to the depth of 5.3 m below the ground surface with elevations ranging between Elev. 284.7 m and 285.3 m. The explored thickness of this layer was between 0.7 m and 2.2 m.

The composition of these fill layers was generally sand and gravel with some black asphalt inclusions, trace to little silt and clay. The material is brown/greyish brown in color, and moist. The SPT 'N' values obtained within this layer ranged from 3 to 14 blows per 0.3 m penetration, suggesting very loose to compact material, but generally loose to compact in relative density.

Laboratory testing performed on selected samples consisted of seven (7) moisture content tests and one (1) grain size distribution test. The test results are as follows:

Moisture Contents:

- 3.2% to 20.6%

Grain Size Distribution:

- 27% gravel;
- 60% sand; and
- 13% silt and clay

The results of the moisture content and grain size distribution tests are provided on the record of borehole sheets in Appendix C. The result of the grain size distribution test is also provided on Figure 1 in Appendix D.

1.4.1.2 Fill: Clayey Silt

Clayey silt fill was encountered at the surface of BH(11+595)-1 and BH(11+595)-4 and below the gravelly sand fill layer in BH(11+595)-2 and BH(11+595)-3. This fill layer extended to depths ranging between 1.5 m and 4.6 m below ground surface corresponding to elevations ranging between Elev. 285.1 m and 287.0 m. The explored thickness of this layer ranged from 1.5 m to 2.4 m.

The composition of this layer was generally silt and clay with occasional cobbles, some topsoil, some roots, trace to some sand and trace to some gravel. The material is brown/greyish brown in color, and moist. The SPT 'N' values obtained within this layer were between 3 to 26 blows per 0.3 m penetration, suggesting soft to very stiff material, but generally stiff consistency.

Laboratory testing performed on selected samples consisted of eight (8) moisture content tests. The test results are as follows:

Moisture Content:

- 16.2% to 31.6%

The results of the moisture tests are provided on the record of borehole sheets in Appendix C.

1.4.1.3 Fill: Silty Clay

Silty clay fill was encountered below lower gravelly sand fill layer only in BH(11+595)-2. The fill layer extended to the depth of 6.1 m below ground surface with Elev. 284.5 m. The explored thickness of this layer was 0.8 m.

The composition of this layer was generally silt and clay with trace gravel, trace sand and trace roots and rootlets. The material is grey in color, and moist. One SPT 'N' value obtained within this layer was 17 blows per 0.3 m penetration, suggesting very stiff consistency.

Laboratory testing performed on a selected sample consisted of one (1) moisture content test and one (1) grain size distribution test. The test results are as follows:

Moisture Content:

- 26.1%

Grain Size Distribution:

- 2% gravel;
- 12% sand;
- 34% silt; and
- 52% clay

The results of the moisture content and grain size distribution tests are provided on the record of borehole sheets in Appendix C. The result of the grain size distribution test is also provided on Figure 2 in Appendix D.

1.4.1.4 Clayey Silt with Organics

A layer of native clayey silt with organics was encountered below silty clay/clayey silt fill in BH(11+595)-1, BH(11+595)-2 and BH(11+595)-4. The clayey silt with organics layer extended to depths ranging between 3.1 m and 8.4 m below the ground surface with elevations ranging between Elev. 282.2 m and 284.7 m. The explored thickness of this layer was between 1.4 m and 2.3 m.

The composition of this layer was generally silt and clay with organics, some roots and rootlets and trace sand. The material is blackish brown in color, and moist to wet. The SPT 'N' values obtained within this layer ranged from 3 to 7 blows per 0.3 m penetration, suggesting soft to firm consistency.

Laboratory testing performed on selected samples consisted of six (6) moisture content and two (2) organic content tests. The test results are as follows:

Moisture Content:

- 33.2% to 60.1%

Organic Content:

- 15.5% to 17.1%

The results of the moisture content tests are provided on the record of borehole sheets in Appendix C. The results of the organic content test is also provided in Appendix D.

1.4.1.5 Silty Clay/Clayey Silt

A native silty clay/clayey silt layer was encountered below the clayey silt with organics layer in BH(11+595)-1, BH(11+595)-2 and BH(11+595)-4 and below the gravelly sand fill layer in BH(11+595)-3. The silty clay/clayey silt layer extended to depths ranging between 5.3 m and 9.9 m below the ground surface with elevations ranging between Elev. 280.7 m and 282.4 m. The explored thickness of this layer was between 1.5 m and 3.1 m.

The composition of this layer was silt and clay with trace to some sand, trace organics, some rootlets and trace roots. The material is grey or blackish brown in color, and wet. The SPT 'N' values obtained within this layer ranged from weight hammer (WH) to 17 blows per 0.3 m penetration, suggesting very soft to very stiff material, but generally firm to stiff consistency. The measured undrained shear strengths in BH(11+595)-1 and BH(11+595)-4 by field vane tests were 19 kPa and 32 kPa, respectively.

Laboratory testing performed on selected samples consisted of seven (7) moisture content tests, four (4) grain size distribution tests and four (4) Atterberg Limits tests. The test results are as follows:

Moisture Content:

- 22.2% to 67.9%

Grain Size Distribution:

- 0% gravel;
- 2% to 16% sand;
- 31% to 86% silt; and
- 12% to 67% clay

Atterberg Limits:

- Liquid Limit: 50% to 75%;
- Plastic Limit: 20% to 47%; and
- Plasticity Index: 30% to 33%

The results of the moisture content, grain size distribution and Atterberg Limits tests are provided on the record of borehole sheets in Appendix C. The results of the grain size distribution and Atterberg Limits tests are also provided on Figure 3 and 4, respectively, in Appendix D.

1.4.1.6 Silt

A layer of native silt was encountered below the clayey silt/silty clay layer in BH(11+595)-1 to BH(11+595)-3 and below the clayey silt with organics layer in BH(11+595)-4. The silt layer extended to depths ranging between 9.8 m and 14.3 m below the ground surface with elevations ranging between Elev. 275.7 m and 279.3 m. The explored thickness of this layer was between 1.4 m and 6.7 m. All boreholes are terminated in this layer.

The composition of this layer was generally silt with trace to some sand and trace to little clay. The material is grey in color, and wet. The SPT 'N' values obtained within this layer ranged from 4 to more than 100 blows per 0.3 m penetration, suggesting very loose to very dense, but generally loose to compact in relative density.

Laboratory testing performed on selected samples consisted of seventeen (17) moisture content tests, three (3) grain size distribution tests and one (1) Atterberg Limits test. The test results are as follows:

Moisture Content:

- 18.2% to 24.7%

Grain Size Distribution:

- 0% gravel;
- 1% to 3% sand;
- 86% to 91% silt; and
- 6% to 12% clay

Atterberg Limits: Non-plastic

The results of the moisture content, grain size distribution and Atterberg Limit tests are provided on the record of borehole sheets in Appendix C. The result of the grain size distribution are also provided on Figure 5 in Appendix D.

1.4.2 Culvert #2 (CV20+603.5)

In general, the subsurface conditions along the proposed Culvert #2 site consist of a layer of gravelly sand fill underlain by a layer of silty clay fill followed by native deposit of varved silty clay. A detailed description of the subsurface conditions encountered along the proposed culvert location is discussed further in subsequent sections.

1.4.2.1 Fill: Sand and Gravel

Sand and gravel fill was encountered at the surface of BH(20+603.5)-2 and BH(20+603.5)-3. The fill layer extended to depths ranging between 1.5 m to 2.1 m below ground surface with elevations ranging between Elev. 266.7 m and 267.2 m.

The composition of this fill layer was generally sand and gravel with little silt and few to some clay. The material is brown/greyish brown in color, and moist to wet. One SPT 'N' value obtained within this layer was 10 blows per 0.3 m penetration, suggesting compact in relative density.

Laboratory testing performed on selected samples consisted of three (3) moisture content tests and one (1) grain size distribution tests. The test results are as follows:

Moisture Content:

- 6.1% to 19.7%

Grain Size Distribution:

- 14% gravel;
- 42% sand;
- 18% silt; and
- 26% clay

The results of the moisture content and grain size distribution tests are provided on the record of borehole sheets in Appendix C. The result of the grain size distribution are also provided on Figure 6 in Appendix D.

1.4.2.2 Fill: Silty Clay to Clay

Silty clay to clay fill was encountered at the surface of BH(20+603.5)-1 and BH(20+603.5)-4 and below the sand and gravel fill layer in BH(20+603.5)-2 and BH(20+603.5)-3. This fill layer extended to depths ranging between 2.3 m and 5.3 m below ground surface with elevations ranging between Elev. 263.5 m and 265.0 m. The explored thickness of this layer ranged from 2.3 m to 3.2 m.

The composition of this layer was generally silt and clay with trace to some organics, some roots and rootlets, trace wood, trace gravel and trace to few sand. The material is blackish/greyish brown in color, and moist. The SPT 'N' values obtained within this layer were between 2 to 17 blows per 0.3 m penetration, suggesting soft to very stiff consistency.

Laboratory testing performed on selected samples consisted of thirteen (13) moisture content tests, four (4) grain size distribution tests and three (3) Atterberg Limits tests. The test results are as follows:

Moisture Content:

- 18.8% to 57.6%

Grain Size Distribution:

- 0% to 1% gravel;
- 1% to 4% sand;
- 17% to 22% silt; and
- 75% to 82% clay

Atterberg Limits:

- Liquid Limit: 62% to 68%;
- Plastic Limit: 22% to 23%; and
- Plasticity Index: 40% to 46%

The results of the moisture content, grain size distribution and Atterberg Limits tests are provided on the record of borehole sheets in Appendix C. The results of the grain size distribution and Atterberg Limit tests are also provided on Figures 7 and 8, respectively, in Appendix D.

1.4.2.3 Silty Clay (Varved)

Varved silty clay was encountered below silty clay to clay fill layer in all the boreholes drilled at this location. The varved silty clay layer extended to the depths ranged from 9.0 m to 15.1 m below ground surface with elevations ranging from Elev. 253.7 m to 259.7 m. The explored thickness of this layer ranged from 4.4 m to 9.8 m. All boreholes were terminated in this layer.

The composition of this layer was generally silt and clay with trace sand seams. The material is grey in color, and wet. The SPT 'N' values obtained within this layer ranged from weight hammer (WH) to 4 blows per 0.3 m penetration, suggesting very soft to soft consistency.

The results of field vane tests for undrained shear strength of the varved silty clay to clay are presented on the borehole logs. Based on these tests, the undrained shear strength of the varved silty clay to clay deposit was around 19 kPa, confirming the soft consistency of this layer. The sensitivity of this deposit,

estimated from the field vane tests, ranges from 2.0 to 2.5, implying the varved silty clay to clay layer at this site is low sensitive based on the classification system provided in CFEM (2006).

Laboratory testing performed on selected samples consisted of seventeen (17) moisture content tests, four (4) grain size distribution tests and four (4) Atterberg Limits tests. The test results are as follows:

Moisture Content:

- 37.4% to 60.5%

Grain Size Distribution:

- 0% gravel;
- 1% sand;
- 27% to 41% silt; and
- 58% to 72% clay

Atterberg Limits:

- Liquid Limit: 36% to 44%;
- Plastic Limit: 18% to 28%; and
- Plasticity Index: 18% to 25%

The results of the moisture content, grain size distribution and Atterberg Limits tests are provided on the record of borehole sheets in Appendix C. The results of the grain size distribution and Atterberg Limits tests are also provided on Figures 9 and 10, respectively, in Appendix D.

1.4.3 Culvert #3 (CV20+832.5)

In general, the subsurface conditions along the proposed Culvert #3 site consist of layers of embankment fill (i.e. gravelly sand fill underlain by a layer of clayey silt fill followed by sand fill and silty clayey fill) underlain by native deposit of varved silty clay to clay. A detailed description of the subsurface conditions encountered along the proposed culvert location is discussed further in subsequent sections.

1.4.3.1 Fill: Gravelly Sand

Gravelly sand fill was encountered at the surface of BH(20+832.5)-2 and BH(20+832.5)-3. The fill layer extended to the depth of 1.5 m below ground surface with elevations ranging between Elev. 268.5 m and 268.7 m. The explored thickness of this layer was about 1.5 m.

The composition of this fill layer was generally sand and gravel with few clay and silt. The material is brown in color, and moist.

Laboratory testing performed on selected samples consisted of two (2) moisture content tests. The test results are as follows:

Moisture Content:

- 17.7% to 19.0%

The results of the moisture content tests are provided on the record of borehole sheets in Appendix C.

1.4.3.2 Fill: Clayey Silt

Clayey silt fill was encountered at the surface of BH(20+832.5)-1 and BH(20+832.5)-4 and below the gravelly sand fill layer in BH(20+832.5)-2 and BH(20+832.5)-3. The fill layer extended to depths ranging between 0.8 m and 3.1 m below ground surface corresponding to elevations ranging between Elev. 266.2 m and 268.5 m. The explored thickness of this layer ranged from 0.3 m to 2.3 m.

The composition of this layer was generally silt and clay with trace organics, trace roots and rootlets, trace gravel and trace sand. The material is blackish brown/brown in color, and moist. The SPT 'N' values obtained within this layer were between 2 to 22 blows per 0.3 m penetration, suggesting soft to very stiff material, but generally stiff to very stiff consistency.

Laboratory testing performed on selected samples consisted of five (5) moisture content tests and one (1) grain size distribution test. The test results are as follows:

Moisture Content:

- 19.3% to 43.8%

Grain Size Distribution:

- 0% gravel;
- 4% sand;
- 57% silt; and
- 39% clay

The results of the moisture content and grain size distribution tests are provided on the record of borehole sheets in Appendix C. The result of the grain size distribution is also provided on Figure 11 in Appendix D.

1.4.3.3 Fill: Sand

Sand fill was encountered below silty clay fill in BH(20+832.5)-2 and BH(20+832.5)-3. The sand fill layer extended to depths ranging between 3.8 m and 3.9 m below ground surface corresponding to elevations ranging between Elev. 266.1 m and 266.4 m. The explored thickness of this layer ranged from 0.8 m to 2.0 m.

The composition of this layer was generally sand with few gravel, trace silt and trace clay. The material is brown in color, and moist. The SPT 'N' values obtained within this layer were between 7 to 25 blows per 0.3 m penetration, suggesting loose to compact compactness.

Laboratory testing performed on selected samples consisted of three (3) moisture content tests and one (1) grain size distribution test. The test results are as follows:

Moisture Content:

- 12.0% to 22.8%

Grain Size Distribution:

- 5% gravel;
- 85% sand; and
- 10% silt and clay

The results of the moisture content and grain size distribution tests are provided on the record of borehole sheets in Appendix C. The result of the grain size distribution is also provided on Figure 12 in Appendix D.

1.4.3.4 Fill: Silty Clay

Silty clay fill was encountered below clayey silt fill in BH(20+832.5)-1 and below the sand fill layer in BH(20+832.5)-3. The silty clay fill layer extended to the depth of 3.1 m below ground surface corresponding to elevations ranging between Elev. 264.4 m in BH(20+832.5)-1 and 264.7 m in BH(20+832.5)-3. The explored thickness of this layer ranged from 1.4 m to 2.3 m.

The composition of this layer was generally silt and clay with trace sand seams and trace organics. The material is brown/greyish brown/grey in color, and moist to wet. The SPT 'N' values obtained within this layer were between 3 to 13 blows per 0.3 m penetration, suggesting soft to stiff material, but generally stiff consistency. The measured undrained shear strength in BH(20+832.5)-2 by a field vane test was 18 kPa.

Laboratory testing performed on selected samples consisted of four (4) moisture content tests, one (1) grain size distribution test and one (1) Atterberg Limits test. The test results are as follows:

Moisture Content:

- 27% to 42.5%

Grain Size Distribution:

- 0% gravel;
- 1% sand;
- 28% silt; and

- 71% clay

Atterberg Limits:

- Liquid Limit: 55%;
- Plastic Limit: 20%; and
- Plasticity Index: 35%

The results of the moisture content, grain size distribution and Atterberg Limits tests are provided on the record of borehole sheets in Appendix C. The results of the grain size distribution and Atterberg Limit tests are also provided on Figures 13 and 14, respectively, in Appendix D.

1.4.3.5 Silty Clay to Clay (Varved)

Varved silty clay to clay was encountered below silty clay/clay silt fill layer in all boreholes. The varved silty clay to clay layer extended to the depths ranged from 9.0 m to 14.3 m below ground surface corresponding to elevations ranging from Elev. 255.9 m to 260.3 m. The explored thickness of this layer ranged from 4.5 m to 7.5 m. All the boreholes are terminated in this layer.

The composition of this layer was generally silt and clay with trace organics, trace sand and sand seams. The material is greyish brown/brown/brownish grey in color, and wet. The SPT 'N' values obtained within this layer ranged from weight hammer (WH) to 4 blows per 0.3 m penetration, suggesting very soft to soft consistency.

The results of field vane tests for undrained shear strength of the varved silty clay to clay are presented on the borehole logs. Based on these tests, the undrained shear strength of the varved silty clay to clay deposit ranges from 16 kPa to 20 kPa, confirming the soft consistency of this layer. The sensitivity of this deposit, estimated from the field vane tests, ranges from 1.5 to 2.4, implying the varved silty clay to clay layer at this site is low sensitive based on the classification system provided in CFEM (2006).

Laboratory testing performed on selected samples consisted of twenty-one (21) moisture content tests, four (4) grain size distribution tests and four (4) Atterberg Limits tests. The test results are as follows:

Moisture Content:

- 33.2% to 65.4%

Grain Size Distribution:

- 0% gravel;
- 1% to 2% sand;
- 14% to 28% silt; and
- 70% to 85% clay

Atterberg Limits:

- Liquid Limit: 46% to 64%;
- Plastic Limit: 20%to 23%; and
- Plasticity Index: 26% to 41%

The results of the moisture content, grain size distribution and Atterberg Limits tests are provided on the record of borehole sheets in Appendix C. The results of the grain size distribution and Atterberg Limit tests are also provided on Figures 15 and 16, respectively, in Appendix D.

1.5 Groundwater Conditions

Information regarding groundwater levels at the site was obtained by measuring water levels in the open holes of all the boreholes after completion of drilling. The groundwater levels measured in the boreholes are shown on Table 1.1 and on the borehole logs. Water levels measured in open boreholes might not be stabilized due to the relatively short period of observation. The creek water levels at the locations of Culvert #1, #2 and #3 at the time of the investigation were approximately Elev. 285.7 m, 265.0 m and 266.0 m, respectively. Measured groundwater levels are below the creek levels. However, actual water level of creeks may be influenced by season.

Table 1.1 Groundwater data

Site	Borehole	Date Completed and Measured	Ground Surface Elevation (m)	Groundwater Elevation (m)	Groundwater Depth (m)
Culvert #1	BH(11+595)-1	5/31/2018	287.7	281.9	5.8
	BH(11+595)-2	5/31/2018	290.6	281.7	8.9
	BH(11+595)-3	5/30/2018	290.1	281.6	8.5
	BH(11+595)-4	5/30/2018	287.5	281.1	6.4
	Creek water level Elevation 285.7 m				
Culvert #2	BH(20+603.5)-1	6/3/2018	267.3	259.8	7.5
	BH(20+603.5)-2	6/3/2018	268.8	258.0	10.8
	BH(20+603.5)-3	6/2/2018	268.7	Dry in the open hole	
	BH(20+603.5)-4	6/2/2018	267.3	259.8	7.5
	Creek water level Elevation 265.0 m				
Culvert #3	BH(20+832.5)-1	6/4/2018	267.5	Dry in the open hole	
	BH(20+832.5)-2	6/4/2018	270.2	258.9	11.3
	BH(20+832.5)-3	6/3/2018	270.0	262.5	7.5
	BH(20+832.5)-4	6/4/2018	268.5	Dry in the open hole	
	Creek water level Elevation 266.0 m				

2 ENGINEERING DISCUSSION & RECOMMENDATIONS

2.1 General

This section of the report provides engineering guideline on the geotechnical design aspect for replacement of three pipe culverts on Highway 11, New Liskeard Area, Ontario, Ministry of Transportation (MTO) Northeastern Region (i.e. at Station 11+595, Station 603.5 and Station 20+832.5). The recommendations are based on our interpretation of the factual data obtained from the boreholes advanced during the current investigation at the sites performed by **exp** and our understanding of the project requirements. The compiled factual data for each site is presented in **Part I-Foundation Investigation Report** of this report. The interpretation and recommendations provided are intended solely to permit designers, to assess foundation alternatives and design new culverts at the sites. Comments on construction are only provided to highlight issues that could affect the design. Contractors bidding on the works should make their own assessments of the factual data and how it might affect construction means and methods, scheduling and the like. The report is subject to limitations which follows the text.

Based on information provided by MTO, it is understood that the existing three culverts are corrugated steel pipes (CSP) which will be replaced with new culverts using a trenchless approach. It is proposed that: (i) the existing Culvert #1 at Station 11+595, which is a 1.22 m diameter by 58.67 m long CSP culvert, will be replaced by a new culvert (1.22 m diameter by 43 m long) installed at a new proposed location to the south of the existing culvert; (ii) the existing Culvert #2 at Station 20+603.5, which is a 0.9 m diameter by 36.85 m long CSP culvert, will be replaced by a new culvert (0.9 m diameter by 30 m long) installed at a new proposed location to the north of the existing culvert; and (iii) the existing Culvert #3 at Station 20+832.5, which is a 1.05 m diameter by 39.96 m long CSP culvert, will be replaced by a new culvert (1.05 m diameter by 32 m long) installed at a new proposed location to the south of the existing culvert. It is proposed that temporary cut slopes for launch pits would be positioned such to provide minimum 12 m working platform with 1H:1V slopes. The locations of the existing and proposed culverts are provided by MTO and shown in Drawings No. 1 to 3, Appendix B.

This report addresses the geotechnical design of the foundation for the proposed culverts by providing geotechnical design parameters in accordance with the latest edition of the *Canadian Highway Bridge Design Code (CHBDC)* (November 2006), the *Canadian Foundation Engineering Manual (CFEM)* (2006), MTO Gravity Pipe Design Guidelines (May 2007), NSSP "Pipe Installation by Trenchless Method" and good practice. As requested from MTO, this section provides discussion about the trenchless methods (i.e. jack and bore, pipe ramming, micro-tunneling, etc.), the stability of cut slopes including temporary for the launch pits positioned such to provide minimum 12 m working platform, and permanent, and temporary protection systems. Pertinent construction issues from a geotechnical standpoint are examined in general accordance with the instructions from MTO provided in their email dated April 20, 2018.

2.2 Expected Ground Conditions

The following ground conditions along the proposed culverts alignments are interpreted from the current investigation:

Culvert #1 (CV11+595)

- a) Highway 11 is a two lane, north/south roadway having approximately 4 m wide sand and gravel shoulders.
- b) The elevation of the crest of the roadway at Station 11+595 is about Elev. 290.5 m. The highway embankment at the existing culvert is approximately 5.0 m high, having side slopes of approximately 2H:1V and 5H:1V from the top of the embankment to the toe of the embankment at the west and east side, respectively. The height of the embankment at the proposed culvert will be approximately 5.3 m and 5.5 m on the inlet and outlet sides of the roadway, having side slopes 2H:1V and 3H:1V from the top of the embankment to the toe of the embankment at the west and east side, respectively. The highway embankment at Station 11+595 consists of gravelly sand fill (~1.5 m to 3.1 m thick) underlain by clayey silt fill (~1.5 m to 1.6 m thick) followed by lower gravelly sand fill (0.7 m to 2.0 m).
- c) The embankment fill is underlain by soft to firm clayey silt with organics (~1.6 m to 4.5 m thick) followed by very soft to very stiff silty clay/clayey silt then followed by very loose to very dense silt to the depth of 14.3 m (~Elev. 275.7 m).
- d) The sink hole of approximately 1.2 m diameter and 0.7 m deep observed on the west side slope at the existing culvert location, probably resulted from washout of fine-grained clay and silt particles.
- e) The approximate proposed elevations of new Culvert #1 inverts are between Elev. 284.9 m at the inlet and Elev. 284.5 m at the outlet. The foundation soil of the proposed culvert is anticipated to be native clayey silt with organics or silty clay/clayey silt.
- f) The undrained shear strength of the silty clay/clayey silt and clayey silt with organics soil located Station 11+595 below the existing roadway is measured to be 19 kPa and 32 kPa, respectively.
- g) The groundwater levels in the open boreholes were recorded between approximate Elev. 281.1 m to 281.9 m at Station 11+595 at the time of investigation, which is well below the invert level. However, based on moisture content of the soil samples observed during drilling and measured subsequently in the lab, the inferred groundwater levels below the embankment could be estimated to be at approximate Elev. 284.5 m. The creek level at Station 11+595 was measured at Elev. 285.7 m, which is slightly higher than the invert level. Seasonal variations in the water table should be expected.

Culvert #2 (CV20+603.5)

- a) Highway 11 is a two lane, north/south roadway having approximately 4 m wide sand and gravel shoulders.
- b) The elevation of the crest of the roadway at Station 20+603.5 is about Elev. 268.9 m. The highway embankment at the existing culvert is approximately 4.0 m high, having side slopes of approximately 2H:1V from the top of the embankment to the toe of the embankment. The height of the embankment at the proposed culvert will be also approximately 4.0 m high on both sides of the roadway, having side slopes 2H:1V from the top of the embankment to the toe of the

embankment. The highway embankment at Station 20+603.5 consists of sand and gravel fill (~1.5 m to 2.1 m thick) underlain by silty clay/clayey silt fill (~3.1 m to 4.6 m thick). The embankment fill is underlain by very soft to soft varved silty clay (~4.4 m to 9.8 m thick) to the depth of 15.1 m (~Elev. 253.7 m).

- c) The sink hole of approximately 0.8 m diameter was observed on the west side slope at the existing culvert location, probably resulted from washout of fine-grained clay and silt particles.
- d) The proposed approximate elevations of new Culvert #2 inverts are between Elev. 265.3 m at the inlet and Elev. 264.9 m at the outlet. The foundation soil of this culvert is anticipated to be silty clay to clay fill and native varved silty clay.
- e) The undrained shear strength of the varved silty clay to clay soil located at Station 20+603.5 below the existing roadway is measured to be around 19 kPa.
- f) The groundwater levels in the open boreholes were recorded between approximate Elev. 258.0 m and 262.5 m at Stations 20+603.5 at the time of investigation, which is well below the invert level. However, based on moisture content of the soil samples observed during drilling and measured subsequently in the lab, the inferred groundwater levels below the embankment could be estimated to be at approximate Elev. 264.5 m. The creek level at Stations 20+603.5 was measured at Elev. 265.0 m, which is slightly higher than the invert level at the outlet. Seasonal variations in the water table should be expected.

Culvert #3 (CV20+832.5)

- a) Highway 11 is a two lane, north/south roadway having approximately 4 m wide sand and gravel shoulders.
- b) The elevation of the crest of the roadway at Station 20+832.5 is about Elev. 270.4 m. The highway embankment at the existing culvert is approximately 4.0 m high, having side slopes of approximately 4H:1V and 5H:1V from the top of the embankment to the toe of the embankment at west and east, respectively. The proposed embankment will be approximately 4.5 m high on both sides of the roadway, having side slopes 2H:1V from the top of the embankment to the toe of the embankment. The highway embankment at Station 20+832.5 consists of gravelly sand fill (~1.5 m thick) underlain by clayey silt fill (~0.3 m to 1.6 m thick) followed by sand fill (~0.8 m to 2.0 m) then silty clay fill (~2.3 m). The embankment fill is underlain by very soft to stiff varved silty clay to clay (~4.5 m to 7.5 m thick) to the depth of 14.3 m (~Elev. 255.9 m).
- c) The sink hole of approximately 0.8 m diameter was observed on the west side slope at the existing culvert location, probably resulted from washout of fine-grained clay and silt particles.
- d) The proposed approximate elevations of new Culvert #3 inverts are between Elev. 266.4 m at the inlet and Elev. 266.1 m at the outlet. The foundation soil of the proposed culvert is anticipated to be native varved silty clay to clay. The actual founding level will depend on the thickness of the bottom of the culvert, and design invert levels.
- e) The undrained shear strength of the varved silty clay to clay soil located at Station 20+832.5 below the existing roadway is measured to be 16 kPa to 20 kPa.

- f) The groundwater levels in the open boreholes were recorded between approximate Elev. 258.0 m and 262.5 m at Stations 20+832.5 at the time of investigation, which is well below the invert levels. However, based on moisture content of the soil samples observed during drilling and measured subsequently in the lab, the inferred groundwater levels below the embankment could be estimated to be at approximate Elev. 266.0 m which is the creek level at Stations 20+832.5, which is slightly lower than the invert level. Seasonal variations in the water table should be expected.

Give no significant grade raise is planned at the locations of new culverts, the anticipated maximum total settlements for the new proposed culverts are not expected to exceed 25 mm for construction done in accordance with these design parameters and assuming good construction practice including sound base preparation. These recommendations are applicable if the new culverts are installed by non-trenchless methods.

2.3 Construction Options

In order to minimize grading, to reduce the length of trenchless installation, and to mitigate impacts to surrounding utilities, a trenchless method was chosen for culvert replacements by MTO. According to the findings in this investigation, the excavation for the new culverts will be through clayey silt fill underlining clayey silt with organics at Station 11+595 (Culvert #1), and though silty clay/clayey silt fill underlining varved clayey silt to clay at Station 20+603.5 and 20+832.5.

For three culvert replacements at the new proposed locations, several options were considered as possible alternatives for the new culvert trenchless installation and cut and cover method:

- Jack and auger bore;
- Pipe ramming;
- Micro-tunneling;
- Cut and cover.

If the new culvert is placed at the location of the existing culvert, the replacement of these culverts through trenchless swallowing technique using pipe ramming method is also a viable option. In general this culvert replacement option is much like the process for new installation using the pipe ramming method, except that a larger diameter pipe is rammed over the existing culvert. Even though the placement of the new culvert at the location of the existing culvert is not requested in the TOR, that option is also considered briefly in this report. Therefore, advantages, disadvantages and respective estimated cost of suggested methods along the new proposed alignments and along the existing alignments, are summarized in Tables 2.1A and 2.1B, respectively.

The selection of appropriate construction methods for these culverts considered the soil conditions at zone of culvert installation, and diameter and length of the culvert. However, there are some soft silty clay with organics/varved silty clay to clay layers were found to exist under the proposed inverts of culverts. It is our

opinion that due to existence of soft layers, construction support planform and reaction beams have to be built for jack and boring machine. It is also our opinion to consider cut and cover with half and half construction option, has to be revisited for all the culvert sites, especially for Culvert #1 site. The details will be discussed in the following sections. The traditional cut and cover method is considered as less favorable to MTO since it requires disruption of traffic. The trenchless approach does not require disruption of traffic, but it involves construction adjacent to the current alignment with the need to decommission the existing culvert by grouting and sealing. Sufficient separation (i.e. more than one tunnel diameter) will be required for tunneling approaches.

TBM tunneling is not applicable since this method would require oversizing of pipe to minimum 1.8 m. The pipe bursting method for trenchless replacement of these culverts was not considered as applicable in this project, since the size and nature of the host CSPs classify these culverts as unsuitable candidates for this technique. According to OPSS 463 pipe diameters between 500 to 900 mm are categorized as difficult to extremely difficult to be replaced by bursting techniques.

Table 2.1A Trenchless (Tunneling) installation methods for culvert replacement along the new proposed culverts alignments

Installation Method		Advantages	Disadvantages	Relative Cost*	Ranking
Trenchless Approach	Jack and Auger Bore	<ul style="list-style-type: none"> • No traffic interruption and requirement for detour route • Commonly used in Ontario • Relatively simple operation • Short mobilization time • Best applied in uniform soil with no free water present • Applicable for relatively short culverts • The existing CSP culvert can be used to maintain the surface water flow during the construction • Less expensive than other trenchless methods 	<ul style="list-style-type: none"> • Pipe can be difficult to steer/direct • Settlement of existing embankment due to loss of ground during jack and bore operations. Short and long term settlement • Excavation and shoring required to achieve starting grade, as well as to minimize possible impact on the global stability of the embankment • Large entry pit size • Dewatering possibly required at launching pit if groundwater level in the embankment above the invert level (should not be a case in this project) • Risk of cost overrun and instability to finish job: low to moderate 	Less expensive than other trenchless methods	1
	Pipe Ramming (New Installation)	<ul style="list-style-type: none"> • No traffic interruption and requirement for detour route • Not very sensitive to ground condition • Suitable for steel pipes up to 1.8 m in diameter and best up to 50 m long • Accommodates obstructions well • Little surface settlement • Soil removed after pipe in place • The existing CSP culvert can be used to maintain the surface water flow during the construction 	<ul style="list-style-type: none"> • Pipe can be difficult to steer/direct • Vibrations could potentially impact the stability of the existing slope • Ground heave • Requires decommissioning of old culvert, including grouting and sealing • Excavation and possible shoring required to achieve starting grade • Large entry pit size • Slower than other trenchless methods • Dewatering possibly required at launching and receiving pits if groundwater level in 	Slightly more expensive than jack and bore method	2

Installation Method		Advantages	Disadvantages	Relative Cost*	Ranking
			<p>the embankment above the invert level (should not be a case in this project)</p> <ul style="list-style-type: none"> • More expensive than jack and bore method • Risk of cost overrun and instability to finish job: moderate to high 		
	Micro-tunneling	<ul style="list-style-type: none"> • No traffic interruption and requirement for detour route • Handles wide variety of ground conditions • Ability to control excavation face stability • No dewatering required • Minimum surface disruption • Very accurate • The existing CSP culvert can be used to maintain the surface water flow during the construction 	<ul style="list-style-type: none"> • High construction cost • Obstruction problematic • Excavation and shoring require to achieve starting grade, as well as to minimize possible impact on the global stability of the embankment • Requires large area for jacking shaft and support equipment • Not suitable for short drive • Dewatering possibly required at launching and receiving pits if groundwater level in the embankment above the invert level (should not be a case in this project) • Fluid to support annular space, if necessary • More expensive than jack and bore method • Risk of cost overrun and instability to finish job: moderate to high 	Significantly more expensive than jack and bore method	5

Installation Method		Advantages	Disadvantages	Relative Cost*	Ranking
Cut and Cover Approach	Half and Half Construction - Shoring System with Unsupported Cut Sides	<ul style="list-style-type: none"> • Short mobilization time • Straight forward construction and construction procedures • Experienced contractors • Likely relatively less expensive than trenchless methods, however the shoring can be costly and traffic interruption will occur 	<ul style="list-style-type: none"> • Traffic interruption • Roadway protection required for up to 5.5 m deep excavation • High cost of shoring system (i.e. road protection) • Large amount of soil to be excavated • Removal and/or post-construction grouting for decommissioning of the existing CSP culvert required • Risk of cost overrun and instability to finish job: low to moderate 	More expensive due to high costs of shoring system	3
	Shoring System with Braced Cut Sides	<ul style="list-style-type: none"> • One or possibly two lanes of traffic flow maintained on existing road (e.g. steel decking, but costly) • Global stability of excavation enhanced by narrow geometry • Less traffic interruption than shoring system with unsupported cut sides approach • Temporary decking could be usable over braced cut to allow for excavation of both halves prior to diverting stream and backfilling • Cost savings due to limited excavation and backfill 	<ul style="list-style-type: none"> • Traffic interruption • Bracing (e.g. struts) may interfere with excavation • Excavation of material and placement of bracing required in limited space • Removal and/or post-construction grouting for decommissioning of the existing CSP culvert required • Risk of cost overrun and instability to finish job: low to moderate 	More expensive than due to high costs for roadway protection and temporary decking (if feasible) to maintain continuous flow of traffic	4

Notes:

* *Relative Cost* is determined for 0.9 m to 1.2 m diameter pipes based on Table 1 "Average cost of trenchless techniques with more than five data records, in Construction and Rehabilitation Costs for Buried Pipe with Focus on Trenchless Technologies", NRC-CNRC report No. IRC-RR-101.

Table 2.1B Trenchless (Tunneling) installation methods for culvert replacement along the existing culverts alignments

Installation Method		Advantages	Disadvantages	Relative Cost*	Ranking
	Pipe Ramming (Swallowing Technique)	<ul style="list-style-type: none"> • Does not requires decommissioning of old culvert • No traffic interruption and requirement for detour route • Not very sensitive to ground condition • Suitable for steel pipes up to 1.8 m in diameter and best up to 50 m long • Little surface settlement • Existing pipe and other spoils are removed after new pipe in place 	<ul style="list-style-type: none"> • The existing CSP culvert cannot be used to maintain the surface water flow during the construction • Pipe can be difficult to steer/direct • Vibrations could potentially impact the stability of the existing slope • Ground heave • Excavation and possible shoring required to achieve starting grade • Large entry pit size • Dewatering possibly required at launching and receiving pits if groundwater level in the embankment above the invert level (should not be a case in this project) • Risk of cost overrun and instability to finish job: moderate to high 	Less expensive than open cut methods	1
Cut and Cover Approach	Half and Half Construction - Shoring System with Unsupported Cut Sides	<ul style="list-style-type: none"> • Short mobilization time • Straight forward construction and construction procedures • Experienced contractors • Likely relatively less expensive than trenchless methods, however the shoring can be costly and traffic interruption will occur 	<ul style="list-style-type: none"> • Traffic interruption • The existing CSP culvert cannot be used to maintain the surface water flow during the construction • Roadway protection required for up to 5.5 m deep excavation • High cost of shoring system (i.e. road protection) • Large amount of soil to be excavated • Removal of the existing CSP culvert required • Risk of cost overrun and instability to finish job: low to moderate 	More expensive due to high costs of shoring system	2

Installation Method		Advantages	Disadvantages	Relative Cost*	Ranking
	Shoring System with Braced Cut Sides	<ul style="list-style-type: none"> • One or possibly two lanes of traffic flow maintained on existing road (e.g. steel decking, but costly) • Global stability of excavation enhanced by narrow geometry • Less traffic interruption than shoring system with unsupported cut sides approach • Temporary decking could be usable over braced cut to allow for excavation of both halves prior to diverting stream and backfilling • Cost savings due to limited excavation and backfill 	<ul style="list-style-type: none"> • Traffic interruption • The existing CSP culvert cannot be used to maintain the surface water flow during the construction • Bracing (e.g. struts) may interfere with excavation • Excavation of material and placement of bracing required in limited space • Removal of the existing CSP culvert required • Risk of cost overrun and instability to finish job: low to moderate 	More expensive than due to high costs for roadway protection and temporary decking (if feasible) to maintain continuous flow of traffic	3

Notes:

* *Relative Cost* is determined for 0.9 m to 1.2 m diameter pipes based on Table 1 "Average cost of trenchless techniques with more than five data records, in Construction and Rehabilitation Costs for Buried Pipe with Focus on Trenchless Technologies", NRC-CNRC report No. IRC-RR-101.

Based on the above list of advantages and disadvantages of all trenchless (tunneling) construction methods for the culvert installation at the new proposed alignments, jack and argue bore method might be considered as the most viable method for replacement of these three culverts from a geotechnical and/or foundation perspective since the groundwater levels are lower than the pipe invert elevations. However, in our opinion the cut and cover method is more preferable for Culvert #1 due to existence of soft clayey silt underneath the proposed culvert. Micro-tunneling is ranked as the least viable tunneling method since the size of the tunnel is not favorable for this method (i.e. the tunnel is relatively short to be economical for this method). If the interruption of traffic could be accepted, half and half construction method might be more viable than trenchless methods.

For the culvert installation at the existing alignments, pipe swallowing using pipe ramming is the most viable option for this project. The major advantage of this method is no need for decommissioning of old CSP culverts. However, the existing culvert cannot be used to maintain the surface water flow during the construction.

Therefore, based on the site conditions and method characteristics elaborated above, the following options for the culvert trenchless construction at the proposed alignments are discussed in the following sections: jack and auger bore, pipe ramming, and micro-tunneling. The pipe swallowing method is essentially similar as the pipe ramming method,

2.4 Culvert Installation by Trenchless (Tunnelling) Method

Several tunneling methods are considered and discussed in Section 2.3 based on soil and groundwater conditions at the site and dimensions of the three proposed culverts. For all trenchless installation methods the procedures should conform to the MTO "Pipe Installation by Trenchless Method" NSSP and industrial standards. According to OPSS.PROV 421, the minimum spacing allowed between new culvert and existing culvert is 600 mm for the pipe diameter less than 1200 mm and 1/2 pipe diameter for the diameter between 1200 mm and 2400 mm. However, since the existing pipe is deteriorated and has to be decommissioned, it is recommended that the new alignment has to be more than one pipe diameter offset to the south or north, relative to the existing culvert. The existing abandoned culvert must be properly decommissioned including grouting and sealing.

According to the MTO drawings provided and our findings during the geotechnical investigation, the new culverts at Stations 11+595, 20+603.5 and 20+832.5 are proposed to be installed mostly in the layer of clayey silt/silty clay to clay fill as shown in Drawings No.1 to 3 in Appendix B. However, the invert portion of Culvert #1 (i.e. inlet and outlet sides) will be installed in soft to firm clayey silt with organics, while the invert portion of Culverts #2 and #3 at the outlet side will be installed in soft and firm varved silty clay to clay, respectively.

Based on measurement of groundwater levels in the open boreholes, the groundwater levels at the location of the proposed culverts alignments are estimated to be between Elev. 281.1 m and 281.9 m at Station 11+595, and between Elev. 258.0 m and 262.5 m at Station 20+603.5 and 20+832.5 at the time of investigation. Based on these measurements and moisture contents of the soil samples observed during drilling and testing, it is expected that the groundwater levels will be approximately 2.0

m below the inverts of the proposed culverts at the inlet side and decline gradually toward the outlet side. However, the actual groundwater levels could be higher according to moisture content results obtained by lab tests and the creek water levels, which is slightly higher than the pipe inverts. Therefore, it is projected that the culvert trenchless excavation will be carried out mostly through clayey silt/silty clay to clay fill with the groundwater table slightly above the inlet level. Cobbles and boulders were not encountered in the zone of tunneling during borehole investigations. However, considering the nature of deposition of these sediments, it is recommended that the Contractor is alerted that cobbles and boulders should be anticipated in the deposits at the sites as per "Pipe Installation by Trenchless Method" NSSP, Section 7.01.11.

The viable tunnel excavation methods assessed in Table 2.1A are discussed in the subsequent sections as well general tunneling construction considerations.

2.4.1 Tunnel Excavation Methods

2.4.1.1 Pipe Jack and Auger Bore

Pipe jack and auger bore method involves jacking a pipe through the soil with a hydraulic ram and removal of soil with an auger. A cutting head is fixed to the leading edge of the pipe. The auger transports spoils from the cutting head back to the bore pit. The direction of the auger head can only be controlled using a rudimentary steering system where minor adjustments can be made. One of the advantages of using the jack and bore method for the pipe installation is that the auger can be manually removed to permit cleaning of obstructions such as cobbles and boulders. However, the steering ability and grade is limited.

The elevation and gradient of the pipe must be closely controlled during the course of the jack and bore. It is recommended that auger would always be maintained at least 1 m behind the cutter edge. In addition, the volume and type of mucked soil should be continuously monitored by the geotechnical engineer to provide an indication of any ground loss. The jacking and boring operations should be continued without stoppage until completion. To reduce (but not eliminate) loss of ground and associated disturbance, consideration may be given to jacking the pipe across the alignment as far as practical, prior auguring. However, obstacles, if encountered in the embankment fill, could make this difficult or impractical. Lubrication may be provided to reduce the friction between the pipe and the borehole walls. The characteristics of the surrounding soil should be considered in selecting the appropriate lubricant.

Since the inverts of the culverts could be slightly below the groundwater at the jacking pit, dewatering would need to be carried out to temporarily lower the ground water level below the bottoms of the jacking pit. Further, surface water flow should be controlled at all three sites. This would likely utilize the existing culverts prior to its decommissioning.

Excavation and/or shoring for the bore/jacking pits can be completed as recommended in subsequent sections of this report.

Ultimate jacking pressure (σ) that can be exerted at the reaction plate on the pit wall before passive failure occurs may be calculated using the following formula:

$$\sigma = (\gamma) (D) (K_p)$$

where

σ = passive earth pressure resistance at depth D, kPa per m of width

γ = unit weight of soil, kN/m³

D = depth below ground surface, m

K_p = passive pressure coefficient

2.4.1.2 Pipe Ramming

Pipe ramming is a trenchless method for installation of steel pipes over distances typically up to 50 m long and up to 1.8 m in diameter. The method uses pneumatic percussive blows to drive the pipe into ground. Spoil removal from the pipe can be done by an auger. It typically requires excavation of two pits, the insertion pit and the receiving pit. However, the ramming can be launched without an insertion pit if the ram is designed to start at the side of a slope. For replacement of the existing culvert, a larger diameter casing could be rammed over the existing culvert. Then the existing culvert will be swallowed along with the spoils. Once the large diameter pipe has been rammed into place, the old culvert and remaining spoils can be removed. The pipe ramming (with and without pipe swallowing) can be suitable for installation of the proposed culverts, since the required lengths are at the upper limit of the method. However, installation is very noisy and difficult to steer. Ground heave could be developed.

2.4.1.3 Micro-tunneling

Micro-tunnelling is a non-entry, remotely controlled, guided pipe-jacking process. This technique provides the ability to control excavation face stability by applying fluid pressure to counterbalance the earth pressure using either of two basic modes, slurry shield or earth pressure balance. Usually a pipe is jacked into place behind the cutting head with hydraulics. In order to minimize the resistance along the pipe exterior, a bentonite grout lubricant can be injected behind the cutting face. Steel, concrete or fibreglass pipes can be installed with this method.

The major advantage of micro-tunnelling method is that its performance is not affected by high groundwater levels, so the dewatering is not required. For this particular project it is not crucial since the groundwater level is not high. Major disadvantages of micro-tunnelling for this project are considered to be the relatively high cost of mobilization and lack of locally skilled contractors.

2.4.2 Considerations of Tunnelling

2.4.2.2 Groundwater Control

The groundwater levels at three sites measured in the open holes upon completion of drilling are lower than culvert inverts. The creek water levels at the locations of Culvert #1, #2 and #3 at the time of the

investigation were approximately Elev. 285.7 m, 265.0 m and 266.0 m, respectively. Based on moisture content of the soil samples observed during drilling and measured subsequently in the lab, the inferred groundwater level within the embankment was estimated to be at approximate Elev. 284.5 m at Station 11+595, Elev. 264.5 m at Station 20+603.5 and Elev. 266.0 m at Station 20+832.5.

Taking into account these inferred groundwater levels it can be estimated that at Stations 11+595 and 20+832.5, the inferred groundwater levels were at the culvert invert levels, while at Station 20+603.5 the inferred groundwater level was approximately 0.5 m below the invert level. Therefore, a small amount of groundwater seepage into the tunnel should be expected in the zone of tunnelling, and consequently, the dewatering might be required prior to advancing the pipe to ensure dry working conditions, reduce groundwater seepage, and stabilize the excavation in that zone. The dewatering would need to be carried out to temporarily lower the groundwater level to at least 1 m below the base of the excavation for a launching pit. Alternatively, clear stone wrapped with geotextile may be considered as a working subgrade platform to allow construction under the less dry condition. Dewatering requirements will be governed by the time of the year when the construction is performed. However, as previously mentioned, seasonal variations in the water table should be expected, with higher levels occurring during wetter periods of the year and lower levels during drier periods. It is the responsibility of the Contractor to propose a suitable dewatering system based on the time of construction and groundwater levels. Dewatering shall conform to OPSS 517.

Based on information provided in the Ontario Water Well Records, there are no wells within a 500 m distance from these three culverts. However, the depths of the highest groundwater well records obtained in the wells distanced more than 500 m were 26.8 m (Well ID 10055321) at Station 11+595 and 39.6 m at Stations 20+603.5 and 20+832.5 (Well ID 10055918).

2.4.2.3 Ground Settlement

Settlement around the culvert is generally a combination of ground loss or “immediate” settlement caused by tunneling, and consolidation settlement. The immediate settlement is a direct result of the overcut and movement of ground at the heading during tunneling. The factors that influence the immediate settlement include the soil strength and the method of tunneling. Based on soil characteristics of the site, an experienced Contractor should be able to keep the settlement under the MTO’s required limit of 10 mm. Technical specifications should ensure that:

- The use of over-cutters (excavating to a diameter greater than the pipe diameter) is kept under 10 mm;
- The overcut area is grouted in a timely manner (if a man-entry tunnel is constructed grout should be injected immediately after support is installed); and
- The program of instrumentation is carried out as per MTO guidelines.

In the event that the settlement is greater than the allowable 10 mm, some soil stabilization measures such as grouting or ground freezing might be applied to arrest or reduce settlement. However, there are no ground raises at these three sites, so no any settlement issue is expected.

2.4.2.4 Excavation of Pits

The launching and receiving pits for the tunneling equipment are expected to be located at the inlet and outlet of the proposed culvert locations, respectively. The bases of the pits are expected to be set at about 0.5 to 1 m depth from invert of the proposed culverts. Excavations for launching and receiving pits will be conducted through any surficial fill on the embankment slopes and will extend into the underlying clayey silt with organics or varved silty clay to clay deposits. In order to provide the required excavation geometry for the drilling (e.g. vertical front face for tunnel entry and a vertical rear face with a ballast system to act as a reaction force), the sides of the excavation will have to be shored. Recommendations for shoring are addressed in Section 2.4.3 of this report.

The groundwater control during excavation is discussed in Section 2.4.2.2. However, for the shallow depth of excavation anticipated, a small amount of groundwater flow is expected to enter the underground works at the launching pits. It is expected that this amount of water could be managed by a sump pump method. Technical specifications must ensure that the Contractor submits a groundwater and surface water control plan describing the proposed method for control.

2.4.2.5 Backfilling in Pits

It is anticipated that backfilling work will be required at the launching and receiving pits to return site condition to pre-construction grades and/or to the proposed permanent embankment slopes. The following comments and recommendations are provided for backfilling such excavations.

The on-site excavated silty clay/clayey silt fill can be used as backfill, provided the material is within 3 percent of optimum moisture as determined in the standard proctor test. All excavations should be backfilled with inorganic on-site soils placed in maximum 300 mm thick lifts and compacted to at least 95% of the Standard Proctor Maximum Dry Density (SPMDD). Any organic, excessively wet, compressible or otherwise deleterious materials should not be used for backfilling purposes. Any shortfall of suitable on-site excavated materials can be made up with imported and approved materials.

All backfill and compaction operations should be monitored by qualified geotechnical personnel to approve materials, to evaluate placement operations, and to verify that the specified degree of compaction is being achieved throughout the fill.

2.4.3 Excavations

As understand the temporary cut slopes for the launching pits will be positioned such to provide minimum 12 m working platform for all three sites for tunnel excavations with any trenchless method. All these open cut excavations must be conducted in accordance with the Occupational Health and Safety Act (OHSA) and Regulations for Construction (O.Reg 213/91). Sand and gravel fill and silty clay/clayey silt fill may be classified as Type 3 soil above the groundwater table. The native clayey silt with organics may also be Type 3 soil above the groundwater table, in conformance with the OHSA. Excavations are expected to be slightly above the groundwater level measured in the boreholes on the embankment crest during this investigation. To avoid disturbance of the founding subgrade and to allow placement of backfill in dry conditions, groundwater must be controlled to be below the proposed excavation levels prior to digging to final levels.

In general, temporary excavations side slopes for Type 3 soil should not exceed 1H:1V in accordance with OHSA, and 2H:1V is recommended for global stability of deep cuts (i.e. to maintain a global factor of safety greater than 1.3) where excavation will be left open for some time. There is a potential for sloughing to occur if the trench remains open for an extended period of time (i.e. > 24 hours) or during a rainfall event. For this project, the global slope stability analyses for a 1H:1V temporary cut slope of the existing embankment at the launching face were performed and the results are presented in Section 2.6. Based on these results the 1H:1V cut slope could have a global factor of safety of 1.3 for a short-term steady state condition (i.e. approximately a period of 2 to 3 weeks). Further than 2 to 3 weeks, it is recommended to flatten the slope or to apply shoring. Under any circumstances the crest and surface of the slope should be monitored/examined by a geotechnical engineer especially immediately after any heavy rainfall event.

2.4.3.1 Temporary Protection System

For the temporary cut slopes (up to 5 m), temporary shoring will be required as a roadway protection system. A shoring system such as steel sheet piles or soldier piles and lagging system can be employed for temporary excavations at these three sites. Given the setting, the most likely steel sheet piles would be internal and the impact on excavation operations must be accommodated. It will be the Contractor's responsibility to design a suitable temporary support system for the MTO review prior to installation. The Contractor is to follow OPSS.PROV 539 regarding temporary protection systems (e.g. braced soldier pile and lagging system).

The Contractor should be responsible for the complete design, construction, monitoring and removal of the installed protection system. The protection system should be designed to provide protection for excavations as required by the OHSA, at locations specified in the contract, and at any locations where the stability, safety or function of an existing structure and/or utility may be impaired by construction work. Decommissioning of temporary shoring must be consistent with good practice to avoid interference with highway systems and utilities, if any. The protection system should be designed for the Performance Level 2 (for small, less important sections). The minimum requirements for monitoring should include the survey measurements of 6 m apart scaled targets attached to the shoring wall at the elevations specified. If movement approaches the allowable limit of 25 mm (Performance level 2), suitable measures should be taken to ensure stability of the protection system and to ensure that the movement does not exceed the performance level specified.

For the half-and-half construction approach, temporary shoring is required as a roadway protection system. Shoring scheme can likely include two main forms:

OPTION A: Half-and-Half Construction Using Shoring System and Unsupported Cut Sides

This method provides roadway protection parallel to the highway between two lanes (at NBL) and the divert traffic and undertake open cut (i.e. sloping cut parallel to the highway). The roadway protection can take the form of reversible shoring such as a soldier pile and lagging with rakers for horizontal support. Where the cut extends below prevailing groundwater a suitable control/system is required. Once one lane is completed the supports can be reversed and the other lane constructed in similar fashion. The shoring system would likely be decommissioned in place. Temporary surface water flow

diversion (e.g. through the existing culvert) and/or control (e.g. pumping) must be developed by contractor.

OPTION B: Half-and-Half Construction Using Shoring System and Braced Cut Sides

This method provides braced cut shoring system perpendicular to the highway (or angled for the new alignment) with bulkheads for face protection and to allow culvert construction. Excavation in this case would have to accommodate the necessary cross-bracing such as struts. With this option, consideration would have been given to how the new culvert sections will be installed given the relatively narrow work area and potential for obstructions from the lateral bracing (e.g. struts). Temporary decking could possibly be used over the braced cut to allow for excavation of both halves prior to diverting stream and backfilling. However decking would be costly. As well as Option A, temporary surface water flow diversion (e.g. through the existing culvert) and/or control (e.g. pumping) must be developed by contractor.

Option A could be more economical due to possible cost savings for reversible wall configuration, but it will be more disruptive to the highway embankment. Option B will disrupt less of the embankment but would cost more, i.e. about 1.8 times of Option A. Excavation and backfilling operations will also be more challenging with Option B.

As mentioned before, the Contractor is responsible for temporary shoring work and design that should accommodate all relevant conditions including local and global stability for all stages of installation and any necessary ground water controls.

2.4.3.2 Lateral Earth Pressure

The temporary shoring required for temporary excavation should be designed to resist lateral earth pressure. The expression for calculating lateral earth pressure is given by:

$$P = K(\gamma h + q) \text{ for non-braced cut or } K(0.65\gamma h + q) \text{ for braced cut}$$

where P = earth pressure intensity at depth h , kPa

K = earth pressure coefficient

γ = unit weight of retained soil, kN/m³

q = surcharge near wall, kPa

h = depth to point of interest, m

The above expression does not take into account hydrostatic pressure, which must be included for the groundwater levels measured on the site. Table 2.2 lists earth pressure parameters for given materials.

The mobilization of full active or passive resistance requires a measurable and perhaps significant wall movement or rotation. Therefore, unless the structural element can tolerate these deflections, the at-rest earth pressure should be used in design.

The effect of compaction surcharge should be taken into account in the calculations of active and at-rest earth pressures. The lateral pressure due to compaction should be taken as at least 12 kPa at the surface, and its magnitude should be assumed to diminish linearly with depth to zero at the depth where the active (or at rest) pressure is equal to 12 kPa. This pressure distribution should be added to the calculated active (or at rest) pressure. Notwithstanding, lighter compaction equipment and smaller lifts should be used adjacent to culvert walls to prevent overstressing.

It is likely that bracing for the temporary support system will be required at a maximum interval of 5 m. For multiple support systems refer to *Canadian Foundation Engineering Manual* (CFEM) for apparent earth pressure distributions (CFEM, Section 26.10.3, Figure 26.8)

Table 2.2 Material types and earth pressure properties

Material	Unfactored Friction Angle ϕ'	Coefficient of Active Earth Pressure (K_a)	Coefficient of Passive Earth Pressure (K_p)	Coefficient of Earth Pressure at Rest (K_o)	Unit Weight γ (kN/m ³)
Gravelly Sand to Sand and Gravel Fill	32°	0.31	3.25	0.47	21
Silty Clay to Clayey Silt Fill	31°	0.32	3.12	0.48	20
Clayey Silt with Organics	24	0.42	2.37	0.59	18
Silty Clay/Clayey Silt	24	0.42	2.37	0.59	18
Silt	29	0.35	2.88	0.52	20
Varved Silty Clay to Clay	23	0.44	2.28	0.61	18

2.4.4 Monitoring and Contingency Plan

It is emphasized that the resulting performance of the installed culverts will largely be dependent upon construction procedures and techniques. However, regardless of the method of tunnelling selected for this project, it is recommended that the contractor develop a contingency plan incorporating appropriate soil volume monitoring to address loss of material from outside the pipe during the tunnelling operation. This plan should include at a minimum the following items:

- an “Alert” level(s), e.g. the percentage of soil in excess of 100% of the displaced soil, at which the plan would be implemented;
- a means to close the tunnel, and preferably to pressurize the pipe; and
- an emergency personnel/agency contact list.

Settlements should be monitored during construction to ensure compliance with MTO guidelines and the contract requirements. The instrumentation program should adequately verify effects of tunneling on the overlying highway and obtain advance warning of ground movements. The scope and layout of

settlement instruments should be in general accordance with the MTO guidelines provided in “Pipe Installation by Trenchless Method” NSSP, Section 7.06. This should include surface settlement markers installed at the pavement/ground surface level on the shoulder, side slope and pavement at not greater than 5 m intervals along the culvert alignment and as an array of three in-ground (1.5 m deep) measurement points on the shoulder of highway perpendicular to the alignment. The Contractor should installed all surface settlement instruments a minimum of one week prior to the start of works.

A reading schedule should be as follows:

- Three consecutive readings at least one week prior to commencement of the work (Baseline readings);
- Once per shift during tunneling operation periods;
- Weekly after completion of the work for one month, or until such time at which all parties agree that further movement has stopped.

Instrumentation plans should be finalized once the Contractor is selected and when his construction methods are known.

As mentioned, control of ground settlement on this project depends on the behaviour of soil at the tunnel face and on the tunneling methodology employed by the Contractor. Therefore, it is recommended that a geotechnical engineer be present during active excavation to verify that the ground conditions are consistent with those encountered in the investigation boreholes. Furthermore, it is recommended that the volume of the material removed from the tunnel be monitored and continuously compared to the rate of tunnel advance. This will provide an indication if any over-excavation is taking place.

The criteria for evaluation of settlement should be based on the following action levels:

1. *Review Level:* If a maximum value of 10 mm relative to the baseline readings is reached, the method, rate or sequence of construction, or ground stabilization measures shall be reviewed or modified to mitigate further ground displacements.
2. *Alert Level:* If a maximum of 15 mm relative to the baseline readings is reached, the Contractor shall be required to cease construction operation or to execute pre-planned measures to secure the site to mitigate further unacceptable settlement and to assure safety of public.

2.5 Inlet and Outlet

2.5.1 Erosion Protection at Outlet

Rip-rap protection should be provided at the culvert outlet. The rip-rap should extend approximately 5 m beyond the ends of the culvert and line the embankment slope to the spring line of the culvert. The size of the rip-rap is a function of the surface water hydrology. As a rule of thumb the thickness of the rip-rap should be a minimum of twice the median particle size, and 300 mm thick as a minimum. The

rip-rap configuration at the downstream bed should generally follow the OPSD 810.010, which is included in Appendix F of this report. Rip-rap placed at 1V:1H will be stable.

2.5.2 Stream Bed Rip-Rap

The stream bed rip-rap thickness is to be twice the median particle size, and/or 300 mm thick as a minimum as outlined by OPSD 810.010 included in Appendix F of this report.

2.5.3 Frost Protection

As noted before in Section 2.4.3, a frost penetration depth of approximately 2.4 m can occur in open unheated areas of New Liskeard Area without snow cover. At the culvert inlets and outlets, and beneath the proposed culverts, the native soils consist of silty clay to clayey silt material. However, for pipe culverts for trenchless method and concrete box culverts are not required frost protection.

2.6 Assessment of Slope Stability

To assess the global and surficial stability of the temporary cut slopes and permanent embankment slopes for these three proposed culverts, a series of slope stability analyses was performed. The slope stability analyses were performed using the Morgenstern-Price method developed on the basis of limit equilibrium. The SLOPE/W computer program developed by GeoSlope International was employed for computation.

Stability assessments of east and west slopes were performed on the cross-sections perpendicular to the highway at the proposed culvert locations. The cross-sections with the proposed embankment slopes were provided by MTO. The stratigraphy and groundwater condition at the sites were developed based on the results of the geotechnical investigation presented in Part I - Foundation Investigation Report. The groundwater level was defined based on its measurements during the geotechnical investigation (see Section 1.5 in Part I - Foundation Investigation). However, it should be noted that the groundwater levels could vary from the conditions used in the model.

Effective stress analyses for long term stability were only considered to be appropriate to assess the stability of the proposed permanent embankment slopes. Total stress analyses (short term stability) using undrained shear strength values for cohesive materials, were performed for the proposed temporary cut slopes. However, total stress analyses using undrained shear strength values for cohesive materials, were also performed for the proposed permanent embankment slopes assuming that the new slopes will be reconstructed after the pipe installation. The SLOPE/W graphical printouts, for analyses performed are included in Appendix E.

Culvert #1 (CV11+595)

Table 2.3 shows the soil parameters used for the slope stability analyses for Culvert #1. The soil parameters were generally estimated based on the results of field and laboratory investigation.

Table 2.3 Soil properties used in slope stability analyses based on the proposed geometries provided by MTO for Culvert #1

Location	Material Type	Total Stress Conditions			Effective Stress Conditions		
		ϕ (degrees)	c (kPa)	γ (kN/m ³)	ϕ (degrees)	c (kPa)	γ (kN/m ³)
Culvert #1	Gravelly Sand Fill (Compact)	32	0	21	32	0	21
	Clayey Silt Fill (Firm to Stiff)	0	90	20	31	0	20
	Silty Clay Fill (Very Stiff)	0	110	20	32	0	20
	Clayey Silt with Organics (Soft to firm)	0	30	18	24	0	18
	Silty Clay/Clayey Silt (Very soft to firm)	0	25	18	24	0	18
	Silt (Loose to Compact)	29	0	20	29	0	20

The results of slope stability analyses are graphically presented in Figures 1 to 9 in Appendix E and summarized in Table 2.4.

Table 2.4 The results of global and surficial slope stability analyses

Location		Analysis Condition	Ref. Figure	Min. FOS
Culvert #1	Permanent East Slope (3H:1V)	Total stress analysis - undrained short-term	Fig. 1	1.4
		Effective stress analysis - drained long-term	Fig. 2 Fig. 3	1.3 (Surficial) 1.4 (Global)
	Permanent West Slope (2H:1V)	Total stress analysis - undrained short-term	Fig. 4	1.5
		Effective stress analysis - drained long-term	Fig. 5 Fig. 6	1.0 (Surficial) 1.1 (Global)
	Permanent West Slope (3H:1V)	Effective stress analysis - drained long-term	Fig. 8 Fig. 9	1.5 (Surficial) 1.6 (Global)
	Temporary Cut Slope (1H:1V)	Total stress analysis - undrained short-term	Fig. 7	1.3

The results of surficial and global slope stability analyses performed using the soil parameters listed in Table 2.3 and the geometry of proposed permanent and temporary embankment slopes show that the minimum factors of safety (FOS) for the slopes are greater than 1.3 except for the proposed permanent west slope for Culvert #1 which FOS is 1.0 (surficial) and 1.1 (global). To achieve the required minimum

FOS 1.3, the west slope should be flattened to 3H:1V as shown on Figures 8 and 9 (i.e. FOS of 1.5 (surficial) and 1.6 (global)).

Culvert #2 (CV20+603.5)

Table 2.5 shows the soil parameters used for the slope stability analyses for Culvert #2. The soil parameters were generally estimated based on the results of field and laboratory investigation.

Table 2.5 Soil properties used in slope stability analyses based on the proposed geometries provided by MTO for Culvert #2

Location	Material Type	Total Stress Conditions			Effective Stress Conditions		
		ϕ (degrees)	c (kPa)	γ (kN/m ³)	ϕ (degrees)	c (kPa)	γ (kN/m ³)
Culvert #2	Sand and Gravel Fill	32	0	21	32	0	21
	Silty Clay to Clay Fill (Soft to Stiff)	0	50	20	30	0	20
	Varved Silty Clay (Very Soft to Soft))	0	18	18	23	0	18

The results of slope stability analyses are graphically presented in Figures 10 to 16 in Appendix E and summarized in Table 2.6.

Table 2.6 The results of global and surficial slope stability analyses

Location		Analysis Condition	Ref. Figure	Min. FOS
Culvert #2	Permanent East Slope (2H:1V)	Total stress analysis - undrained short-term	Fig. 10	1.4
		Effective stress analysis - drained long-term	Fig. 11 Fig. 12	1.5 (Surficial) 1.6 (Global)
	Permanent West Slope (2H:1V)	Total stress analysis - undrained short-term	Fig. 13	1.5
		Effective stress analysis - drained long-term	Fig. 14 Fig. 15	1.6 (Surficial) 1.7 (Global)
	Temporary Cut Slope (1H:1V)	Total stress analysis - undrained short-term	Fig. 16	1.5

The results of surficial and global slope stability analyses performed using the soil parameters listed in Table 2.5 and the geometry of proposed permanent and temporary embankment slopes show that the minimum factors of safety (FOS) for the analyzed slopes are greater than 1.3.

Culvert #3 (CV20+832.5)

Table 2.7 shows the soil parameters used for the slope stability analyses for Culvert #3. The soil parameters were generally estimated based on the results of field and laboratory investigation.

Table 2.7 Soil properties used in slope stability analyses based on the proposed geometries provided by MTO for Culvert #3

Location	Material Type	Total Stress Conditions			Effective Stress Conditions		
		ϕ (degrees)	c (kPa)	γ (kN/m ³)	ϕ (degrees)	c (kPa)	γ (kN/m ³)
Culvert #3	Gravelly Sand Fill						
	Clayey Silt Fill (Soft)	0	25	18	24	0	18
	Silty Clay Fill (Soft to Stiff)	0	60	20	30	0	20
	Sand Fill (Compact)	32	0	21	32	0	21
	Varved Silty Clay to Clay (Very Soft to Firm)	0	20	18	23	0	18

The results of slope stability analyses are graphically presented in Figures 18 to 23 in Appendix E and summarized in Table 2.8.

Table 2.8 The results of global and surficial slope stability analyses

Location		Analysis Condition	Ref. Figure	Min. FOS
Culvert #3	Permanent East Slope (3H:1V)	Total stress analysis - undrained short-term	Fig. 17	2.0
		Effective stress analysis - drained long-term	Fig. 18 Fig. 19	1.6 (Surficial) 2.1 (Global)
	Permanent West Slope (2H:1V)	Total stress analysis - undrained short-term	Fig. 20	1.8
		Effective stress analysis - drained long-term	Fig. 21 Fig. 22	1.2 (Surficial) 1.4 (Global)
	Temporary Cut Slope (1H:1V)	Total stress analysis - undrained short-term	Fig. 23	1.5

The results of global slope stability analyses performed using the soil parameters listed in Table 2.7 and the geometry of proposed permanent and temporary embankment slopes show that the minimum factors of safety (FOS) for the slopes are greater than 1.3. The results of surficial slope stability analyses performed in drained long-term condition show that the surficial failures are possible happened at the permanent west slope of Culvert #3, since the minimum FOSs are less than 1.3. It is

recommended that the slope should be vegetated by grass and shrubs to minimize the effects of surface erosion at the slopes.

The results of global slope stability analyses for temporary cut slopes at all three locations show that a 1H:1V temporary cut slope at the launching face could be stable for a short-term steady state condition, which is estimated to be approximately a period of 2 to 3 weeks. Beyond that time, it is recommended to flatten the slope or to apply shoring. Under any circumstances the crest and surface of the slope should be monitored by a geotechnical engineer especially right after any heavy rain period. However, the final decision if a temporary cut or a temporary protection system will be used at the launching face, should be made after the method of installation is chosen.

3 CLOSURE

The recommendations made in this report are in accordance with our present understanding of the project and are provided solely for the team responsible for the design of the works described herein.

We recommend that we be retained to review our recommendations as the design nears completion to ensure that the final design is in agreement with the assumptions on which our recommendations are based and that our recommendations have been interpreted as intended. If not accorded this review, **exp** will assume no responsibility for the interpretation and use of the recommendations in this report.

A subsurface investigation is a limited sampling of a site; the subsurface conditions have been established only at the test hole locations. Should conditions at the site be encountered which differ from those reported at the test locations, we require that we be notified immediately in order to assess this additional information and our recommendations, as appropriate. It may then be necessary to perform additional investigation and analysis.

Contractors bidding on or undertaking any proposed work at this site should, relative to the subsurface conditions, decide on their own investigations, if deemed necessary, as well as their own interpretations of the factual results provided herein, so they may draw their own conclusions as to how the subsurface conditions may affect them.

This Foundation Investigation and Design Report has been prepared by Ms. Jia He, M.Eng, EIT. and Dr. Silvana Micic, P.Eng. It was reviewed by Mr. TaeChul Kim, M.E.Sc., P.Eng. and by Mr. Stan E. Gonsalves, M.Eng., P.Eng., Designated MTO Foundation Contact. The field investigation was supervised by Mr. Nimesh Tamrakar, M.Eng. P.Eng.

exp Services Inc.

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Technical Specialist

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Silvana Micic, Ph.D., P.Eng.
Senior Geotechnical Engineer
Project Manager



TaeChul Kim
for TaeChul Kim, M.E.Sc., P.Eng.
Senior Geotechnical/Foundation Specialist

Stan E. Gonsalves
Stan E. Gonsalves, M.Eng., P.Eng.
Principal Engineer
Designated MTO Foundation Contact



4 LIMITATIONS AND USE OF REPORT

BASIS OF REPORT

This report ("Report") is based on site conditions known or inferred by the geotechnical investigation undertaken as of the date of the Report. Should changes occur which potentially impact the geotechnical condition of the site, or if construction is implemented more than one year following the date of the Report, the recommendations of exp may require re-evaluation.

The Report is provided solely for the guidance of design engineers and on the assumption that the design will be in accordance with applicable codes and standards. Any changes in the design features which potentially impact the geotechnical analyses or issues concerning the geotechnical aspects of applicable codes and standards will necessitate a review of the design by exp. Additional field work and reporting may also be required.

Where applicable, recommended field services are the minimum necessary to ascertain that construction is being carried out in general conformity with building code guidelines, generally accepted practices and exp's recommendations. Any reduction in the level of services recommended will result in exp providing qualified opinions regarding the adequacy of the work. exp can assist design professionals or contractors retained by the Client to review applicable plans, drawings, and specifications as they relate to the Report or to conduct field reviews during construction.

Contractors contemplating work on the site are responsible for conducting an independent investigation and interpretation of the borehole results contained in the Report. The number of boreholes necessary to determine the localized underground conditions as they impact construction costs, techniques, sequencing, equipment and scheduling may be greater than those carried out for the purpose of the Report.

Classification and identification of soils, rocks, geological units, contaminant materials, building envelopment assessments, and engineering estimates are based on investigations performed in accordance with the standard of care set out below and require the exercise of judgment. As a result, even comprehensive sampling and testing programs implemented with the appropriate equipment by experienced personnel may fail to locate some conditions. All investigations or building envelope descriptions involve an inherent risk that some conditions will not be detected. All documents or records summarizing investigations are based on assumptions of what exists between the actual points sampled. Actual conditions may vary significantly between the points investigated. Some conditions are subject to change over time. The Report presents the conditions at the sampled points at the time of sampling. Where special concerns exist, or the Client has special considerations or requirements, these should be disclosed to exp to allow for additional or special investigations to be undertaken not otherwise within the scope of investigation conducted for the purpose of the Report.

RELIANCE ON INFORMATION PROVIDED

The evaluation and conclusions contained in the Report are based on conditions in evidence at the time of site inspections and information provided to exp by the Client and others. The Report has been prepared for the specific site, development, building, design or building assessment objectives and purpose as communicated by the Client. exp has relied in good faith upon such representations, information and instructions and accepts no responsibility for any deficiency, misstatement or

inaccuracy contained in the Report as a result of any misstatements, omissions, misrepresentation or fraudulent acts of persons providing information. Unless specifically stated otherwise, the applicability and reliability of the findings, recommendations, suggestions or opinions expressed in the Report are only valid to the extent that there has been no material alteration to or variation from any of the information provided to exp.

STANDARD OF CARE

The Report has been prepared in a manner consistent with the degree of care and skill exercised by engineering consultants currently practicing under similar circumstances and locale. No other warranty, expressed or implied, is made. Unless specifically stated otherwise, the Report does not contain environmental consulting advice.

COMPLETE REPORT

All documents, records, data and files, whether electronic or otherwise, generated as part of this assignment form part of the Report. This material includes, but is not limited to, the terms of reference given to exp by its client ("Client"), communications between exp and the Client, other reports, proposals or documents prepared by exp for the Client in connection with the site described in the Report. In order to properly understand the suggestions, recommendations and opinions expressed in the Report, reference must be made to the Report in its entirety. exp is not responsible for use by any party of portions of the Report.

USE OF REPORT

The information and opinions expressed in the Report, or any document forming part of the Report, are for the sole benefit of the Client. No other party may use or rely upon the Report in whole or in part without the written consent of exp. Any use of the Report, or any portion of the Report, by a third party are the sole responsibility of such third party. exp is not responsible for damages suffered by any third party resulting from unauthorised use of the Report.

REPORT FORMAT

Where exp has submitted both electronic file and a hard copy of the Report, or any document forming part of the Report, only the signed and sealed hard copy shall be the original documents for record and working purposes. In the event of a dispute or discrepancy, the hard copy shall govern. Electronic files transmitted by exp have utilize specific software and hardware systems. exp makes no representation about the compatibility of these files with the Client's current or future software and hardware systems. Regardless of format, the documents described herein are exp's instruments of professional service and shall not be altered without the written consent of exp.

Appendix A – Site Photographs



Photo 1. Hwy 11 at Culvert #1 location, looking south



Photo 2. Outlet and east slope viewing south at Culvert #1



Photo 3. Inlet viewing west at Culvert #1



Photo 4. Sinkhole on west side slope at Culvert #1



Photo 5. Hwy 11 at Culvert #2 looking south



Photo 6. East side slope looking south at Culvert #2



Photo 7. Inlet/west slope looking east at Culvert #2



Photo 8. Sinkhole on west side slope at Culvert #2



Photo 9. East (outlet) side of the embankment looking east at Culvert #2



Photo 10. Outlet looking west at Culvert #2



Photo 11. Hwy 11 viewing north at Culvert #3



Photo 12. East (inlet) side of embankment slope viewing south at Culvert #3



Photo 13. West (outlet) side of embankment slope viewing north at Culvert #3



Photo 14. East (inlet) side of embankment slope viewing north at Culvert #3

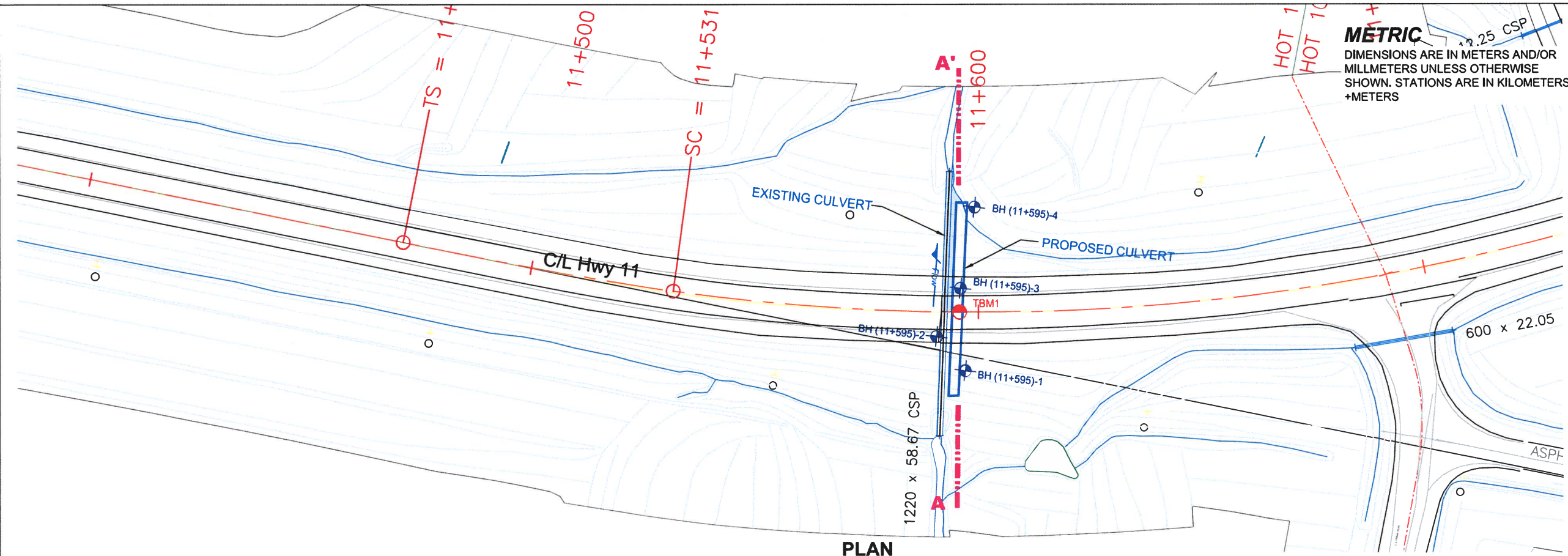


Photo 15. Culvert #3 outlet and west side slope viewing east

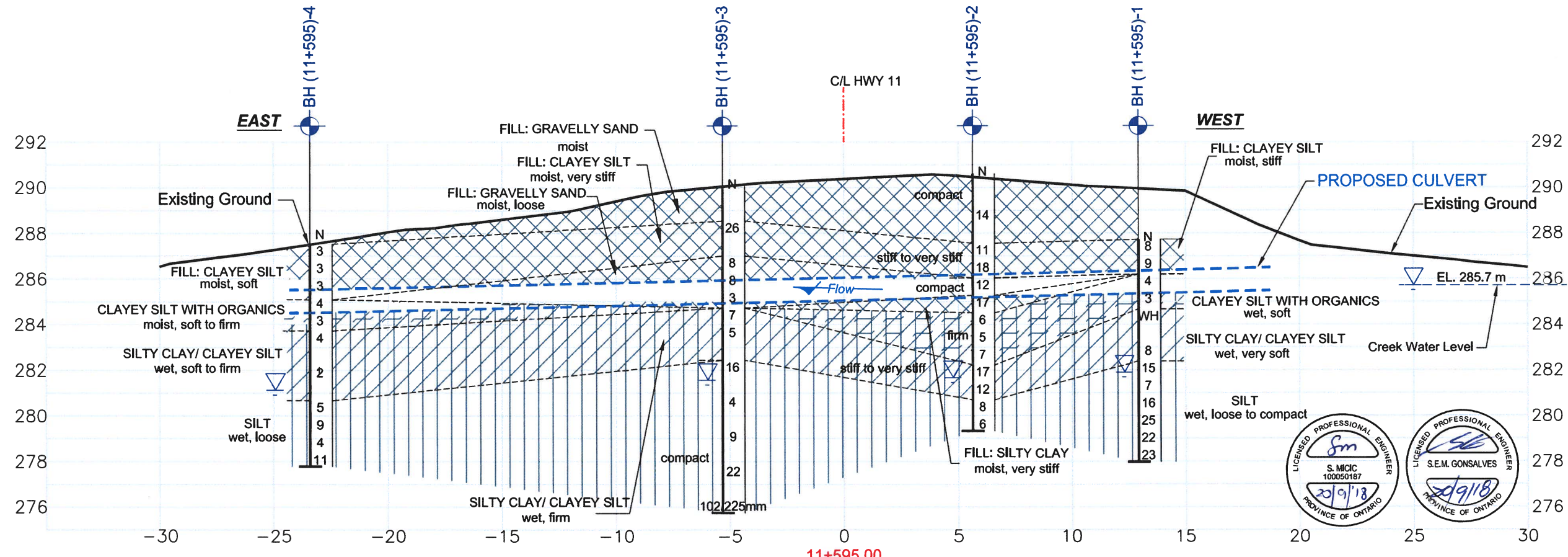


Photo 16. Sinkhole with separated culvert at west side slope at Culvert #3

Appendix B – Drawings



PLAN



SECTION A-A'

NER Agreement No. 5015-E-0007
Assignment No. 9
GWP - 5205-10-00

TRENCHLESS INSTALLATION OF THREE PIPE
CULVERTS ON HWY 11
CULVERT #1- CV(11+595)
Latitude 48.696883; Longitude 80.790053

BOREHOLE LOCATION PLAN AND SOIL STRATA

exp Services Inc.

KEY PLAN

LEGEND

- Borehole Location
- Standard Penetration Test (Blows/0.3 m)
- Groundwater level measured in open hole
- Temporary Bench Mark Location

SOIL STRATA SYMBOLS

BH No.	ELEV. (m)	MTM CO-ORDINATES/ ZONE ON-12	
		NORTHING	EASTING
BH(11+595)-1	287.72	5395392.8	320241.9
BH(11+595)-2	290.61	5395400.5	320248.1
BH(11+595)-3	290.06	5395397.3	320259.7
BH(11+595)-4	287.53	5395397.6	320277.9

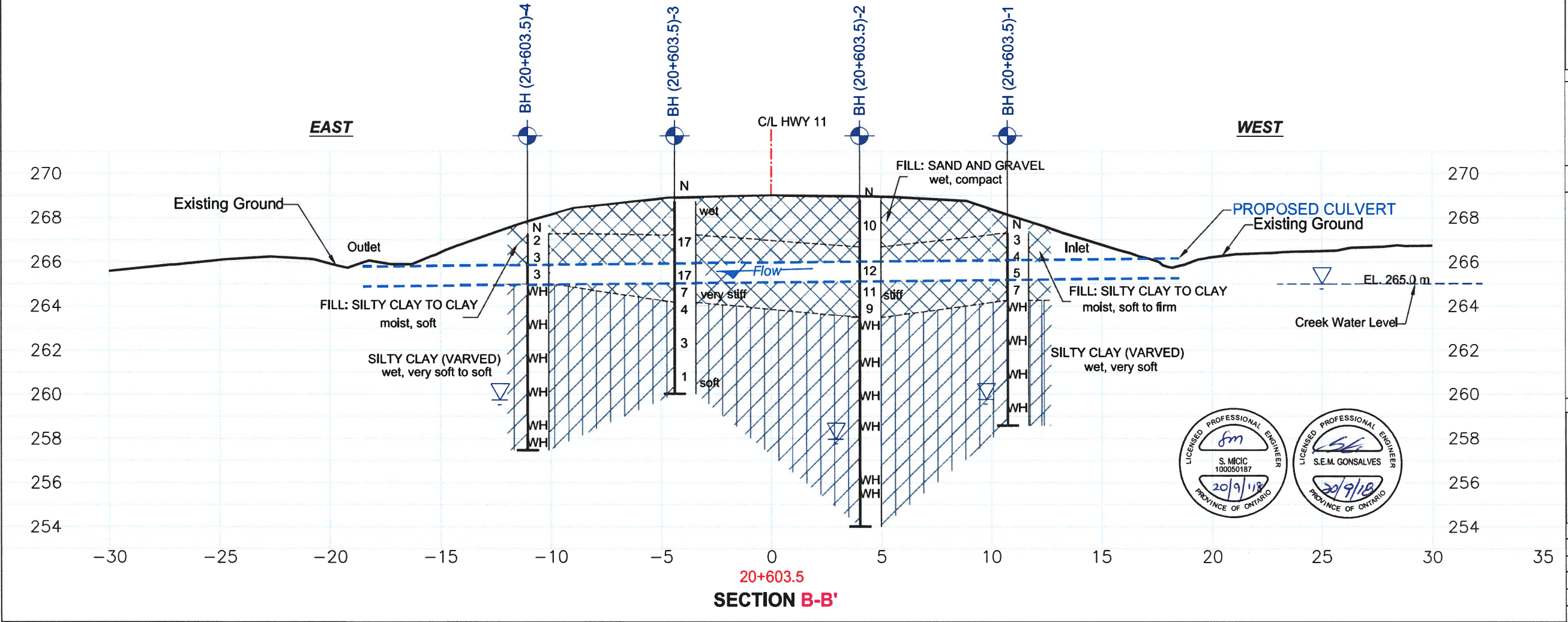
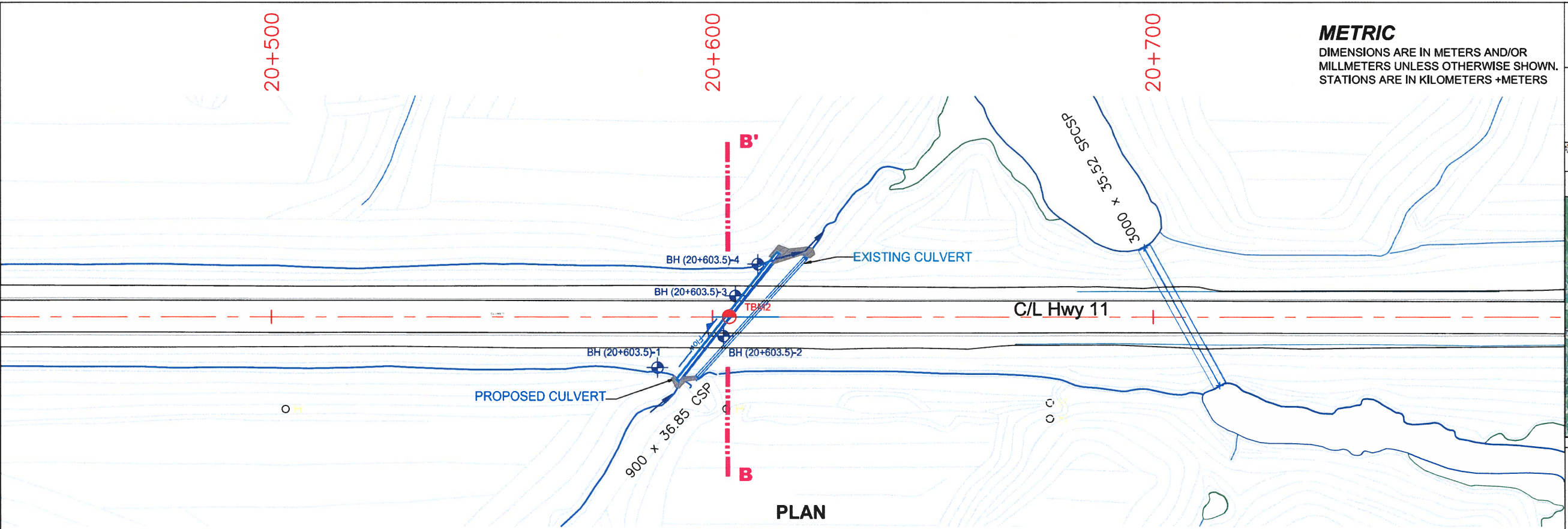
NOTES

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 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 the report and related documents are specifically excluded in accordance with the conditions of Section GC 2.01 of OPS Gen. Cond.


SCALE: PLAN 0 5 25 m
PROFILE 0 1 5 m

DATE	SM	SUBMISSION FOR MTO REVIEW	
	BY	DESCRIPTION	
		GEOCRE NO. 42A-125	
		PROJECT NO. ADM-00233185-J0	
SUBMD SH	CHECKED SM	DATE	Sep. 20, 18
DRAWN SH	CHECKED TC	APPROVED SG	DWG. 1




METRIC
DIMENSIONS ARE IN METERS AND/OR
MILLIMETERS UNLESS OTHERWISE SHOWN.
STATIONS ARE IN KILOMETERS +METERS

Agreement No. 5015-E-0007
Assignment No. 9
GWP - 5205-10-00


SHEET
1

TRENCHLESS INSTALLATION OF THREE PIPE
CULVERTS ON HWY 11
CULVERT #2-CV(20+603.5)
Latitude 48.564769; Longitude 80.587706





BOREHOLE LOCATION PLAN AND SOIL STRATA

exp Services Inc.



KEY PLAN



LEGEND

 Borehole Location (EXP 2017)
 Standard Penetration Test (Blows/0.3 m)
 Groundwater level measured in open hole
 Temporary Bench Mark Location

SOIL STRATA SYMBOLS

 FILL
 SILTY CLAY (VARVED)

BH No.	ELEV. (m)	MTM CO-ORDINATES/ ZONE ON-12	
		NORTHING	EASTING
BH(20+603.5)-1	267.31	5380502.3	335455.6
BH(20+603.5)-2	268.81	5380495.9	335471.0
BH(20+603.5)-3	268.73	5380500.0	335479.6
BH(20+603.5)-4	267.27	5380501.1	335488.3


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 contract documents.

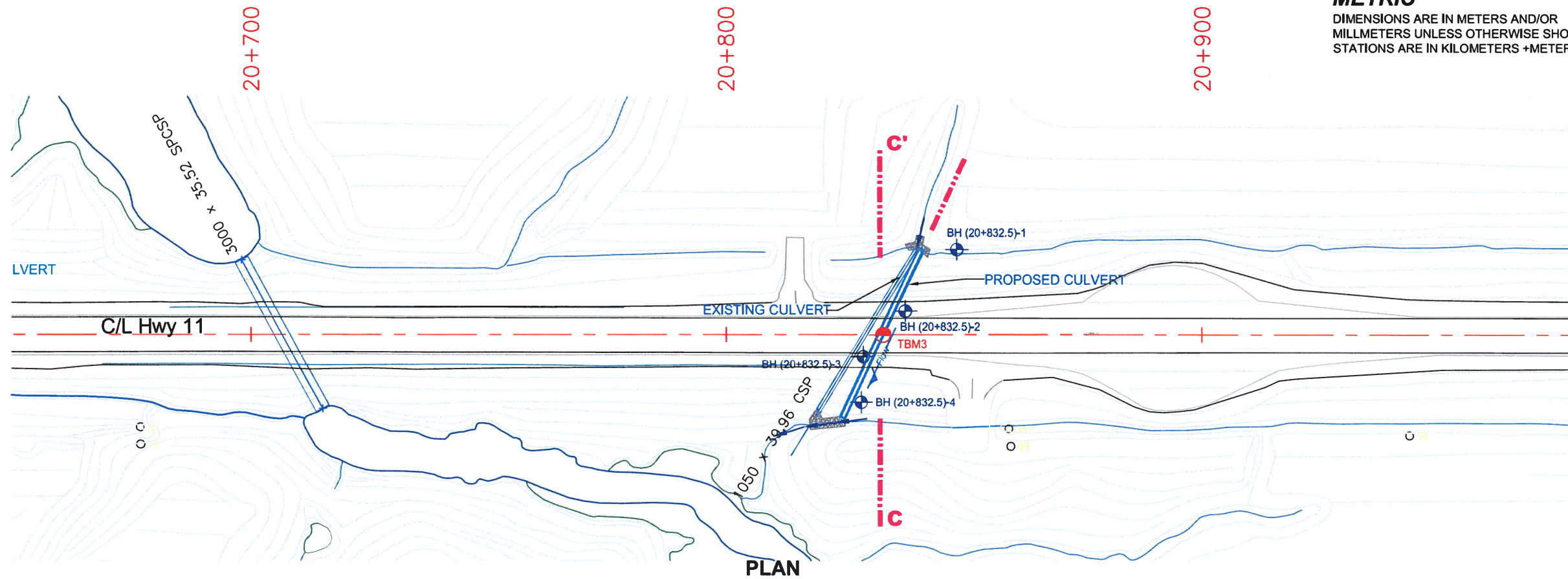
The complete foundation investigation and design report for this project and other related documents may be examined at the Materials Engineering and Research Office, Downsview. Information contained in the report and related documents are specifically excluded in accordance with the conditions of Section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

SCALE: PLAN 0 5 25 m
PROFILE 0 1 5 m

DATE	BY	DESCRIPTION
	SM	SUBMISSION FOR MTO REVIEW
		GEORES NO. 42A-125
		PROJECT NO. ADM-00233185-10
SUBMD SH	CHECKED SM	DATE Sep. 20, 18
DRAWN SH	CHECKED TC	APPROVED SG DWG. 2

S. MICIC
100050187
20/9/18
PROVINCE OF ONTARIO

S.E.M. GONSALVES
20/9/18
PROVINCE OF ONTARIO



Appendix C – Borehole Logs

Brampton, Ontario

RECORD OF BOREHOLE No BH(11+595)-1

1 OF 1

METRIC

W.P. WO 2018-11006 LOCATION Hwy 11, Porquis Junction, MTM ON12 ORIGINATED BY NT
 DIST Cochrane HWY 11 BOREHOLE TYPE CME 55, Hollow stem auger drill COMPILED BY SH
 DATUM Geodetic DATE 2018.05.31 - 2018.05.31 LATITUDE 48.69681301 LONGITUDE 80.79021308 CHECKED BY SM

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT W _p	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W _L	UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL		
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa							WATER CONTENT (%)	
								○ UNCONFINED + FIELD VANE	● QUICK TRIAXIAL P. PENETROMETER							
287.7 0.0	Ground Surface FILL: CLAYEY SILT with few sand, few gravel, brown, moist, stiff		1	SS	8		287								0 3 23 74	
			2	SS	9											
286.2 1.5	CLAYEY SILT WITH ORGANICS with some roots and rootlets, blackish brown, wet, soft		3	SS	4		286									
		4	SS	3	285											
284.7 3.1	SILTY CLAY/CLAYEY SILT trace to some sand, trace roots, grey, wet, very soft		5	SS	WH		284									
				VANE												
			6	SS	8		283									
282.4 5.3	SILT trace sand, trace to little clay, grey, wet, loose to compact		7	SS	15		282									
		8	SS	7	281											
		9	SS	16	280											
		10	SS	25	279											
		11	SS	22												
		12	SS	23												
278.0 9.8	End of borehole at 9.8 m depth. Notes: 1. This drawing is to be read with the subject report and project numbers as presented above. 2. Borehole open up to 6.1 m below ground surface on completion. 3. Groundwater level was observed at 5.8 m in the open hole upon completion of drilling.						278									

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

ONTARIO MTO NER- ASSIGNMENT #9.GPJ ONTARIO MTO.GDT 7/25/18

Brampton, Ontario

RECORD OF BOREHOLE No BH(11+595)-2

1 OF 2

METRIC

W.P. WO 2018-11006 LOCATION Hwy 11, Porquis Junction, MTM ON12 ORIGINATED BY NT
 DIST Cochrane HWY 11 BOREHOLE TYPE CME 55, Hollow stem auger drill COMPILED BY SH
 DATUM Geodetic DATE 2018.05.31 - 2018.05.31 LATITUDE 48.69688187 LONGITUDE 80.7901284 CHECKED BY SM

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT W _P	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W _L	UNIT WEIGHT γ	REMARKS & GRAIN SIZE DISTRIBUTION (%)			
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa										WATER CONTENT (%)		
								○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL X P. PENETROMETER												
290.6	Ground Surface							20	40	60	80	100								
0.0	FILL: GRAVELLY SAND some black asphalt inclusion, trace to little silt, brown, moist, compact		1	AS			290													
			2	SS	14		289										27 60 (13)			
							288													
287.6	FILL: CLAYEY SILT trace to some sand, trace gravel, occ. cobbles, brown, moist, stiff to very stiff		3	SS	11		287													
			4	SS	18															
286.0	FILL: GRAVELLY SAND trace asphalt inclusion, trace silt, trace clay, blackish brown, moist, compact		5	SS	12		286													
285.3	FILL: SILTY CLAY trace gravel, some sand, trace roots and rootlets, grey, moist, very stiff		6	SS	17		285										2 12 34 52			
284.5	CLAYEY SILT WITH ORGANICS with some roots and rootlets, blackish brown, wet, firm		7	SS	6		284													
			8	SS	5		283													
			9	SS	7															
282.2	CLAYEY SILT trace sand, trace organics, grey, wet, stiff to very stiff		10	SS	17		282													
			11	SS	12		281										0 2 71 27			
280.7	SILT some sand, grey, wet, loose		12	SS	8															
			13	SS	6		280													
279.3	End of borehole at 11.3 m depth.																			
11.3	Notes: 1. This drawing is to be read with the subject report and project numbers																			

Continued Next Page

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

ONTARIO MTO NER- ASSIGNMENT #9.GPJ ONTARIO MTO.GDT 7/25/18

Brampton, Ontario

RECORD OF BOREHOLE No BH(11+595)-2

2 OF 2

METRIC

W.P. WO 2018-11006 LOCATION Hwy 11, Porquis Junction, MTM ON12 ORIGINATED BY NT
 DIST Cochrane HWY 11 BOREHOLE TYPE CME 55, Hollow stem auger drill COMPILED BY SH
 DATUM Geodetic DATE 2018.05.31 - 2018.05.31 LATITUDE 48.69688187 LONGITUDE 80.7901284 CHECKED BY SM

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT			PLASTIC NATURAL LIQUID LIMIT MOISTURE CONTENT LIMIT			UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%)				
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa			Wp W Wl				WATER CONTENT (%)	GR	SA	SI	CL
								○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL P. PENETROMETER											
	as presented above. 2. Borehole open up to 9.1 m below ground surface on completion. 3. Groundwater level was observed at 8.9 m in the open hole upon completion of drilling.							20 40 60 80 100				20 40 60							

METRICContinued Next Page

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

Brampton, Ontario

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

ONTARIO MTO NER- ASSIGNMENT #9.GPJ ONTARIO MTO.GDT 7/25/18

Brampton, Ontario

RECORD OF BOREHOLE No BH(11+595)-4

1 OF 1

METRIC

W.P. WO 2018-11006 LOCATION Hwy 11, Porquis Junction, MTM ON12 ORIGINATED BY NT
 DIST Cochrane HWY 11 BOREHOLE TYPE CME 55, Hollow stem auger drill COMPILED BY SH
 DATUM Geodetic DATE 2018.05.30 - 2018.05.30 LATITUDE 48.69685298 LONGITUDE 80.78972357 CHECKED BY SM

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT			PLASTIC LIMIT W _P	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W _L	UNIT WEIGHT γ	REMARKS & GRAIN SIZE DISTRIBUTION (%)			
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa								WATER CONTENT (%)		
								○ UNCONFINED + FIELD VANE										
						● QUICK TRIAXIALX P. PENETROMETER												
287.5	Ground Surface							20	40	60	80	100						
0.0	FILL: CLAYEY SILT some topsoil, some roots, black to brown, moist, soft		1	SS	3		287											
			2	SS	3		286											
	-becoming trace sand, trace rootlets, greyish brown		3	SS	3		285											
285.1			4	SS	4		284											
2.4	CLAYEY SILT WITH ORGANICS trace sand, trace rootlets, blackish brown, moist, soft to firm		5	SS	3		283											
283.7			6	SS	4		282											
3.8	SILTY CLAY trace sand, grey, wet, soft to firm		7	SS	2		281											
			VANE				280											
280.7			8	SS	5		279											
6.9	SILT few sand, few clay, grey, wet, loose		9	SS	9		278											
			10	SS	4													
	-wet to dialated, very loose, silt blow up 4' at bottom		11	SS	11													
	-becoming compact																	
277.8																		
9.8	End of borehole at 9.8 m depth.																	
	Notes: 1. This drawing is to be read with the subject report and project numbers as presented above. 2. Borehole open up to 6.6 m below ground surface on completion. 3. Groundwater level was observed at 6.4 m in the open hole upon completion of drilling.																	

ONTARIO MTO, NER- ASSIGNMENT #9.GPJ, ONTARIO MTO.GDT 7/25/18

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

Brampton, Ontario

RECORD OF BOREHOLE No BH(20+603.5)-1

1 OF 1

METRIC

W.P. WO 2018-11006 LOCATION Hwy 11, Val Gagne, MTM ON12 ORIGINATED BY NT
 DIST Cochrane HWY 11 BOREHOLE TYPE CME 55, Hollow stem auger drill COMPILED BY SA
 DATUM Geodetic DATE 2018.06.03 - 2018.06.03 LATITUDE 48.56233686 LONGITUDE 80.58463148 CHECKED BY SM

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT W _P	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W _L	UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL	
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa							WATER CONTENT (%)
								○ UNCONFINED + FIELD VANE	● QUICK TRIAXIAL X P. PENETROMETER						
267.3	Ground Surface							20 40 60 80 100		20 40 60					
0.0	FILL: SILTY CLAY TO CLAY some organics, few sand, some roots and rootlets, blackish brown, moist, soft to firm		1	SS	3		267							0 1 17 82	
	-becoming blackish/greyish brown, wet		2	SS	4		266								
			3	SS	5		265								
	-becoming trace rootlets, trace sand, brown, moist		4	SS	7		264								
264.3	SILTY CLAY (VARVED) trace sand seams, grey, wet, very soft		5	SS	WH		264								0 1 28 71
3.1				VANE			263	2.0							
			6	SS	WH		262								
				VANE			261	2.3							
			7	SS	WH		260								
				VANE			259	2.3							
			8	SS	WH										
				VANE											
258.3	End of borehole at 9.0 m depth.														
9.0	Notes: 1. This drawing is to be read with the subject report and project numbers as presented above. 2. Borehole open up to 7.6 m below ground surface on completion. 3. Groundwater level was observed at 7.5 m in the open hole upon completion of drilling.														

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

ONTARIO MTO NER- ASSIGNMENT #9.GPJ ONTARIO MTO.GDT 7/25/18





Brampton, Ontario

RECORD OF BOREHOLE No BH(20+603.5)-2

1 OF 2

METRIC

W.P. WO 2018-11006 LOCATION Hwy 11, Val Gagne, MTM ON12 ORIGINATED BY NT
 DIST Cochrane HWY 11 BOREHOLE TYPE CME 55, Hollow stem auger drill COMPILED BY SA
 DATUM Geodetic DATE 2018.06.03 - 2018.06.03 LATITUDE 48.56227857 LONGITUDE 80.58442266 CHECKED BY SM

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT w _p	NATURAL MOISTURE CONTENT w	LIQUID LIMIT w _L	UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%)					
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa						WATER CONTENT (%)		GR	SA	SI	CL
								20	40	60	80	100							
268.8	Ground Surface		1	AS															
0.0	FILL: SAND AND GRAVEL few clay, brown, wet, compact																		
	-becoming more silt and clay		2	SS	10														
266.7	FILL: SILTY CLAY TO CLAY trace gravel, trace sand, brown, moist, stiff																		
2.1			3	SS	12														
			4	SS	11														
		5	SS	9															
263.5	SILTY CLAY (VARVED) trace sand seams, grey, wet, very soft		6	SS	WH														
5.3																			
				VANE															
			7	SS	WH														
				VANE															
			8	SS	WH														
		9	SS	WH															
			VANE																

Continued Next Page

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

ONTARIO MTO, NER- ASSIGNMENT #9.GPJ, ONTARIO MTO.GDT, 7/25/18

Brampton, Ontario

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

ONTARIO MTO NER- ASSIGNMENT #9.GPJ ONTARIO MTO.GDT 7/25/18

Brampton, Ontario

RECORD OF BOREHOLE No BH(20+603.5)-3

1 OF 1

METRIC

W.P. WO 2018-11006 LOCATION Hwy 11, Val Gagne, MTM ON12 ORIGINATED BY NT
 DIST Cochrane HWY 11 BOREHOLE TYPE CME 55, Hollow stem auger drill COMPILED BY SA
 DATUM Geodetic DATE 2018.06.02 - 2018.06.02 LATITUDE 48.56231511 LONGITUDE 80.58430638 CHECKED BY SM

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT				PLASTIC LIMIT W _P	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W _L	UNIT WEIGHT γ	REMARKS & GRAIN SIZE DISTRIBUTION (%)				
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa									WATER CONTENT (%)			
								○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL X P. PENETROMETER												
268.7 0.0	Ground Surface FILL: SAND AND GRAVEL greyish brown, moist to wet		1	AS			268									0 4 17 79				
267.2 1.5	FILL: SILTY CLAY TO CLAY trace sand, trace organics, trace woods, greyish brown to brown, moist, very stiff		2	SS	17		267													
							266													
			3	SS	17		265													
	-becoming firm		4	SS	7		264													
264.2 4.6	SILTY CLAY (VARVED) trace fine sand seams, grey, wet, soft		5	SS	4		263													
				VANE			262													
			6	SS	3		261													
				VANE			260													
	-becoming very soft		7	SS	1															
				VANE																
259.7 9.0	End of borehole at 9.0 m depth.																			
	Notes: 1. This drawing is to be read with the subject report and project numbers as presented above. 2. Borehole open up to 7.5 m below ground surface on completion. 3. Borehole was dry in the open hole.																			

ONTARIO MTO, NER- ASSIGNMENT #9.GPJ, ONTARIO MTO.GDT, 7/25/18

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

Brampton, Ontario

RECORD OF BOREHOLE No BH(20+603.5)-4

1 OF 1

METRIC

W.P. WO 2018-11006 LOCATION Hwy 11, Val Gagne, MTM ON12 ORIGINATED BY NT
 DIST Cochrane HWY 11 BOREHOLE TYPE CME 55, Hollow stem auger drill COMPILED BY SA
 DATUM Geodetic DATE 2018.06.02 - 2018.06.02 LATITUDE 48.56232421 LONGITUDE 80.58418775 CHECKED BY SM

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%)		
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIALX P. PENETROMETER		W _P	W	W _L			WATER CONTENT (%)	
267.3 0.0	Ground Surface FILL: SILTY CLAY TO CLAY some rootlets, trace sand, brown, moist, soft		1	SS	2		267								0 2 21 77	
			2	SS	3		266									
			3	SS	3		265									
265.0 2.3	SILTY CLAY (VARVED) trace sand seams, grey, wet, very soft to soft		4	SS	WH		264									0 1 41 58
				VANE			263									
			5	SS	WH		262									
				VANE			261									
			6	SS	WH		260									
				VANE			259									
			7	SS	WH	258										
				VANE												
			8	SS	WH											
			VANE													
257.5 9.8	End of borehole at 9.8 m depth. Notes: 1. This drawing is to be read with the subject report and project numbers as presented above. 2. Borehole open up to 7.6 m below ground surface on completion. 3. Groundwater level was observed at 7.5 m in the open hole upon completion of drilling.		9	SS	WH											

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

ONTARIO MTO_NER_ASSIGNMENT #9.GPJ ONTARIO MTO.GDT 7/25/18

Brampton, Ontario

RECORD OF BOREHOLE No BH(20+832.5)-1

1 OF 1

METRIC

W.P. WO 2018-11006 LOCATION Hwy 11, Val Gagne, MTM ON12 ORIGINATED BY NT
 DIST Cochrane HWY 11 BOREHOLE TYPE CME 55, Hollow stem auger drill COMPILED BY SH
 DATUM Geodetic DATE 2018.06.04 - 2018.06.04 LATITUDE 48.56076567 LONGITUDE 80.58197556 CHECKED BY SM

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT			PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%)			
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIALX P. PENETROMETER			W _P	W	W _L		GR	SA	SI	CL
267.5	Ground Surface																	
0.0	FILL: CLAYEY SILT trace sand, trace rootlets, brown, moist, soft		1	SS	2		267											
266.7																		
0.8	FILL: SILTY CLAY trace sand seams, brown, moist, stiff		2	SS	8		266											
	-becoming greyish brown to grey clay, soft		3	SS	3		265											
264.4							264											
3.1	SILTY CLAY TO CLAY (VARVED) trace sand seams, grey, wet, very soft to soft		4	SS	WH													
				VANE			263											
			5	SS	WH		262											
				VANE			261											
			6	SS	WH		260											
				VANE			259											
			7	SS	WH													
				VANE														
258.5																		
9.0	End of borehole at 9.0 m depth.																	
	Notes: 1. This drawing is to be read with the subject report and project numbers as presented above. 2. Borehole open up to 7.6 m below ground surface on completion. 3. Borehole was dry in the open hole.																	

ONTARIO MTO NER- ASSIGNMENT #9.GPJ ONTARIO MTO.GDT 7/25/18

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

Brampton, Ontario

RECORD OF BOREHOLE No BH(20+832.5)-2

1 OF 2

METRIC

W.P. WO 2018-11006 LOCATION Hwy 11, Val Gagne, MTM ON12 ORIGINATED BY NT
 DIST Cochrane HWY 11 BOREHOLE TYPE CME 55, Hollow stem auger drill COMPILED BY SH
 DATUM Geodetic DATE 2018.06.04 - 2018.06.04 LATITUDE 48.56076013 LONGITUDE 80.58220212 CHECKED BY SM

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT W _P	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W _L	UNIT WEIGHT γ	REMARKS & GRAIN SIZE DISTRIBUTION (%)	
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa							WATER CONTENT (%)
								○ UNCONFINED	+ FIELD VANE						
								20 40 60 80 100							
								20 40 60 80 100							
270.2	Ground Surface														
0.0	FILL: GRAVELLY SAND with few clay, few silt, brown, moist		1	AS			270								
							269								
268.7															
1.5	FILL: CLAYEY SILT brown, moist, very stiff		2	SS	25		268								
268.4	FILL: SAND trace gravel, brown, moist, loose to compact														
1.8															
	-becoming more gravel, more silt and clay, wet		3	SS	7		267								
266.4															
3.8	SILTY CLAY TO CLAY (VARVED) greyish brown, moist, very soft to soft		4	SS	2		266								
	-becoming wet		5	SS	1		265								
				VANE			264	2.25							
	-becoming grey, trace sand seams		6	SS	WH		263	2.0							
				VANE											
			7	SS	WH		262								
			8	SS	WH		261								
				VANE			260	2.0							
			9	SS	WH										
							259								

Continued Next Page

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

ONTARIO MTO, NER- ASSIGNMENT #9.GPJ, ONTARIO MTO.GDT, 7/25/18

2 OF 2

METRIC

W.P.	WO 2018-11006	LOCATION	Hwy 11, Val Gagne, MTM ON12			ORIGINATED BY	NT		
DIST	Cochrane	HWY	11	BOREHOLE TYPE	CME 55, Hollow stem auger drill		COMPILED BY	SH	
DATUM	Geodetic	DATE	2018.06.04 - 2018.06.04	LATITUDE	48.56076013	LONGITUDE	80.58220212	CHECKED BY	SM

[illegible]

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

Brampton, Ontario

RECORD OF BOREHOLE No BH(20+832.5)-3

1 OF 1

METRIC

W.P. WO 2018-11006 LOCATION Hwy 11, Val Gagne, MTM ON12 ORIGINATED BY NT
 DIST Cochrane HWY 11 BOREHOLE TYPE CME 55, Hollow stem auger drill COMPILED BY SH
 DATUM Geodetic DATE 2018.06.03 - 2018.06.03 LATITUDE 48.56076198 LONGITUDE 80.58237713 CHECKED BY SM

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT				PLASTIC LIMIT W _P	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W _L	UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL		
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa									WATER CONTENT (%)	
								○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL X P. PENETROMETER										
270.0	Ground Surface						20	40	60	80	100	20	40	60				
0.0	FILL: GRAVELLY SAND with few clay, few silt, brown, moist		1	AS														
268.5	FILL: CLAYEY SILT trace gravel, trace sand, brown, dry, very stiff		2	SS	22													
267.0	FILL: SAND few gravel, trace silt, trace clay, brown, moist, compact		3	SS	16													
266.1	-becoming some rootlets, wet																	
3.9	FILL: SILTY CLAY trace organics, trace sand, brown, wet, stiff		4	SS	13													
			5	SS	10													
264.7	SILTY CLAY TO CLAY (VARVED) trace organics, trace sand seams, greyish brown, wet, stiff		6	SS	11													
5.3	-becoming grey, very soft to soft		7	SS	WH													
				VANE														
			8	SS	WH													
				VANE														
			9	SS	WH													
260.3	End of borehole at 9.8 m depth.																	
9.8	Notes: 1. This drawing is to be read with the subject report and project numbers as presented above. 2. Borehole open up to 7.6 m below ground surface on completion. 3. Groundwater level was observed at 7.5 m in the open hole upon completion of drilling.																	

ONTARIO MTO_NER_ASSIGNMENT #9.GPJ ONTARIO MTO.GDT 7/25/18

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



Brampton, Ontario

RECORD OF BOREHOLE No BH(20+832.5)-4

1 OF 1

METRIC

W.P. WO 2018-11006 LOCATION Hwy 11, Val Gagne, MTM ON12 ORIGINATED BY NT
 DIST Cochrane HWY 11 BOREHOLE TYPE CME 55, Hollow stem auger drill COMPILED BY SH
 DATUM Geodetic DATE 2018.06.04 - 2018.06.04 LATITUDE 48.56070762 LONGITUDE 80.58247955 CHECKED BY SM

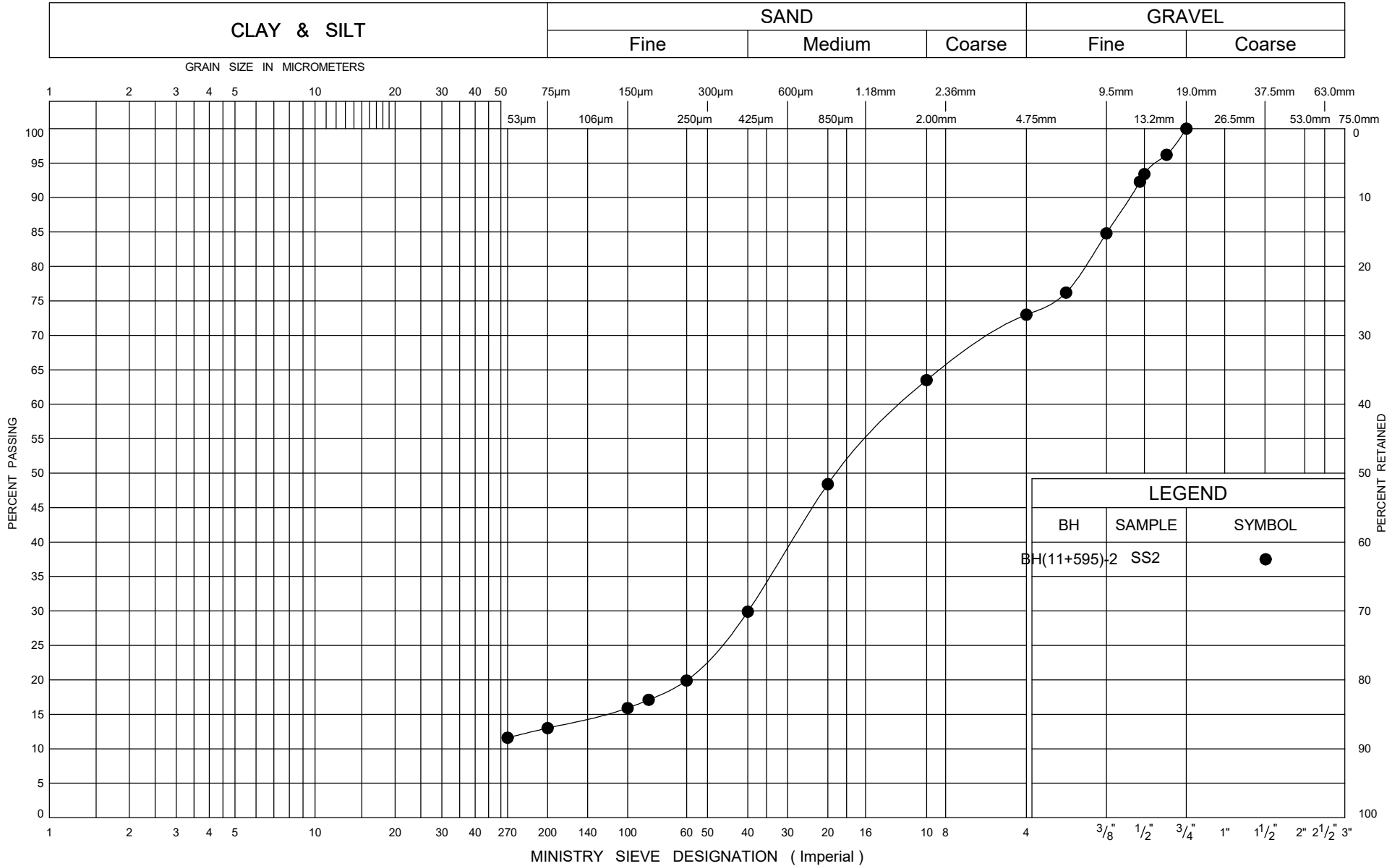
SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%)					
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIALX P. PENETROMETER		W _P W W _L WATER CONTENT (%)				GR	SA	SI	CL		
268.5 0.0	Ground Surface		1	SS	12		268								0 4 57 39				
	-becoming black organics, trace sand		2	SS	11														
	-becoming brown		3	SS	8														
266.2 2.3	SILTY CLAY TO CLAY (VARVED) trace sand, brown, moist, firm		4	SS	4			266											
	-becoming brownish grey, trace sand seams, wet, very soft to soft		5	SS	WH														
				VANE					264	2.25 +									
	-becoming grey		6		WH														
				VANE						263	2.25 +								
			7	SS	WH														
				VANE		261	2.25 +												
			8	SS	WH											0 1 23 76			
				VANE			260		1.8 +										
258.8 9.8	End of borehole at 9.8 m depth.		9	SS	WH	259													
	Notes: 1. This drawing is to be read with the subject report and project numbers as presented above. 2. Borehole open up to 7.0 m below ground surface on completion. 3. Borehole was dry in the open hole.																		

ONTARIO MTO_NER-ASSIGNMENT #9.GPJ ONTARIO MTO.GDT 7/25/18

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

Appendix D – Laboratory Data

UNIFIED SOIL CLASSIFICATION SYSTEM



GRAIN SIZE DISTRIBUTION

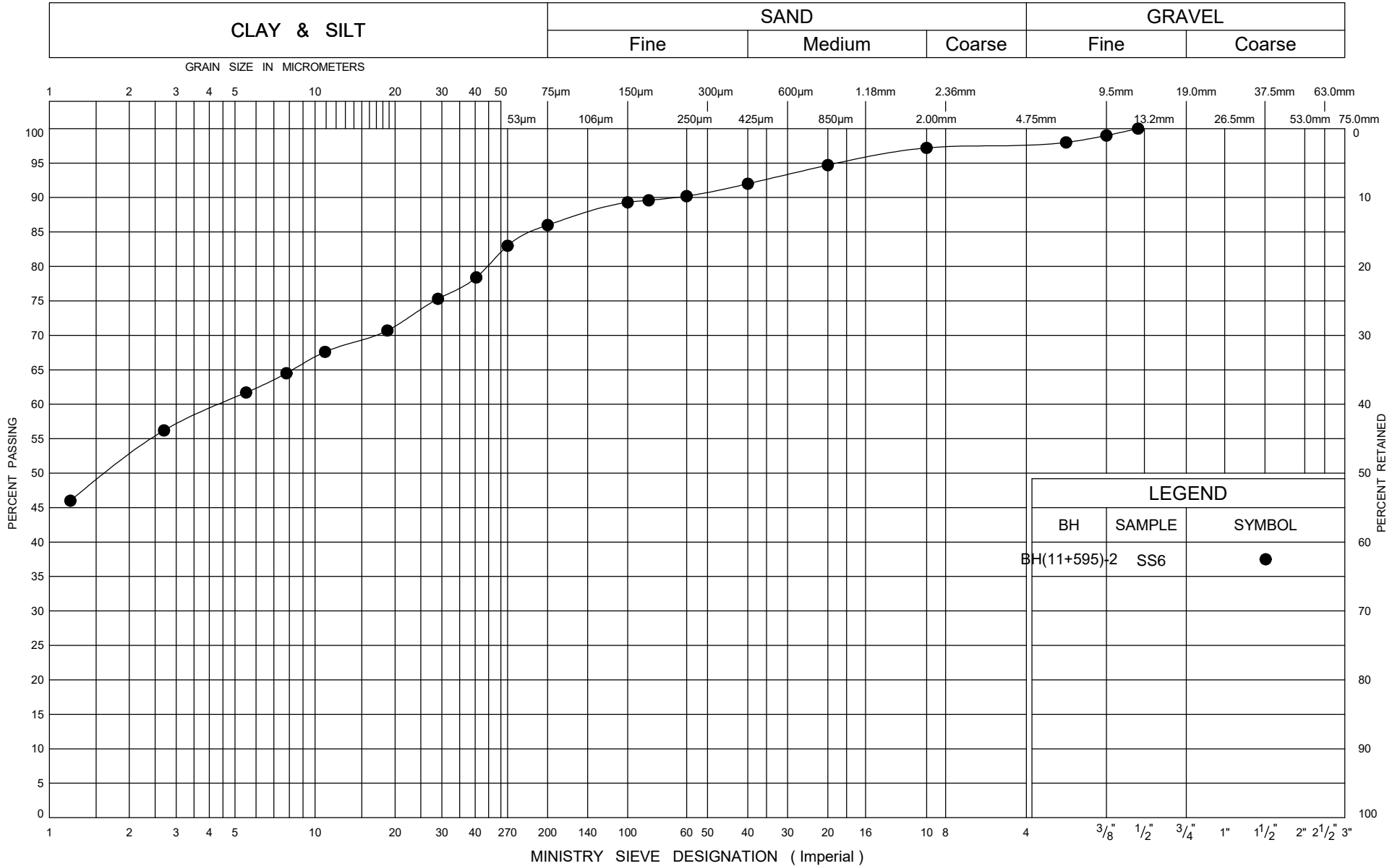
Fill: Gravelly Sand

FIG No 1

W PWO 2018-11006

5015-E-0007, Assignment 9

UNIFIED SOIL CLASSIFICATION SYSTEM



GRAIN SIZE DISTRIBUTION

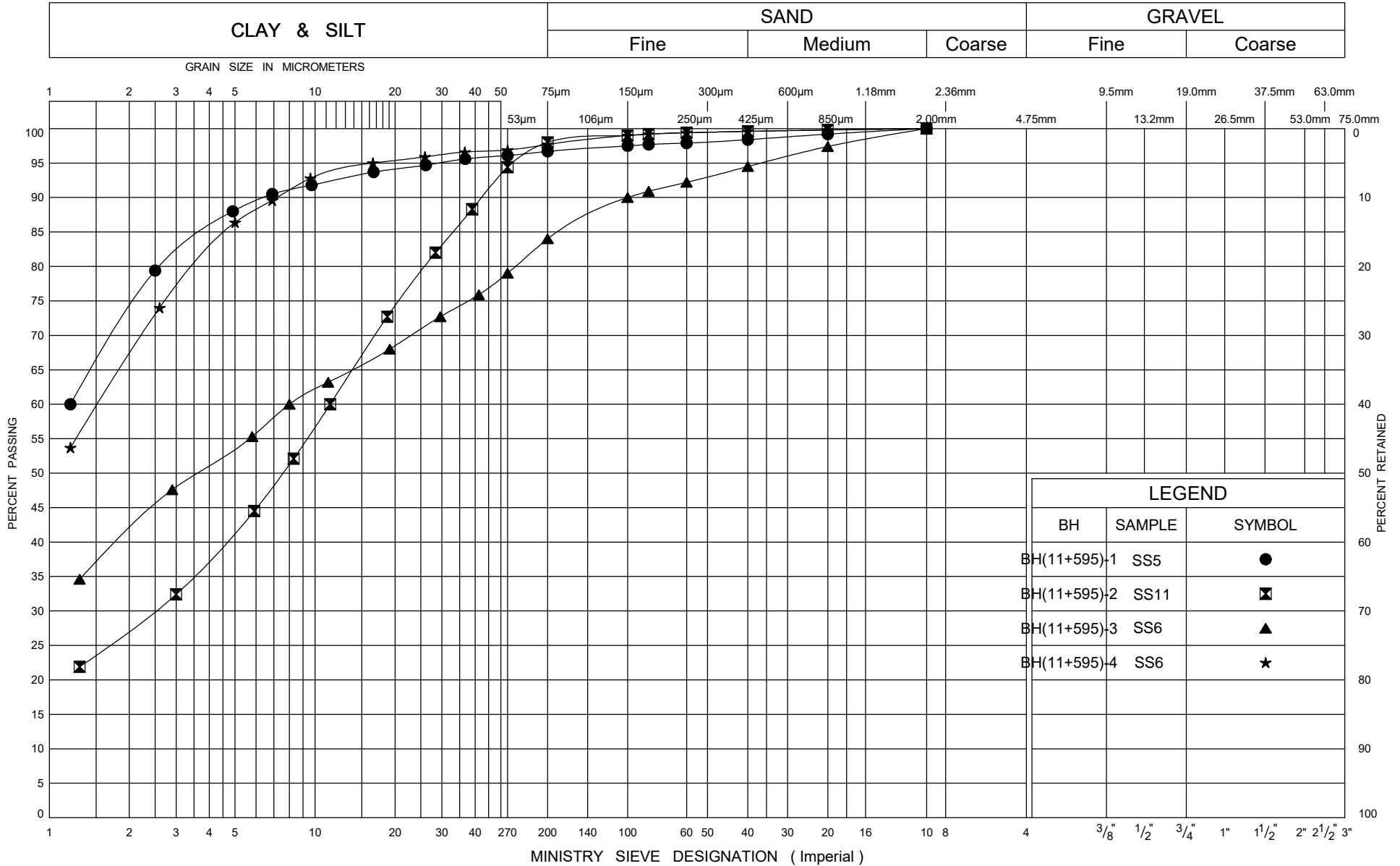
Fill: Silty Clay

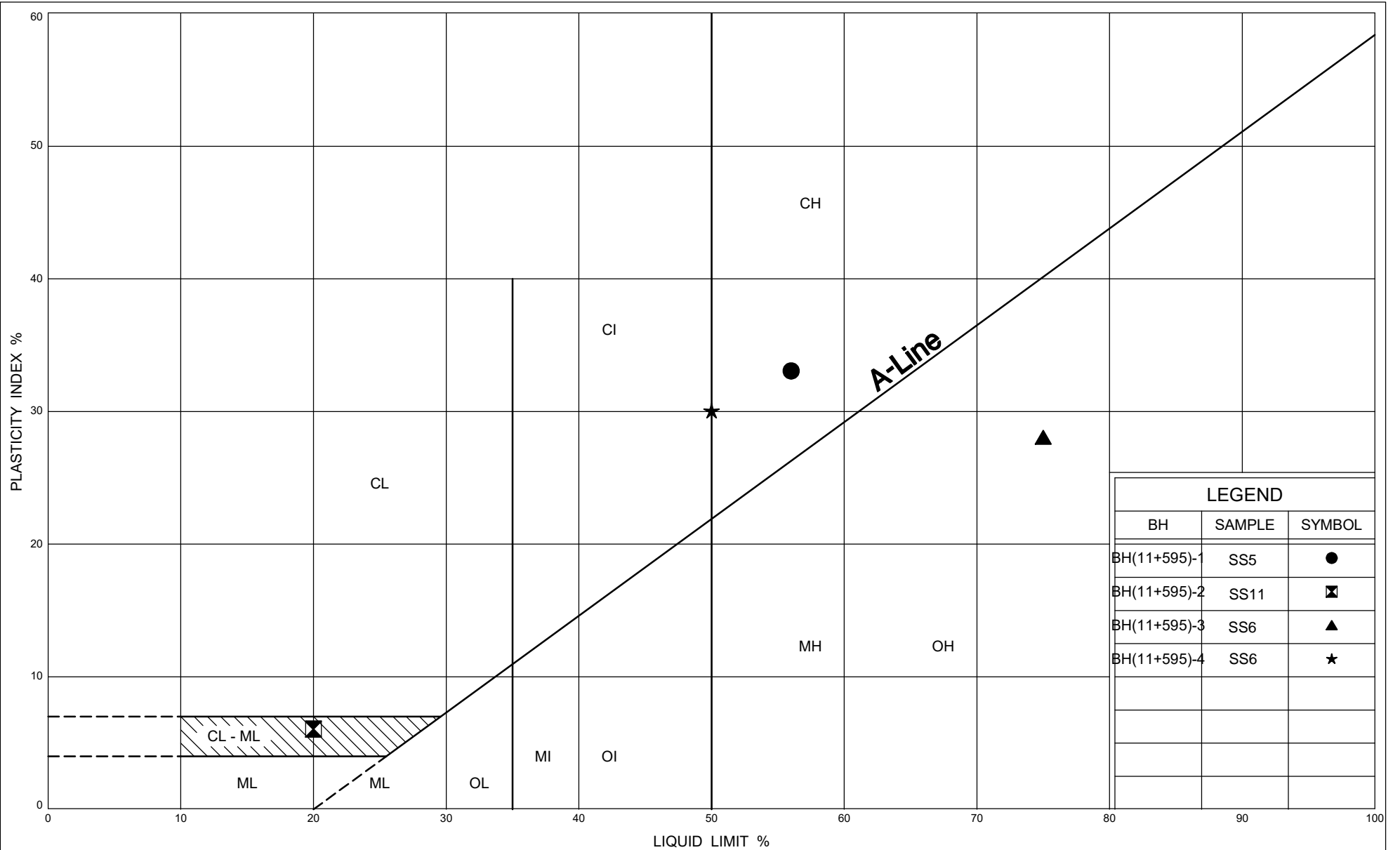
FIG No 2

W PWO 2018-11006

5015-E-0007, Assignment 9

UNIFIED SOIL CLASSIFICATION SYSTEM





Ministry of
Transportation

PLASTICITY CHART

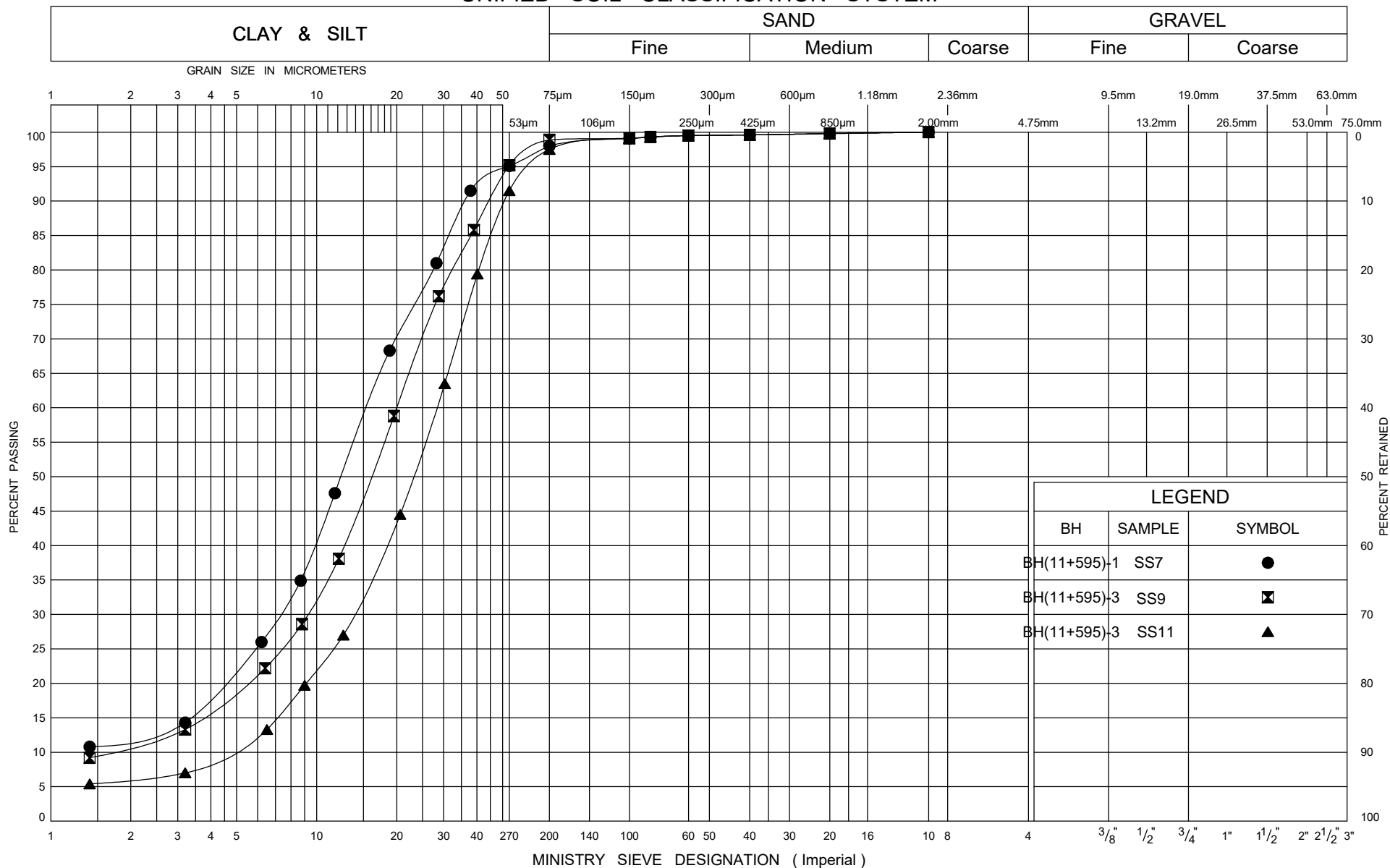
Silty Clay/Clayey Silt

FIG No 4

W PWO 2018-11006

5015-E-0007, Assignment 9

UNIFIED SOIL CLASSIFICATION SYSTEM

Ministry of
Transportation

GRAIN SIZE DISTRIBUTION

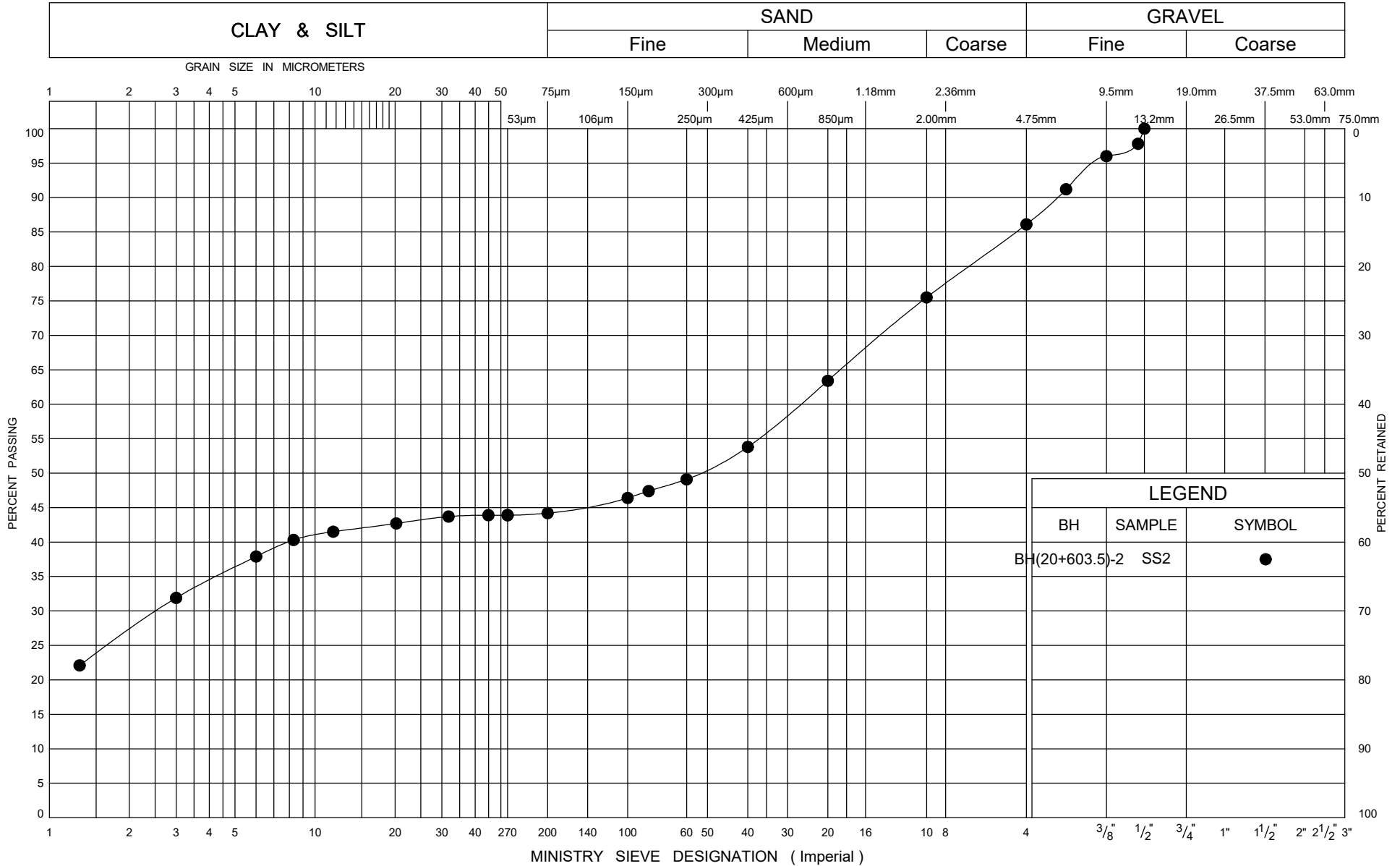
Silt

FIG No 5

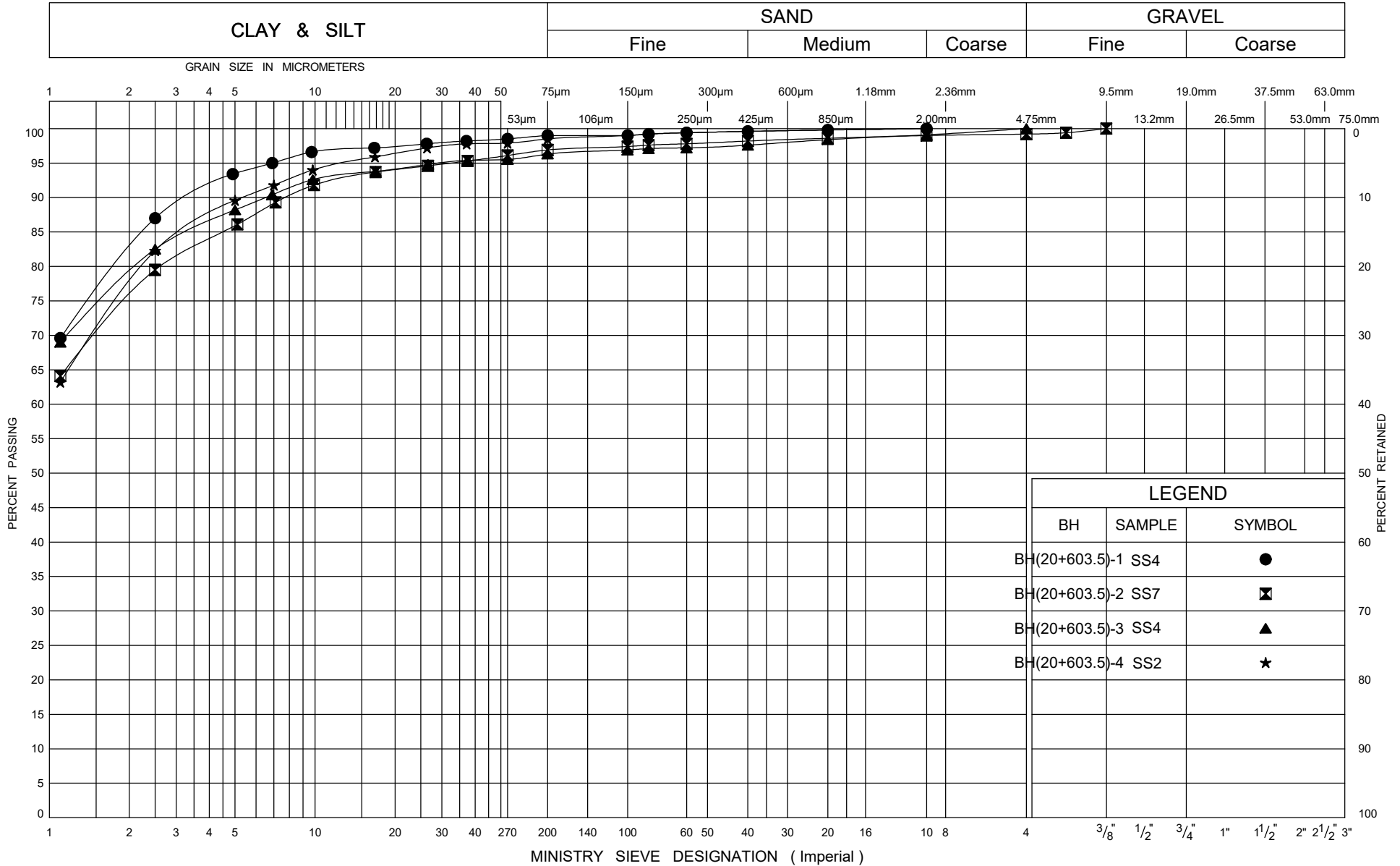
W PWO 2018-11006

5015-E-0007, Assignment 9

UNIFIED SOIL CLASSIFICATION SYSTEM



UNIFIED SOIL CLASSIFICATION SYSTEM



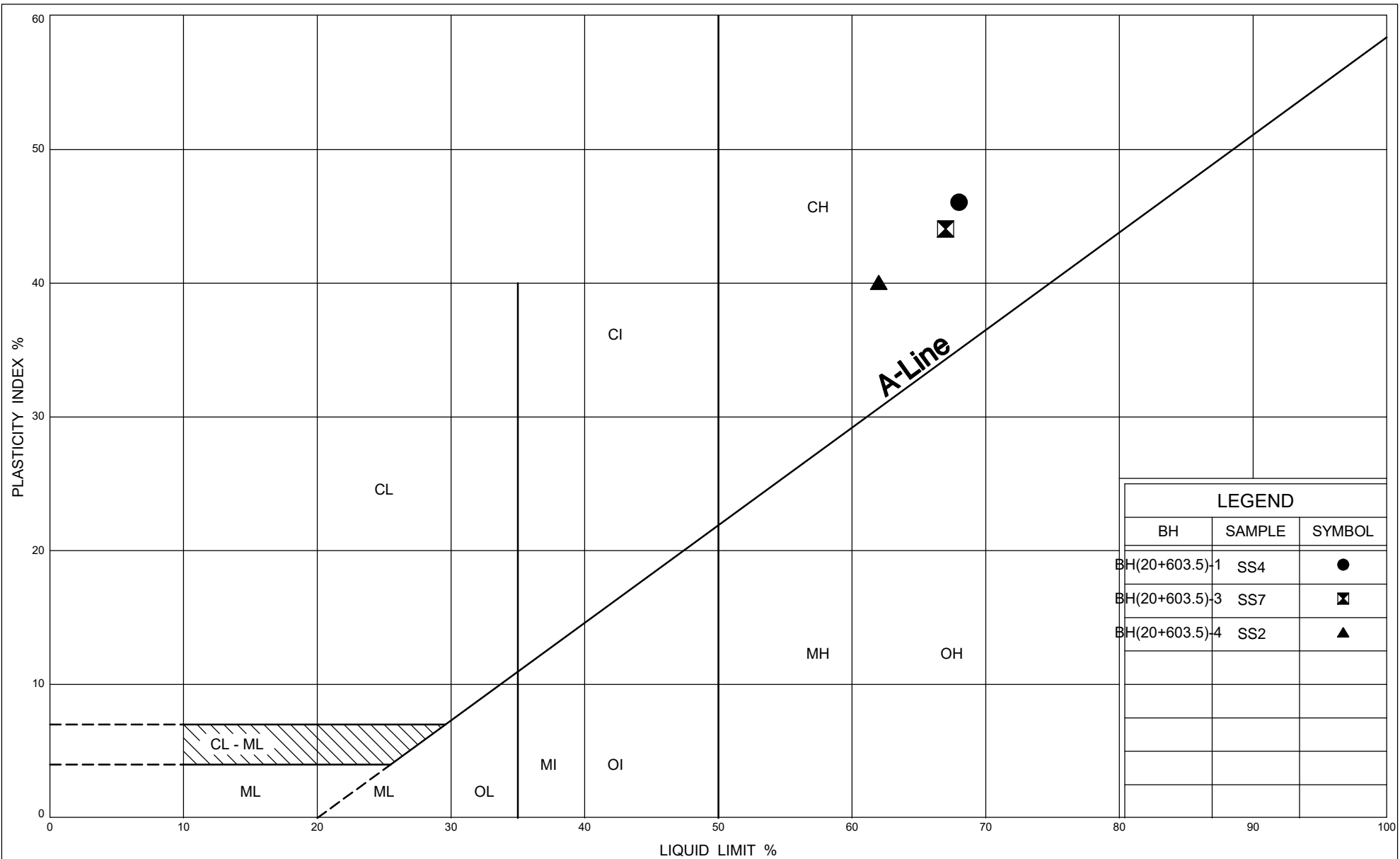
GRAIN SIZE DISTRIBUTION

Fill: Silty Clay to Clay

FIG No 7

W PWO 2018-11006

5015-E-0007, Assignment 9



Ministry of
Transportation

PLASTICITY CHART

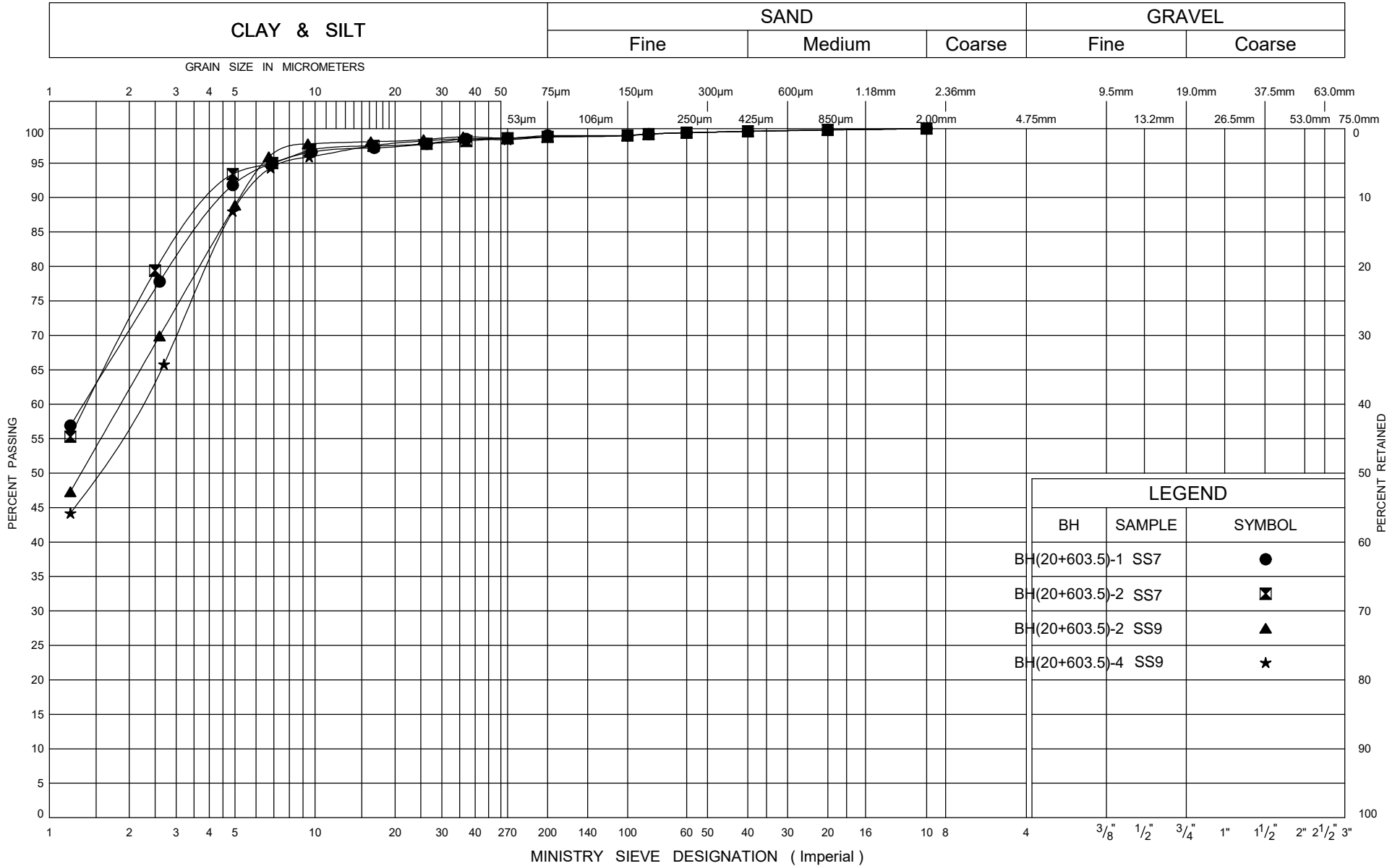
Fill: Silty Clay to Clay

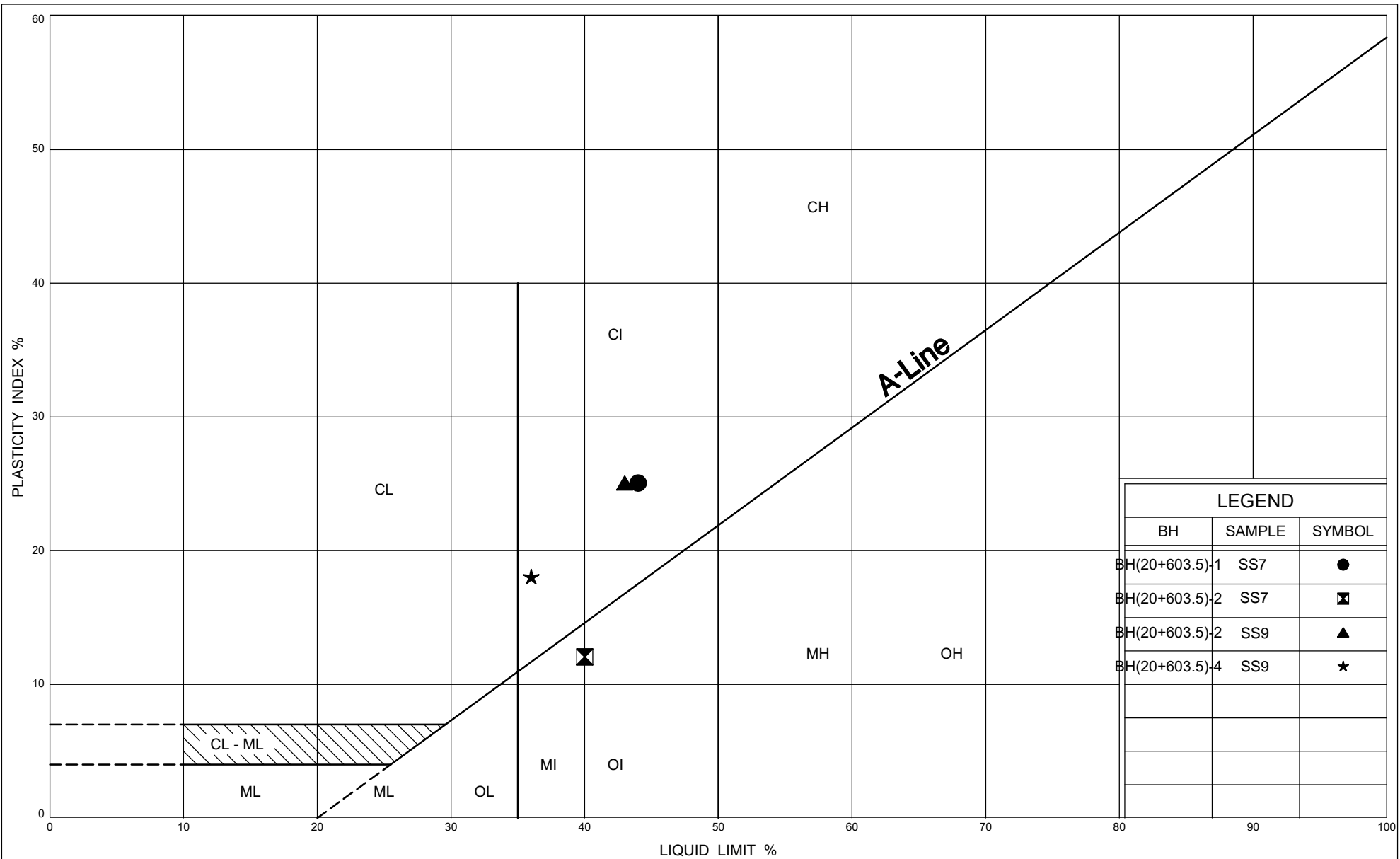
FIG No 8

W PWO 2018-11006

5015-E-0007, Assignment 9

UNIFIED SOIL CLASSIFICATION SYSTEM





Ministry of
Transportation

PLASTICITY CHART

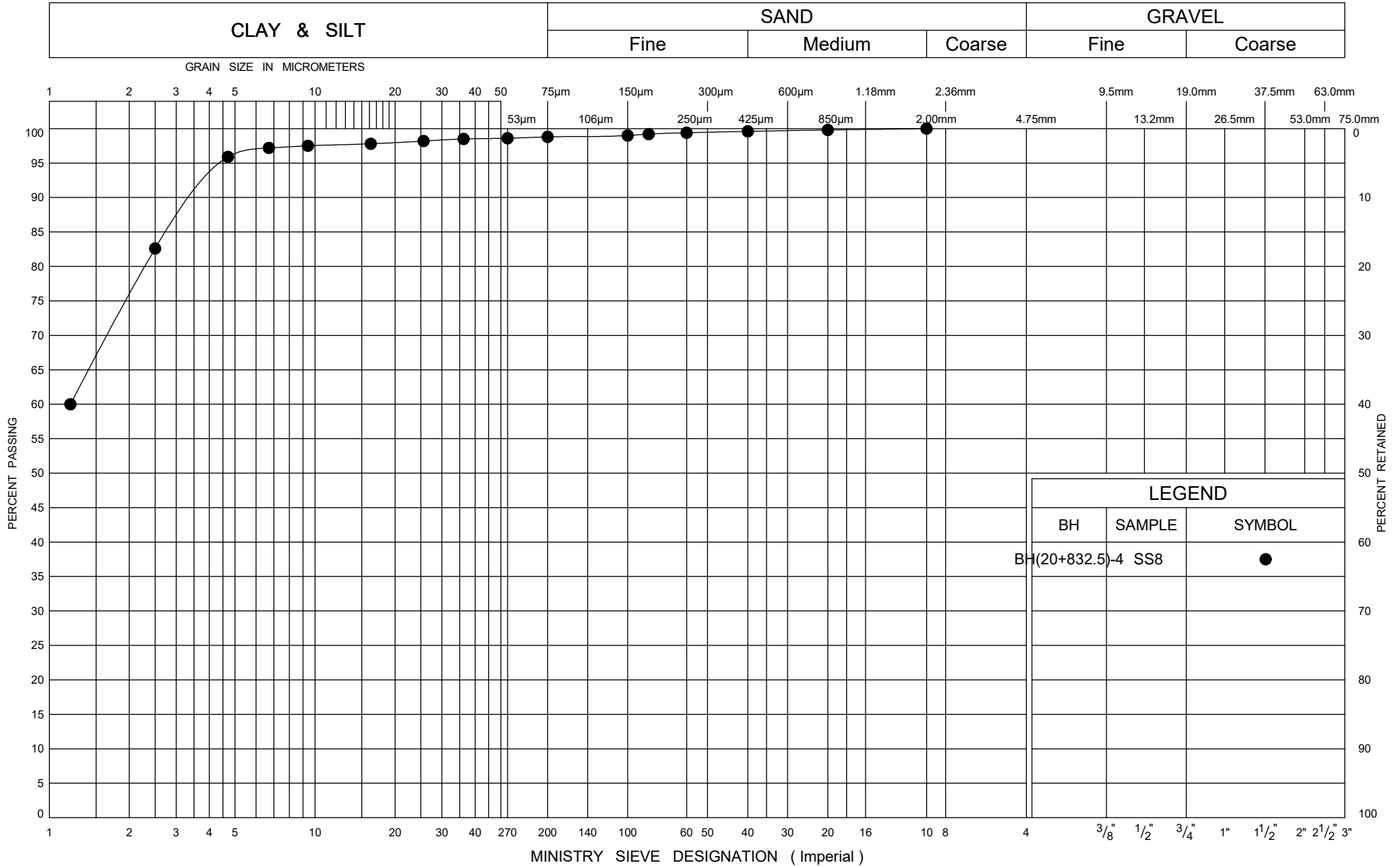
Varved Silty Clay

FIG No 10

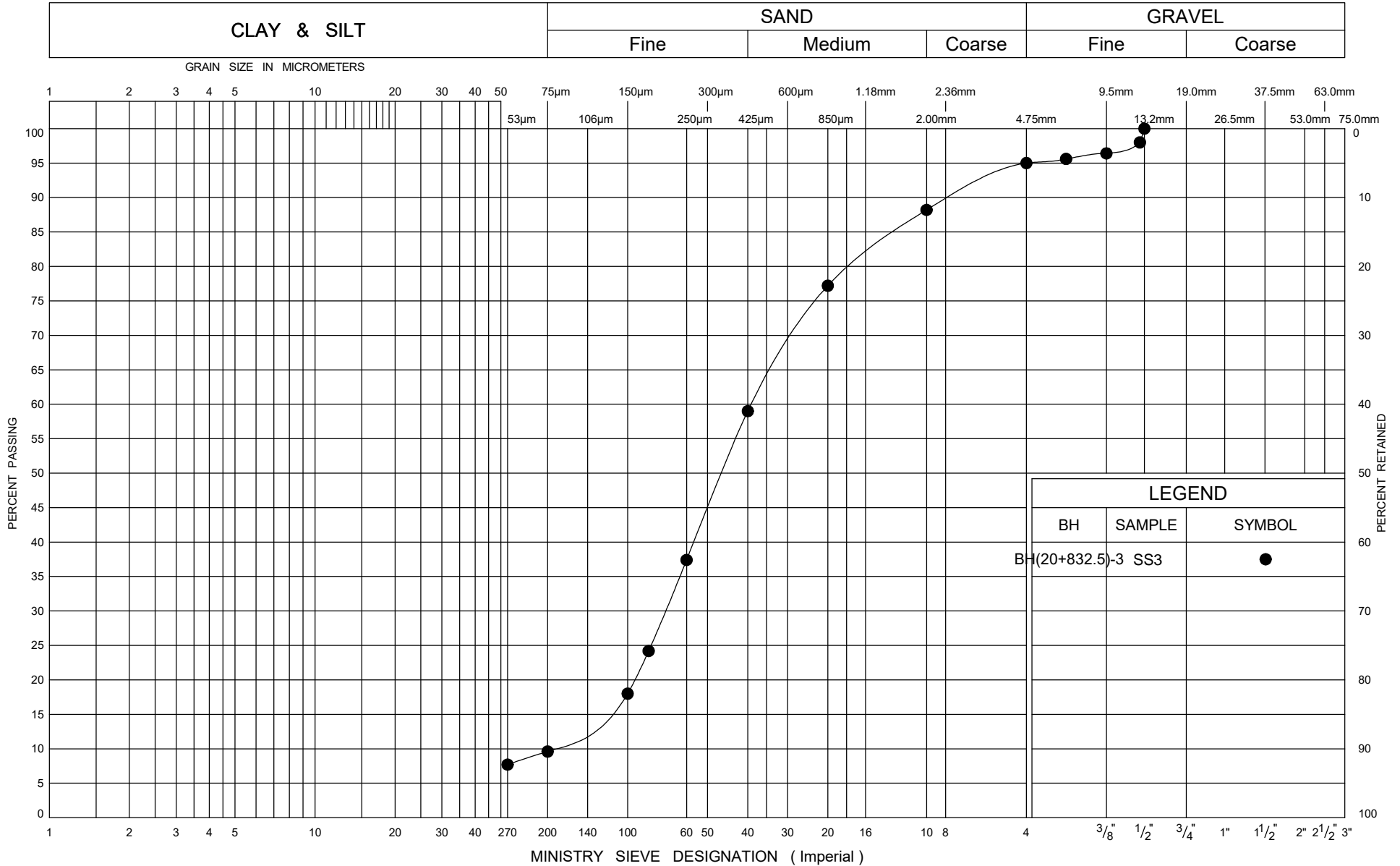
W PWO 2018-11006

5015-E-0007, Assignment 9

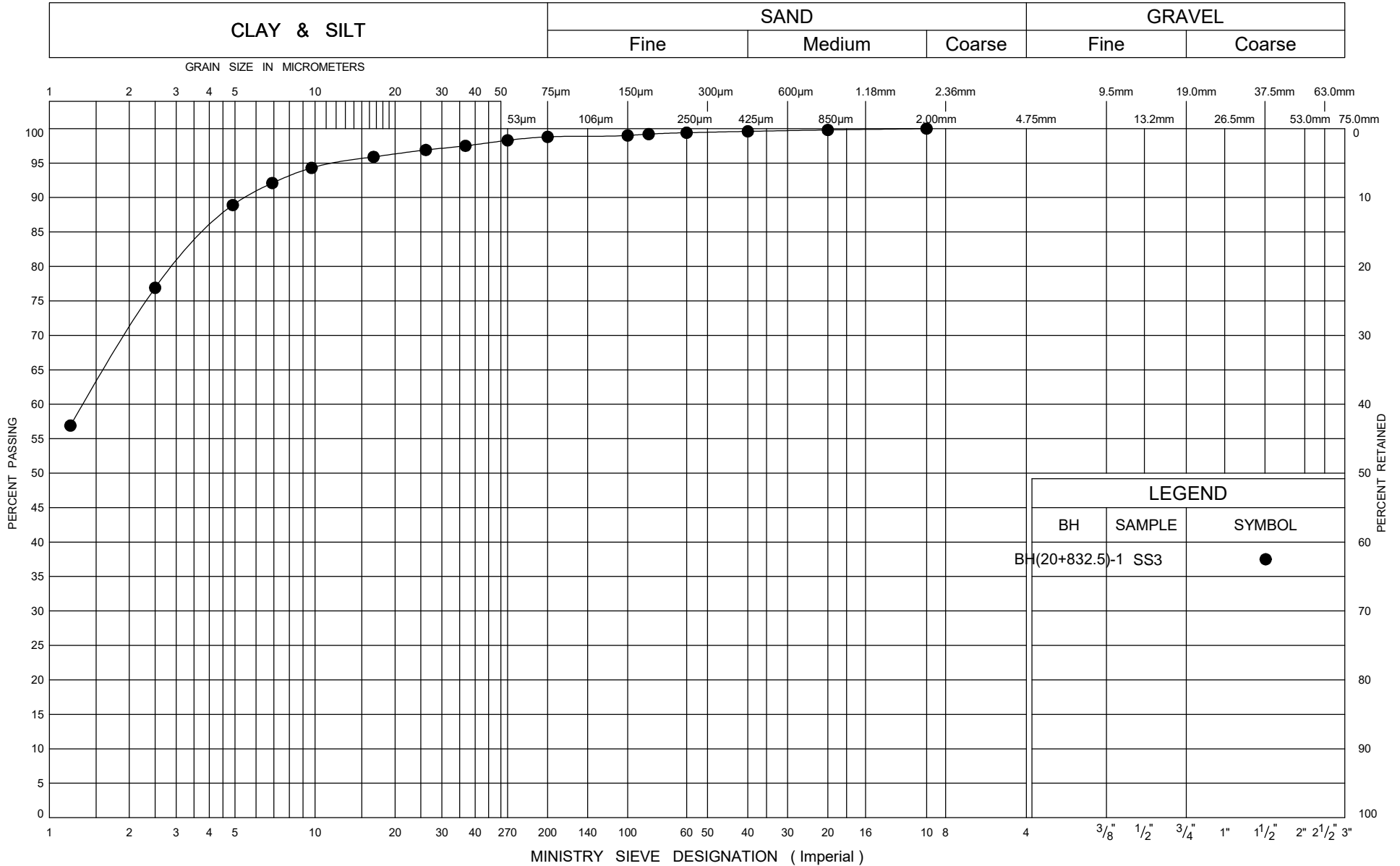
UNIFIED SOIL CLASSIFICATION SYSTEM



UNIFIED SOIL CLASSIFICATION SYSTEM



UNIFIED SOIL CLASSIFICATION SYSTEM



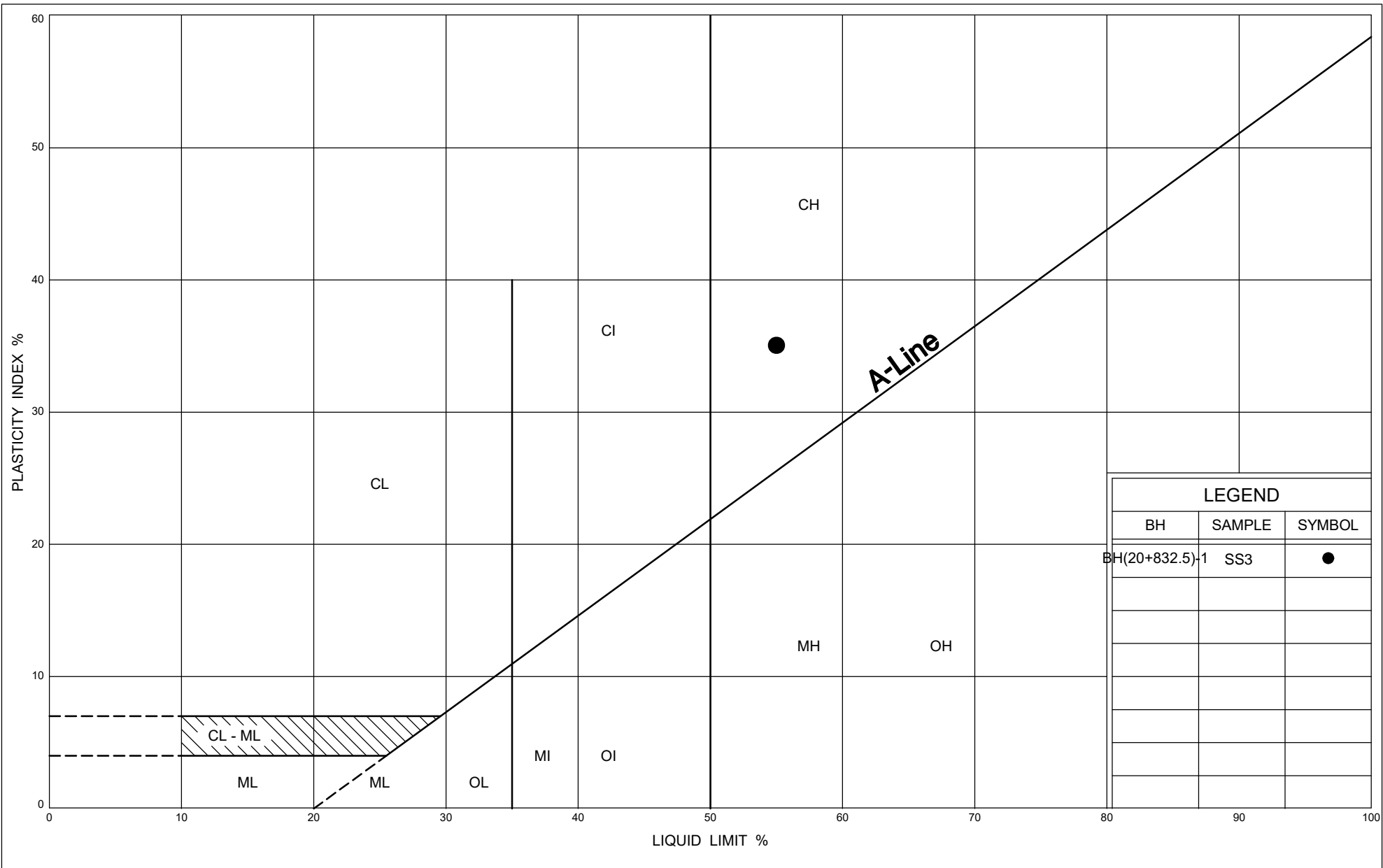
GRAIN SIZE DISTRIBUTION

Fill: Silty Clay

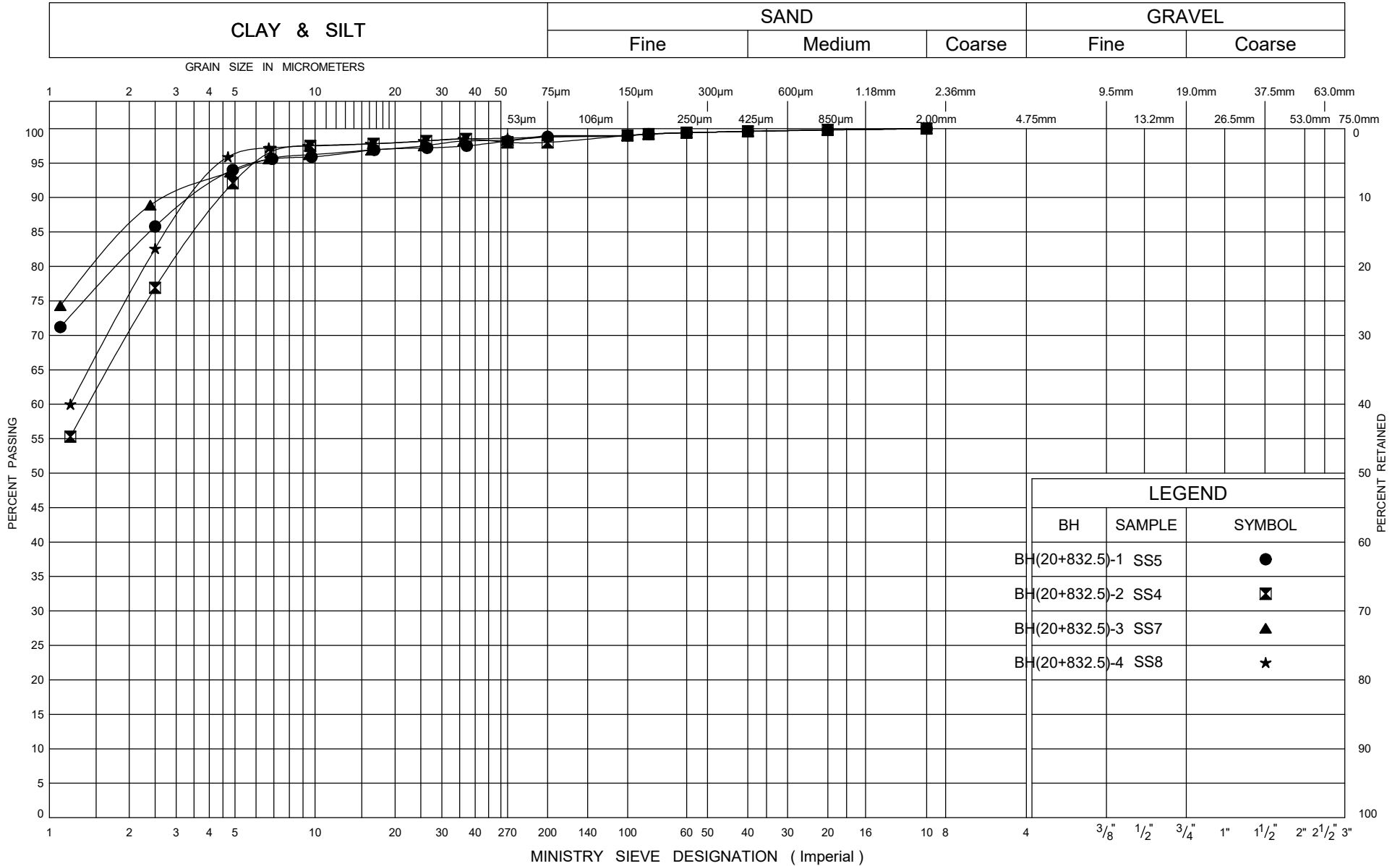
FIG No 13

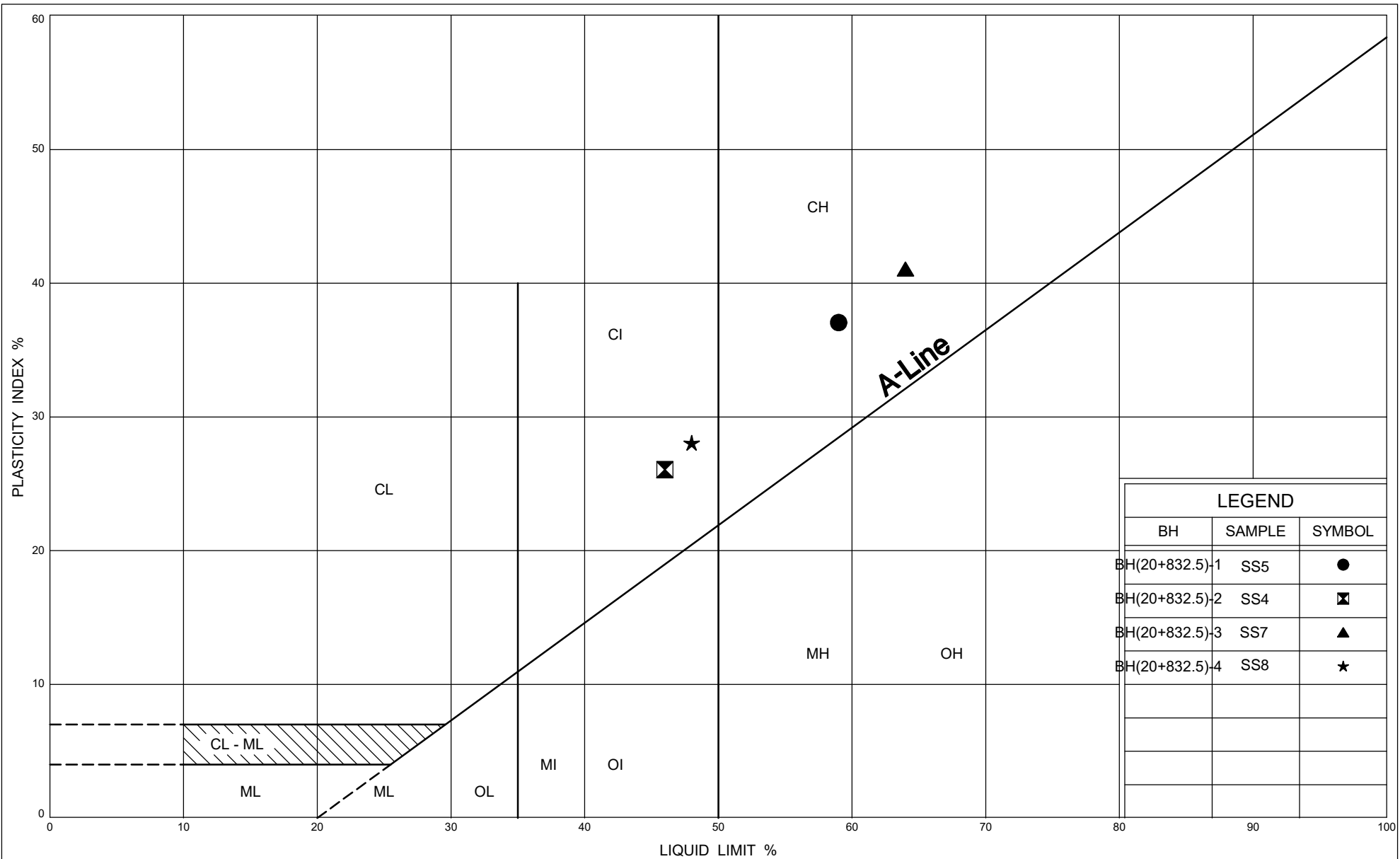
W PWO 2018-11006

5015-E-0007, Assignment 9



UNIFIED SOIL CLASSIFICATION SYSTEM





Ministry of
Transportation

PLASTICITY CHART

Varved Silty Clay to Clay

FIG No 16

W PWO 2018-11006

5015-E-0007, Assignment 9

Appendix E – Results of Stability Analysis

Culvert CV11+595
East Embankment Permanent Slope
Total Stress Analysis

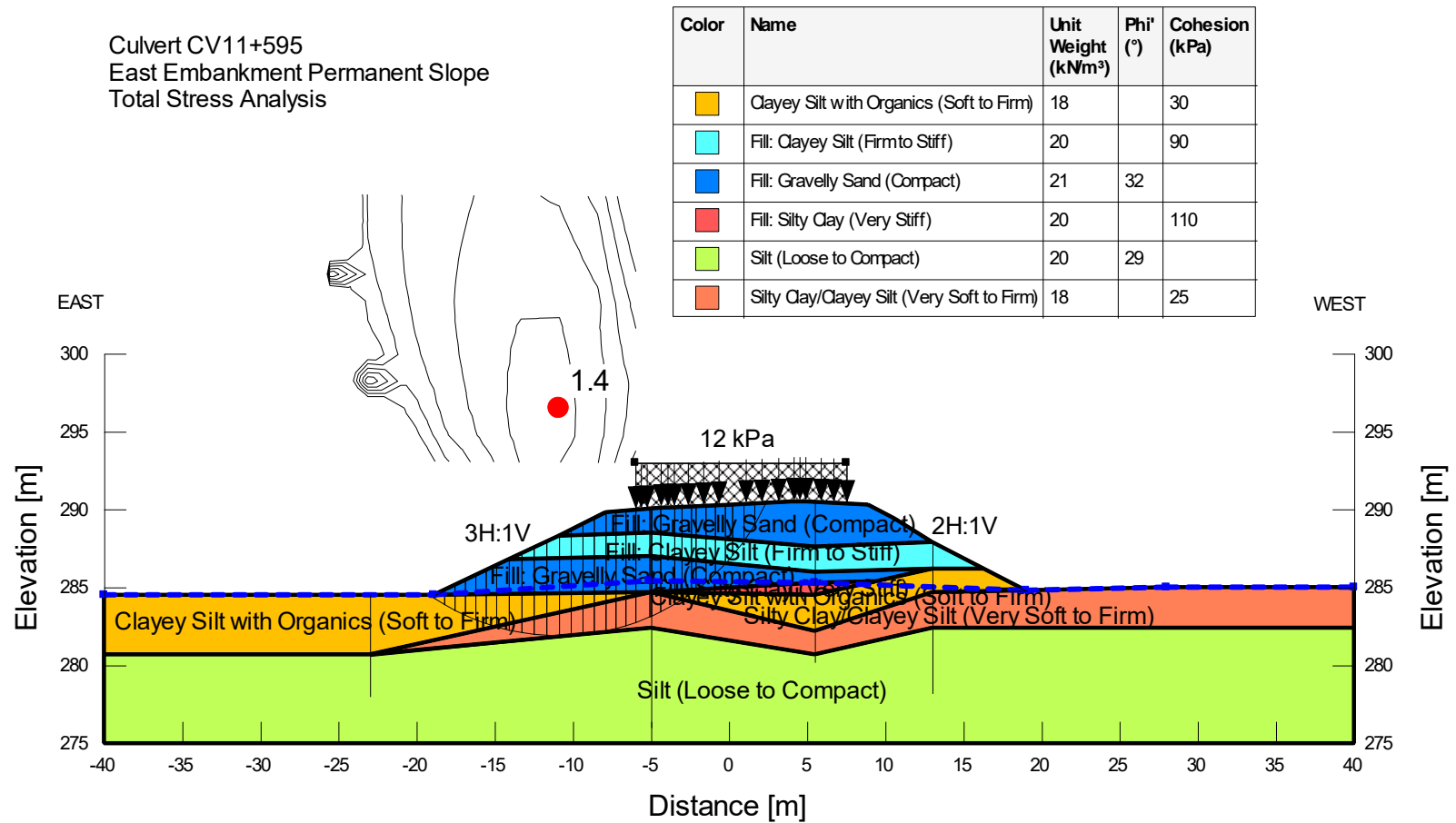


Fig. 1

Culvert CV11+595
East Embankment Permanent Slope
Effective Stress Analysis

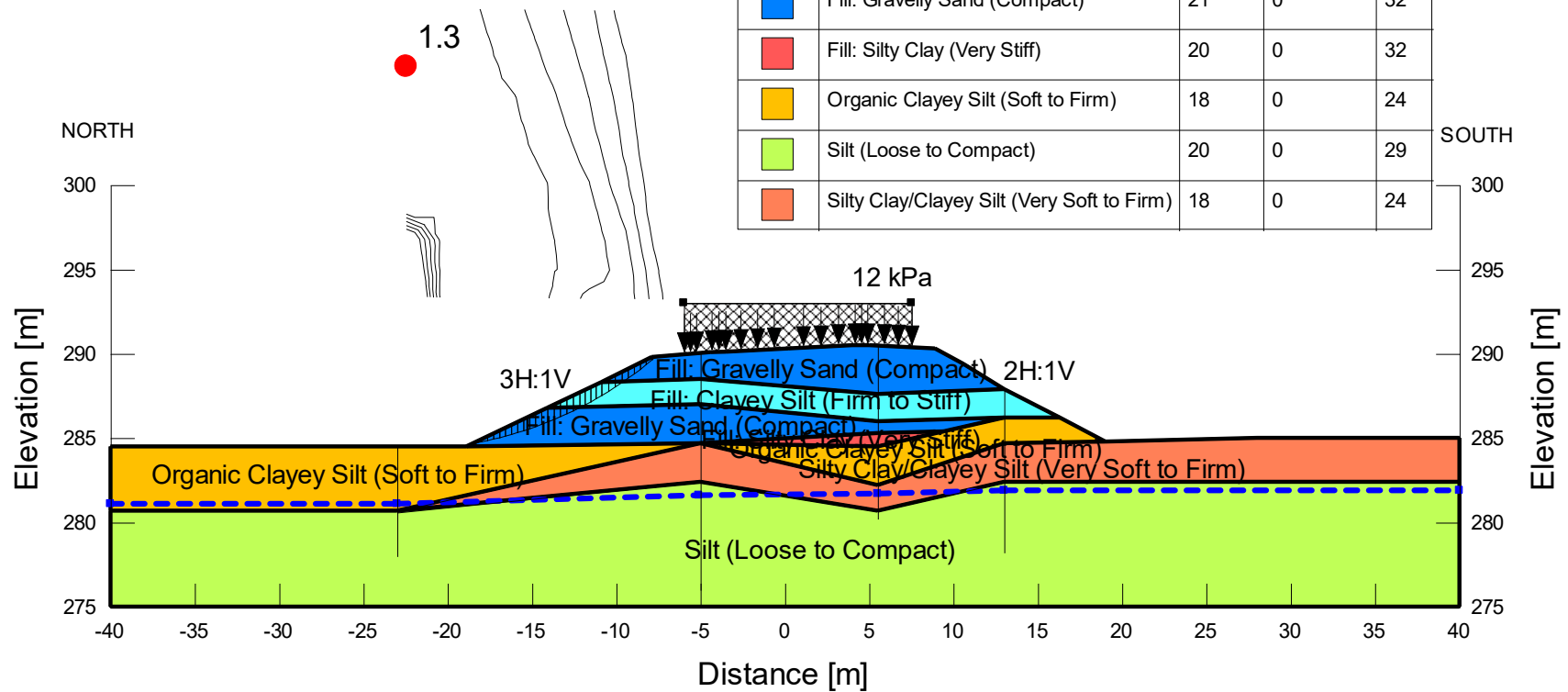








Fig. 2

Culvert CV11+595
East Embankment Permanent Slope
Effective Stress Analysis

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Clayey Silt with Organics (Soft to Firm)	18	0	24
	Fill: Clayey Silt (Firm to Stiff)	20	0	31
	Fill: Gravelly Sand (Compact)	21	0	32
	Fill: Silty Clay (Very Stiff)	20	0	32
	Silt (Loose to Compact)	20	0	29
	Silty Clay/Clayey Silt (Very Soft to Firm)	18	0	24

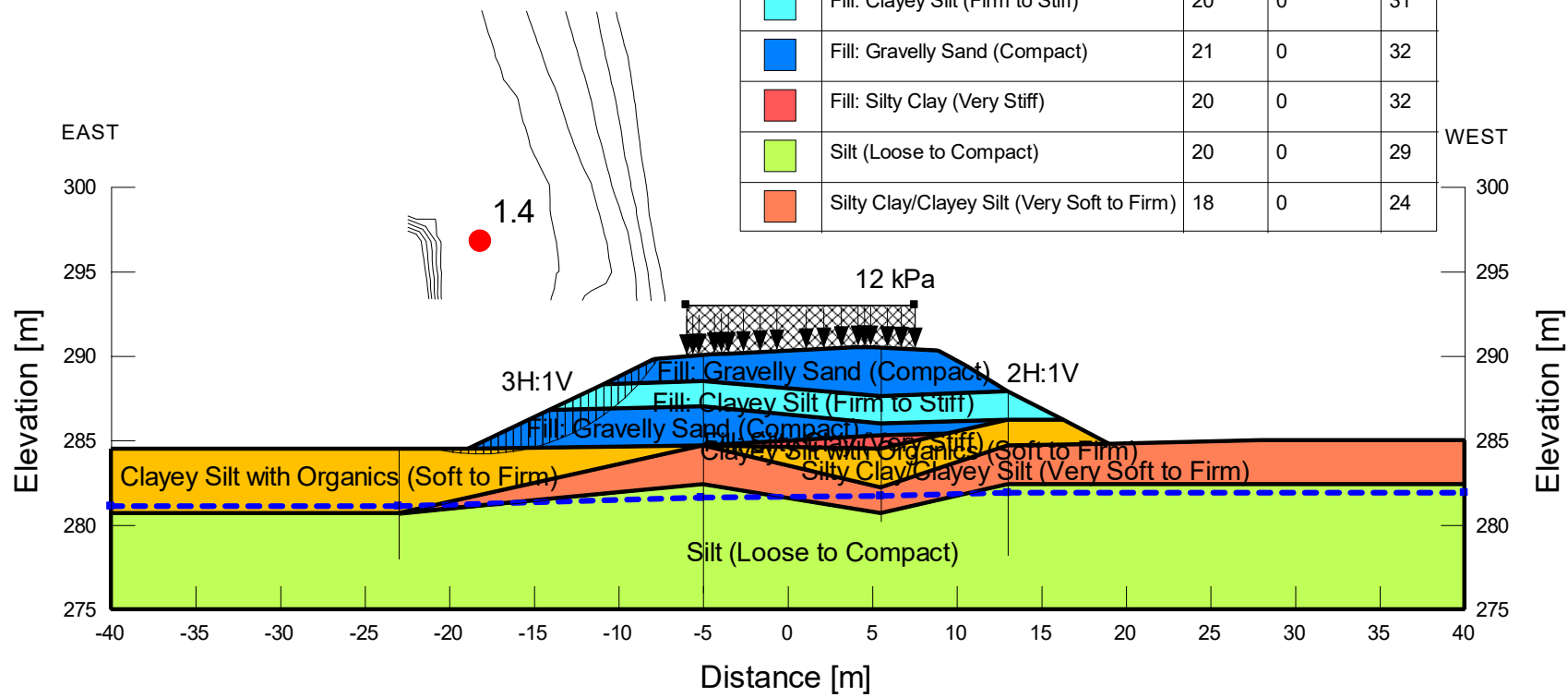


Fig. 3

Culvert CV11+595
 West Embankment Permanent Slope
 Total Stress Analysis

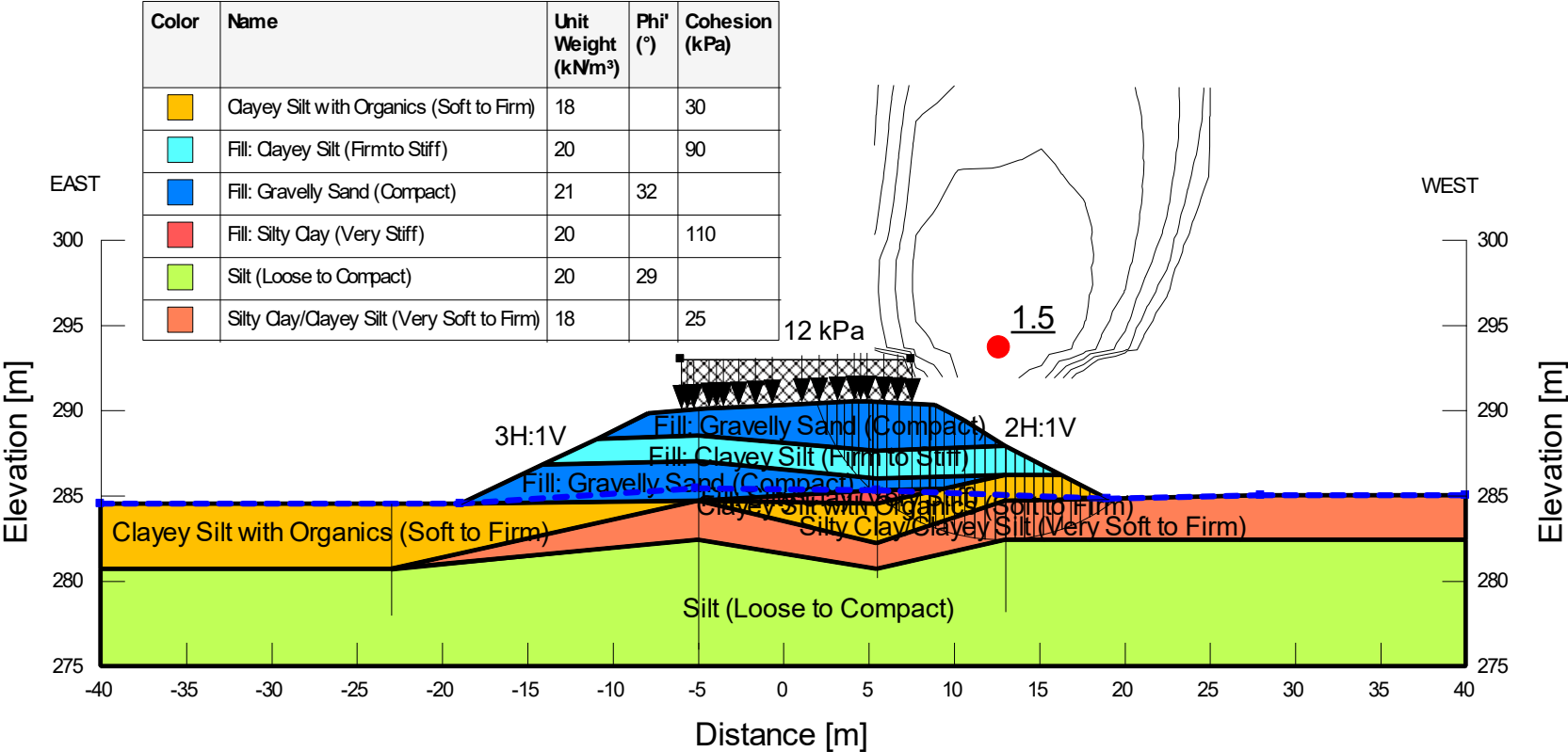


Fig. 4

Culvert CV11+595
West Embankment Permanent Slope
Effective Stress Analysis

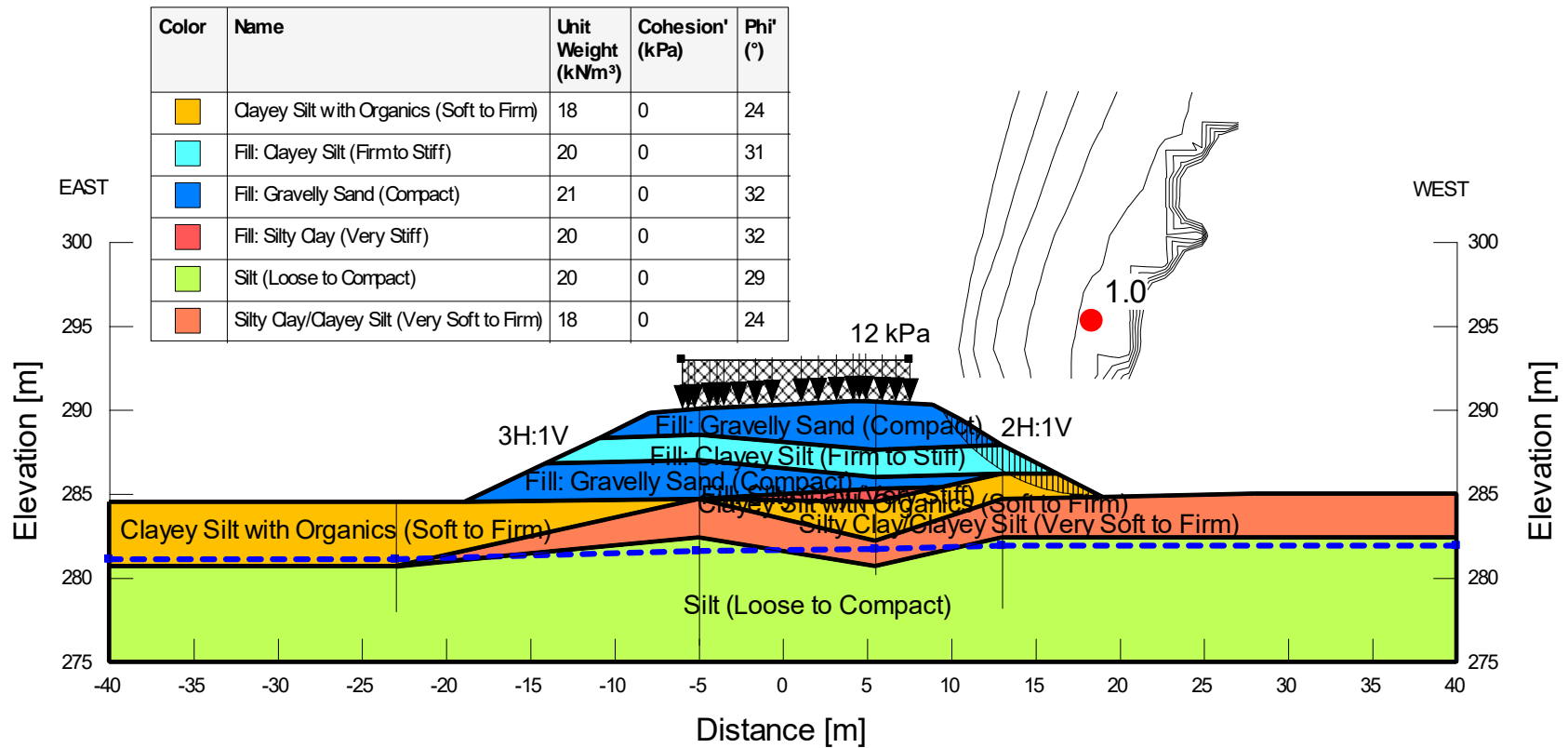






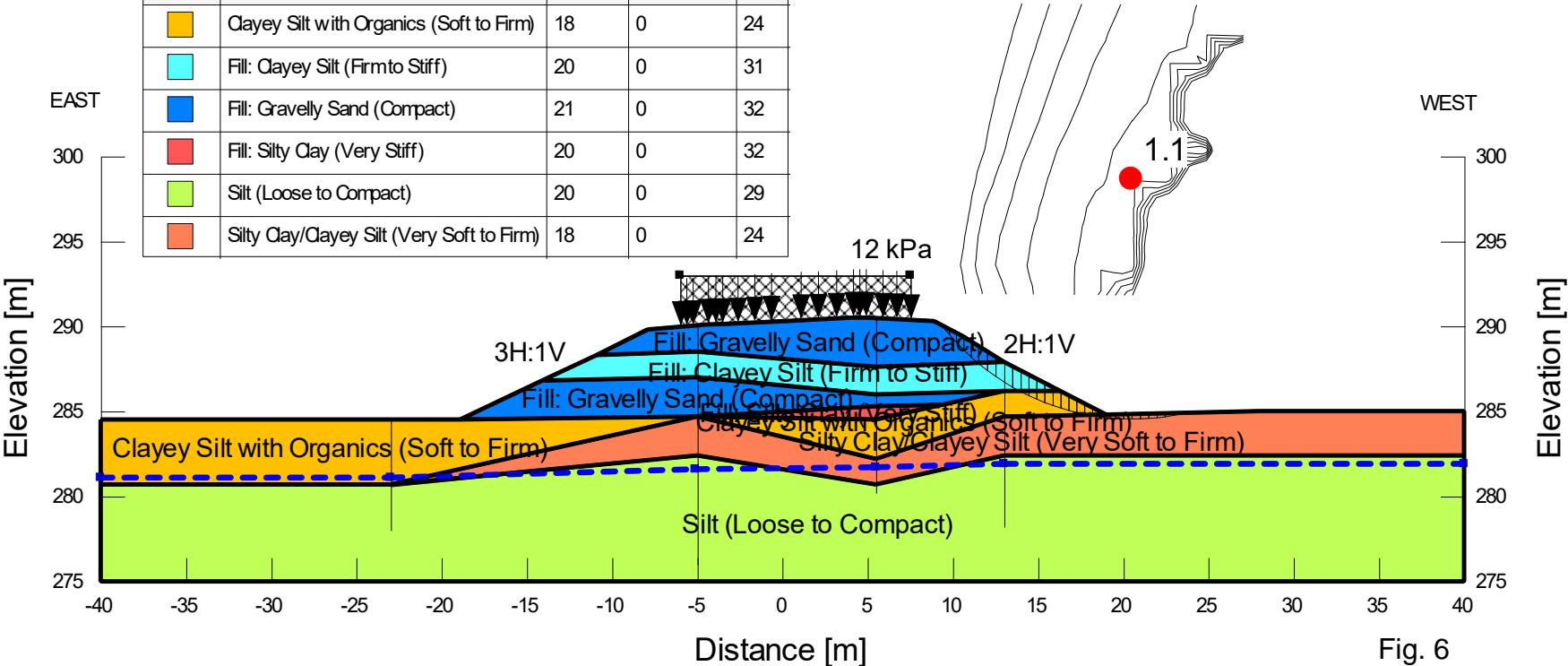


Fig. 5

Culvert CV11+595
 West Embankment Permanent Slope
 Effective Stress Analysis

Color	Name	Unit Weight (kNm ³)	Cohesion' (kPa)	Phi' (°)
	Clayey Silt with Organics (Soft to Firm)	18	0	24
	Fill: Clayey Silt (Firm to Stiff)	20	0	31
	Fill: Gravelly Sand (Compact)	21	0	32
	Fill: Silty Clay (Very Stiff)	20	0	32
	Silt (Loose to Compact)	20	0	29
	Silty Clay/Clayey Silt (Very Soft to Firm)	18	0	24



Culvert CV11+595
Temporary Cut Slope
Total Stress Analysis

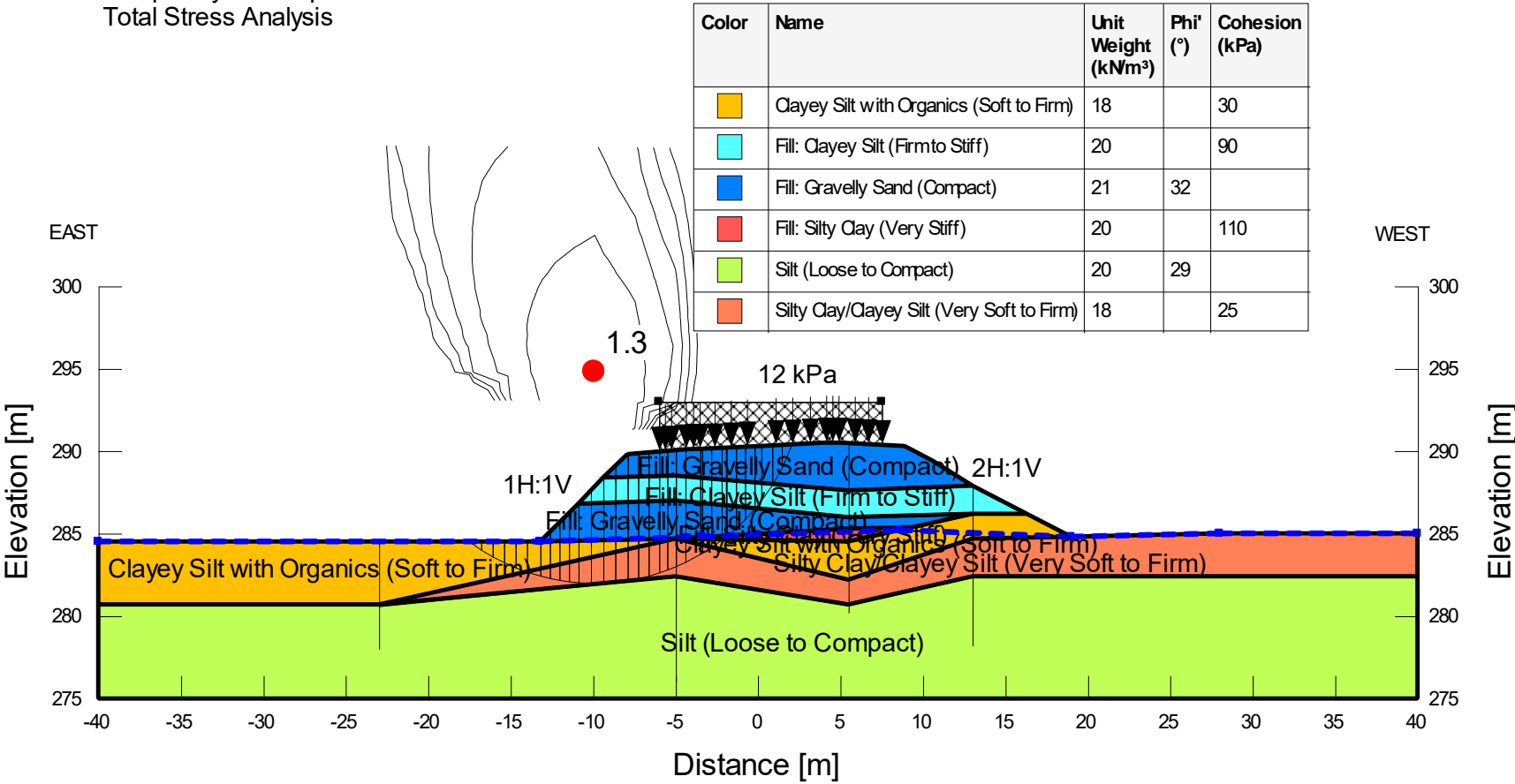


Fig. 7

Culvert CV11+595
West Embankment Permanent Slope
Effective Stress Analysis

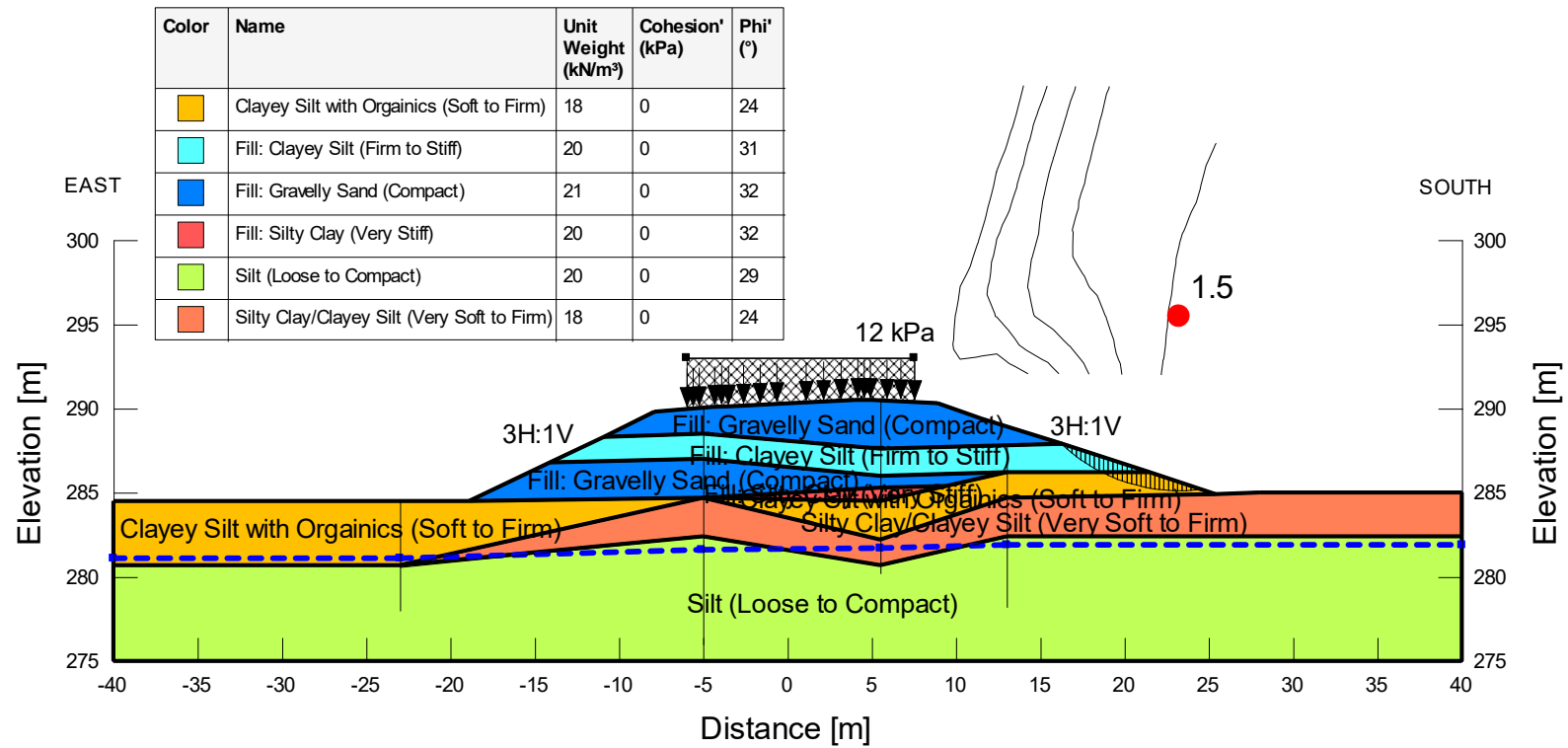


Fig. 8

Culvert CV11+595
West Embankment Permanent Slope
Effective Stress Analysis

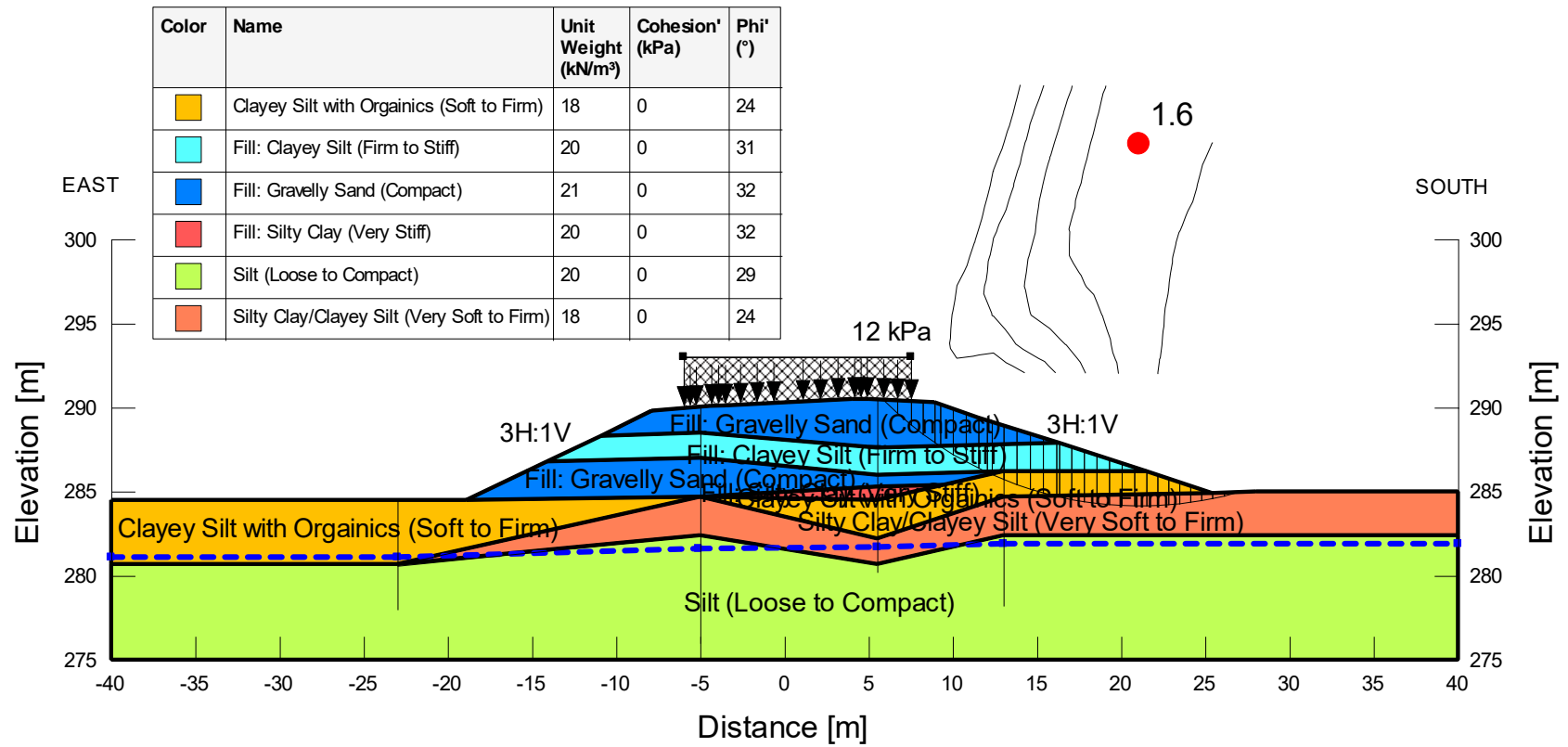


Fig. 9

Culvert CV20+603.5
East Embankment Permanent Slope
Total Stress Analysis

Color	Name	Unit Weight (kN/m³)	Cohesion (kPa)	Phi' (°)
Blue	Fill: Sand and Gravel (Compact)	21		32
Red	Fill: Silty Clay to Clay(Soft to Stiff)	20	50	
Yellow	Varved Silty Clay (Very Soft to Soft)	18	18	

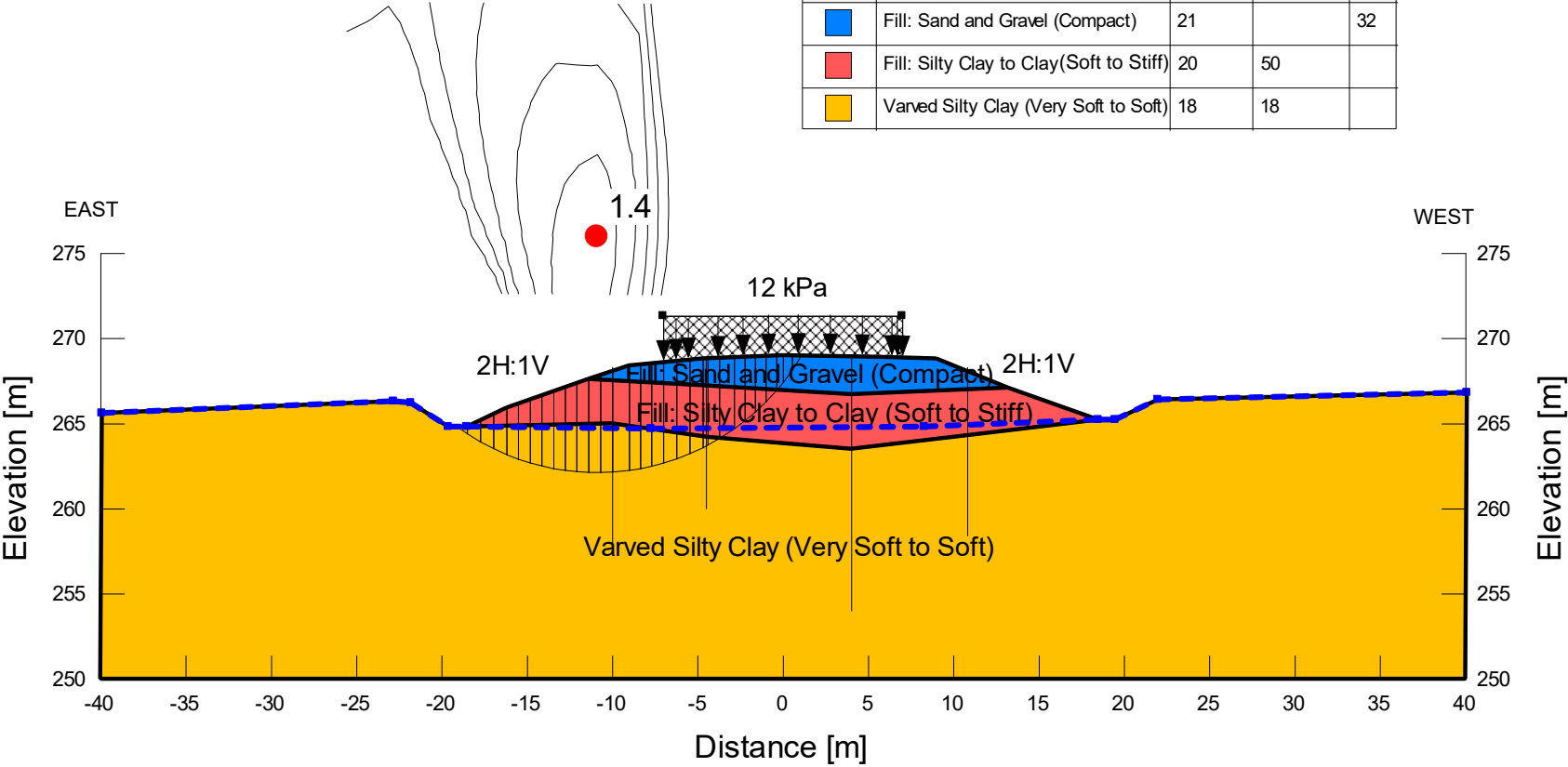


Fig. 10

Culvert CV20+603.5
 East Embankment Permanent Slope
 Effective Stress Analysis

Color	Name	Unit Weight (kN/m ³)	Phi' (°)
Blue	Fill: Sand and Gravel (Compact)	21	32
Red	Fill: Silty Clay to Clay (Soft to Stiff)	20	30
Yellow	Varved Silty Clay (Very Soft to Soft)	18	23

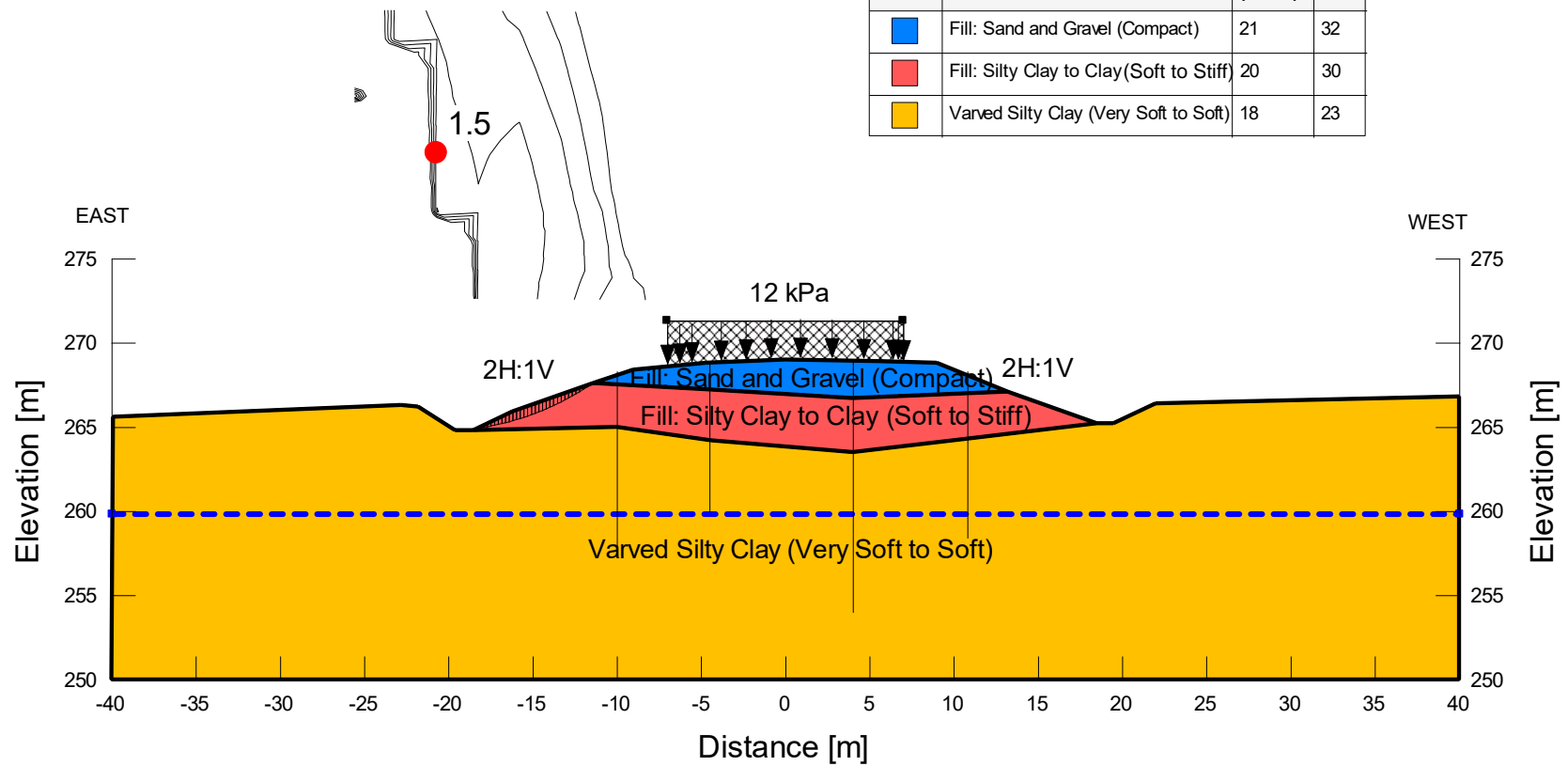


Fig. 11

Culvert CV20+603.5
East Embankment Permanent Slope
Effective Stress Analysis

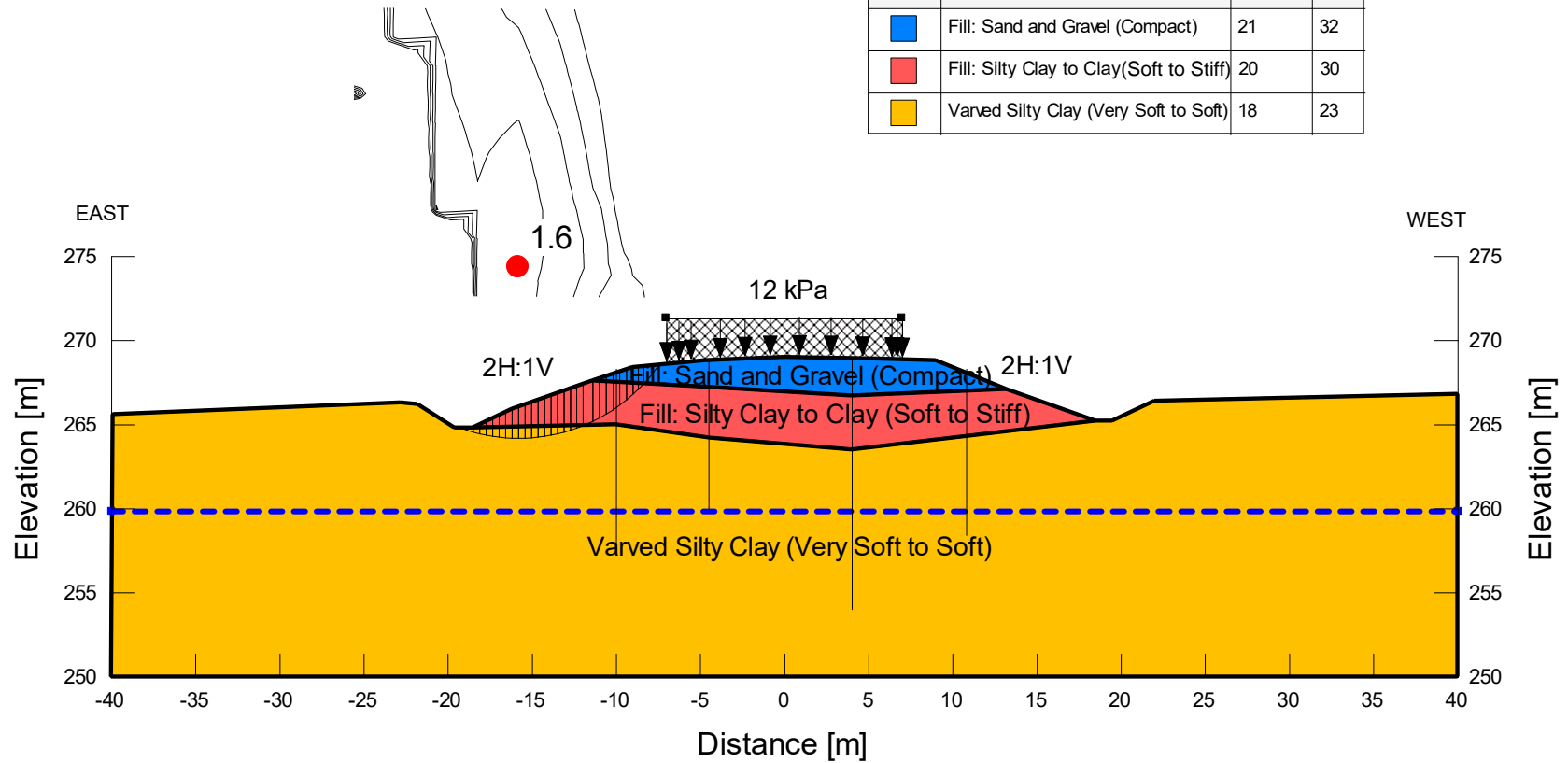


Fig. 12

Culvert CV20+603.5
West Embankment Permanent Slope
Total Stress Analysis

Color	Name	Unit Weight (kN/m ³)	Cohesion (kPa)	Phi' (°)
Blue	Fill: Sand and Gravel (Compact)	21		32
Red	Fill: Silty Clay to Clay (Soft to Stiff)	20	50	
Yellow	Varved Silty Clay (Very Soft to Soft)	18	18	

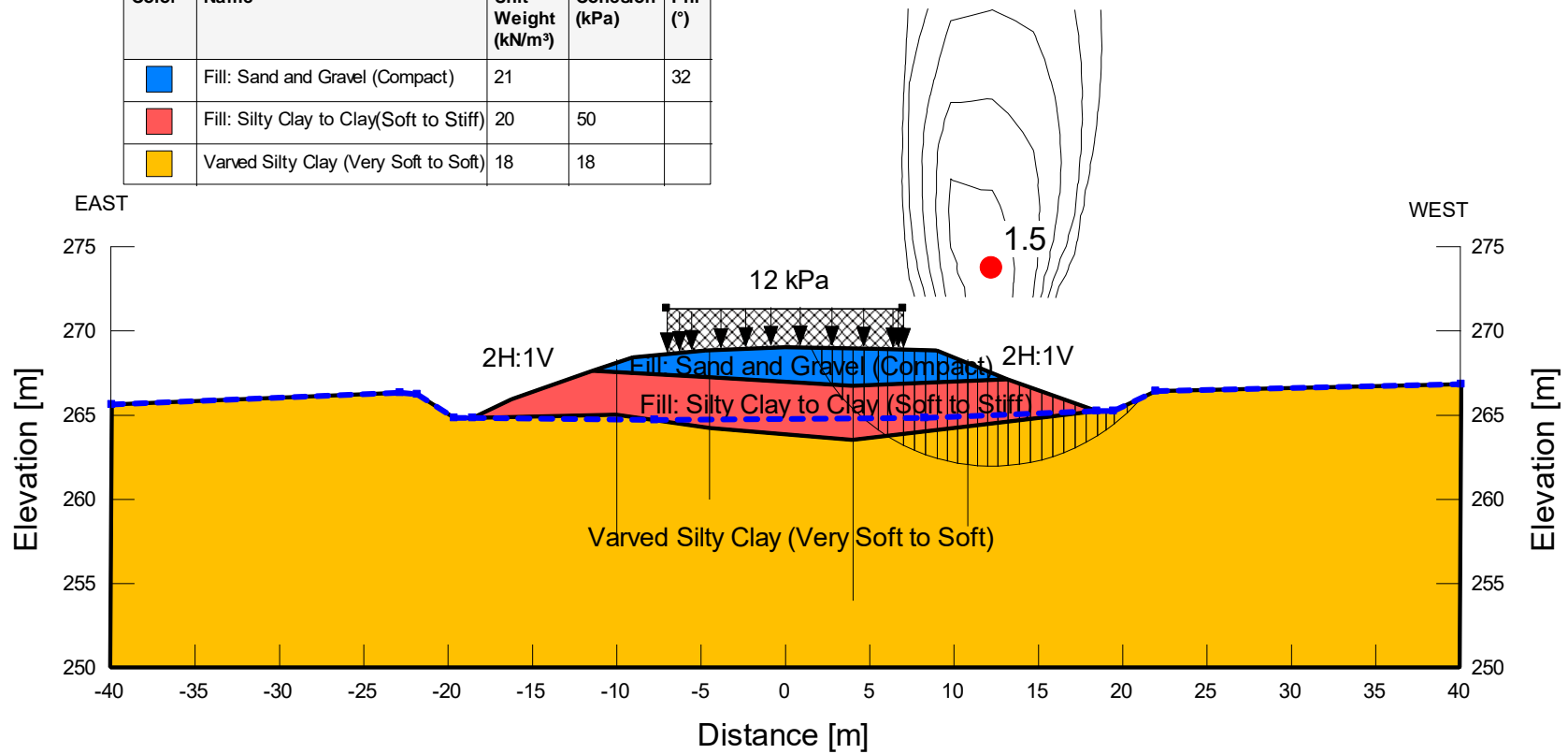


Fig. 13

Culvert CV20+603.5
East Embankment Permanent Slope
Effective Stress Analysis

Color	Name	Unit Weight (kN/m ³)	Cohesion' (kPa)	Phi' (°)
Blue	Fill: Sand and Gravel (Compact)	21	0	32
Red	Fill: Silty Clay to Clay (Soft to Stiff)	20	0	30
Yellow	Varved Silty Clay (Very Soft to Soft)	18	0	23

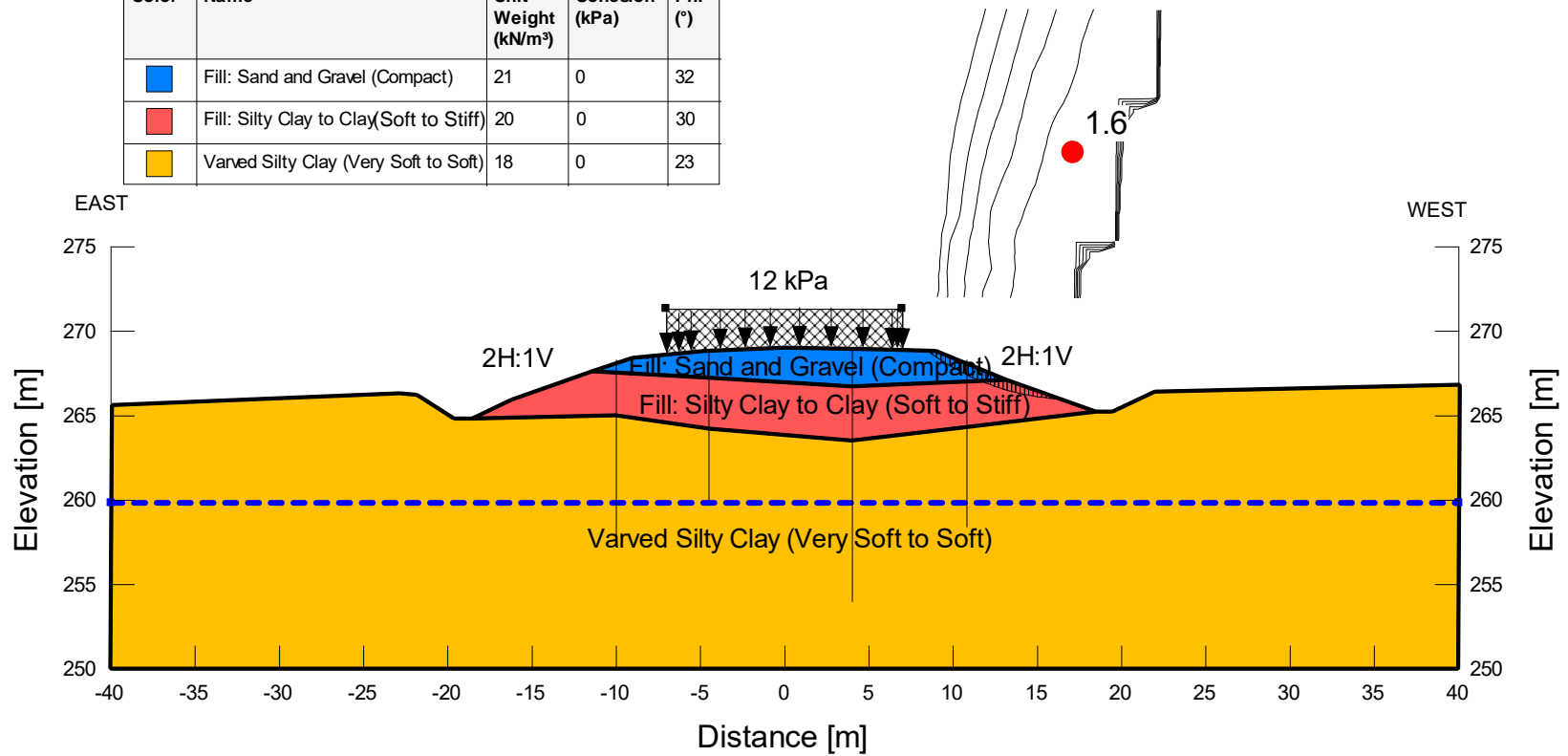


Fig. 14

Culvert CV20+603.5
West Embankment Permanent Slope
Effective Stress Analysis

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
■	Fill: Sand and Gravel (Compact)	21	0	32
■	Fill: Silty Clay to Clay(Soft to Stiff)	20	0	30
■	Varved Silty Clay (Very Soft to Soft)	18	0	23

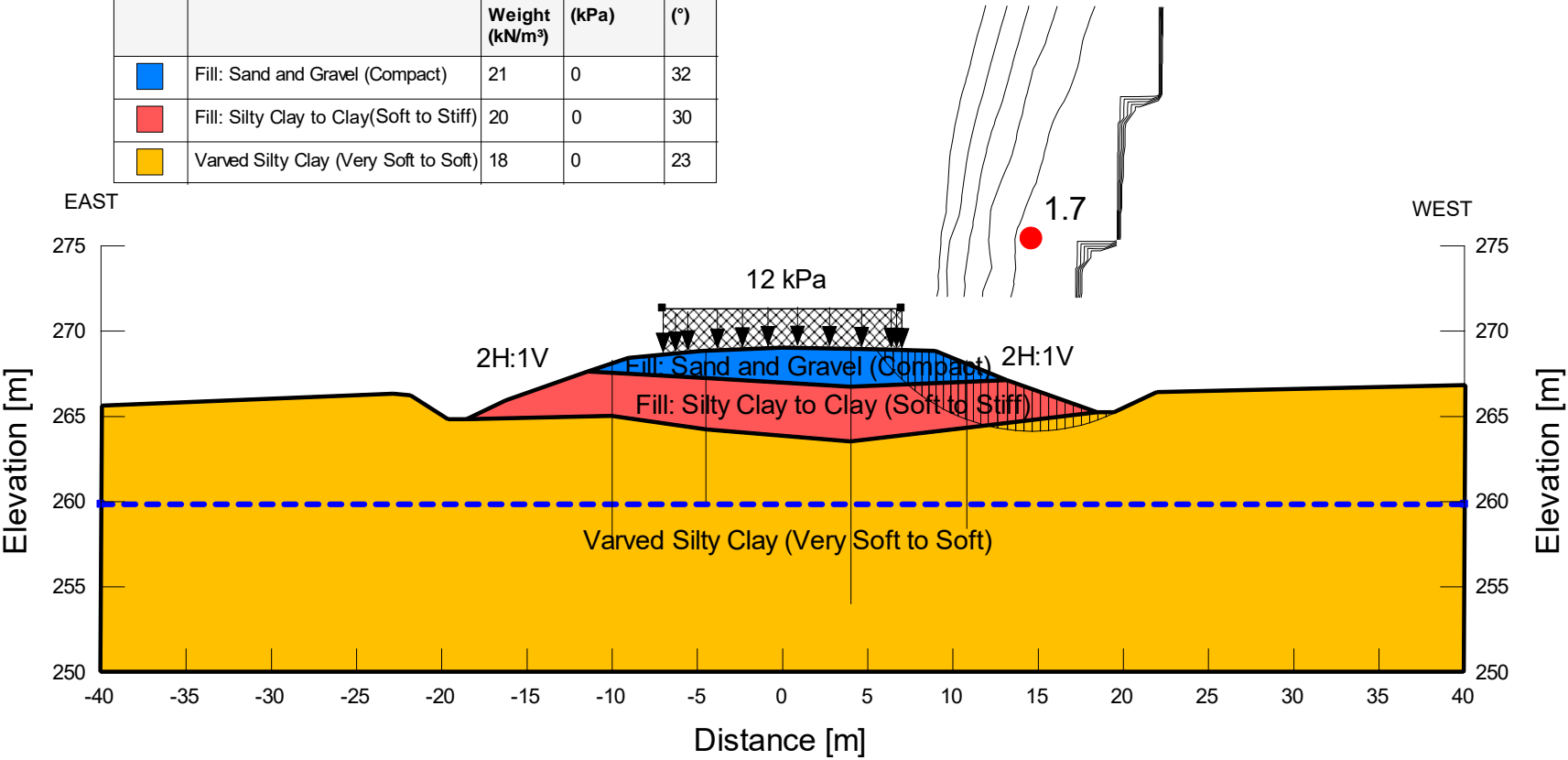


Fig. 15

Culvert CV20+603.5
Temporary Cut Slope
Total Stress Analysis

Color	Name	Unit Weight (kN/m ³)	Cohesion (kPa)	Phi' (°)
Blue	Fill: Sand and Gravel (Compact)	21		32
Red	Fill: Silty Clay to Clay (Soft to Stiff)	20	50	
Yellow	Varved Silty Clay (Very Soft to Soft)	18	18	

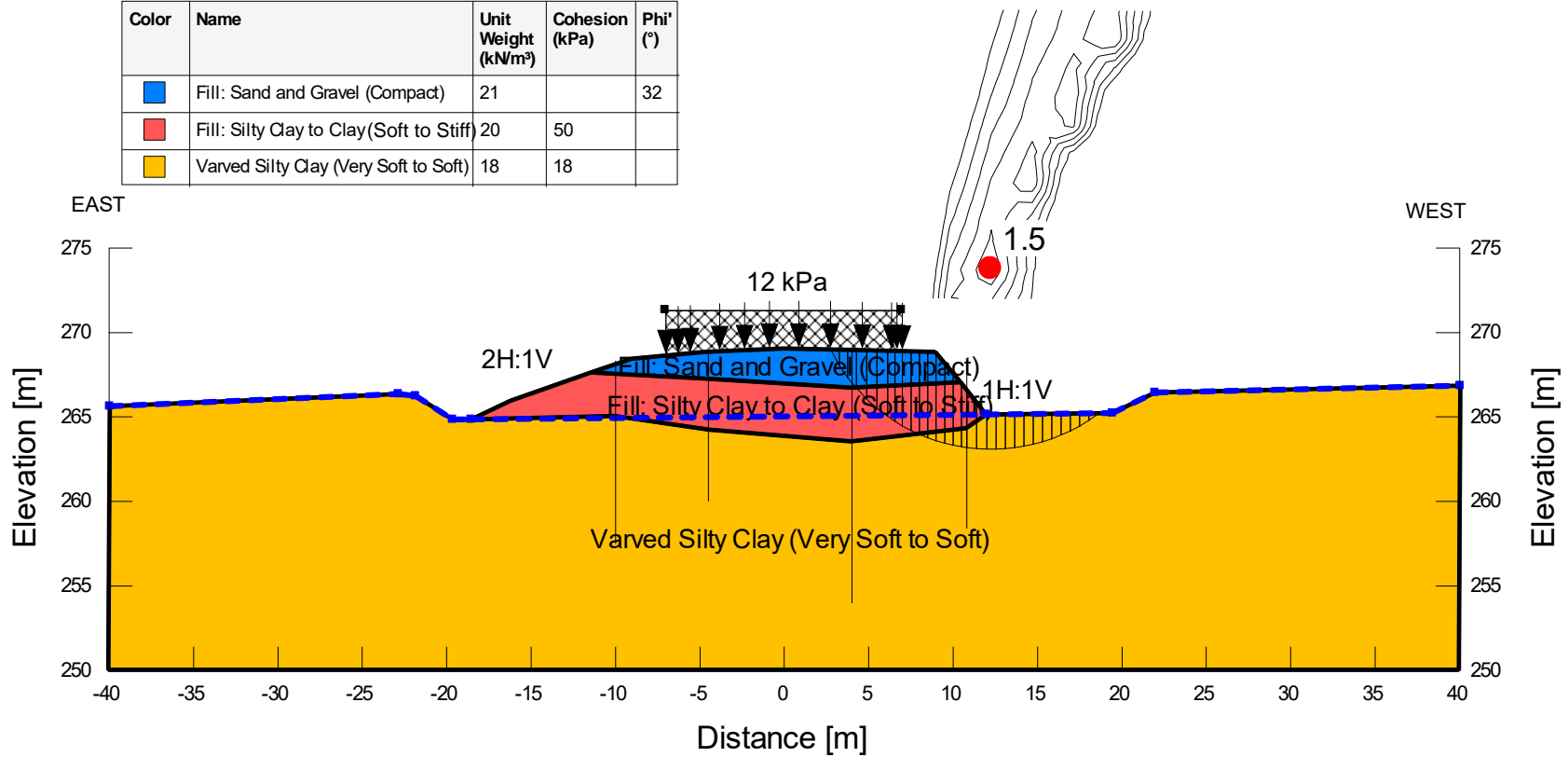


Fig. 16

Culvert CV20+832.5
East Embankment Permanent Slope
Total Stress Analysis

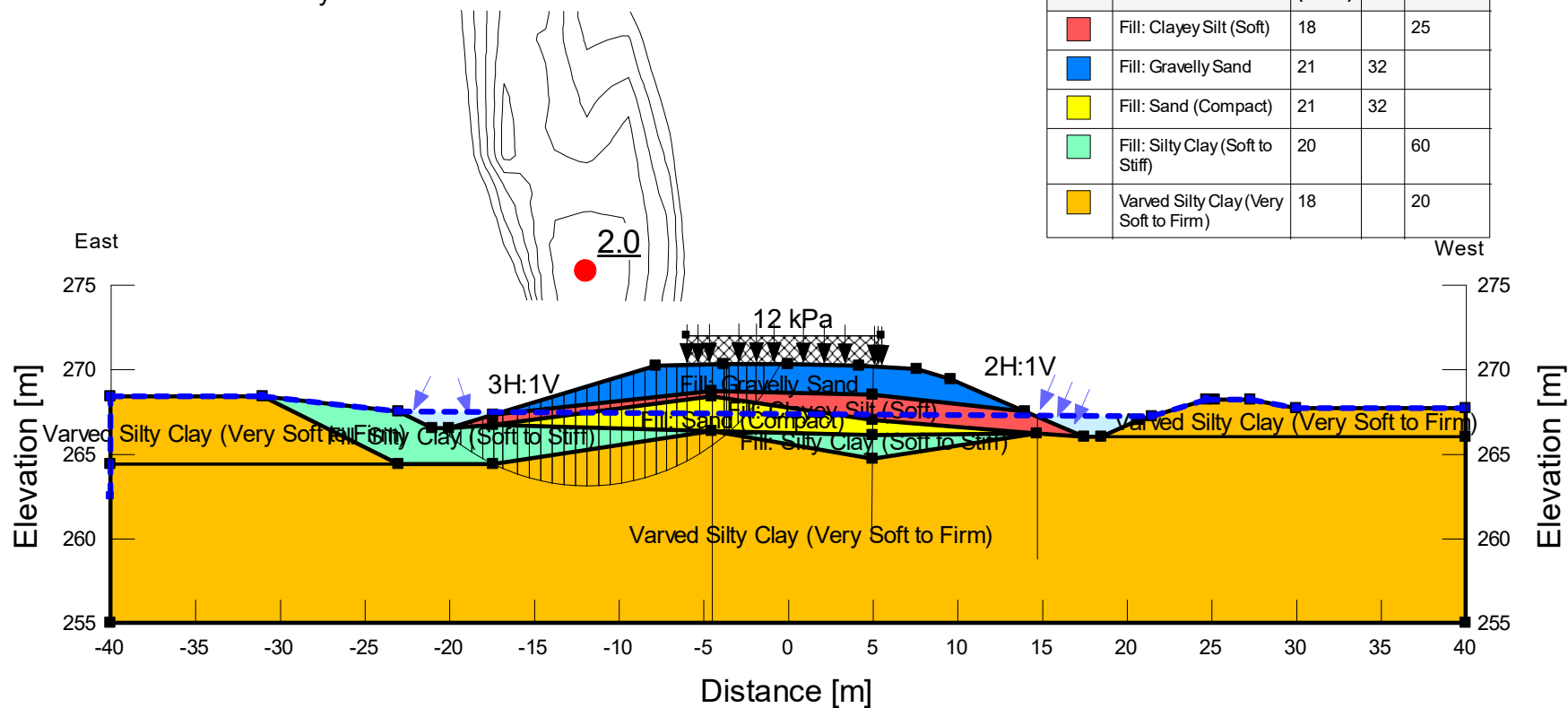







Fig. 17

Fig. 18

Color	Name	Unit Weight (kNm³)	Phi' (°)
	Fill: Clayey Silt (Soft)	18	24
	Fill: Gravelly Sand	21	32
	Fill: Sand (Compact)	21	32
	Fill: Silty Clay (Soft to Stiff)	20	30
	Varved Silty Clay (Very Soft to Firm)	18	23

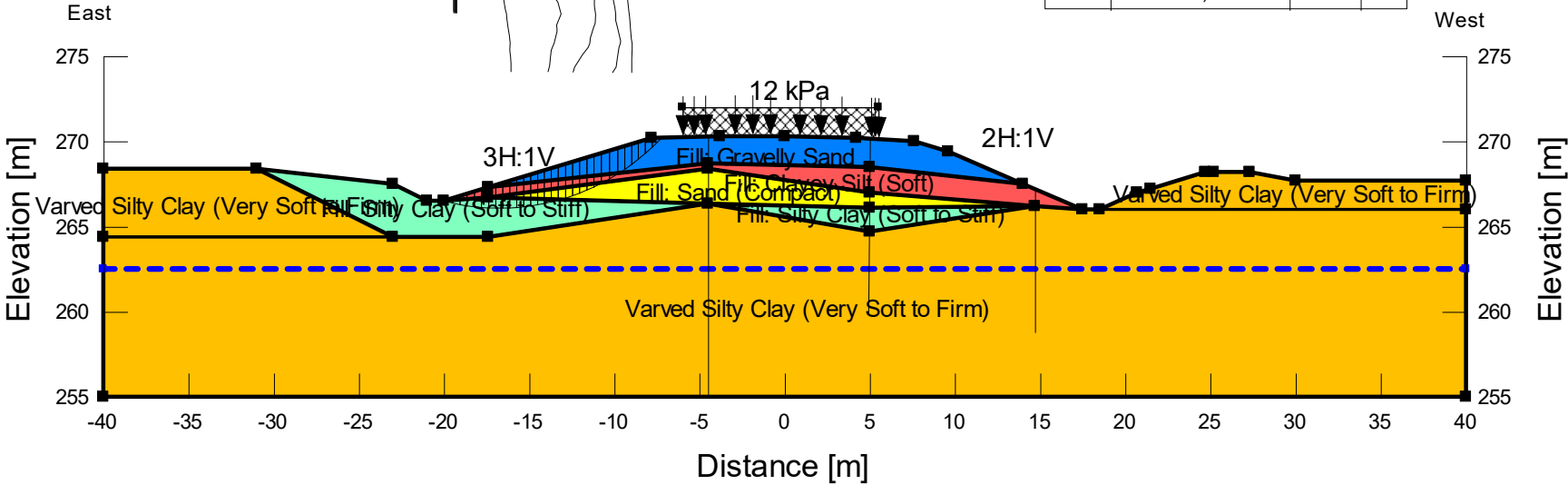


Fig. 19

Culvert CV20+832.5
West Embankment Permanent Slope
Total Stress Analysis

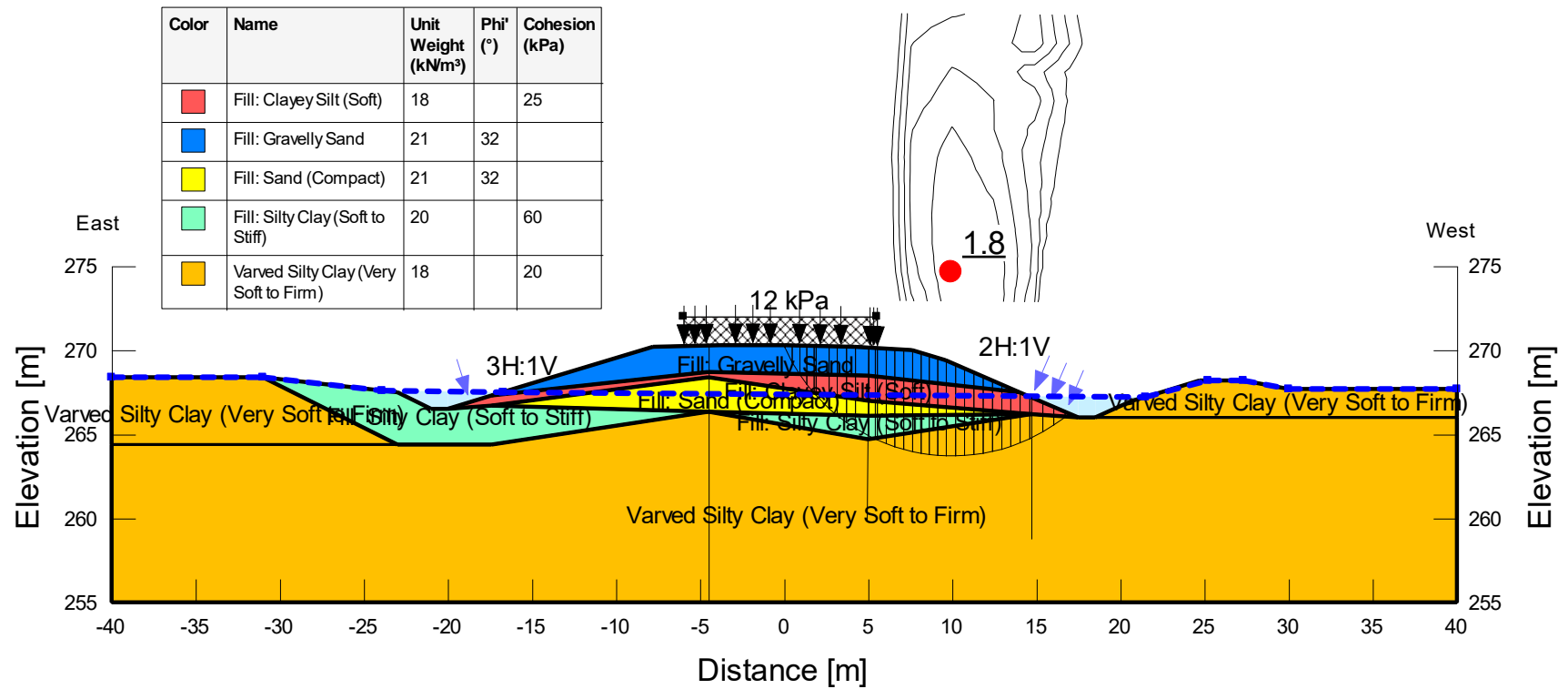


Fig. 20

Culvert CV20+832.5
West Embankment Permanent Slope
Effective Stress Analysis

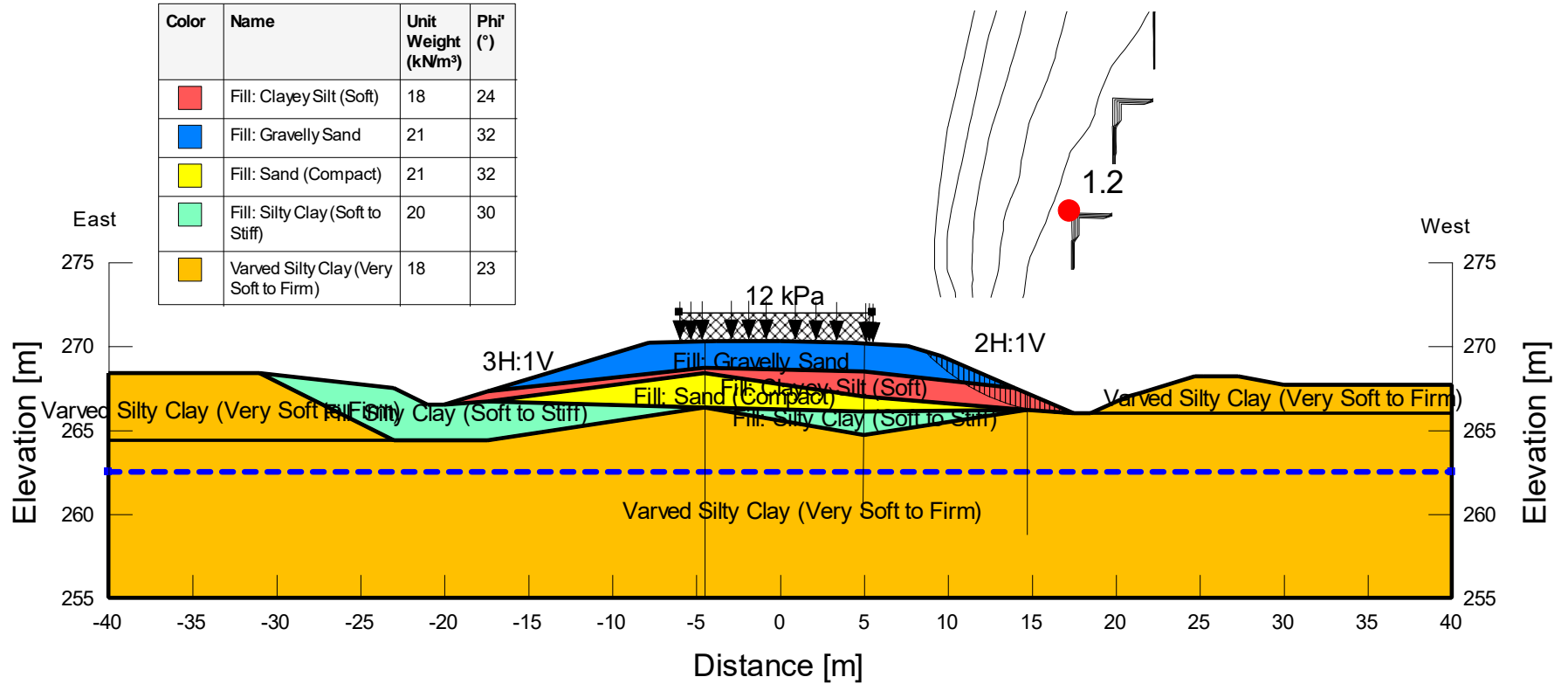


Fig. 21

Culvert CV20+832.5
West Embankment Permanent Slope
Effective Stress Analysis

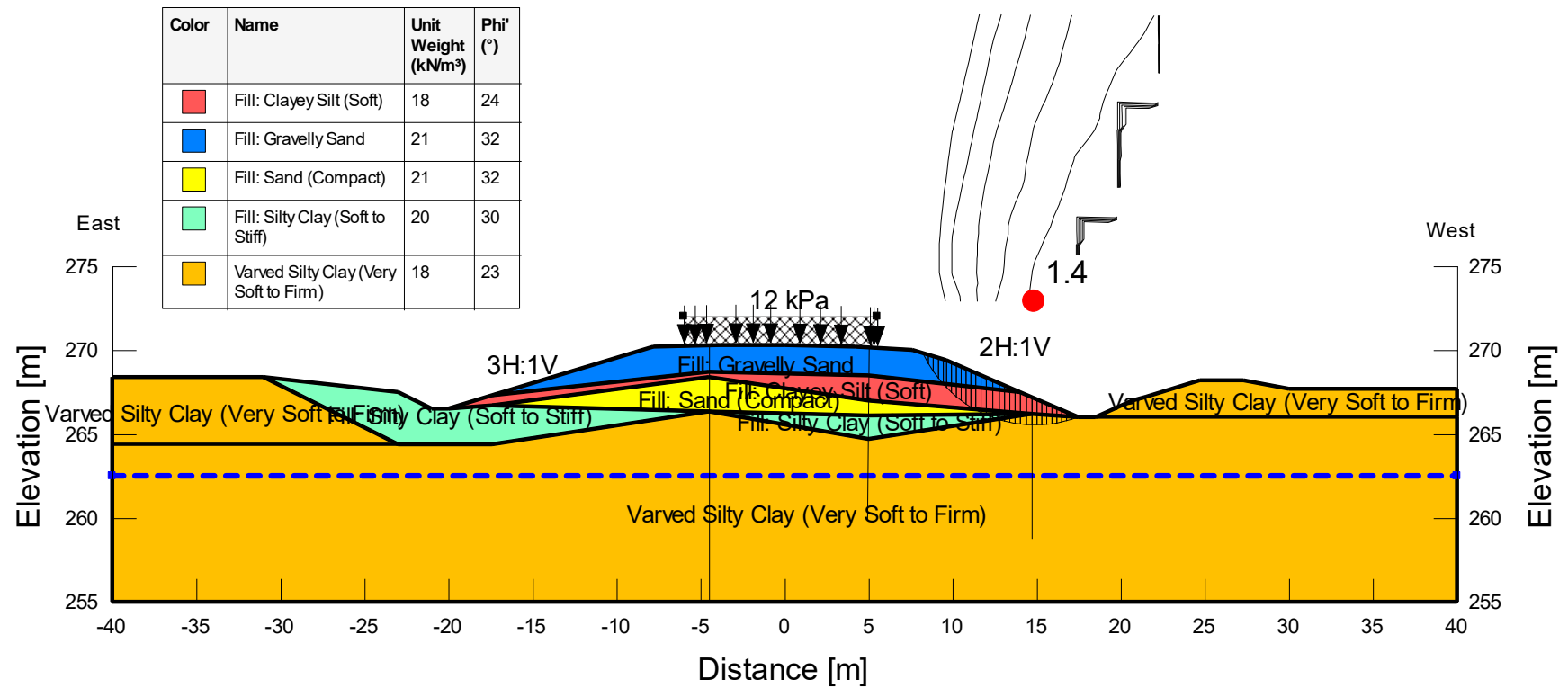


Fig. 22

Culvert CV20+832.5
 Temporary Cut Slope
 Total Stress Analysis

Color	Name	Unit Weight (kN/m ³)	Phi°	Cohesion (kPa)
Red	Fill: Clayey Silt (Soft)	18		25
Blue	Fill: Gravelly Sand	21	32	
Yellow	Fill: Sand (Compact)	21	32	
Green	Fill: Silty Clay (Soft to Stiff)	20		60
Orange	Varved Silty Clay (Very Soft to Firm)	18		20

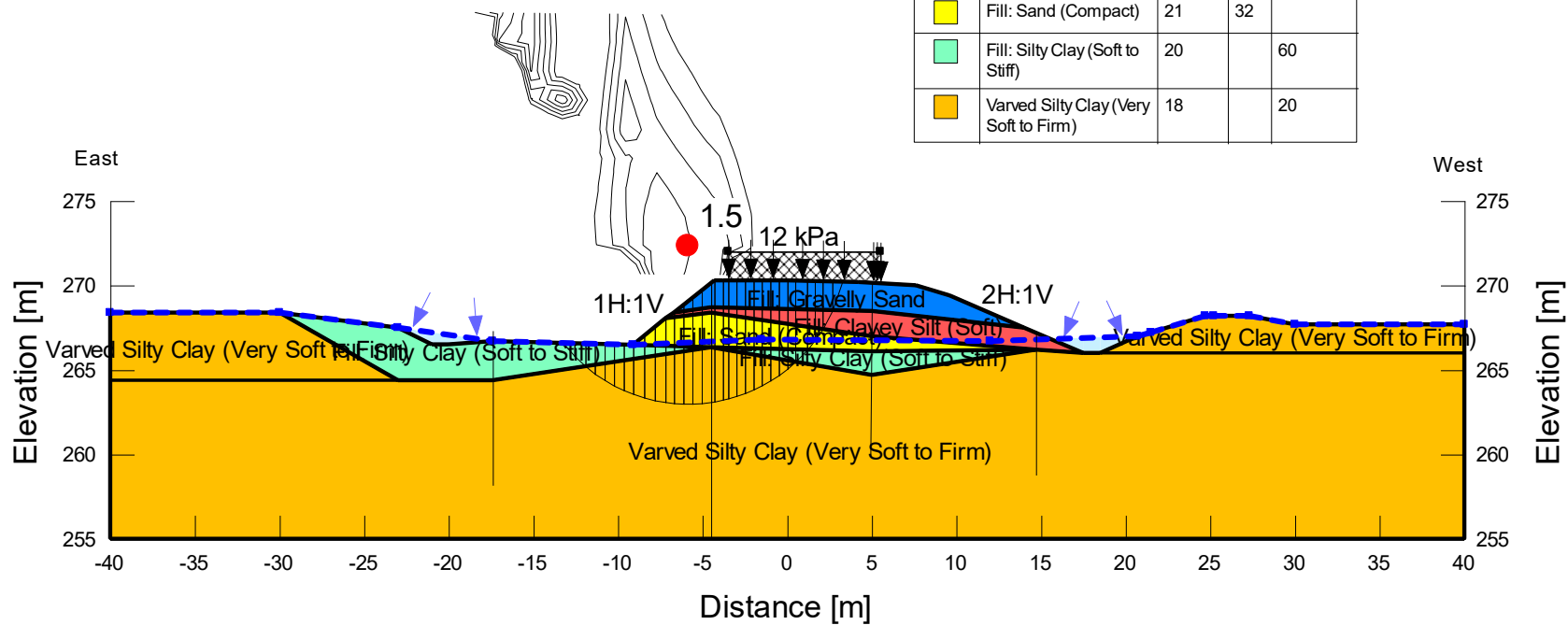
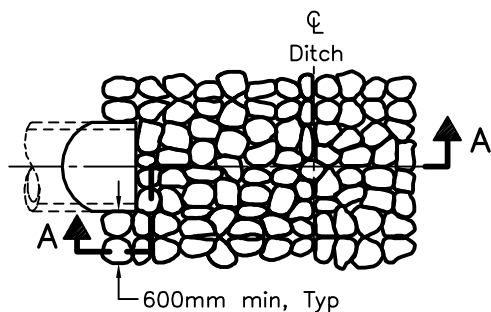
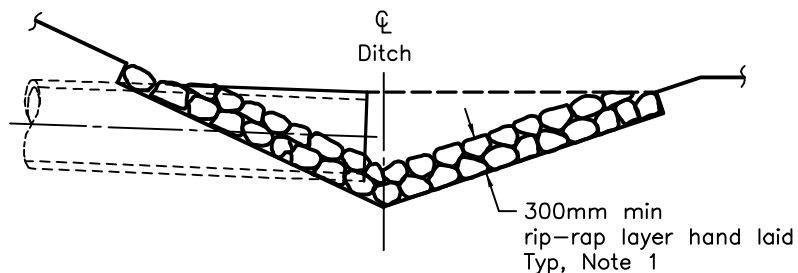


Fig. 23

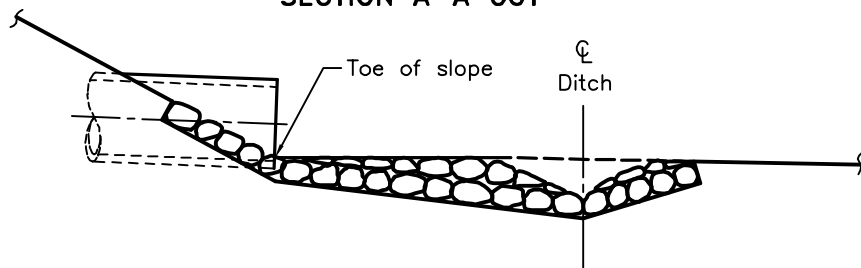
Appendix F – OPSD



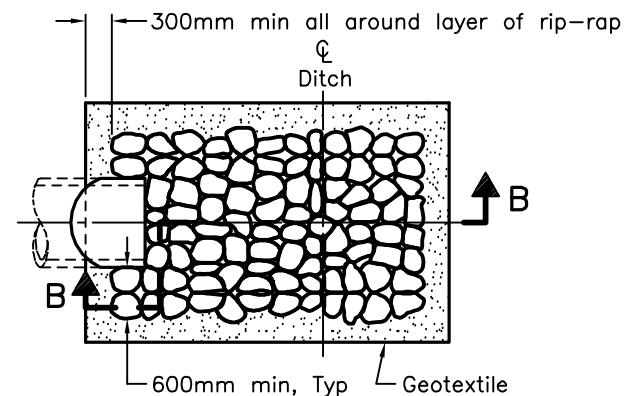
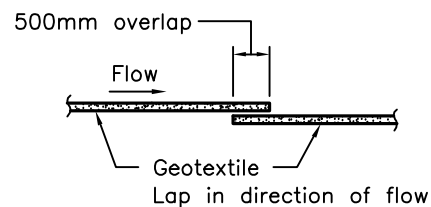
PLAN
CUT OR FILL



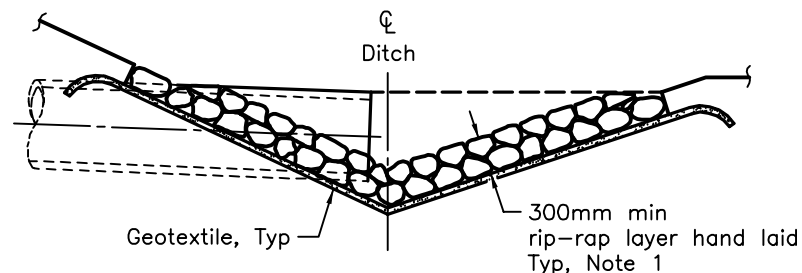
SECTION A-A CUT



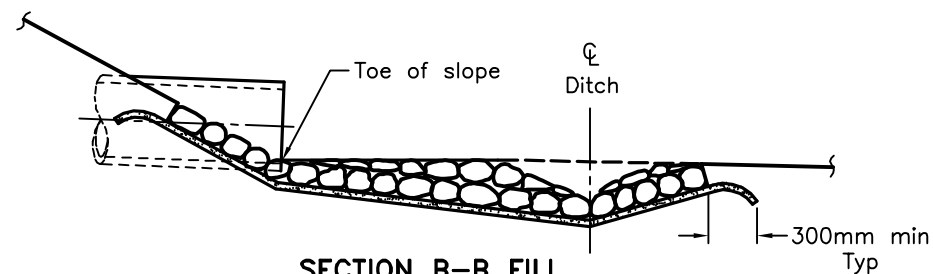
SECTION A-A FILL
TYPE A – WITHOUT GEOTEXTILE



PLAN
CUT OR FILL



SECTION B-B CUT



SECTION B-B FILL
TYPE B – WITH GEOTEXTILE

NOTES:

1 The thickness of the rip-rap layer shall be at least 1.5 times the rip-rap mean diameter.

A All dimensions are in millimetres unless otherwise shown.

ONTARIO PROVINCIAL STANDARD DRAWING

Nov 2013

Rev 2

**GENERAL RIP-RAP LAYOUT
FOR SEWER AND CULVERT OUTLETS**

OPSD 810.010

