Ontario

Ontario Ministry of Transportation (MTO) Guideline for Foundation Engineering Services Version 3.0

April 2022

NOTICE TO USER

This guideline is intended for the approved consultants (the Service Provider) in MTO's consultant acquisition system, "Registry, Appraisal and Qualification System (RAQS)" in low, medium and high complexity for Foundation Engineering.

The Service Provider undertaking a MTO Foundation Engineering assignment must refer to project Terms of Reference (TOR) for project scope details and required services to successfully complete all the necessary tasks and that all MTO Foundation Engineering requirements are met. The minimum requirements for Foundation Engineering specified in project TOR shall govern where any conflict exist with this Guideline.

MTO Foundation Office is the custodian for this guideline. This guideline may be amended by the MTO Foundation Office in the future as required to maintain and ensure quality of Foundation Engineering services for MTO projects.

Table of Contents

1 INTRODUCTION

This guideline specifies Ontario Ministry of Transportation (MTO) minimum requirements for Foundation Engineering services and deliverables for the following specialties:

- Geotechnical (Structures and Embankments) Specialty
- Tunnelling Specialty
- Hydrogeological Specialty
- Rock Engineering Specialty

Foundation Engineering specialty listings and detailed description of specialties and complexity levels may be viewed from MTO's consultant acquisition system, "Registry, Appraisal and Qualification System (RAQS)": https://discover.merx.com/mto-raqs-esp-resources/

The purpose of the guideline is to establish the requirements for foundation investigation, engineering and reporting for temporary and permanent structure foundations and related earth/rock works and to ensure consistent application across the province.

The nature and scope of a foundation investigation and design must reflect the project specific conditions and requirements. It is impractical to provide guidelines that cover every possible situation for all project types. Consequently, this guideline is intended to be generic.

As this guideline illustrates the typical minimum requirements, the Service Provider undertaking the Foundation Engineering assignment must refer to project Terms of Reference (TOR) for project specific requirements and to employ sound engineering judgement to successfully complete all the necessary tasks.

2 BACKGROUND

The Service Provider shall undertake a background study to assess existing subsurface investigation data. A site visit should be considered depending on the complexity of the project to assess the nature of the terrain and performance of the existing structures and/or roads.

The background study shall include, but not limited to, reviewing the available geological, information, aerial photographs and the performance of existing facilities, structures and/or roads.

Existing subsurface investigation data (i.e. boreholes logs or other relevant data) available from previous studies shall be reviewed and may be used to supplement the proposed new boreholes provided that the data meets the Minimum Requirements for Site Investigation, Field Testing and Engineering Materials Testing and Evaluation in the Terms of Reference (TOR). The existing subsurface investigation data used in the project shall be provided as per the requirement in sections entitled Borehole Log Records and Foundation Drawings.

If the Service Provider proposes to use existing subsurface investigation data to satisfy the TOR, the Service Provider must submit sufficient documentation to demonstrate that the existing subsurface investigation data comply with the requirements in the TOR in the Technical Proposal.

Information from past foundation investigations in the MTO Foundation database may be viewed from the following sources:

- Foundation Library (Web-Based): http://www.mto.gov.on.ca/FoundationLibrary/index.shtml

3 PROJECT INITIATION

The Service Provider shall address all requirements, quality control (QC) documentation, permits and approvals for site access and investigation, traffic protection and health and safety under project initiation. The requirements and quality control documentation under project initiation are generally as follows:

- Supplementary QC Plan
- QC Checklist
- Health and Safety Plan (Project Specific)
- Guidance on supervisor's role, field level
- Hazard assessments, daily check-in procedures)
- Underground Utility and Service Clearances
- Traffic Protection Plan (Ontario Traffic Manual Book 7)
- Notice of Project Form and Form 1000
- Ministry of Labour- Registration of Constructors and Employers Engaged in Construction
- Road Occupancy and/or MTO Encroachment Permits
- Right of Way Usage and/or Closure Notifications Forms
- Environmental Protection Plan
- Endangered Species Act and Species at Risk (S.A.R.)
- Migratory Bird Convention Act
- Fisheries and Oceans Canada (D.F.O.)
- Permission-To-Enter (PTEs)

3.1 Permits and Approvals for Site Access and Investigation

The Service Provider shall ensure that all required permits and approvals to proceed with the foundation field investigations are obtained prior to any works carried out, including:

- Permits associated with specific investigation activities such as those related to Ministry of Labour/constructor permits;
- Environmental related permits, such as navigable waterways, fish habitats and water quality;
- Permission to enter private or municipality properties or Railway Right-of-Way (ROW) in writing from the property owner; and
- Utilities locate and clearance.

When obtaining permission, the Service Provider shall inform the property owner of the full impacts of the site investigation on the property, including any temporary and permanent damage to vegetation.

3.2 Traffic Protection and Health and Safety

Traffic protection shall be provided to MTO requirements during the course of any site investigations. The Service Provider shall comply with the Ontario Traffic Manual Book 7 - Temporary Conditions and all signing shall be in accordance with Ontario Traffic Manual.

Fieldwork shall be carried out in accordance with the Occupational Health and Safety Act and MTO Occupational Health and Safety Field Guide for Engineering Functions.

For works carried out within Railway ROW, the Service Provider shall contact Railway Authorities regarding the safety training requirement to work within Railway ROW.

For all site investigations, the Service Provider shall submit a Lane and Ramp Closure Notification Form to the appropriate MTO Communication Centre at least 48 hours prior to commencing field investigations. This provides sufficient lead time to confirm no conflicting operations and to post notice of the work for the travelling public.

The Service Provider is responsible to confirm with Ministry staff that there are no adjacent service provider investigation or construction operations occurring in the area of any individual assignment area prior to the submission of the Scheduled Work Lane and Ramp Closure Notification Form to the Ministry Regional Office.

The Service Provider shall coordinate the work with other Service Providers or Contractors within and/or adjacent to the individual assignment such that work not be performed in the same area at the same time, or adversely affect each other's work.

The Service Provider shall provide that adequate separation of time and/or distance is maintained between the operation included in each individual assignment and work within and/or adjacent to each individual assignment done by others. When requested, the Service Provider shall provide a written submission explaining how the work with other Service Providers and/or Contractors will be coordinated to the Ministry representative that ordered the assignment.

When directed, the Service Provider shall remove all equipment, vehicles, and staff from the pavement and shoulders when seasonal maintenance operations such as snow plowing, grading, etc. is expected, or when inclement weather conditions are anticipated and/or encountered.

The Service Provider is responsible for roadside safety when performing work and shall adhere to the following work constraints:

- Site investigation operations shall be carried out in such a manner as to minimize disruptions to highway operations;
- All vehicles used by the Service Provider must be equipped with vehicle-mounted 360 degrees amber light; and
- Site investigation operations adversely affecting public traffic (i.e. lane restrictions) and the loading or unloading of materials and equipment onto and from the travelled portion of the highway and the shoulders shall be carried out in a safe manner as directed and within the hourly restrictions as specified for each assignment.

If the Service Provider fails to comply with any of the above conditions, or the Occupational Health and Safety Act (OHSA) or its regulations and poses an **immediate danger** to the health or safety of a worker or the public, the Ministry will order the Service Provider to immediately cease all operations. The Service Provider shall then remove itself and any traffic control devices from the highway. The Service Provider will not be allowed to regain access to the site until the Service Provider demonstrates that it is able to conform to the requirements of this section and provides written notification to the Ministry outlining how the situation has been rectified and requesting permission to recommence work at no additional cost to the Ministry.

Immediate danger is defined as a violation of the OHSA or its regulations where the violation poses a danger and any delay in stopping the work may result in a serious injury to a worker or the public. A situation of insufficient traffic control may pose an immediate danger.

4 FIELD INVESTIGATION AND TESTING

4.1 General

The Service Provider shall conduct field investigations and testing of sufficient scope to determine a level of understanding of the subsurface and groundwater conditions, to verify design assumptions and to provide sufficient factual subsurface information (stratigraphical model of the vertical and horizontal extent and their pertinent engineering properties) to the Construction Contractor or Consortium to plan construction of all foundation works.

4.2 Minimum Exploration Requirements – Location, Number and Depth

For the purposes of this guideline, explorations are defined as methods of retrieving soil/rock samples and facilitating in situ testing. Explorations include boreholes (BH), dynamic cone penetration tests (DCPT), cone penetrometer test with pore pressure dissipation measurements (CPTU) and/or test pits (TP). In appropriate cases, CPTU tests may be substituted for up to 25 percent of boreholes. Geophysical methods may be used to supplement minimum exploration requirements for the purpose of subsoil investigation.

Minimum number of boreholes, location and depth of exploration for each foundation item are provided in **Table 1**. The Service Provider must refer to project-specific TOR for supplementary requirements and any additional directions regarding the location, number and depth of explorations considered appropriate for the project.

Where no existing subsurface information is available, the Foundations Engineering Service Provider shall assume exploration depths will not exceed 30 m. Where competent stratum is not reached within 30m, additional boring shall be negotiated with MTO as extra work prior to being carried out. The Service Provider shall not proceed with the work unless approval is provided to conduct the exploration beyond the 30 m depth.

Refusal is defined by material for which the resistance measured by the Standard Penetration Test (SPT) exceeds 100 blows per 0.3 m of penetration.

For the design of structure foundations and embankments, boreholes shall extend to refusal or to a competent stratum that will permit an economical foundation design based on sound engineering judgement.

Boreholes and any explorations shall be drilled and installed with due regard for the subsurface environment, protection of groundwater resources from surface contamination, and prevention of aquifer cross-connection and cross-contamination in accordance with Ontario Ministry of the Environment, Conservation and Parks (MECP) requirements/guidelines.

Explorations shall be strategically located and advanced within the foundation plan extent to define subsurface conditions for the foundation elements.

Dual purpose boreholes are allowed in order to meet these minimum requirements.

Where possible, explorations shall be located to minimize disruption to traffic, environmentally sensitive areas and not to interfere with private property.

If location criteria cannot be met due to any restrictions (e.g. traffic, access, obstructions from existing structures and utilities), the Service Provider may propose an alternate borehole program that provides equivalent borehole coverage with explanation in the proposal. If changes to the borehole locations are required during field investigation, the Service Provider shall consult with MTO Foundations Office prior to implementing the changes.

Table 1. Minimum Exploration Requirements – Location, Number and Depth

Items		Location, Number and Depth of Exploration
Bridge	Foundation Element	<u>New/Replace</u> • 2 BHs at each foundation element advancing to a minimum of 3 m below refusal. • If bedrock is encountered, a minimum of 50% of explorations shall be cored for a minimum depth of 3 m. • For shallow foundations, if igneous or metamorphic bedrock is encountered at shallow depth, 5 BHs/TPs (center and 4 corners of the footing) are required within the shallow foundation zone. All BHs shall be cored for a minimum depth of 3 m. <u>Widen</u> • 1 BH at each widened side of foundation element advancing to a minimum of 3m below refusal. • If bedrock is encountered, BH shall be cored for a minimum depth of 3 m. <u>Temporary Bridge</u> • 1 exploration (BHs/TPs) at each foundation element advancing to a minimum of 3 m below refusal. • If bedrock is encountered, BH shall be cored for a minimum depth of 3 m. <u>Re-Use of Existing Foundation</u> • 1 BH at each foundation element advancing to a minimum of 3 m below refusal. • If bedrock is encountered, BH shall be cored for a minimum depth of 3 m. <u>Rehabilitation</u> • Bridge rehabilitation projects may necessitate foundation engineering services. Requirements for field investigation for bridge rehabilitation, if required, are addressed in project specific TOR.
	Approach Embankment	• 1 BH at each bridge approach embankment within 20 m of the abutment, advancing to 3 m into a competent stratum or 10 m below the base of the fill or 6 m below the base of the cut, whichever is less. • If bedrock is encountered, no coring is required.
Retaining Wall Structure		• BHs shall be placed at a maximum of 50 m spacing. • 1 BH at each end of the retaining structure. • BHs shall be advanced to 3 m into a competent stratum or 10 m below the base of the wall, whichever is less. • If bedrock is encountered, bedrock shall be cored for a minimum depth of 3 m.

Items	Location, Number and Depth of Exploration
Retaining Soil Structure (RSS)	<u>Location and Spacing</u> • BHs shall be located along the proposed wall facing, retained soil zone area (behind facing) and fore-slope area (in front of facing). • BHs shall be advanced at each end of the RSS wall and at a maximum longitudinal spacing of 50 m. • If soft compressible soils and/or organics (swamp) are known to exist or are encountered during the investigation, maximum longitudinal spacing shall be reduced to 25 m. • BHs for the retained soil zone area shall be located within 1.5H offset behind the wall facing, where H = proposed RSS wall height. • BHs for the fore-slope area shall be located within 0.75H offset in front of the wall facing. <u>Depth</u> • BHs along the wall facing and retained soil zone area shall be advanced to a target minimum depth of 2H or 10 m below the proposed base of RSS, whichever is greater, unless bedrock or very dense / hard soils is encountered at shallower depth. • BHs along the fore-slope area shall be advanced to a target minimum depth of H. • BHs shall be advanced to refusal or 3 m into a competent stratum that will provide sufficient geotechnical bearing resistance for the RSS foundation.
Culvert	<u>New/Replacement</u> • 1 BH at each end of the culvert (i.e. inlet and outlet) • Minimum of 1 BH at the embankment crest. • BHs shall be placed at a maximum of 25 m spacing. • BHs shall be advanced to a minimum of 10 m below culvert invert or to refusal, whichever is less. • If bedrock is encountered, bedrock shall be cored for a minimum depth of 3 m. <u>Extension</u> • 1 BH at the extended end and 1 BH at the crest of the embankment of the extended side. • BHs shall be advanced to a minimum of 10 m below culvert invert or to refusal, whichever is less. • If bedrock is encountered, bedrock shall be cored for a minimum depth of 3 m.
Deep Cut and High Fill Embankment (> 4.5 m in height)	<u>New Alignment</u> • BHs shall be placed along the proposed embankment alignment at a maximum of 50 m spacing. • 1 BH at each end of proposed embankment alignment. • BHs shall be advanced 3 m into a competent stratum or 10 m below the base of the fill or 6 m below the base of the cut, whichever is less. • If bedrock is encountered, no coring is required. • CPTU tests can be substitute for BH’s for up to 25 percent of the boreholes. <u>Widening</u> • BHs shall be placed at the crest of existing embankment and between the toes of the existing and widened embankments, alternating at a maximum of 50 m spacing. • 1 BH at each end of widened side of alignment. • BHs shall be advanced 3 m into a competent stratum or 10 m below the base of the fill or 6 m below the base of the cut, whichever is less. • If bedrock is encountered, no coring is required. • CPTU tests can be substitute for BH’s for up to 25 percent of the boreholes.

Items	Location, Number and Depth of Exploration
High Fill Embankment on Very Soft to Firm Soils (> 4.5 m in height)	<u>Primary Exploration</u> • 1 BH at each end of the centreline of embankment fill footprint. • BHs shall be placed along the centreline at a maximum of 50 m spacing • BHs shall be advanced to a minimum of 3 m into competent stratum • Relatively undisturbed soil samples shall be retrieved using piston samplers or equivalent • In situ vane testing using the MTO 'N' Vane shall be carried out between soil samples per BH • Continuous vane testing using the MTO 'N' Vane shall be carried out at two BH locations adjacent to the original BH. Vane testing is not required in the original borehole where samples are being retrieved. <u>Secondary Exploration/In situ Testing</u> • Secondary explorations at mid-points between primary exploration locations shall include CPTU that includes dissipation tests to compute hydraulic conductivities and coefficients of consolidation and subsurface characterization. • Secondary explorations shall be staggered at the mid points such that one CPTU is advanced sequentially to the left and right respectively
Swamp Crossing	<u>Primary Exploration</u> • 1 BH at each end of the centreline of swamp crossing • If swamp crossing length ≤ 250 m, BHs shall be placed along the centreline at a maximum of 25 m spacing. • If swamp crossing length > 250 m, BHs shall be placed along the centreline at a maximum of 50 m spacing. • BHs shall be advanced to a minimum of 3 m into competent stratum. • In-situ vane testing using the MTO 'N' Vane shall be carried out between soil samples per BH. • Continuous vane testing using the MTO 'N' Vane shall be carried out at two BH locations adjacent to the original BH. Vane testing is not required in the original borehole where samples are being retrieved. <u>Secondary Exploration</u> • Secondary explorations shall be placed along the embankment toes at the mid-points between primary exploration locations. • 1 BH at one side of embankment toe and 1 dynamic cone penetration test (DCPT) or Auger probes at the other side of embankment toe. BH and DCPT shall be staggered. • BH and DCPT/Auger probes shall be advanced to a minimum of 3m into competent stratum. • CPTU that includes dissipation tests to compute hydraulic conductivities and coefficients of consolidation and subsurface characterization shall be conducted as a substitute for boreholes at 25 percent of the BH locations. • Secondary explorations shall be staggered at the mid points such that one CPTU is advanced sequentially to the left and right respectively. • Test Pits shall be conducted as a substitute for 25 percent of the boreholes.
Storm Water Management Pond (SWMP)	• 4 BHs located strategically at each SWMP advancing to a competent stratum or 6 m below the base of the SWMP, whichever is less.
Temporary Protection System (TPS)	• 1 BH at each end of the TPS. • If TPS length ≤ 100 m, BHs shall be placed along the centreline at a maximum of 50 m spacing. • If TPS length > 100 m, BHs shall be placed along the centreline at a maximum of 75 m spacing. • BHs shall be advanced 3 m into a competent stratum or 10 m below the base of the excavation, whichever is less. • If bedrock is encountered, bedrock shall be cored for a minimum depth of 3 m.

Items	Location, Number and Depth of Exploration
Temporary Cofferdam	• 2 BHs at each cofferdam location advancing to a minimum depth of 10 m. • If bedrock is encountered, bedrock shall be cored for a minimum depth of 3 m.
Construction Staging Area for Rapid Replacement of Bridge/Deck	• 3 BHs located strategically at the construction staging area advancing to a minimum depth of 10 m or to a competent stratum for deep foundation alternative. • If bedrock is encountered, bedrock shall be cored for a minimum depth of 3 m.
Geotechnical Assessment of Heavy Construction Equipment (Crane Pads, Drilling Rigs, Pile Driving Equipment, etc.)	• 2 BHs located strategically within the footprint of the equipment, advancing to a minimum depth of 10 m or to a competent stratum for deep foundation alternative. • If bedrock is encountered, bedrock shall be cored for a minimum depth of 3 m. • Minimum exploration requirements specified herein are per location. Refer to project TOR for project specific exploration requirements.
Noise Barrier Wall	• BHs shall be placed along the noise barrier wall location at a maximum of 75 m spacing. • 1 BH at each end of the noise barrier wall. • BH shall be advanced to a minimum depth of 6 m below frost depth. • If bedrock is encountered, bedrock shall be cored for a minimum depth of 3 m.
High Mast Lighting (HML) and Closed-Circuit Television (CCTV) Poles	• 1 BH at each HML and CCTV pole advancing to a minimum depth of 10 m below frost depth. • If bedrock is encountered, bedrock shall be cored for a minimum depth of 3 m.
Sign Support Structure	• 1 BH at each sign structure foundation element advancing to a minimum depth of 6 m below frost depth • If bedrock is encountered, bedrock shall be cored for a minimum depth of 3 m.
Median Sewer	• 1 BH and/or TP at each end of the median sewer. • BHs and/or TP shall be placed at a maximum of 100 m spacing. • BHs and/or TP shall be advanced into a competent stratum or 3m below the base of the excavation, whichever less.
Tunnel and Trenchless Installations	• BH’s shall be advanced at a maximum 25 m spacing. • 1 vertical BH each end of tunnel at the entry/exit portals. • A minimum of 1 vertical BH shall be placed on the embankment. • All vertical BHs shall be located outside of the tunnel alignment diameter but within 2 m of the tunnel’s alignment. • BHs shall be advanced to a depth of 3x the tunnel diameter below invert. • If bedrock is encountered, bedrock shall be cored for a minimum depth of 3 m below the invert of tunnel. • BH’s between the portals and the crest of the embankment shall be carried out as specified in the Project Specifics. • Horizontal BH’s/probes shall be advanced as specified in the Project Specifics.
For Hydrogeological Study	• 3 BHs at each site to the depth specified in the Terms of Reference ‘Project Specific’
For Rock Engineering	• See Rock Engineering Section of this Guideline and Terms of Reference ‘Project Specific

For Temporary Protection System and Temporary Cofferdam, boreholes shall be extended to depth that to provide sufficient tip resistance, lateral resistance and resistance to basal heave.

For Hydrogeological Study, boreholes shall extend to the depth that can be used to determine groundwater flow direction and to obtain samples to characterize soil and/or bedrock conditions of the site. The Service Provider shall coordinate hydrogeological investigation concurrently with foundation/geotechnical investigation to maximize the fieldwork and sampling program.

Where necessary, the minimum requirements for investigations shall be supplemented as required with additional conventional or more advance explorations techniques to verify consistent conditions within critical foundation zones. Where a significant change in subsurface conditions is encountered between explorations or problematic site conditions are encountered during investigation, the Service Provider shall notify the MTO Foundations Office and the MTO Project Manager as soon as possible to determine modified and/or additional borehole requirements as additional work.

4.3 Sampling and In-Situ Testing

Sampling and in-situ testing, such as, Standard Penetration Tests (SPT), thin wall tube sampling, piston sampling, rock coring, and MTO 'N' Field Vane Test where appropriate, are minimum requirements to develop a comprehensive subsurface model.

Where appropriate and with justification, more specialized sampling and testing methods may be utilized by the Service Provider or may be requested in project specific TOR, such as other field vanes, dynamic cone tests, piezocone penetration tests (CPTU), pressure-meter testing, dilatometer testing, test pits, soundings and/or geophysical methods.

For typical subsurface investigation sampling/testing at 0.75 m (2.5 ft) intervals is required within critical foundation zones for structures. The maximum sampling interval shall be 1.5 m (5 ft) to a depth 20 m and 3 m (10 ft) beyond 20 m.

For high fill on very soft to firm cohesive deposits (>4.5 m in height), sampling shall include use of a fixed end piston sampler (in accordance with ASTM D6519) to obtain relatively undisturbed soil samples for complex laboratory testing. Within the cohesive deposits, a nearly continuous determination of the undrained shear strength profiles shall be carried out. This undrained shear strength profile shall be determined by advancing a series of field vane tests within the deposit. A series of two field vane tests shall be taken following each standard penetration test within any cohesive deposit. The testing shall be spaced 0.75 m increments throughout the entire cohesive deposit (i.e. testing within a cohesive deposit would be Standard Penetration Test at 0.75 m depth, field vane at 1.5 m depth, field vane at 2.25 m depth, Standard Penetration Test at 3.0 m depth, field vane at 3.75 m depth etc.).

Determination of the remolded shear strength and soil sensitivity shall be carried out during each field vane test.

For tunnel and trenchless installation, sampling at 0.75 m (2.5 ft) intervals is required. From one tunnel diameter above obvert to one diameter below invert of the proposed tunnel/trenchless crossing, continuous sampling shall be carried out.

The Service Provider shall retain samples for a period of one (1) year after completion of the design assignment unless otherwise advised in writing by the MTO**.**

The rock classification shall present the Rock Quality Designation (RQD) and Rock Mass Rating (RMR) classification or equivalent. Bedrock should be described in detail including geological classification, weathering state, bedding thickness, joint and foliation spacing, grain size, hardness and abrasiveness of the intact rock, discontinuity and strength, utilizing a lithological and geotechnical rock description terminologies.

4.4 Groundwater Investigation

Groundwater investigation is required to select appropriate foundation design and determine need for groundwater control. Groundwater levels shall be determined by open borehole observation, standpipe piezometer, and/or vibrating wire piezometer.

If groundwater is encountered, sufficient factual information is required to determine groundwater conditions, including perched groundwater levels, stabilized groundwater level at the time of investigation, the location of aquifers, the location and characteristics of any artesian groundwater, the quantity and direction of groundwater flow, and the observation of any natural gas or chemicals dissolved in groundwater or surface water which might prove harmful to structures and/or to personnel engaged in construction of the project.

Per project site, a minimum two (2) monitoring wells shall be installed for groundwater investigation. Only one monitoring well shall be installed at each borehole location. If required, nested monitoring wells shall be installed (in separate boreholes) to allow assessment of vertical gradients.

The Service Provider shall refer to project specific TOR for any supplementary requirements and directions regarding additional investigations such as instructions on monitoring well installation, minimum number of readings, pump tests, hydraulic conductivity testing in overburden and/or bedrock and chemical testing of groundwater.

Borehole permeability tests, pumping tests, slug tests and other procedures, shall be carried out as per project specific TOR to measure the hydraulic parameters of the aquifer(s) and in-situ permeability of geologic materials at the site. The tests shall conform to the applicable standards/requirements such as ASTM D 2434 “Permeability of Granular Soils by Constant Head Method”.

All monitoring wells installed at the site must be constructed in accordance with Ontario Regulation 903 as amended. They will be used in the detailed groundwater impact mitigation design. Specifically, as a minimum, all monitoring wells with the exception of the larger diameter pumping well (which shall be a minimum of 150 mm diameter) shall consist of 50 mm diameter, schedule 40 flush threaded PVC casing, and #10 slot PVC screen, or equivalent. The PVC casing shall extend to above ground surface and protected with a lockable steel protective casing. The appropriate sand filter materials shall be used around the PVC screen and bentonite seals shall be installed to prevent vertical migration of groundwater through confining layers or between aquifer systems.

If specified as per project specific TOR, groundwater sampling in selected monitoring wells shall be collected, in accordance with Ontario Ministry of the Environment, Conservation and Parks (MECP) requirements/guidelines, to establish the groundwater quality.

4.5 Decommissioning

All aspects of implementation of foundation engineering test holes including, but not limited to, planning, licensing, construction, maintenance, abandonment, and reporting, shall be in accordance with MECP Regulation 903 as amended (the water well regulation under the OWRA).

Explorations shall be constructed, maintained and abandoned, or otherwise restored, to ensure the safety and environmental integrity of the site. Amongst other requirements, test holes and piezometer tubes shall be backfilled with a suitable bentonite/cement mixture. Test pits shall be backfilled with suitable material and re-vegetated or otherwise protected from erosion. Temporary open holes shall be adequately covered. Holes in roads shall be backfilled as required to prevent future settlement and acceptably patched where pavement surfaces have been damaged. Backfilling procedures shall be described in the Foundation Investigation Report.

Where encountered, artesian groundwater conditions shall be sealed at their source. Full details of the artesian condition and the sealing operation shall be included in the Investigation Report.

The Service Provider shall protect utilities and property from damage and restore the site as near to original conditions as practical. If damage is not restorable, the Service Provider shall submit property damage reports to the Ministry.

Project specific TOR may preclude decommissioning requirements.

4.6 Surveying

The location and elevation of all boreholes, test pits, and soundings shall be surveyed and referred to the following horizontal and vertical datum:

- Horizontal Datum: North American Datum 1983 NAD83 (CSRS) v6 (2010 epoch)
    - Northing and Easting Grid Coordinates in metres, in the 3° Modified Transverse Mercator (MTM) projection (corresponding zone shall be indicated), reported to a precision of one (1) decimal place
    - Latitude and Longitude Geographic Coordinates in decimal degrees reported to a precision of six (6) decimal places
- Vertical Datum: Canadian Geodetic Vertical Datum (CGVD) 1928
    - Elevation in metres reported to one (1) decimal place

The vertical accuracy of survey readings shall be within 0.1 m. Horizontal accuracy shall be within 0.5 m.

5 ENGINEERING MATERIALS TESTING AND EVALUATION

5.1 General

Engineering Materials Testing (Laboratory Testing) shall be carried out to:

- Verify strata boundaries;
- Determine soil and bedrock properties and behaviour of critical subsurface zones, and
- Determine the chemical content in soil that may deteriorate concrete or corrode steel/metal which used in foundations or buried infrastructures.

5.2 Routine Laboratory Testing

A routine laboratory test includes natural water content, Atterberg Limits, and grain size distribution analyses. Routine laboratory testing shall be conducted on a minimum 25% of samples, representative of the subsoil.

5.3 Complex Laboratory Testing

Complex laboratory testing includes unconfined compression tests, unconsolidated-undrained triaxial compression tests, consolidated-drained triaxial compression tests, one-dimensional consolidation tests using increment loading and/or controlled-strain loading, consolidation creep tests and shear box tests. Sufficient number of tests shall be carried out for design purposes. If soft compressible soils are anticipated and/or encountered, complex laboratory testing shall be carried out.

Specific complex laboratory testing requirements may be required as per project specific TOR.

5.4 Soil Chemical Laboratory Testing

A soil chemical test includes pH, water soluble sulphate, sulphide, chloride, resistivity and electrical conductivity analyses. For bridges, culverts, high mast lighting poles and sign structures, a minimum of one (1) soil chemical test shall be conducted on each foundation element. For retaining structures, tunnel and trenchless installations, and noise barrier walls, a minimum of one (1) soil chemical test shall be conducted at maximum of 100 m spacing.

5.5 Laboratory Testing for Bedrock

Unconfined compressive strength (UCS) testing should be carried out on select core samples for foundation design. A minimum of one (1) UCS testing shall be carried out per foundation element. Service provider shall refer to project specific TOR for additional bedrock laboratory testing requirements.

Additional testing, such as Point Load Strength Index, Joint Shear Strength, Hardness and Abrasiveness tests may be required as per project specific TOR.

5.6 Laboratory Testing for Organic Soils

Routine laboratory testing for organic soils shall include water content, sieve and hydrometer analysis, Atterberg Limits, specific gravity and organic content.

Peat specific testing may include:

- Fibers content as per ASTM D1997;
- Degree of decomposition as per ASTM D5715;

- Pore fluid extract and pH as per ASTM D4972;
- Water Retention;
- Xray Diffraction (XRD);
- Scanning Electron Microscope; and
- Organic Content Furnace Burn, as per ASTM D2974.

Complex laboratory testing for organic soils includes:

- Oedometer Tests as per ASTM D2435;
- CRS Tests as per ASTM D4186;
- Permeability as per ASTM D4511; and
- Triaxial CIU as per ASTM D4767.

Specific complex laboratory testing for organic soils may be required as per project specific TOR.

6 ENGINEERING AND REPORTING

6.1 General

Reports submitted to MTO shall be in compliance with minimum requirements of this guideline, project specific TOR, the Quality Control Plan and that recommendations are consistent with MTO protocol. Geocres Number, GWP/WP Numbers, MTO Structure Site ID (if applicable) and Latitude and Longitude Geographic Coordinates to represent the location of structure or study area shall be indicated on the cover page of the report. If there is no specific structure, a mid-point of the project alignment or study area shall be used.

6.1.1 Design Codes, Manuals, and Guidelines

The Foundations Engineering Services shall be provided in accordance with the most recent versions of the relevant design codes, manuals, and guidelines (where applicable):

- MTO Special Provisions
- Ontario Provincial Standard Specification (OPSS)
- Canadian Highway Bridge Design Code (CHBDC CSA S6-19) For Highway Applications and the Exceptions in the MTO Structural Manual
- American Railway Engineering and Maintenance-Of-Way Association (AREMA), Manual for Railway Engineering, Volume 2, Chapter 28, Temporary Structure for Construction, For Railway Applications
- National Building Code/ Ontario Building Code
- MTC Soil Classification Manual
- MTO Laboratory Testing Manual
- MTO Retained Soil System (RSS) Design Guidelines
- MTO Embankment Settlement Criteria for Design
- MTO Guideline for Rock Fill Settlement and Rock Fill Quantity Estimates
- MTO Integral Abutment Bridge and Semi-Integral Abutment Bridge
- MTO Bridge Office Bulletin related to Foundations
- MTO Concrete Culvert Design and Detailing Manual
- Designated Sources of Materials List
- Canadian Foundation Engineering Manual
- MTO Structural Manual
- TAC Design, Construction, Maintenance and Inspection Guide for Mechanically Stabilized Earth Walls (July 2017).
- Guideline for Professional Engineers Providing Geotechnical Engineering Services Published by Professional Engineers of Ontario
- ASTM Standards
- MTO Sign Support Manual
- MTO Guidelines for the Design of High Mast Pole Foundations
- Association of Professional Geoscientist of Ontario (APGO), General Professional Practice Guidelines for Environmental Geoscience
- MTO Environmental Protection Requirements for Transportation Planning and Highway Design, Construction, Operation and Maintenance
- Environmental Activity and Sector Registry (EASR)
- Professional Practice Guidelines for Groundwater Resources Evaluation, Development, Management and Protection Programs in Ontario (2004) – Association of Professional Geoscientists of Ontario (APGO)
- MTO Technical Guidelines for the Identification, Assessment and Remediation of

Contaminated Property (May 1997), published by the Ministry of Transportation

6.1.2 Borehole Log Records

Borehole Log Record Sheet shall be prepared in accordance with MTO standards and include the following:

- Both Northing and Easting Grid Coordinates and Latitude and Longitude Geographic Coordinates of the borehole location.
- The soil classification for coarse-grained soils (non-cohesive) shall be in accordance with the Unified Soil Classification System as specified in ASTM D2487. Although Group Symbols are used as part of the USCS, Group Symbols are not required.
- The soil classification for fine-grained soils (cohesive) shall be in accordance with the current MTO Soil Classification Manual, except that soils classified by the Group Symbol (CL) shall be assigned the Group Name “CLAYEY SILT”. In all cases, the secondary components in the soil description shall be defined and described using the recommendations in the most recent edition of the Canadian Foundation Engineering Manual.
- A detailed description of all retrieved soil sample rock cores.
- The rock core description shall include, as a minimum, geological classification, weathering state, bedding state, structural features of rock mass, engineering properties of rock mass, strength, hardness and abrasiveness of the intact rock and characteristics of discontinuities/joints.
- Groundwater conditions including groundwater encountered during drilling, stabilized groundwater level, artesian condition, piezometer installation, and dry condition.
- Groundwater symbols shall be included on the List of Symbols sheet(s) that accompany the Record of Boreholes.
- Closed or solid water level symbols shall represent stabilized water level including perched water conditions.
- Open or hollow water level symbol shall represent not-stabilized groundwater conditions upon completion of drilling the borehole and artesian water conditions.

6.1.3 Foundation Figures

Foundation figures shall be prepared in accordance with MTO standards and include the following:

- Grain size distribution, with grain size envelopes when appropriate or specified in the Terms of Reference ‘Project Specific’;
- Plasticity chart;
- Undrained shear strength vs. Elevation;
- Overburden pressure and pre-consolidation pressure vs. Elevation; and
- Slope stability analysis.

For high fill, on very soft to firm cohesive deposits (>4.5 m in height), following figures shall be included as part of reporting:

- Soil strata vs. Elevation;
- SPT N values vs. Elevation;
- Moisture content vs. Elevation;

- Atterberg Limits vs. Elevation;
- Void Ratio vs. Elevation; and
- Shear Strength Parameters (c', friction angle) vs. Elevation.

Figures shall be included in the Appendix and presented relative to each other.

6.1.4 Foundation Drawings

Foundation Drawing (Borehole Locations and Soil Strata) shall be prepared in accordance with MTO standards and include the following:

- Geocres Number, Key Map, MTO Structure Site ID (if applicable) and Latitude and Longitude Geographic Coordinates to represent the location of structure or study area. If there is no specific structure, a mid-point of the project alignment or study area shall be used.
- All exploration locations in Plan View.
- Stratigraphical Cross-Section at each bridge foundation element, culvert foundation element, critical embankment and excavation cut locations.
- Stratigraphical Profile along the centreline of the foundation item and shows groundwater levels.

Additional drawing requirements for each of Foundation Engineering specialties are presented in respective sections in this guideline.

6.1.5 Photographs

Colour Photographs, depicting the general and specific site conditions, shall be taken for each project site. Photographs shall be dated; location and view direction identified and shall include a description of the presented visual information.

6.2 Geotechnical (Structures and Embankments) Specialty

6.2.1 General

The preliminary and detail design level of Foundations Engineering and Reporting Investigation and Design for Geotechnical Specialty (Structures and Embankments) shall be prepared in a report format and consist of the following:

- Part A - Foundation Investigation Report
- Part B - Foundation Design Report

Other reporting formats and requirements, such as technical memoranda, will be specified in project specific TOR and/or during engineering design liaison.

6.2.2 Foundation Investigation Report

The Foundation Investigation Report for Geotechnical Specialty shall:

- Consist of factual information only, with no reference to recommendations and project proposals;
- Present details of subsurface conditions and to ultimately become part of the Contract Documents, providing the Construction Contractor with a model of the subsurface conditions; and
- Present a comprehensive subsurface model for each structure under the plan limits of foundation elements and at the immediate approaches within 20 m of the structure

abutments, including any associated wingwalls and any other Foundations Engineering related items such as embankment fills/excavation cuts in the project. A comprehensive subsurface model shall include stratigraphic profiles and sections of soil, groundwater and bedrock within project limits.

The Foundation Investigation Report for Geotechnical Specialty shall consist of the following sections:

- Introduction;
- Site Description – including topography, vegetation, drainage, existing land use, structures performance of existing structures;
- Investigation Procedures – including site investigation, site preparation, equipment and methods, laboratory testing, seismic investigation (if applicable per CHBDC and refer to Terms of Reference 'Project Specific' for detail), decommissioning details, source of water supply for the investigation (if required) and traffic protection (if required). Indicate all existing boreholes to be considered;
- Description of Subsurface Conditions – including site geology, soil, rock and groundwater conditions, if encountered. Subsurface conditions shall be reported in text format under subsections for each stratum;
- Soil and/or groundwater chemical laboratory test results;
- Miscellaneous – identifies the name of the drilling company, where the laboratory testing was performed, the persons who carried out the field supervision, and the persons who wrote and reviewed the report; and
- Appendices – Borehole Logs, Foundation Figures and Drawings, Laboratory Testing Results and Colour Photographs.

6.2.3 Foundation Design Report

The Foundation Design Report shall include discussion and recommendations for design purposes. Recommendations shall be in accordance with the requirements of the most recent edition of the codes, manuals, and guidelines in effect for MTO projects.

Foundation Design Report shall include the following (where applicable) and the minimum discussion and recommendation requirements presented in **Table 2**.

- Discussion of the proposed project and an overview of foundation considerations;
- An overview of the subsurface conditions, field data and test results;
- Comprehensive and practical recommendations for appropriate foundation options for structures and embankments pertaining to temporary, interim and permanent conditions of the project;
- Table(s) which identifies and presents overview assessments of the advantages, disadvantages, risks/consequences and relative costs of alternative foundation engineering options for structures and embankments;
- Settlement analysis and assessment, including immediate, long-term, total and differential settlement to address MTO Embankment Settlement Criteria for Design;
- Static Stability analysis (short term and long term) and assessment;
- Analysis and assessment of surficial slope stability including a table that identifies alternatives and compares the alternatives based on advantages, disadvantages, cost, risk and consequences;

- Seismic analysis and assessment per CHBDC and refer to Terms of Reference ‘Project Specific’ for detail, including seismic stability analysis, cyclical mobility and liquefaction potential;
- Applicable consequence and geotechnical resistance factors per CHBDC;
- Recommendations for level of site understanding classification and factors;
- Impact on the land use and property, traffic and transportation and environment;
- Conclusion(s) on the preferred foundation option for structures and embankments from a foundation technical and cost effectiveness perspective;
- Bridge specific recommendations for soil pressure distribution shall be provided for the case where the abutment pushes into the backfill when the bridge expands such as for semi-integral and integral abutments. Consideration shall be given to the specific geometry of the bridge and the soil conditions at the site: the actual height of the abutment, the movement of the abutment due to expansion of the bridge at service conditions (which may be a combination of translation and rotation), and the backfill material. Bridge-specific geometry and information shall be obtained from the structural engineer. As a baseline, the Service Provider shall include a minimum of two (2) design liaison iterations and liaison with the structural engineer to advance their design to the point that the Structural Engineer is able to define the actual geometry;
- Recommendation regarding the possible degradation of concrete under the presence of sulphates and the corrosion potential for steel/metal elements due to chloride ions;
- Recommendation for activities requiring foundations engineering specialist services, such as deep foundations, pile driving control, excavation and backfill, dewatering, embankment constructions, wick drains and lightweight fill;
- Discussion and recommendation on Frost Protection and Frost Taper;
- Discussion and recommendation on Scour Protection, Drainage, Run-off and Erosion Protection;
- Recommendation for suitability of the ground to support construction equipment;
- Discussion and recommendations for Permit to Take Water (PTTW) and Environmental Activity and Sector Registry (EASR) based on the anticipated groundwater levels encountered, estimated hydraulic conductivity of the soils encountered and flow quantities;
- Construction considerations and recommendation for methods of overcoming anticipated construction problems, such as:
    - Ground Water Control, Dewatering, Channel Diversion;
    - Requirement for Temporary Protection System (TPS);
    - Requirement for Temporary Cofferdam;
    - Temporary Excavation and Cut Slopes;
    - Presence of Cobbles and Boulders;
    - Presence of other obstructions;
    - Bedrock Excavation;
    - Stability of Excavations and Embankments;
    - Staged Construction; and
    - Removal of Existing Foundations
- Current specifications, special provisions, for materials and specialized construction activities, and non-standard special provisions for any changes or new specifications/special provisions shall be discussed and included in the Appendices; and
- Critical issues that may involve complex subsurface conditions or design requirements that would require specialized construction procedures should be ‘red-flagged’. 'Red- flagging' shall disclose conditions and requirements that were deemed to be critical, based on the information available at the design stage of the project. The Foundations Engineering Service Provider shall qualify 'red-flagging' so that no responsibility or liability for alerting

the Contractor to 'red-flag' all critical issues is assumed, and to indicate that the requirement to deliver acceptable construction quality remains the responsibility of the Contractor.

6.2.4 Groundwater Assessment Report

The Groundwater Assessment Report (GAR) may be required on a project specific basis as part of Foundation Investigation and Design Report and may require liaison with Hydrogeological Specialty. The purpose of the GAR is to provide information for the Contractor to plan, organize, install, operate, maintain and remove dewatering, unwatering and temporary flow passage/diversions to control and manage groundwater and surface water to permit construction in a dry and stable excavation.

Lowering of the groundwater level must precede soil excavation to avoid base heave/boiling and sloughing of the foundation soil.
The Service Provider shall recommend that a dewatering specialist contractor shall assess the dewatering requirements and provide the method of dewatering to adequately control the groundwater in order to support the construction.

Requirements for GAR are provided in **Table 2.**

Table 2. Minimum Discussion and Recommendation Requirements - Geotechnical

Foundation Items	Minimum Discussion and Recommendation Requirements (where applicable)
Bridge (Foundation Element and Approach Embankment)	• Foundations Type Options (Shallow and Deep) • Assessment of downdrag on pile • Associated Axial, Bearing, Lateral (Subgrade Reaction Values and P-Y Model Curves), Sliding Resistances, Founding Elevations and approximate length of deep foundations • The maximum factored lateral resistance values shall also be provided • PDA testing and conventional Hiley Dynamic Formula • Consideration for advanced Pile Load Tests subjecting piles to Axial Compression, Axial Tension, Lateral Loads • Suitability for Integral or Semi-Integral Abutment Design • Feasibility of re-use of existing foundations • Requirements for Pile Driving Shoes/Rock Points • Lateral Earth Pressure Design including both static and seismic conditions • Slope Stability Analysis and Recommendations for Slope Geometry • Settlement Analysis, including Immediate, Long-term, Total and Differential Settlement • Seismic Design Loading and Potential for Liquefaction • Design and Recommendations for Preload/Surcharge, Soil Improvement, Wick Drains, Lightweight Fill, Geosynthetic Reinforcement, and Retained Soil System (RSS). • If Retaining Structure is considered, see Minimum Discussion and Recommendation Requirement for “Retaining Structures”.
Retaining Wall Structure	• Foundations Type Options (Shallow and Deep) • Associated Axial, Bearing, Lateral, Sliding, and Overturning Resistances and Founding Elevations • Lateral Earth Pressure Design • Global Slope Stability Analysis • Seismic Design Loading and Potential for Liquefaction • Drainage Performance of the Backfill Material • See MTO Retained Soil System (RSS) Design Guideline requirements to determine the suitability of the site for RSS.

Foundation Items	Minimum Discussion and Recommendation Requirements (where applicable)
Retaining Soil Structure (RSS)	The Foundation Design Report shall include an assessment of the suitability of the foundation subsoil to support an RSS wall based on analyses of geotechnical bearing resistance, settlement (total and differential) and global stability with the RSS in place, assuming a reinforced soil zone with height = H and transverse width = 0.7H. The following information shall be included: • The estimated magnitude and duration of settlements under the RSS loading. • The assessment of total settlement for RSS shall address three potential sources: - Consolidation settlement of any deep underlying soil layer (soft, compressible) that would occur over a relatively long period of time (years); - Elastic settlement of shallow soils that would occur during or shortly after construction (days, weeks); and - Settlement within the RSS backfill, considering height of the proposed RSS and proper construction and compaction. • The assessment for settlements shall include the following to ensure that serviceability and aesthetic problems do not occur: - Potential impact on the performance of the RSS and any adjacent structures, including pavement; and - Differential settlement for RSS and False Abutment supported on piles. • Recommendations and details for managing settlement (short-term and long-term) and any poor subsurface conditions, depending on whether the amount of settlement is excessive for serviceability or for the acceptable tolerance of the RSS, including sub-excavation and replacement with acceptable granular fill, preload, surcharge, wick drains or other ground improvement methods or technologies: - For sub-excavation, the approximate depth and lateral extent of excavation shall be determined. - For preloading, the amount of preload, duration and possibility of accelerating settlements (e.g. wick drains) shall be provided. • The geotechnical bearing resistances at ULS and SLS with foundation elevations for the RSS and foundation preparation requirements. • Global stability analysis with the RSS in place. • Recommendations for embedment and erosion / scour protection. The Foundations Design report shall address RSS SP 599S22 and SP 599S23 (if applicable).

Foundation Items	Minimum Discussion and Recommendation Requirements (where applicable)
Culvert	• Foundations Type Options (Shallow and Deep) • Associated Axial, Bearing, Lateral, and Sliding Resistances and Founding Elevations • Lateral Earth Pressure Design • Bedding, Backfill, Backfill Transition and Cover • Inlet and outlet details including requirements for channelling water (head walls or extended culvert inlets) • Inlet Seal, Inlet Erosion Control, Cut-Off, Outlet filter, Outlet Erosion Control, Camber, and Articulation of Structures (precast concrete box sections) • Stability of Slopes at the Culvert • Settlement Analysis, including Immediate, Long-term, Total and Differential Settlement • If Retaining Structure is considered, see Minimum Discussion and Recommendation Requirement for “Retaining Wall Structure”. • If Tunnel or Trenchless Installation Method is considered, Service Provider shall contact the Ministry for the qualification requirement of Tunnelling specialty prior to carry out the work • Recommendations for parameters for scour analysis and countermeasures For Sheet Pile Culvert, additional requirements in consultation with the structural engineer, including: • Axial Capacity • Lateral Earth Pressures and Distribution • Water Pressures • Lateral Capacity • Sheet Pile Installation Methodology • Fixity at toe • Soil-Structure Interaction • Cantilever vs Anchored Walls • Effects of Wall Deformation on Soil Pressures • Load Transfer Mechanism to foundation material
Deep Cut/High Fill Embankment & High Fill Embankment on Very Soft to Firm Deposits (>4.5 m in height)	• Slope Stability Analysis and Recommendations for Slope Geometry • Surficial slope stability assessment and recommendations • Settlement Analysis, including Immediate, Long-term, Total and Differential Settlement • Consideration, recommendations, and design of the following options: - Full/partial excavation of soft compressible foundation soils; - Staged construction; - Preload - Preload and Surcharge; - Ground Improvement; - Wick Drains; - Lightweight Fill; - Geosynthetic Reinforcement; and - Retained Soil System (RSS) • Recommendations for monitoring • Impact on construction scheduling • Final Design on the Preferred Alternative(s) shall be based on the discussion and agreement between the Ministry and Prime/Foundations Engineering Service Provider • If retaining structures is considered, see Minimum Discussion and Recommendation Requirement for “Retaining Wall Structure”.

Foundation Items	Minimum Discussion and Recommendation Requirements (where applicable)
Swamp Crossing	• See Minimum Discussion and Recommendation Requirements for “Deep Cut/High Fill Embankment” • Embankment Design Alternatives (Full/Partial Excavation, Floatation) • Ground improvement • Reference shall be made to OPSS 209 and OPSD 203.01-04 • Construction and Post-Construction Settlement Analysis • Determine embedment losses in the founding stratum for all embankment areas where swamp excavation and backfilling is recommended • Provide the magnitude and rate of the embedment loss to enable the determination of appropriate backfill quantities. • Impact on construction scheduling • For Full/Partial Excavation, assess the behaviour and properties of the soil being excavated and provide recommendations for the method of excavation and the measurement for payment. • From a Foundation Engineering perspective, recommendation for the measurement for payment of swamp excavation shall be provided in terms of quantity (m^3) and hourly basis. • Final Design on the Preferred Alternative(s) shall be based on the discussion and agreement between the Ministry and Prime/Foundations Engineering Service Provider
Storm Water Management Pond (SWMP)	• Estimated Permeability of Soils (Seepage Rate) • Requirement for Impermeable Liner and Liner Design Recommendations • Embankment (Cut Slope and Pond Base) Stability • Erosion Protection • Foundation Design Recommendation for Inlet/Outlet
Temporary Protection System (TPS) and Temporary Cofferdam	• Performance Level per OPSS 539 Construction Specification for Temporary Protection Systems • Conceptual Protection System Options (sheetpile, soldier pile/lagging installation, anchor/raker/bracing installation and stressing) at anticipated locations • Conceptual Cofferdam Design at anticipated locations • Geotechnical Parameters (Cohesion, Angle of Internal friction, Unit Weight of the Subsurface Materials) • Lateral Earth Pressures Coefficients • Design Groundwater Elevation • Recommendation for Full or Partial Removal of Temporary Protection System and Temporary Cofferdam to avoid disturbance to existing and new structures.

Foundation Items	Minimum Discussion and Recommendation Requirements (where applicable)

Groundwater Assessment Report	• Introduction
	• Project Description and Desktop Study:
	  - Site Description
	  - Site Features
	  - Topography
	  - Surface Water
	  - Geology
	  - Hydrogeology
	• Subsurface Investigations
	  - Subsurface Soil Conditions
	  - Groundwater Conditions
	  - Hydraulic Conductivity Estimation
	• Discussion
	  - Proposed Structure
	    ▪ Excavations
	    ▪ Dewatering Requirements
	  - Dewatering Rate Estimation
	    ▪ Assumptions
	    ▪ Dewatering Rate Equation
	    ▪ Dewatering Rate Estimation
	    ▪ Zone of Influence
	  - Dewatering Discharge Disposal
	  - Dewatering Impact Assessment
	  - Water Taking Permitting
	  - Water Taking Exemption

Construction Staging Area for Rapid Replacement of Bridge/Deck	• Suitability of the subsurface conditions to provide temporary support • Foundations Type Options based on specified total and differential settlements • Associated Axial, Bearing, Lateral, and Sliding Resistances and Founding Elevations • Foundation Preparation Requirements
Geotechnical Assessment of Heavy Construction Equipment (Crane Pads, Drilling Rigs, Pile Driving Equipment, etc.)	• Suitability of the subsurface conditions to provide temporary support • Foundations Type Options • Associated Axial, Bearing, Lateral, and Sliding Resistances and Founding Elevations • The global stability and settlement impact of the heavy equipment loads on embankments and any foundations • Restriction of heavy equipment adjacent to existing slopes, foundations, and utilities • Recommendations for permissible ground pressures • Recommendations for setback distances from slopes, abutments, retaining walls, other structures and utilities • Foundation Preparation Requirements, including access.
Noise Barrier Wall	• Geotechnical Parameters (Undrained Shear Strength, Angle of Internal Friction, Unit Weight of the Subsurface Materials, and Estimated Groundwater Elevations) along the noise barrier wall alignment on a station to station basis • Consideration of sloping ground and bedrock.
High Mast Lighting (HML), CCTV Poles and Sign Support Structure	• Foundations Type Options • Geotechnical Parameters (Undrained Shear Strength, Angle of Internal Friction, Unit Weight of the Subsurface Materials) • Estimated Groundwater Elevation for each HML, CCTV, Poles and Sign Support Structure Location • Consideration of sloping ground, bedrock and tensile resistance. • Confirmation that the design can be carried out in accordance with appropriate MTO Design Standards and Manuals.
Median Sewer	• Recommendations for temporary excavation slope • Requirement for Temporary Protection System • Dewatering • Staged Excavation and backfilling • Bedding, backfill and cover

6.3 Tunnelling Specialty

6.3.1 General

The selection of tunnelling methodology is the responsibility of the Contractor. In order for the Contractor to select the most appropriate method, a comprehensive subsurface and groundwater model needs to be provided in the Contract Documents. A Foundation Investigation and Design Report (FIDR) shall be produced.

Foundations Engineering and Reporting for Tunnelling shall consist of the following:

- Part A - Foundation Investigation Report
- Part B - Foundation Design Report

Other reporting formats and requirements, such as technical memoranda, will be specified in project specific TOR and/or during engineering design liaison.

For applications to Highway Operations, general guidelines that specify MTO's minimum requirements for the Foundation Engineering – Tunnelling Specialty component of submissions from proponents of development within the Ministry of Transportation's (MTO) corridor permit control area are appended in **Appendix E**.

A Geotechnical Baseline Report (GBR) may be required as per project specific TOR. The GBR provides interpretations of the data for the purposes of construction and shall:

- Describe and provide interpretations of subsurface conditions anticipated during construction.
- Describe how those conditions will influence the design
- Describe how those conditions will influence construction
- Identify key risks on the project
- Describe who carries the risks for conditions within and beyond the baselines.

The requirement for a GBR shall be specified in the Project Specifics. The need for a GBR will depend on the assessment of geologic uncertainty or risk and on the assessment of whether bidding/claims will be simplified with a baseline.

6.3.2 Foundation Investigation Report

The Foundation Investigation Report for Tunnelling specialty shall:

- Consist of factual information only, with no reference to recommendations and project proposals;
- Present details of subsurface conditions and to ultimately become part of the Contract Documents, providing the Construction Contractor with a model of the subsurface conditions; and
- Present a comprehensive subsurface model along the proposed alignment and exit/entry portals. Proposed tunnel horizon illustrating the proposed invert/crown of the tunnel shall be superimposed on the drawings.

The Foundation Investigation Report for Tunnelling shall consist of the following sections:

- Introduction;

- Site Description – including topography, vegetation, drainage, existing land use, structures;
- Investigation Procedures – including site investigation, site preparation, equipment and methods, laboratory testing, seismic investigation (if applicable per CHBDC and refer to Terms of Reference 'Project Specific' for detail), decommissioning details, source of water supply for the investigation (if required) and traffic protection (if required). Indicate all existing boreholes to be considered;
- Description of Subsurface Conditions – including site geology, soil, rock and groundwater conditions, if encountered. Subsurface conditions shall be reported in text format under subsections for each stratum;
- Soil and/or groundwater chemical laboratory test results;
- Miscellaneous – identifies the name of the drilling company, where the laboratory testing was performed, the persons who carried out the field supervision, and the persons who wrote and reviewed the report; and
- Appendices – Borehole Logs, Foundation Figures and Drawings, Laboratory Testing Results and Colour Photographs.

6.3.3 Foundation Design Report

The Foundation Design Report for Tunneling shall include discussion and recommendations for design purposes. Recommendations shall be in accordance with the requirements of the most recent edition of the codes, manuals, and guidelines in effect for MTO projects.

Foundation Design Report shall include the following (where applicable) and the minimum discussion and recommendation requirements presented in **Table 3**.

- General subsection discussing the proposed project, including:
  - An overview of the proposed tunnel;
  - Reference to applicable specifications and standards;
  - Contractors responsibility for method statement; and
  - An overview of foundation considerations for tunnel and trenchless installations.
- A subsection entitled Tunnel Alignment with details of:
  - Proposed tunnel diameter;
  - Casing pipe diameter;
  - Pavement/crest shoulder elevation;
  - Obvert/invert elevation; and
  - Cover.

  This section shall include a table that captures the abovementioned details;
- A subsection on assessment of subsurface conditions for the proposed project including:
  - An overview of the subsurface conditions, field data and test results;
  - Behaviour;
  - Cover;
  - Mixed Face;
  - Obstructions;
  - Boulders and Cobbles;
  - Ravelling Conditions;
  - Dewatering;
  - Temporary Protection System; and
  - The invert elevation should be assessed in view of the subsurface conditions and the anticipated open face stability control.

This section shall include a table that describes the anticipated subsurface conditions, behaviour (stand up time), groundwater elevation, distance between invert and groundwater.

- A subsection on pipe materials: concrete, plastic, fibreglass;
- A subsection on discussion of the Trenchless Options:
  - Discusses anticipated ground conditions and identify tunneling alternatives for the proposed tunnel crossing:
    - Target Repair;
    - Closed Fit Liners;
    - Grouted Liners;
    - Replacement Pipe; and
    - New Pipe
  - Options may include, but not limited to:
    - Jack & bore;
    - Pilot tube auger bore;
    - Horizontal Directional Drilling;
    - Pipe ramming;
    - Micro-tunnelling;
    - Tunnelling (two pass system) using TBM or Digger Shield;
    - Tunnelling (single pass system) using TBM;
    - Hand or mechanically assisted mining; and
    - Cut and cover methods
- A subsection that compares the different Trenchless Options;
  - Present assessments of the advantages, disadvantages, risks/consequences and relative costs of alternative tunnelling methods in a table;
  - This section shall include a Risk Register as identified in **Table 3**. The Risk Register shall identify the risks, assess the impact and level of risk for both unmitigated and mitigated, and provide risk mitigation measures and subsequent impact/level of risk;
  - The Impact on the land use and property, traffic and transportation and environment shall be considered in the comparison;
  - Provide a conclusion on a preferred alternative from foundation engineering and cost effectiveness perspective; and
  - Any method that is not suitable shall be identified with recommendations to include restrictions on tunnelling methodologies in the contract documents as an operational constraint.
- A subsection on Entry/Exit Shafts – Temporary Excavation and Groundwater Control:
  - Reference to OPSS 539 recommended Performance Level;
  - Conceptual Temporary Protection Systems;
  - Recommendations for Cofferdam Construction;
  - Reference to OPSS 517 and requirements for Dewatering Specialist;
  - Recommendations for Conceptual Dewatering/Unwatering/Temporary Flow Passage Systems; and
  - Discussion and Recommendations for Permit to Take Water (PTTW) and Environmental Activity and Sector Registry (EASR) based on the anticipated flow quantity.
- A subsection on Instrumentation and Monitoring:
  - Describe purpose;
  - Provide project specific review, contractor response and alert levels;
  - Discussion of instrumentation and monitoring equipment and methodologies and a recommended preferred option to identify adverse movement trends; and

  - Recommendations for monitoring volume of excavated soil/rock and assessment of volume loss ratios.
- A subsection on Corrosion Assessment and Recommendations. Potential for chloride attack and sulphate attack shall be discussed. Recommendation regarding the possible degradation of concrete under the presence of sulphates and the corrosion potential for steel/metal elements due to chloride ions;
- Recommendation for activities requiring foundations engineering specialist services such, excavation and backfill and dewatering;
- Recommendation for suitability of the ground to support construction equipment;
- Discussion and recommendation on Frost Protection and Frost Taper;
- Discussion and recommendation on Scour Protection, Drainage, Run-off and Erosion Protection;
- A subsection on Construction Considerations and Documents. The report shall discuss construction considerations and provide recommendations for methods of overcoming anticipated construction problems:
  - Ground Water Control, Dewatering, Channel Diversion;
  - Requirement for Temporary Protection System (TPS);
  - Requirement for Temporary Cofferdam;
  - Temporary Excavation and Cut Slopes;
  - Presence of Cobbles and Boulders;
  - Presence of other obstructions;
  - Bedrock Excavation;
  - Stability of Excavations and Embankments;
  - Staged Construction; and
  - Removal of Existing Foundations.
- Current specifications, special provisions, for materials and specialized construction activities and non-standard special provisions for any changes or new specifications/special provisions shall be discussed and included in the Appendices; and
- Critical issues that may involve complex subsurface conditions or design requirements that would require specialized construction procedures should be ‘red-flagged’. 'Red- flagging' shall disclose conditions and requirements that were deemed to be critical, based on the information available at the design stage of the project. The Foundations Engineering Service Provider shall qualify 'red-flagging' so that no responsibility or liability for alerting the Contractor to 'red-flag' all critical issues is assumed, and to indicate that the requirement to deliver acceptable construction quality remains the responsibility of the Contractor.

Recommendations shall be provided for qualifications and experience for the Design and Design Checking Engineers, Tunnelling contractors, requirements commensurate with complexity.

Table 3. Minimum Discussion and Recommendation Requirements - Tunneling

Foundation Items	Minimum Discussion and Recommendation Requirements (where applicable)
Tunnel and Trenchless Installations	• Trenchless Method Options • Risk Register that includes: - Risk Item - Impact - Key Issues and Consequences - Risk Mitigation - Unmitigated • Likelihood – High/Moderate/Low • Impact – High/Moderate/Low - Mitigated • Likelihood – High/Moderate/Low • Impact – High/Moderate/Low ▪ Mitigation Measures Recommended • Length and diameter constraints • Control of face stability • Capability of boulder excavation • Evaluation of temporary and permanent support • Alignment control • Estimated settlements and heave and management of these deformations • Special access and egress requirements for tunnelling equipment. • Recommendation for vertical shafts (Shored and un-shored alternatives for open-cut excavation) for entry/exit pits • Recommendation including geotechnical passive resistance for the jacking pit • Long-term stability of the tunnel • Traffic management and contractor access for each alternative • Recommendation for Settlement/Heave Monitoring Program • Consideration for Geotechnical Baseline Report (if applicable, see Term of Reference ‘Project Specific’) • Consideration for Geotechnical Subsurface Condition Baseline Reporting (if applicable, see Term of Reference ‘Project Specific’)

6.3.4 Geotechnical Baseline Report

The purpose of the Geotechnical Baseline Report (GBR) is to describe the subsurface conditions and expected ground behavior during the construction of the portals and the tunnel. Baselines should clearly state how data is to be interpreted for the purposes of bidding.

The GBR is:

- A Contract Document
- A set of contractual assumptions – not necessarily geotechnical facts
- A guidance document for bidding the project
- A tool to help manage risks during construction
- A tool to help manage the payment provisions under the Contract
- A means for administering the Differing Site Conditions clause under the contract

The GBR is NOT

- A warranty that all baselined conditions will be encountered
- A tool for pushing all risks to the Contractor

The GBR shall:

- Provide an overview of the tunnel and the entry/exit portals including construction sequencing.
- Summarize the subsurface and groundwater conditions anticipated during to be encountered during construction
- Summarize how anticipated conditions have been addressed in design
- Establish baselines to be used to resolve disagreements, disputes and claims related to the anticipated subsurface conditions
- Assist bidders in preparing their bid submission and evaluating the requirements for subsurface construction

The baselines shall assume the use of appropriate means, method and workmanship.
The Geotechnical Baseline Report shall be read in conjunction with the Foundation Investigation and Design Report

The GBR shall take precedence over the FIR/FIDR. The GBR shall follow the requirements outlined in Geotechnical Baseline Reports for Construction Suggested Guidelines by the Technical Committee on Geotechnical Reports of the Underground Technology Research Council, American Society.

The requirements for a GBR are provided in **Table 4.**

Table 4. Minimum Discussion and Recommendation Requirements - GBR

Foundation Items	Minimum Discussion and Recommendation Requirements (where applicable)
Geotechnical Baseline Reports (GBR)	• Introduction - Project Description - Purpose of Report • Sources of Information • Subsurface Conditions - Geologic Setting - Topography and Site Conditions - Baseline Stratigraphy - Physical Baselines - Behaviour Baselines • Baseline classification characteristics • Baseline geotechnical engineering parameters • Baseline numbers and sizes of cobbles and boulders • Baseline Straigraphical Profile • Design Considerations • Construction Considerations

6.4 Hydrogeological Specialty

6.4.1 General

The hydrogeological study and assessment shall be of sufficient scope to provide comprehensive evaluations of potential impacts on the groundwater regime that can affect infrastructures, groundwater users or natural functions of ecosystem relying on groundwater and to provide recommendations to mitigate anticipated short-term and long-term impacts related to groundwater quantity.

Assessment of impacts on groundwater quality shall be undertaken by others (environmental specialty) unless identified in the project specific TOR. Project specific TOR will outline the required hydrogeological study and assessment within the study area and shall govern where any conflict exists with this guideline.

The level of detail required in the hydrogeological study is normally expected to correspond with the level of risk posed to the ground and surface water resources, and the level of uncertainty associated with the available information. Where there is a low risk of negative impacts, a desk-top study may be adequate. Where there is a high risk of negative impacts, a detailed site investigation and monitoring program may be required. Sound judgement shall be used to determine the level of hydrogeological study.

A complete hydrogeological study and assessment are normally accomplished by evaluating the available geological, hydrogeological and other pertinent subsurface information, including the nature of the terrain and the performance of existing facilities, structures and/or roads, and conducting an adequate number of boreholes, test pits and soundings (explorations), hydraulic conductivity and site-specific aquifer testing; retrieving an adequate number of soil samples, rock core samples, groundwater and surface water samples, to supplement any existing data, and carrying out laboratory tests on samples to obtain factual information, such as:

- The vertical and horizontal extent of subsurface materials, including both soil and rock, and their pertinent hydrogeological and engineering properties; and
- Groundwater conditions, including groundwater levels perched or otherwise, the location of aquifers and aquitards, the location and characteristics of any artesian groundwater, the quantity of flow and the presence or otherwise, of natural gas or chemicals dissolved in groundwater or surface water.

The hydrogeological study and assessment within the study areas shall be divided into three (3) sections, namely:

- Existing conditions;
- Impact Assessment; and
- Mitigation.

Accordingly, the hydrogeological study and assessment within the study areas shall be conducted in two (2) phases:

- Phase 1 – Hydrogeological Screening: The consultant shall prepare a Hydrogeological Screening Report based on the background information and detailed site inspection and reconnaissance of the project area.
- Phase 2 - Hydrogeological Investigation and Design: Based on the recommendations of Phase 1 scope and the areas of concerns selected by the design team, the Consultant shall

conduct hydrogeological investigation/assessment, laboratory testing and prepare a detail level Hydrogeological Investigation and Design Report in two parts:
- Part A - Hydrogeological Investigation Report
- Part B - Hydrogeological Design Report

General objectives of a hydrogeological study and assessments are to:

- Define groundwater flow characteristics (please see Environmental Specialty for groundwater quality assessment requirements);
- Determine the physical, hydraulic and chemical properties of the surficial materials, and bedrock, where appropriate;
- Establish a groundwater monitoring network (short-term and/or long-term);
- Provide mitigation / remedial options and contingency plans for hydraulic and/or control;
- Estimate the groundwater quantity required to be drawdown for construction purposes to support EASR and PTTW application from the Ministry of the Environment, Conservation and Parks (MECP); and
- Address groundwater impact to nearby monitoring wells as a result of construction dewatering and permanent drainage requirements.

These objectives are achieved by:

- Review and assessment of any existing information;
- A field investigation that can include one or a combination of
    - Drilling of boreholes and obtaining samples to characterize soil and/or bedrock conditions at the site;
    - Measurement of groundwater levels and pressures to define groundwater flow characteristics; and
    - Hydraulic conductivity measurement derived by falling head/rising head tests and/or pump tests.
- Collection of groundwater samples to assess baseline groundwater quality;
- The collection of soil samples to assess soil quality; and
- Interpretation of collected data, including the preparation of site topographic contour and piezometric contour plans, the determination of groundwater flow paths and contaminant attenuation capabilities, and the identification of any unstable soils or geologic conditions.

A detailed design of the most feasible groundwater mitigation option shall be coordinated with the other relevant functions in the overall detailed design of the highway corridor design

6.4.2 Hydrogeological Screening Report

The Hydrogeological Screening shall consist of a site history (desktop) review, a site reconnaissance and reporting as specified below.

The site history (desktop) review shall consist of obtaining existing information related to the existing and previous operations and conditions. A site reconnaissance for Hydrogeological study shall be carried out to assess existing conditions and to provide further information regarding groundwater and surface water resources in the area. Requirements for site history (desktop) review and site reconnaissance are presented in **Table 5**.

A Hydrogeological Screening Report shall be prepared based on the site history and site reconnaissance. The Hydrogeological Screening Report shall include the following sections:

- Introduction;
- Site Description;
- Site History;
- Site Reconnaissance;
- Summarized Subsurface and Groundwater Conditions; and
- Discussions and Recommendations.

The Hydrogeological Screening Report shall append following plans:

- A plan of the site and areas within 1 km of the site indicating water courses and significant drainage features, locations of water wells based on MECP records and location of any Municipal or communal water supply wells;
- A minimum of two geologic profiles and cross-sections shall be prepared using the water well and any other available stratigraphic information to illustrate hydrogeological conditions, including the depth and nature of aquifer systems in the area;
- Ground surface contour plan showing surface watercourses and bodies of surface water;
- Water table contour plan showing expected directions of groundwater movement; and
- Piezometric contour plans for each aquifer showing expected directions of groundwater movement.

Table 5. Hydrogeological Desktop Review and Site Reconnaissance Requirements

Screening Item	Typical sources, information and required visual verifications
Site History (Desktop) Review	• Topographic maps - Description and figure of existing surface topography and drainage patterns of the site. Description and figure of the proposed site alteration that clearly outlines ground elevations and change in drainage patterns • Drainage Conditions and Patterns - Description and figure of existing drainage patterns of the site and of the proposed site alteration that clearly outlines change in drainage patterns. • Physiography - landscape and the type of landforms present. • Geological Maps - an overview of the regional stratigraphy including a description of the overburden and bedrock materials and thicknesses of the formations • Aerial photographs. • MECP well records. • Surface Water Features - General description of surface water features on or near the site and their relationship to groundwater discharge and location to the water table. Figure of watercourses and wetlands on or near the site • EASR and PTTW Database searches • Results of any municipal, provincial or federal groundwater or watershed studies. • Results of geotechnical investigations which may be available for the site and surrounding areas.

Site Reconnaissance	• Verification of the location and nature of all permanent water courses and associated tributaries within 500 m of the site for the presence of active groundwater seepage or discharge. • Description of the location and nature of all significant water courses and associated features including wetlands, tributaries, closed depressions, kettle holes, and drainage ditches on and directly adjacent to the property. • Verification of the existing land use and presence of structures on and within 500 m of the site. • Verification of the presence of municipal piped water to the site and immediately adjacent areas. • General examination of site topography and drainage characteristics. • Inspection and description of significant geologic features or landforms on and directly adjacent to the site, including kettle holes, exposed bedrock outcrops, etc. • Discussions with local municipality to assess the location of any municipal or communal water supply wells. • Identification of such features as unstable areas, springs, water pounding (marshes) and vegetation. • Identification of the location of proposed BHs and/or TPs, as dictated by the project requirements and local site access conditions. • Determine the usability of any previously BHs for the purpose of the hydrogeological investigation. The Service Provider shall assume all responsibility in the determination whether these BHs may be used for the hydrogeological study. • Inspection of water courses, wetlands or low-lying areas for the presence of active groundwater seepage or discharge. • Visual inspection of any wells to obtain data such as size, well diameters and levels, physical conditions of water wells and current usage. Visual inspection shall be discussed with the Project Team prior to carrying out this work.

The Hydrogeological Screening Report shall include a description and assessment of the following:

- Quaternary and Bedrock Geology – Key topographic and geological features, including descriptions of the overburden thickness, composition and grain size distribution. For each bedrock lithologic unit, descriptions of the thickness, composition, texture and known relevant weathering, alteration and structural features (fractures, joints, bedding planes, faults and shear zones).
- Local Hydrogeology – Define hydrogeologic features (aquitards, confined aquifers, unconfined aquifers and semi-confined aquifers) including details of their depth, thickness, lateral continuity, porosity, vertical/horizontal hydraulic gradients, hydraulic conductivity, transmissivity, storativity/specific storage and the location/nature of aquifer recharge. Historical and seasonal groundwater level trends should be identified, and any pump test results and interpretations should be provided.

The Hydrogeological Screening Report shall provide an assessment of the vulnerability of local surface and groundwater resources with respect to potential impact from the proposed construction. The assessment of vulnerability will be based on a range of factors including, but not limited to, the following:

- The location and significance of surface water features at and around the site;
- The current and future use of the groundwater resource in the area for water supply;
- Assessment of the impact of the excavation on existing water wells;
- The vulnerability of local aquifer systems to contamination from surface sources (e.g. highly vulnerable areas may include exposed bedrock outcrop, shallow unconfined aquifers, or aquifers with thin confining layers);

- Assessment of the likely groundwater flow directions and locations of nearest wells, surface watercourses, and other sensitive features down gradient of the site;
- Assessment of the likely degree of connection of the shallow groundwater system with surface water features;
- Assessment of risk of groundwater flows and the influence on the highway drainage system; and
- Recommendations for any Hydrogeological Investigation and Design.

6.4.3 Hydrogeological Investigation Report

The Hydrogeological Investigation Report shall consist of factual information only, with no reference to recommendations, and consist of the following:

- Site description, including a detailed map and colour photographs of the study area and site, topography, vegetation, drainage, existing land use, structures, roadways, highways;
- Investigation procedures, including site investigation and laboratory testing procedures, decommissioning details, source of water supply for the investigation (if required) and traffic protection (if required), indicate all existing boreholes to be considered;
- Description of subsurface conditions, including soil, rock and groundwater conditions (regional and local);
- Description of hydrogeological regime, including hydrogeological units, transmissivities, hydraulic conductivities, groundwater flow directions, gradients and velocities in each major aquifer system encountered at the site;
- Description of groundwater / surface water interaction, including zones of seepage or discharge and recharge;
- Static groundwater levels and pressures (expressed in depths below ground surface and elevations);
- Description of the use of local groundwater and surface water resources, based on MECP well records, municipal records, interviews, etc.;
- Borehole logs with accurate geological descriptions per MTO standards;
- Hydrogeological cross-section(s) with geology, borehole locations and water level measurements;
- Miscellaneous section that identifies the name of the drilling company, the laboratory(s) where testing was performed, the persons who carried out the field supervision, and those persons who wrote and reviewed the report; and
- Appendices – Borehole Logs, Foundation Figures, Drawings and Plans, Laboratory Testing Results and Colour Photographs.

6.4.4 Hydrogeological Design Report

The Hydrogeological Design Report shall present discussion and recommendations for planning, design and operation purposes. The report shall provide an impact assessment and provide mitigation options for both short-term and long-term as applicable.

The Service Provider shall analyse field data and test results and must provide an assessment of potential impacts. The assessment of potential development impact may include, but is not limited to, a description of the following:

- Changes to water table elevation (including seasonal fluctuations);
- Changes in groundwater flow directions;
- Reduction to infiltration/recharge/discharge rates and volumes on varying time scales; and
- Impact to nearby receiving surface waters (wetlands, watercourses or other significant features).

The impact assessment should demonstrate a degree of understanding of site conditions such that the potential impact of the proposed development is recognized and discussed. In addition, the assessment should evaluate the potential changes to existing conditions of the recharge/discharge features and functions resulting from the proposed development.

The Hydrogeological Design Report shall present discussion and recommendations for Environmental Activity and Sector Registry (EASR) and Permit to Take Water (PTTW) applications based on the anticipated groundwater levels encountered, estimated hydraulic conductivity of the soils encountered and flow quantities. Discussions and recommendations shall include permitted and actual planned taking details as well as special conditions of the permit where applicable.

The Hydrogeological Design Report shall include recommendations for actions to mitigate potential impacts identified through the hydrogeological studies. Specific measures shall be described to mitigate the potential impacts. Mitigation recommendations shall address both the anticipated short-term and long-term impacts. Recommendations shall include but not be limited to the following:

- Environmental conditions on the subject property and any recommendations for additional work;
- The design of the site, including existing features and features that will be implemented to control or to mitigate potential groundwater and/or surface water interference or contamination;
- Monitoring – Preconstruction, During Construction and Post Construction;
- Feasibility of contingency plans that can be implemented to control potential groundwater and/or surface water interference or contamination;
- Ability of the site to comply with applicable provincial regulations, standards, policies and guidelines, and appropriate control measures needed to ensure compliance;
- The Service Provider shall identify and present a comprehensive overview of the advantages, disadvantages, relative costs and risks/consequences of viable alternative mitigation schemes in tabular format; and
- The Report should conclude a preferred alternative from a hydrogeological, technical and cost effectiveness perspective.

6.5 Rock Engineering Specialty

6.5.1 General

Foundation Engineering services shall consist of:

- Investigation to characterize the physical and mechanical properties of the rock;
- Application of rock mechanics to assess the mechanical behavior of rock and rock masses; and
- Providing engineering solutions for the design, construction and maintenance of structures built in or on rock and rock slope.

Foundations Engineering and Reporting for Rock Engineering shall consist of the following:

- Part A – Rock Engineering Investigation Report
- Part B – Rock Engineering Design Report

Other reporting formats and requirements, such as technical memoranda, may be specified in project specific TOR and/or during engineering design liaison.

Project specific TOR will outline the required investigation and assessment, scope of the work and reporting requirements within the specified study area and shall govern where any conflict exist with this guideline. The Service Provider undertaking the Rock Engineering assignment must refer to project Terms of Reference (TOR) for project specific requirements to successfully complete all the necessary tasks.

6.5.2 Rock Engineering Investigation Report

The Service Provider shall select the method of investigation to characterize the physical and mechanical properties of the rock. The characterization shall consider anisotropy, heterogeneity and discontinuity.

The method of investigation shall consider the site conditions and project requirements. Methods of investigation include visual observation, geological, geophysical, Lidar, Sonar and rock coring.

The Foundation Investigation Report for Rock Engineering shall consist of the following sections:

- Introduction;
- Site Description – including topography, vegetation, drainage, existing land use, structures;
- Investigation Procedures – including site investigation, site preparation, equipment and methods, laboratory testing, decommissioning details, source of water supply for the investigation (if required) and traffic protection (if required). Indicate all existing data to be considered;
- Description of Subsurface Conditions – including site geology, rock and groundwater conditions, if encountered. Subsurface conditions shall be reported in text format,
- Miscellaneous – identifies the name of the drilling company, where the laboratory testing was performed, the persons who carried out the field supervision, and the persons who wrote and reviewed the report; and
- Appendices –Logs, Figures and Drawings, Laboratory Testing Results and Colour Photographs.

The Service Provider shall provide a detailed rock description of rock mass structure that includes the intact rock and the nature and occurrence of discontinuities, in-situ stresses, groundwater, durability, weathering and erosion. Requirements for intact rock description are presented in **Table 6**.

Table 6. Rock Engineering – Intact Rock Description

Item	Minimum Rock Description Requirements
Rock Mass Structure	For Intact Rock: • Stress-strain curves in compression produced by Unconfined Compressive Strength (UCS); • Deformation Moduli (Elastic modulus, poisson ratio); • Peak strength; • Post peak behaviour; • Point Load Indices; and • Stiffness, Strength and Brittleness

	For discontinuities, description of all the fractures and planes of weakness occurring within the rock mass that govern the size and shape of blocks, including: • Block Size and Shape; - Size(persistence) - Spacing(frequency) - Orientation - Continuity • Shear Resistance; - Wall roughness, aperture size, infilling materials, • Joints and faults; • Bedding planes; and • Fissures.
In-situ Stresses	• Pre-existing state of stress.
Groundwater	• Secondary permeability – flow through discontinuities and connectivity. • Groundwater chemistry • Water under pressure decreasing effective stress that could lead to instabilities.
Durability	• Slaking durability.
Weathering and Erosion	• Freeze thaw action - Ice jacking • Vegetation cover - Root jacking • Surface water • Groundwater seepage • Shoreline Erosion - Wave action

6.5.3 Rock Engineering Design Report

The Rock Engineering Design Report shall include discussion and recommendations for design purposes. Discussions and recommendations provided shall be in accordance with the requirements of the most recent edition of the codes, manuals, and guidelines in effect for MTO projects.

Rock Engineering Design Report shall include the following minimum rock engineering analysis and assessments (where applicable):

- Identification of basic failure mechanisms:
  - Planer;
  - Wedges;
  - Toppling;
  - Ravelling; and
  - Gravity Falls.
- Stability assessment shall consider:
  - Geometry (Height, Length, Slope);
  - Rock Mass Structure; and
  - Weathering;
    - Freeze Thaw
    - Vegetation Cover
    - Erosion

- A foundation assessment shall be provided for:
  - suitability of foundations on bedrock considering degree of weathering, discontinuities, detached slabs of bedrock;
  - rock sockets into bedrock; and
  - suitability and performance of existing structures, utilities, foundations located at crest of rock excavation cut.

Rock Engineering Design Report shall provide a summary of remedial options in a tabular format which identifies and presents overview assessments of the advantages, disadvantages, risks/consequences and relative costs of the different options. Options to be considered include:

- Do Nothing;
- Monitoring;
- Rock removal (OPSS 202) to remove unstable or potentially unstable rock:
  - Manual scaling,
  - Machine scaling,
  - Trim blasting,
  - Recommendations for the limits and method of rock removal shall be provided; and
  - High resolution images of each rock mass requiring rock removal.
- Rock Stabilization (OPSS 203)
  - Establish the limits of the existing rock slope (i.e. offset distance from edge of pavement to face of cut, rock slope height, length and width at the site location;
  - Limits to be recommended;
  - Colour images of locations to be stabilized;
  - Rock bolts:
    - Spacing and inclination of rock bolts
    - Size and properties of the bolts if different from the bolts specified in OPSS 203.
    - Dimensions of the holes to be drilled for grouted rock bolts.
    - Grout material to fill annular space between drilled hole and rock bolt.
    - Testing requirements including acceptance criteria
  - Rock drains,
  - Shotcrete, or
  - Concrete buttresses
    - The size, properties, and installation pattern and depths of dowels and reinforcing steel; and
    - Properties of concrete.

The Service Provider shall develop necessary special provisions to be included in the contract package for all related aspects of the work.

7 CONTRACT PACKAGE REVIEW

The Service provider shall complete a comprehensive review of the foundations engineering aspects of the 90% contract documents to ensure their integration into the contract documents.

The Prime Service Provider shall provide their Foundations Engineering service provider the entire 90% contract document package for their review and comments. The prime service provider shall submit their Foundations Engineering service provider's comments regarding the 90% contract document package to MTO Foundation a minimum of one (1) week prior to the 90% contract document review meeting.

Where directed by MTO Foundations Section depending on their assessment of the complexity of the project the prime service provider shall arrange a 1-day structural-foundation task group meeting at MTO prior to the 90% contract document review meeting to be attended by the MTO project manager, MTO Foundations, MTO Structural, prime service provider, Structural Engineering service provider and Foundations Engineering service provider for the purpose of reviewing foundations related aspects and ensuring the Foundations Engineering requirements are adequately integrated into the contract documents.

Following the 90% contract document review meeting, the Prime Service Provider shall submit to MTO Foundations their Foundations Engineering service provider's signed off QC Plan confirming that the final contract documents have been revised to address all the foundations concerns raised together with an itemized list of the identified concerns and related measures to address those concerns.

8 INDEPENDENT QUALITY REVIEW OF FOUNDATION ENGINEERING COMPONENT OF MTO PROJECTS

The Service provider may be involved in an independent technical third party quality review (peer review) of services and deliverables rendered by a second party.

Independent technical quality review shall be conducted in accordance with PEO Guideline *Professional Engineers Reviewing Work Prepared by Another Professional Engineer* (October 2011) and generally may include the following tasks:

- Review of Foundation Engineering Terms of Reference (TOR), if applicable.
- Review of foundation deliverables (such as memorandums and reports) to determine the Consultant's performance in providing the deliverables as would be required by MTO for similar consultant assignments.
- Review and assess compliance and conformance of all foundation related documentation including but not limited to memorandums, reports, milestone design package drawings, and preliminary general arrangement drawings in accordance with the latest version of the following documents:
    - Canadian Highway Bridge Design Code (CHBDC) CSA-S6.
    - All applicable MTO manuals, guidelines, reports, memos, guidelines, standards, and relevant publications.
- Technical quality independent peer review of Contract Package (i.e. contract drawings, tender documents including standard and non-standard specifications) at various design phases to confirm Foundation Engineering designs, recommendations, and review comments have been satisfactorily incorporated and addressed in the Contract Package.

- Liaise with other Ministry of Transportation offices as required to identify environmental, design and construction issues.

The Service Provider undertaking the Independent technical quality review must refer to project Terms of Reference (TOR) or Work Order for project specific technical requirements, staffing requirements, deliverable and submission schedule to successfully complete all the necessary tasks.

9 OWNER ACCEPTANCE – FOUNDATION ENGINEERING

9.1 General

The Foundations Specialist shall provide foundation engineering services to ensure that the construction of structure foundations and related earth/rock works are carried out in accordance with the Contract Documents. The Foundation Specialist shall report to the CA. The Foundation Specialist is required to provide inspections, liaison, technical assistance, support and reporting as required during and following the construction of the structure, foundations and related earth/rock works.

The Foundations Specialist shall liaise with the project team including the CA team, the design service provider, MTO Operations Office, MTO Planning and Design, MTO Foundations Section, MTO Structural Section and other relevant functional offices. The Foundations Specialist shall be required to provide expert opinion and recommendations on the Contractor’s clarifications, change proposals and submissions related to foundations-related Work.

9.2 Staffing and Qualifications

The Foundations Specialist Services shall be sub-contracted by the CA Service Provider from the list of foundation firms registered and approved in MTO’s Registry, Appraisal & Qualification System (RAQS) for the corresponding Foundation Engineering specialty and Complexity.

The Foundations Specialty Plan shall identify the name(s) of the person(s) responsible for the Foundations Specialist Services to be provided in this assignment. The Foundations Specialty Plan shall include a Foundations Specialist, a Senior Foundations Engineer and the RAQS approved Key Contact. The number of years of experience for the Foundation Specialist and the Senior Foundations Engineer is typically 5 and 10 years respectively but this is to be customized on a project specific basis.

9.3 Foundations Specialist Services, Deliverables and Records

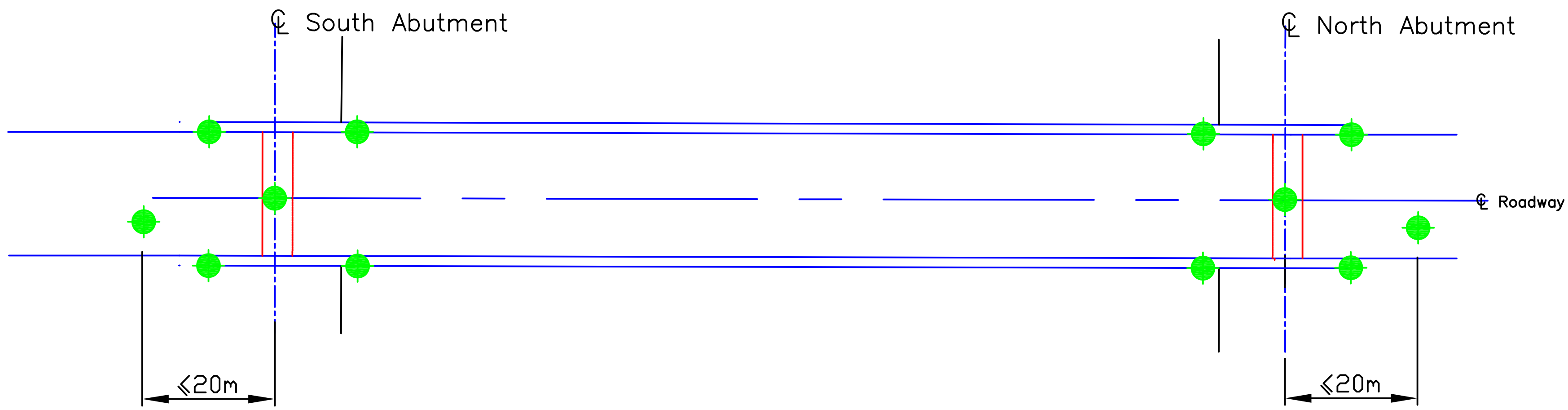
The Foundations Specialist shall:

- Conduct a background review of the project, Foundation Investigation and Design Reports, relevant Contract Drawings and Contract Documents;
- Conduct site visits as per CAITM during foundation activities and be available on-call for immediate assistance to the CA as required during foundation construction;
- Conduct full time, onsite inspection in accordance with CAITM requirements;
- Conduct testing to verify the installation conform with the contract documents and as amended;

- Conduct visual monitoring of the materials and procedures;
- Identify and notify the CA of any quality control and quality assurance concerns, deviations, deficient or non-conforming work or other foundation-related non-compliance situations to the Contract requirements;
- Provide “front-line” interpretation for inquiries and clarifications for contract and site issues;
- Review questions and clarifications and provide immediate recommendations to the CA;
- When required (upon discussion with the MTO Operations), liaise with the MTO Foundations Office and/or Designer to minimize delays to the overall construction schedule;
- Complete the milestone inspections and submit inspection report(s) in accordance to the latest CAITM/CAITM Amendment requirements; and
- Complete a final inspection report which is signed and sealed by two (2) professional engineers licensed in Ontario. The report shall summarize all inspection reports and confirms that the foundations work has been carried out in general conformance with the contract documents.

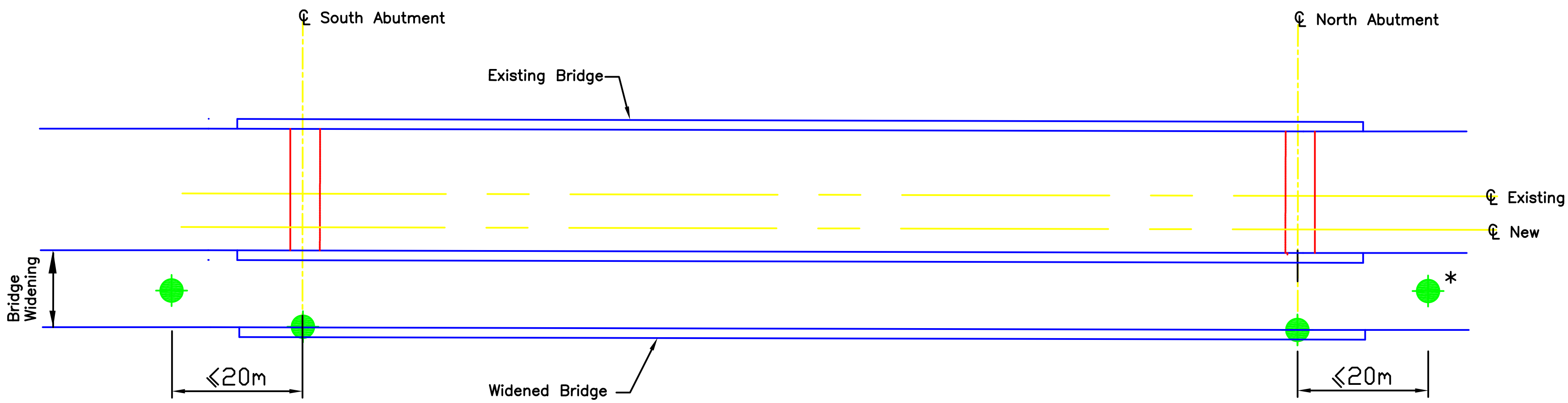
Written recommendations and communication records are to be provided in all cases to the MTO Foundations Office and MTO designer. All communications with the MTO project team staff must be maintained and distributed in a timely manner. Any communication provided to MTO shall be submitted through the CA Service Provider and MTO Operations Office.

Appendix A
Sample Borehole Location Plans



Foundations Section	Oct 2020

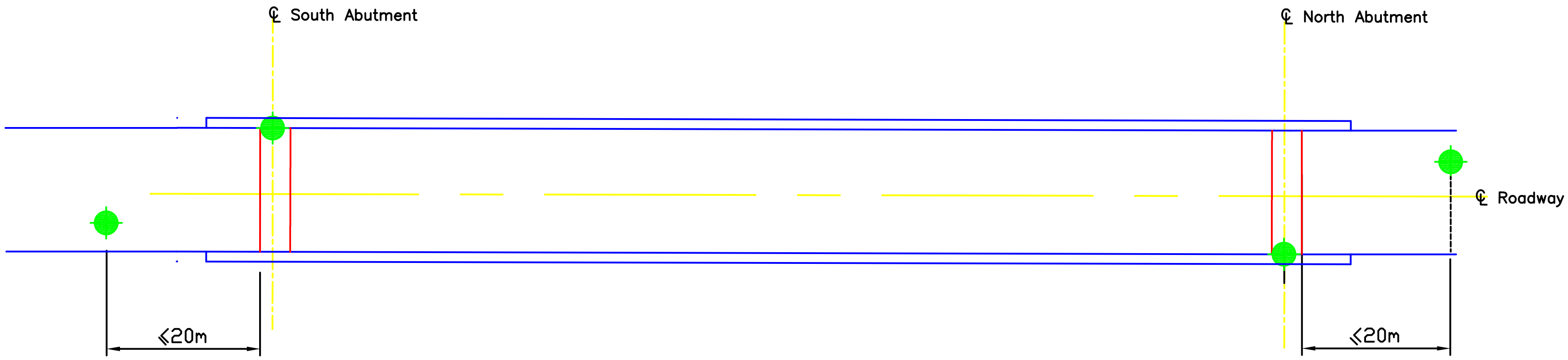
Conceptual Borehole Layout
Bridge – New Replacement
(Shallow Bedrock)



* For Overpass Structure Configuration

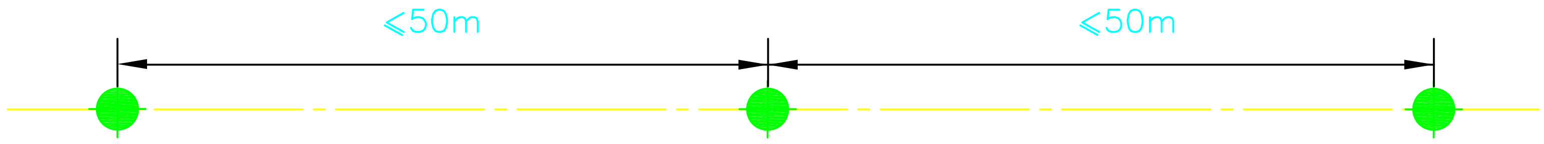
Foundations Section	Oct 2020

Conceptual Borehole Layout
Bridge Widen



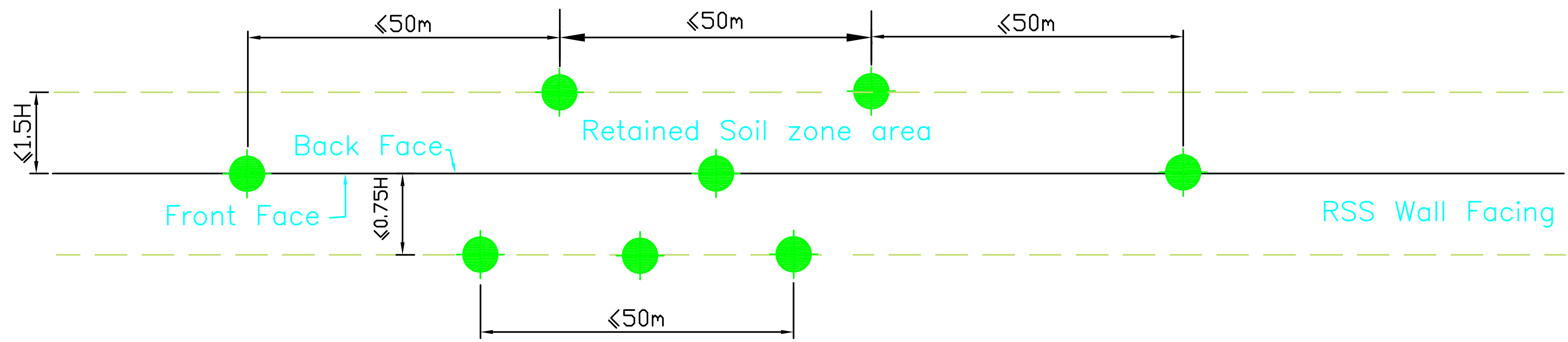
Foundations Section	Oct 2020

Temporary Bridge, Re-use of Foundation and Pedestrian Bridge Borehole Layout



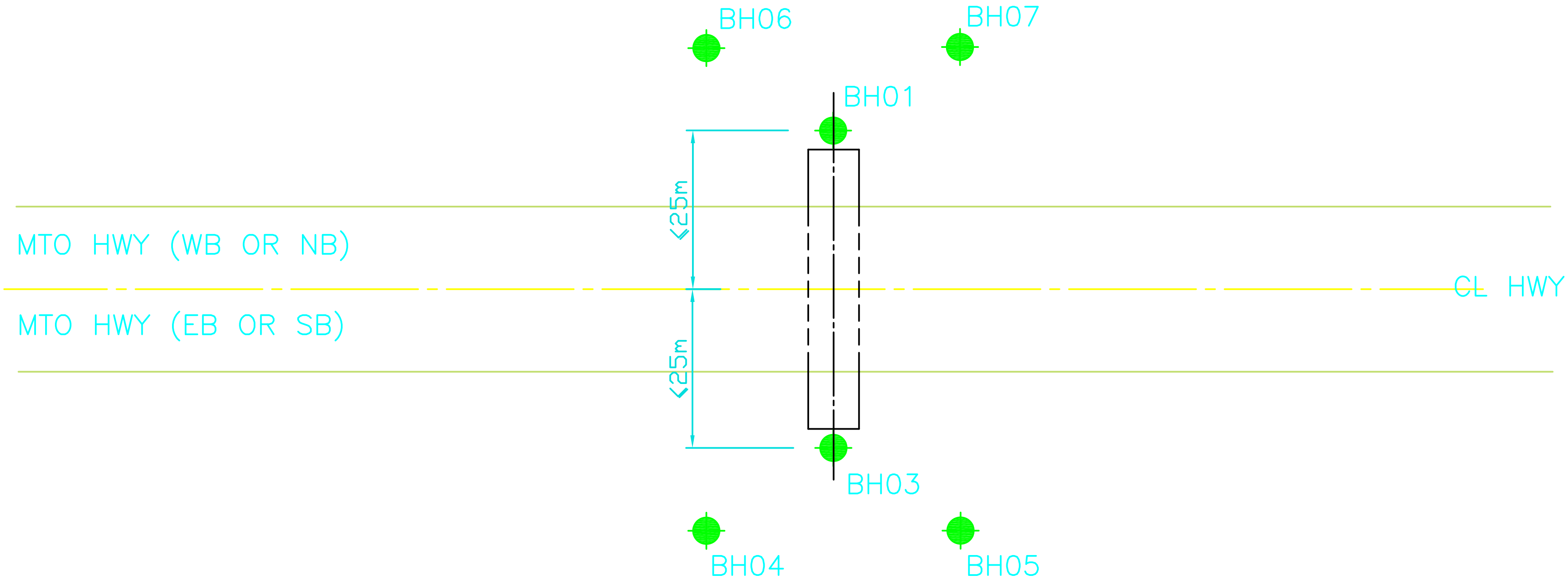
Foundations Section	Oct 2020

Retaining Wall Borehole Layout



Foundations Section | Oct 2020

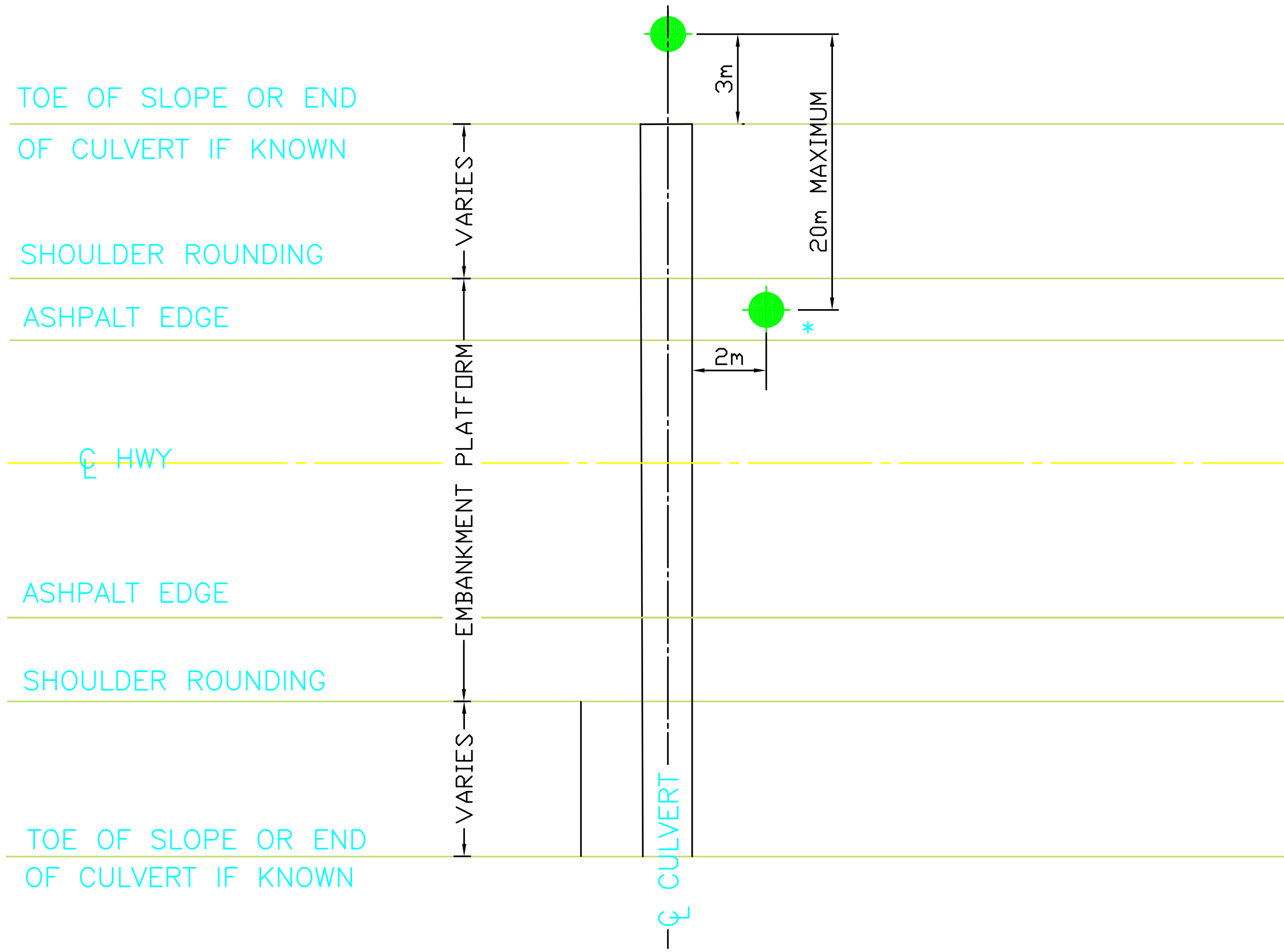
RSS Wall Borehole Layout



Foundations Section | Oct 2020

NEW / REPLACEMENT CULVERT

BOREHOLE LAYOUT WITH COFFERDAM BOREHOLES

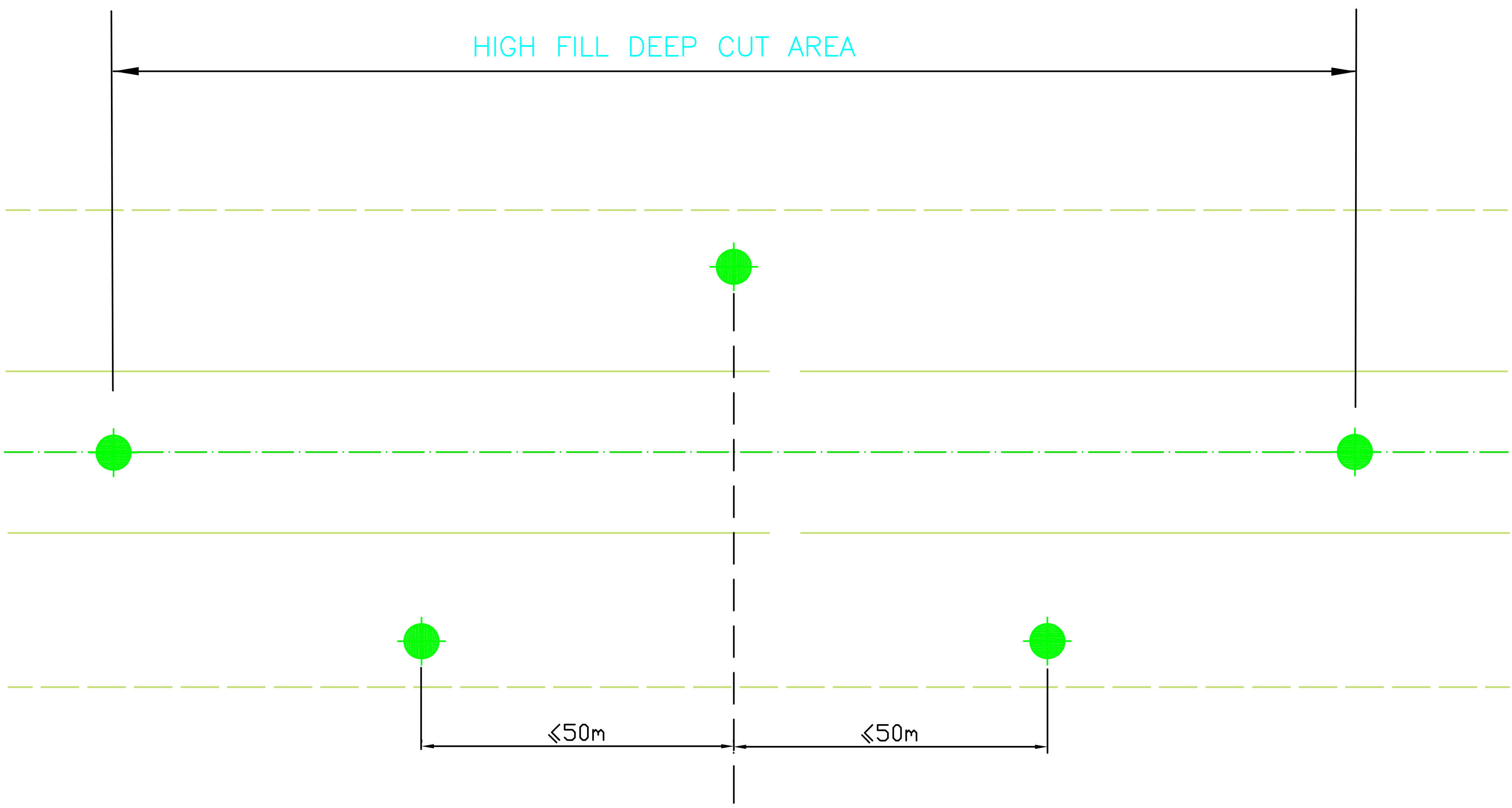


LEGEND

* IF EXISTING EMBANKMENT IS COMPOSED OF ROCK FILL THESE BOREHOLES MAY BE RELOCATED

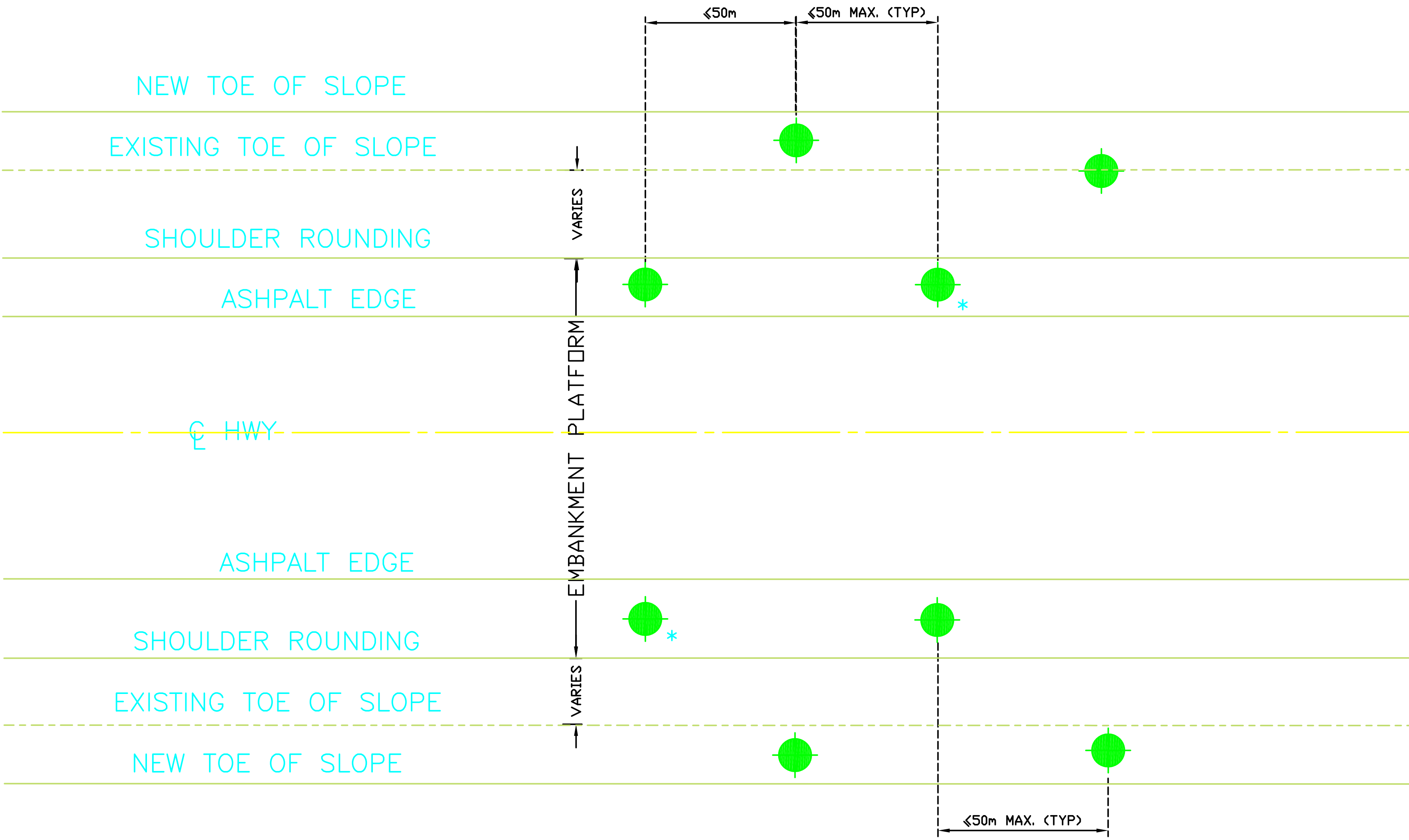
BOREHOLE

Foundations Section	Oct 2020
Culvert Extension– One end only Borehole Layout	



Foundations Section	Oct 2020

New Alignment
Deep Cut & High Fill Embankment (>4.5m in Height)
Borehole Layout



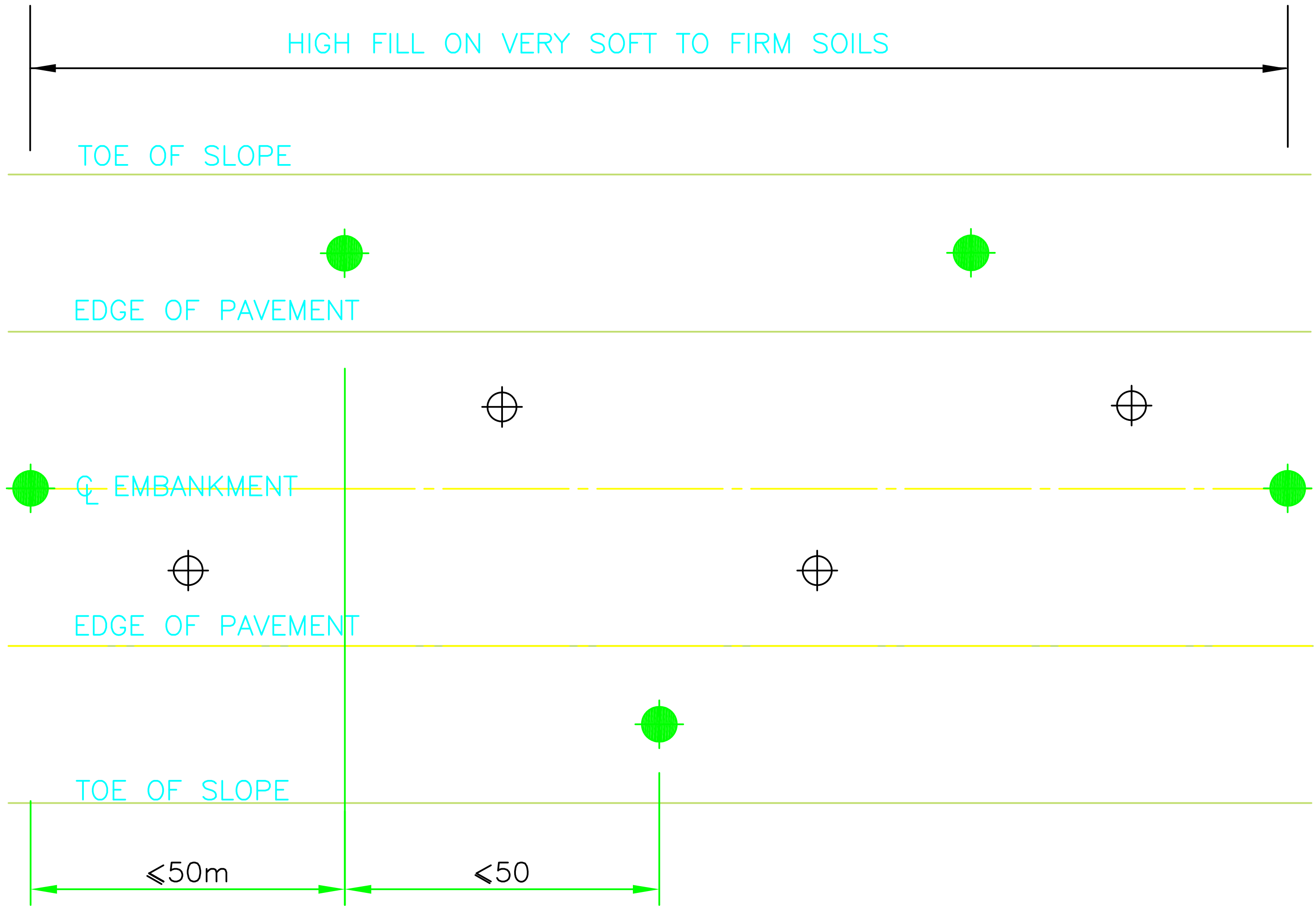
LEGEND

* IF EXISTING EMBANKMENT IS COMPOSED OF ROCK FILL THESE BOREHOLES MAY BE RELOCATED

● BOREHOLE

Foundations Section	Oct 2020

High Fills/Embankments
Embankment Widening – Both Sides
Borehole Layout



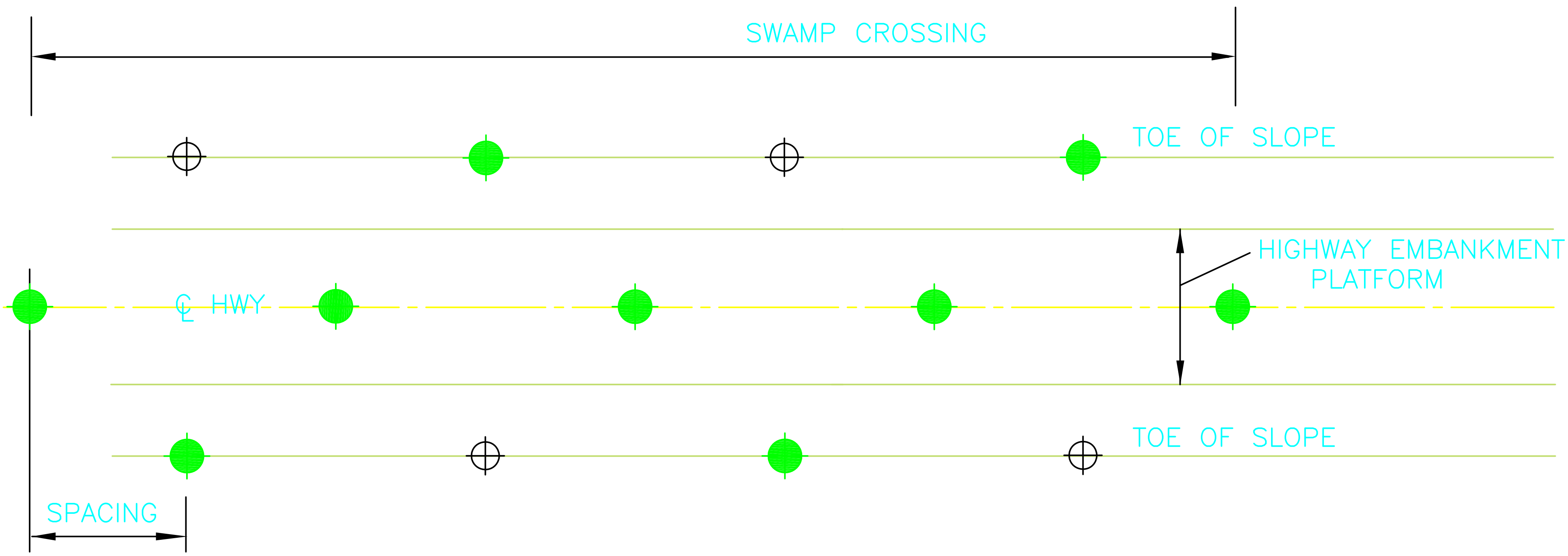
LEGEND

Borehole

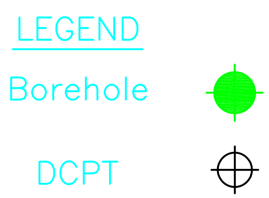
DCPT

Foundations Section	Oct 2020

High Fill on Very Soft to Firm Soils
Borehole Layout

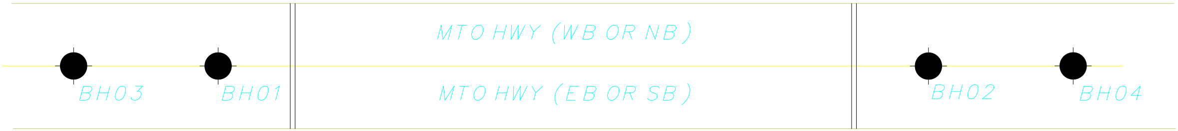


Length	Borehole Spacing
≤250m	25m
≥250m	50m



Foundations Section	Oct 2020

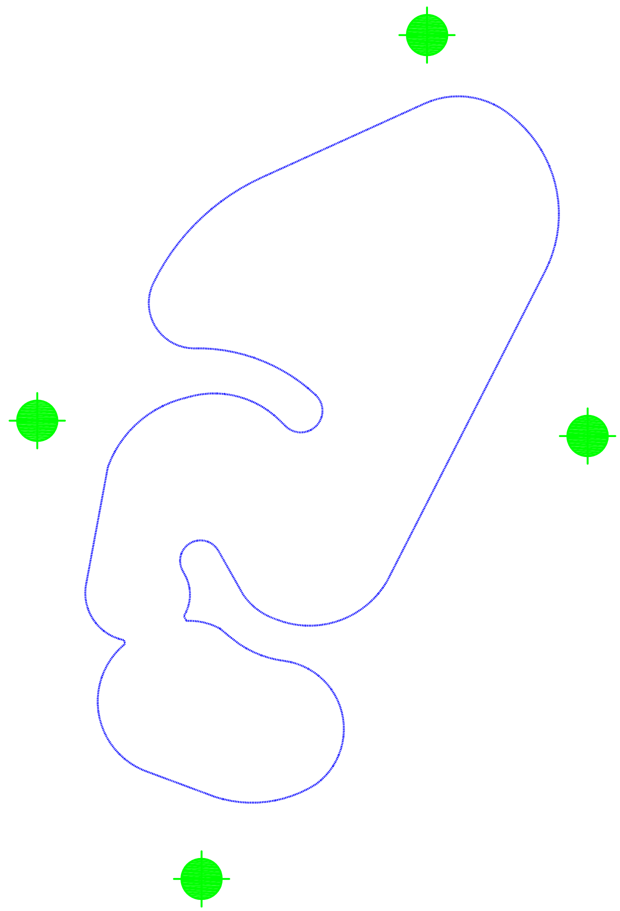
Swamp Crossing Borehole Layout



Borehole Spacing	Length
<50m	When TPS is < 100m (TYP)
<75m	When TPS is >100m (TYP)

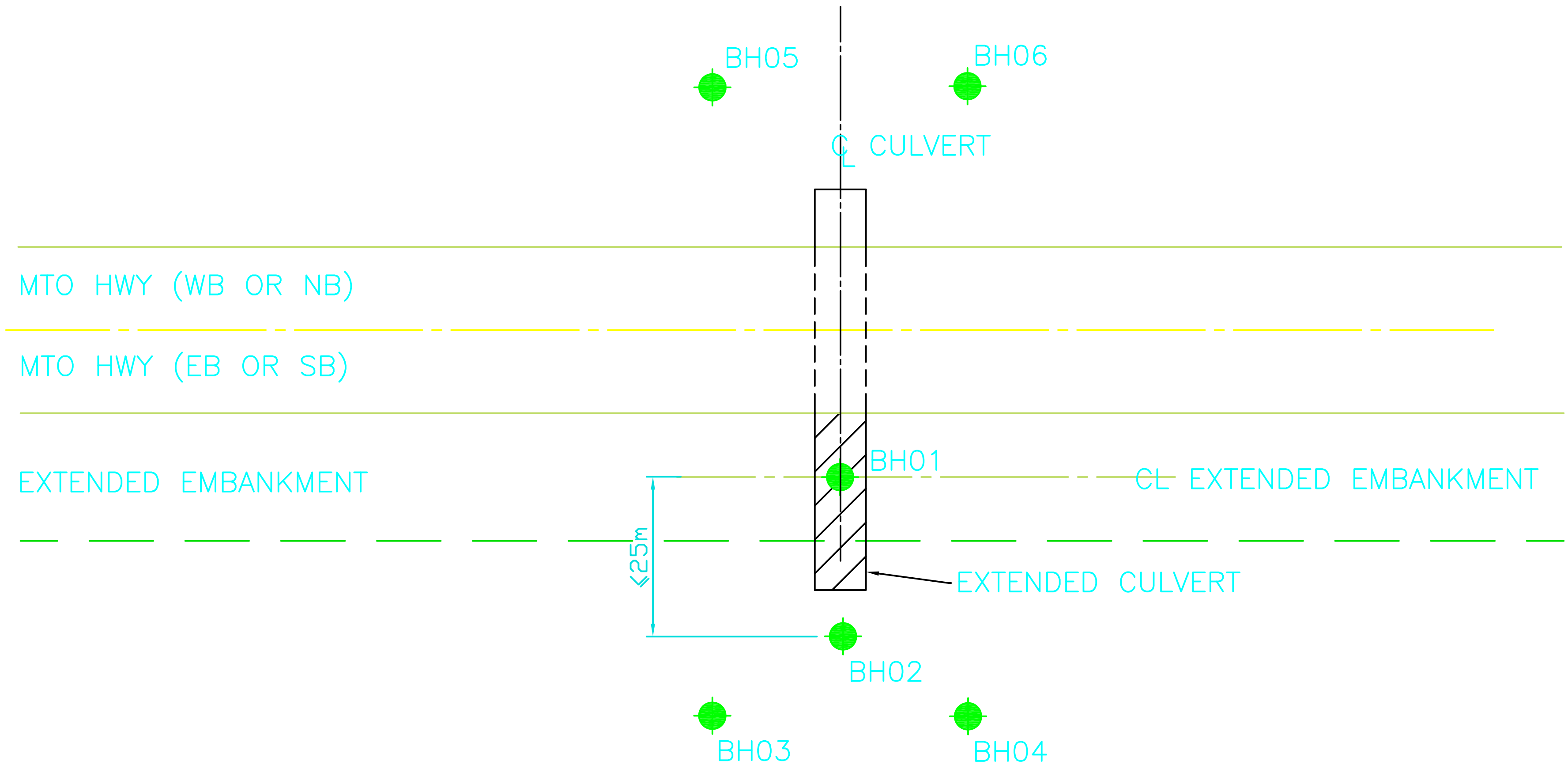
Foundations Section | Oct 2020

MINIMUM TEMPORARY PROTECTION SYSTEM (TPS) BOREHOLE LAYOUT



Foundations Section	Oct 2020

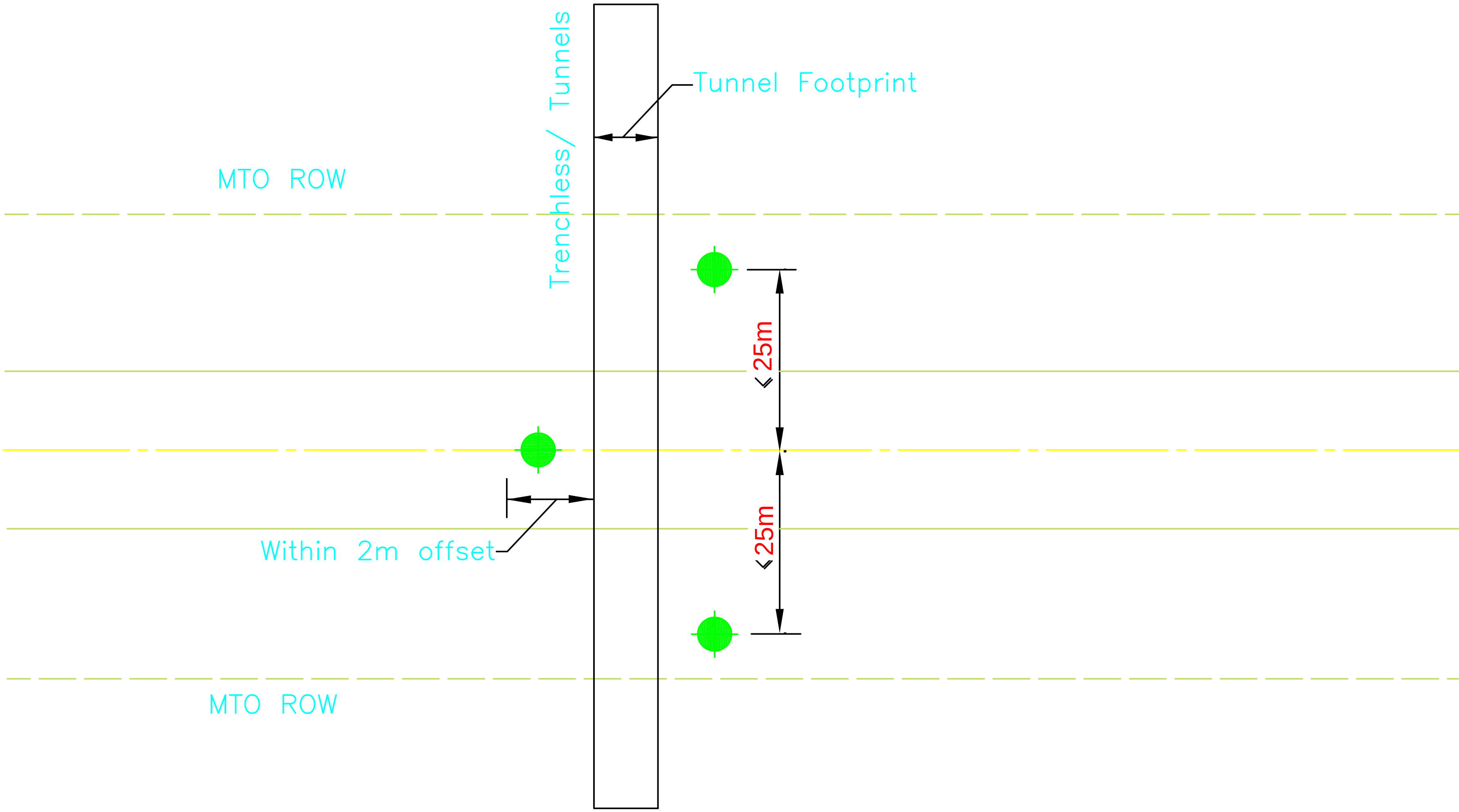
Minimum Stormwater Management Boreholes



Foundations Section | Oct 2020

CULVERT EXTENSION

MINIMUM BOREHOLES WITH COFFERDAM BOREHOLES



Foundations Section

Oct 2020

Tunnels / Trenchless Borehole Layout

Appendix B

MTC Soil Classification Manual

MTC
SOIL CLASSIFICATION
MANUAL

Ministry of
Transportation and
Communications
Ontario

MTC
SOIL CLASSIFICATION
MANUAL

ENGINEERING MATERIALS OFFICE
DOWNSVIEW
JANUARY 1980

NOTES:

The M.T.C. Soil Classification Manual supersedes the draft of the "M.T.C. Soil Classification System, published by the Engineering Materials Office in January, 1979.

Additional copies of the Manual may be obtained by request, addressed to the M.T.C. Record Services Office, 1201 Wilson Ave., Downsview, Ontario. M3M 1J8.

Orders by External Individuals or Agencies should be accompanied by a cheque or money order of $5.00 for each copy requested, payable to the Treasurer of Ontario.

FOREWORD

Upon the recommendation of the Regional Geotechnical Heads it was decided that the Unified Soil Classification System, with some modifications, should be adopted by this Ministry. This new policy was announced in Ministry Directive B-13, Provincial Roads, dated 1978 11 06.

Accordingly, the Manager of the Engineering Materials Office appointed a Task Force to prepare a manual for the uniform usage of this modified system which is now known as "The MTC Soil Classification System".

This publication, prepared by the Task Force, contains a detailed description of the MTC Soil Classification System and explains the procedures for classifying soils, both visually in the field and by laboratory methods.

This classification system shall be used by Ministry staff for the identification and description of soils in the field, based on visual examination and simple manual tests. This system shall also be used in delineating particle size characteristics, liquid limit, and plasticity index, when precise classification is required.

The description of soil layers in borelogs, Soils Design Reports, Foundation Investigation and Design Reports, etc., shall be carried out using the soil terminology and group symbols of the new system.

Suggestions and queries pertaining to the MTC Soil Classification System should be addressed to any member of the Task Force. The Task Force members are:

A.K. Barsvary	Engineering Materials Office (Chairman)
M. Devata	Engineering Materials Office
A.J. Hanks	Engineering Materials Office
S. Chen	Eastern Region
S.G. Wilson	Northern Region

TABLE OF CONTENTS

GLOSSARY

Aggregate – Particles of natural rock or artificial solid materials which satisfy the gradation and quality requirements of the type of material specified.

Clay – Fine grained soil having particles smaller than 75 μm that can be made to exhibit plasticity (putty like property) within a range of water contents, and which exhibits considerable strength when dry.

Coarse-Grained Soils – Soils with more than half of the particles between 75 mm and 75 μm.

Cobbles – Rock fragments, usually rounded or subrounded, with an average dimension between 75 mm and 200 mm.

Cohesionless Soil – A soil that, when unconfined and air-dried, has little or no strength, and that has little or no cohesion when submerged.

Cohesive Soil – A soil that, when unconfined and air-dried, has considerable strength, and that has significant cohesion when submerged.

Dilatancy – The expansion of cohesionless soils when subjected to shearing deformation.

Earth – Earth and soil are synonymous, but the term "earth" is also used as a pay item in contract documents to distinguish any excavation or fill material from rock or granular as specified in MTC Specification Form 200.

Effective Diameter – (D_{10}) – Particle diameter corresponding to 10% finer on the grain-size curve.

Fine-Grained Soils – Soils in which more than half of the particles finer than 75 mm are in the silt and clay range.

Fines – Portion of a soil finer than 75 μm.

Glacial Till – Material deposited by glaciation, usually composed of a wide range of particle sizes, which has not been subjected to the sorting action of water.

Gradation – (Grain Size Distribution). Proportion of material of each grain-size present in a given soil.

Grain Size Analysis – (Mechanical Analysis). The process of determining gradation.

Granular (Soil, Material) – (a) Synonymous to cohesionless soil or material.
(b) Coarse-grained soils from which base and sub-base aggregates can be produced.

Granular 'A' and 16 mm Crushed 'A' & 'B'	– Mixtures of sand and crushed rock, gravel, or slag with specified gradation bands complying with the requirements of MTC Specification Form 1010, usually used for base courses or shoulders.
Granular 'B' & 'C'	– Sands and/or gravels of various proportions (may contain traces of cobbles), having specified gradation bands and complying with the requirements of MTC Specification Form 1010, usually used for sub-base course aggregates.
Granular 'D'	– Crushed rock screenings with a gradation band specified in MTC Specification Form 1010, used as an alternate subbase material.
Gravel	– Rounded, subrounded or angular particles of rock that will pass a 75 mm sieve and be retained on a 4.75 mm sieve.
Ground Water	– Water that is free to move through a soil mass under the influence of gravity.
Ground Water Level	– Elevation at which the pressure in the water is zero with respect to the atmospheric pressure.
Liquid Limit – (w_L)	– (a) The water content corresponding to the arbitrary boundary between the liquid and plastic states of consistency of a soil. (b) The water content at which a pat of soil, parted by a groove of standard dimensions, will flow together for a distance of 13 mm under the impact of 25 blows in a standard liquid limit apparatus.
Muck	– An organic soil of soft to very soft consistency.
Optimum Moisture Content (w_{opt})	– The water content at which a soil can be compacted to a maximum dry density by a given compactive effort.
Organic Soil	– Soil with a high organic content, may contain shells and/or fibres. In general, organic soils are very compressible and have poor load-sustaining properties.
Overburden	– (a) Earth overlying granular deposits which must be removed prior to extraction of the granular deposit. (b) Earth or other unconsolidated materials, either transported or formed in place, overlying bedrock.
Parent Material	– (a) Material from which a soil has been derived. (b) The unconsolidated material, unaltered by weathering, from which the overlying 'A' and 'B' horizons developed.
Peat	– A mass of organic matter usually fibrous in texture in various stages of decomposition, generally dark brown to black in colour and of spongy consistency.
Plasticity	– The property of a soil which allows it to be deformed beyond the point of recovery without cracking or appreciable volume change.

Plasticity Index – (I_P) – Numerical difference between the liquid limit and the plastic limit.

Plastic Limit – (w_P) – (a) The water content corresponding to an arbitrary boundary between the plastic and the semi-solid states of consistency of a soil.
(b) Water content at which a soil will just begin to crumble when rolled into a thread approximately 3 mm in diameter.

Rock – Natural solid mineral matter occurring in large masses or fragments.

Sand – Particles that will pass a 4.75 mm sieve and be retained on a 75 μm sieve.

Silt – Particles passing a 75 μm sieve that are non-plastic or very slightly plastic and that exhibit little or no strength when air-dried.

Soil – (Earth). Sediments or other unconsolidated accumulations of solid particles produced by the physical and chemical disintegration of rocks, and which may or may not contain organic matter.

Soil Profile – Vertical section of a soil showing the nature and sequence of the various layers, as developed by deposition or weathering, or both.

Specific Gravity – The old term 'specific gravity' is replaced by the term 'relative density'.

Stone – Crushed or naturally angular particles of rock that will pass a 75 mm sieve and be retained on the 4.75 mm sieve.

Water Content – (w) (Moisture Content) – The ratio expressed as a percentage of the mass of water to the mass of solid particles in a given soil mass.

INTRODUCTION

The term soil or earth, in engineering practice, is defined as sediments or other unconsolidated accumulations of solid particles produced by the physical and chemical disintegration of rocks, and which may or may not contain organic matter. Only hard rock, which remains firm after exposure, is excluded from the definition.

To the engineer or technician engaged in the design and construction of roads, foundations and earthwork, the physical properties of soil, such as density, permeability, strength, compressibility and interaction with water, are of primary importance. It is apparent that a standard system of describing the soil and placing it into a category or group which has distinct engineering properties is most desirable in order to provide a common language for the transmission of information and experience. **The description of soil** usually gives detailed information on the gradation, plasticity, colour, particle characteristics, moisture content, strength and the like. Few if any soils will have identical descriptions. **Soil classification** on the other hand, places a soil in one of a limited number of groups, on the basis of a few key characteristics. These characteristics must be easy to measure and must be significant in indicating the engineering properties and performance of the particular soil.

Such a classification system was originally proposed by Professor A. Casagrande in 1942 for the U.S. Corps of Engineers to be used in airfield construction. In 1952, after some modification, this sytem was adopted by the U.S. Bureau of Reclamation and was named the "Unified Soil Classification System". The advantages of the Unified System in identifying soils on the basis of their engineering properties was soon recognized and as a result it gained wide acceptance all over the world. Casagrande later suggested an extension to his classification and some of the users also made slight modifications to suit their needs. The principles of the original system however, remain the same. The MTC Soil Classification System introduced in this publication is basically the Unified System modified by Casagrande with some further slight changes implemented by the Task Force including particles larger than 75 mm and metric conversion.

Chapter 1

THE CLASSIFICATION SYSTEM

(1.1) Boulders and Cobbles

Particles larger than 75 mm are excluded from the Unified Soil Classification System. However, the amount of such material is of great importance in Ministry practice, hence any description of soils should always contain information on these particles. They are classified into boulders with an average dimension larger than 200 mm and cobbles with particles between 200 mm and 75 mm.

Because of the large particle sizes, the percentage and dimensions of these materials can only be adequately described by visual observations of excavations or exposures.

If more than half of a mixed coarse grained stratum is larger than 75 mm the deposit shall be called boulders and/or cobbles. The portion of the material smaller than 75 mm shall be described by the constituent soils according to the rules of the MTC Classification System. (See Section 1.3 and 1.4.)

Example: A material consisting of 60% cobbles, 32% gravel and 8% sand may be described thus: *Gravelly cobbles, trace of coarse sand.*

If the material contains less than 50% boulders and/or cobbles, the "oversize" particles should be removed and the classification should be carried out on the portion of the material smaller than 75 mm, according to the rules of the MTC Classification System. The description of the soil should contain information on constituent particles larger than 75 mm.

Example: Soil in a test hole, consisting of approximately 45% gravel, 50% sand and 5% silt and having a few randomly distributed cobbles may be described thus: *Well graded gravelly sand, trace of silt, a few random rounded cobbles of 100 mm to 200 mm size throughout the deposit.*

(1.2) Soil Categories

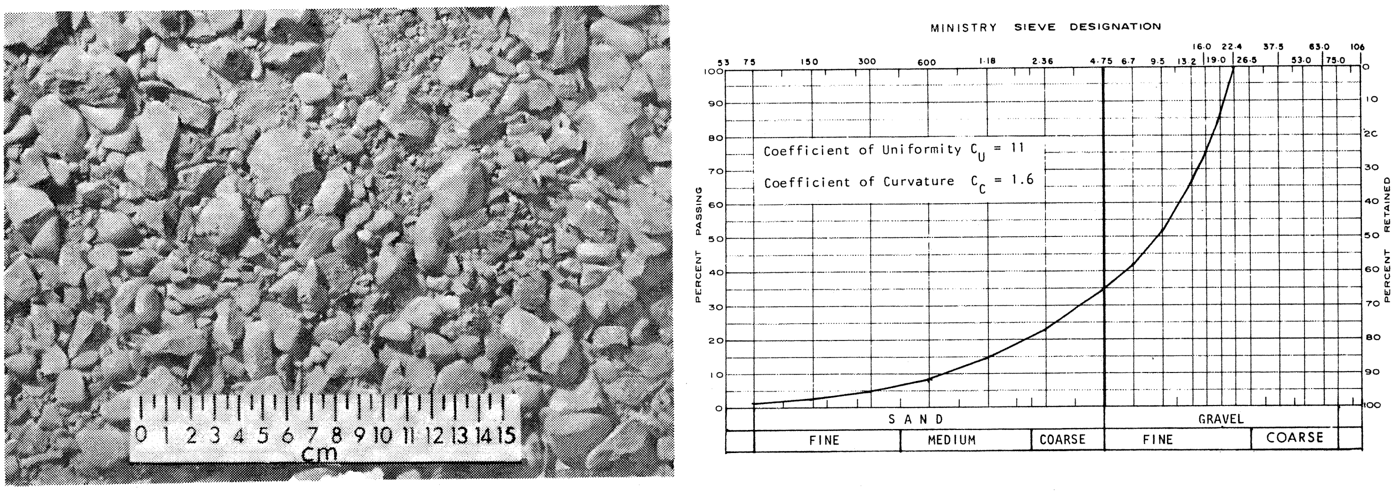
The system is based upon the sizes of the particles smaller than 75 mm, the distribution of the particle sizes, and the properties of the fine-grained portion. First, the soils are divided into three major categories: (1) coarse-grained soils, (2) fine-grained soils, and (3) highly organic soils. Second, the soil is subdivided by either gradation or plasticity characteristics.

Coarse-grained soil (sand and gravel) is that material which has particle sizes between 75 mm and 75 μm. The smallest size in this category is about the smallest particle size which can be distinguished with the naked eye.

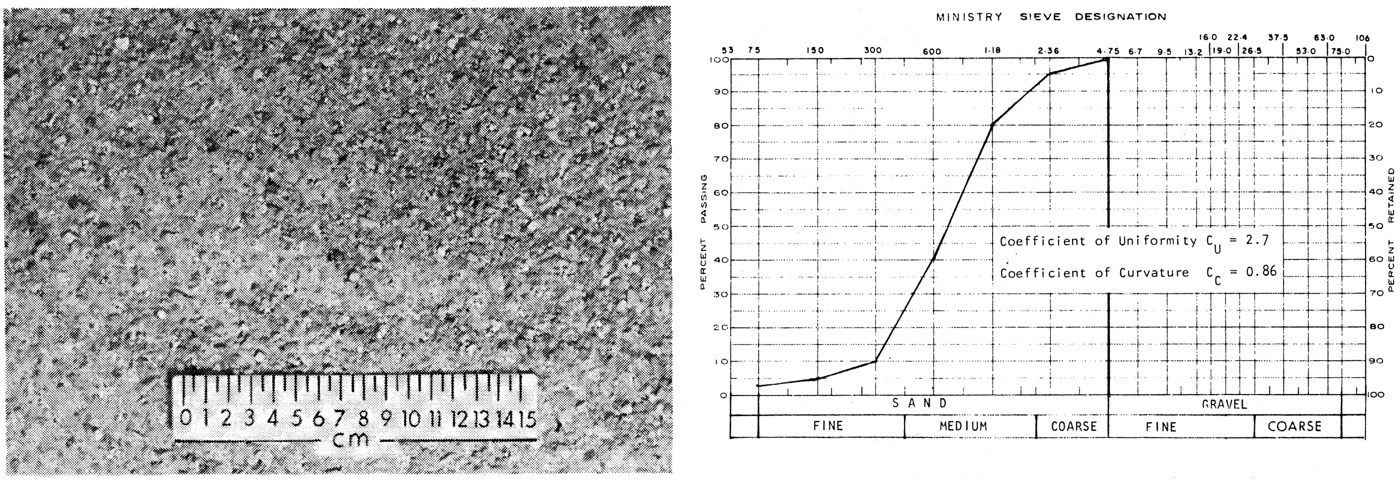
Photographs of typical coarse-grained soils and the corresponding grain size curves are shown in Figure 1.

Fine-grained soil (silt and clay) is that material having particle sizes smaller than 75 μm.

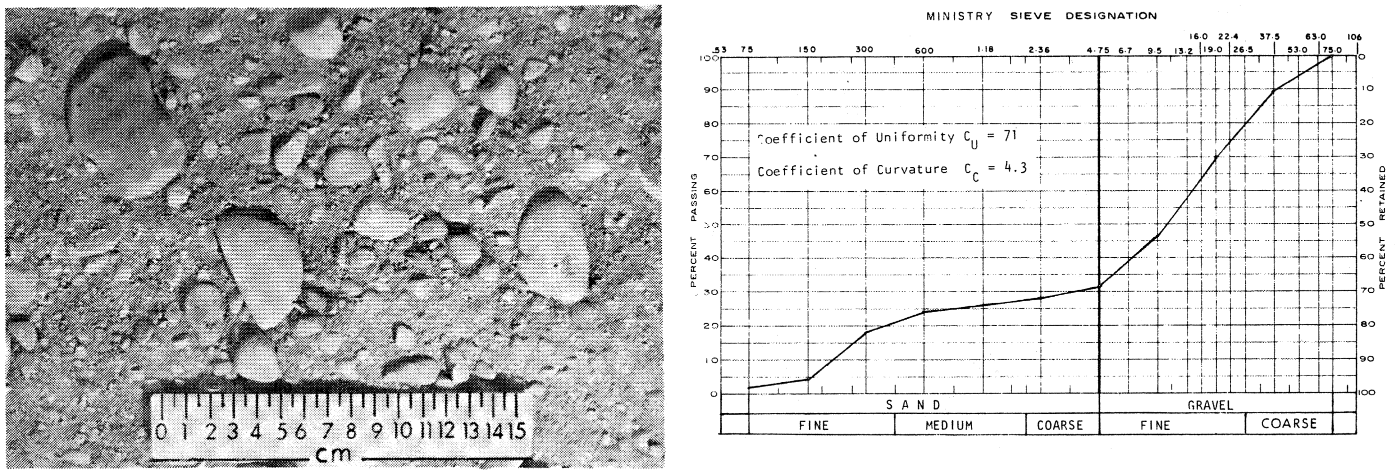
Highly organic soils are peat or other soils which contain substantial amounts of organic matter.



(a) Well-graded sandy gravel (GW)



(b) Poorly-graded coarse to fine (uniform) sand (SP)



(c) Poorly-graded (gap-graded) sandy gravel (GP)

Figure 1. Typical Soil Gradations

In the MTC System, soils having 50% or more material larger than 75 μm are classified as coarse-grained while those having less than 50% are classified as fine-grained. No laboratory criteria are used for the highly organic soils, but generally they can be identified in the field by their distinctive colour and odour and by their spongy feel and fibrous texture.

(1.3) Coarse-Grained Soils

The two major divisions of coarse-grained soils are gravel and sand. A coarse-grained soil having more than 50% of the coarse-grained fraction (larger than 75 μm) retained on a 4.75 mm sieve is classified as gravel, denoted by the symbol G. A coarse-grained soil having more than 50% of the coarse-grained fraction passing a 4.75 mm sieve is classified as sand, denoted by the symbol S. Coarse-grained soils are further sub-divided either by their gradation (distribution of grain sizes) or by the properties of the fine-grained fraction of the soil.

The classification and criteria for each group are given in the MTC Classification Chart in the Appendix, together with a Plasticity Chart which is instrumental in classification by this System.

(a) Less Than 5% Pass the 75 μm Sieve

Those coarse-grained soils having less than 5% passing the 75 μm sieve are subdivided by their gradation and are given the classification of GW, SW, GP and SP meaning, respectively, Gravel – Well-graded, Sand – Well-graded, Gravel – Poorly-graded, and Sand – Poorly-graded. These groups include those soils in which the fine-grained portion is so small that it should not affect engineering characteristics.

GW Group: Well-graded gravels and sandy gravels which contain little or no fines are classified as GW. In these soils, the presence of fines must have no effect on strength characteristics and on free draining characteristics. In addition to the criteria stated previously, this group must have a uniformity coefficient (C_U) greater than 4, and the coefficient of curvature (C_C) of the soil must be between 1 and 3.

The coefficient of uniformity C_U and coefficient of curvature C_C are expressed as follows:

$$C_U = \frac{D_{60}}{D_{10}} \qquad C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}}$$

where

D_{10}, D_{30} and D_{60} are the grain-size diameters corresponding respectively to 10, 30, and 60% passing on the cumulative grain-size curve.

SW Group: This group of soils is similar to the GW group except that the predominant grain size is sand rather than gravel. It includes well-graded sands and gravelly sands. The uniformity coefficient of soil in this classification must be greater than 6 and the coefficient of curvature must be between 1 and 3.

GP Group: Soils which classify as gravels and which will not meet the grading requirements of the GW group are placed in the GP group. These soils include poorly graded gravels and sandy gravels having little or no fines.

SP Group: Soils which classify as sands and which will not meet the grading requirements of the SW group are placed in the SP group. These soils include uniformly graded and gap-graded sands and gravelly sands.

(b) More Than 12% Pass the 75 μm Sieve

Those coarse-grained soils having more than 12% passing the 75 μm sieve are subdivided by the plasticity characteristics of the fine-grained portion and are given the classification of GM*, GC, SM*, and SC meaning, respectively, Gravel – With Silt Fines, Gravel – With Clay Fines, Sand – With Silt Fines, and Sand – With Clay Fines. The amount of fines in these groups is enough to affect engineering characteristics. Gradation is not a factor in classification.

GM Group: Soils comprising this group are those in which the predominant fine-grained fraction is silt. This group of soils includes silty gravels and mixtures of gravel, sand and silt. Soils which classify as gravels and having a fine-grained portion for which the Atterberg limits (liquid limit and plasticity index) will plot below the A-Line or the plasticity index (I_P) is less than 4 are placed in the GM group. The A-Line is shown and defined on the Plasticity Chart located with the MTC Soil Classification Chart in the Appendix. It is also discussed under Fine-Grained Soils in Section (1.4).

GC Group: Soils which classify as gravels and having a fine-grained portion for which the Atterberg limits will plot above the A-Line and for which the plasticity index is more than 7 are placed in the GC group. This group includes clayey gravels and poorly graded gravel-sand-clay mixtures.

SM Group: This group is the same as the GM group except that the predominant coarse-grained fraction is sand. The group includes poorly graded sand-silt mixtures and silty sands.

SC Group: This group is the same as the GC group except that the predominant coarse-grained fraction is sand. The group includes clayey sands and sands with clays.

(c) Borderline (Between 5% and 12% Pass the 75 μm Sieve)

Those coarse-grained soils containing between 5% and 12% material passing the 75 μm sieve are termed borderline and are given a dual classification such as SW-SM. Also, those coarse-grained soils containing more than 12% material passing the 75 μm sieve and for which the Atterberg limits plot in the hatched zone of the Plasticity Chart receive a dual classification such as SM-SC. These double symbols are appropriate to the grading and plasticity characteristics.

(1.4) Fine-Grained Soils

These soils are not subdivided by grain size but by the properties of plasticity and compressibility. Fine-grained soils are classified as silt and clay of low, intermediate or high plasticity. Criteria for classification are based upon the relationship between the liquid limit (w_L) and the plasticity index (I_P) and are given in the form of a Plasticity Chart. On this chart, for classification, the plasticity index is plotted against the liquid limit.**

*Symbol M for the Swedish word 'Mo', meaning silt.

** Soils of low plasticity generally exhibit low compressibility and those of high plasticity are usually highly compressible.

The A-Line shown on the Plasticity Chart divides inorganic clays from silts and organic soils. Those soils for which the Atterberg limits plot above this line are clays and are designated by the symbol C, while those which plot below it are either silts with the designation M or organic soils with the designation O.

Soils (both silt and clay) which have a liquid limit of less than 35 and low plasticity and compressibility are designated by the symbol L. Soils having a w_L between 35 and 50 are called silts or clays of intermediate plasticity and compressibility designated by the symbol I. Those soils having a w_L greater than 50 are termed highly plastic and compressible and are designated by the symbol H. Hence, a soil determined to be a highly plastic and compressible clay is designated as CH, etc.

ML Group: Contains silts having bulky shaped grains, rock flour and sandy silt.

MI Group: Silts of medium compressibility and plasticity are classified in this group, including silty fine sands with some clay, below the A-Line.

MH Group: Silts having flaky shaped grains, including micaceous silts, diatomaceous silts, and elastic silts.

CL Group: Most Kaolinite-type clays are classified in this group, which usually includes gravelly clays, sandy clays, and lean or low plasticity clays.

CI Group: Clays of medium compressibility and plasticity and inorganic silty clays are placed in this category.

CH Group: Montmorillonite-type clays are classified in this group, which includes fat or highly plastic clays, volcanic clays, and bentonites.

Borderline: Those fine-grained soils for which the Atterberg limits plot in the hatched zone on the Plasticity Chart are given the dual classification of CL-ML.

(1.5) Organic Soils

The placement of soils into this group is based upon visual inspection. However, they are subdivided within the group in accordance with their plasticity characteristics. All of these soils should plot below the A-Line on the Plasticity Chart and they are termed organic silts or clays of low (L), intermediate (I), or high plasticity and compressibility (H).

Organic matter tends to decay and thus create more voids in the soil mass. It can be instrumental in chemical alterations which change the physical properties of the soil.

OL Group: This group consists of organic soils having a liquid limit of less than 35. Organic silts and organic silts with sand are usually included in this group.

OI Group: Organic soils having a liquid limit between 35 and 50 belong in this category. Soils in this group are classified as organic clays of medium plasticity or organic silty clays.

OH Group: This group consists of organic soils having a liquid limit of more than 50. Organic clays, and some organic silty clays, will be included in this group.

PT Group: Materials composed mainly of fibrous organic matter are classified separately in this group. Peat and other highly organic soils in various stages of decomposition shall be placed in this category.

Chapter 2

FIELD IDENTIFICATION AND DESCRIPTION OF SOILS

(2.1) General

As implied earlier, soils in nature seldom exist separately as boulders, cobbles, gravel, sand, silt, clay or organic matter but are usually found as mixtures with varying proportions of these components. The MTG Soil Classification System is based on recognition of the type and predominance of the constituents, considering grain size, gradation, plasticity and compressibility. It separates soils into three major divisions – coarse-grained soils, fine-grained soils, and highly organic (peaty) soils and within these divisions it establishes eighteen (18) soil groups.

Two methods for classifying soils have been adopted:

(a) The *visual method* which employs simple manual tests and visual observations to estimate the size and distribution of the coarse-grained soil fractions and to indicate the plasticity characteristics of the fine-grained fractions. The visual method is used predominantly for field classification purposes.

(b) The *laboratory method* which, in addition to visual observations, employs laboratory determinations of the particle-size distribution and plasticity of the fines to assist in assigning soil group names. The laboratory method is used only when confirmation or precise description is required. It is also useful as a training aid for beginners. (See Chapter 3.)

(2.2) Visual Method

No special apparatus or equipment is required for the visual identification and/or description of soils. However, the following items will facilitate the procedure:

(a) A rubber syringe or a small oil can.
(b) A supply of clean water.
(c) Small bottle of dilute hydrochloric acid (HCl).
(d) Classification chart (Appendix).

The classification of a soil by this method is based on visual observations and estimates of its engineering behaviour in a remoulded state. If the soil is to be utilized in a foundation, the condition of the soil in the undisturbed state must also be described, as discussed in section 2.7. The procedure for visual classification of a soil is, in effect, a process of simple elimination, beginning on the left side of the classification chart and working to the right until the proper group name is obtained. It is emphasized that the group name must be supplemented by a detailed description which points out peculiarities of a particular soil and differentiates it from others in the same group.

Many natural soils will have properties not clearly associated with any one soil group, but which are common to two or more groups. Or they may be near the borderline between two groups, either in percentages of the various sizes or in plasticity characteristics. For this substantial number of soils, boundary classifications are assigned and boundary group symbols are used. The two group symbols most nearly indicating the proper soil description are recorded. These are connected by a hyphen as, for example, GW-GC, SC-CL, ML-CL, and others.

Preparation of Sample

The following procedure should be used:

(a) Select a representative sample of the soil.
(b) Estimate the maximum particle size in the sample.
(c) Estimate the percentage by mass of particles larger than 75 mm.
(d) If more than half of the particles are larger than 75 mm, classify the soil as boulders and/or cobbles as explained under section (1.1).
(e) If less than half of the particles are larger than 75 mm, remove all these particles from the sample. Only that fraction of the sample smaller than 75 mm is classified.

Division between Coarse and Fine-Grained Particles

Classify the sample as coarse-grained or fine-grained by estimating the percent by mass, of individual particles which can be seen by the naked eye. Soils containing more than 50% visible particles are coarse-grained soils. Soils containing less than 50% visible particles are fine-grained soils.

(2.3) Visual Procedure for Coarse-Grained Soils

If it has been determined that the soil is predominantly coarse-grained, it is further identified by estimating the percentages of grains in the size range (a) 75 mm to 4.75 mm, and (b) 4.75 mm to 75 μm. If percentage (a) is greater than (b), the soil will finally be placed in one of the GRAVEL groups (Symbol G), and if percentage (b) is greater than (a), it will be placed in one of the SAND groups (Symbol S), as described below.

Gravel – Gravels are further identified as being CLEAN (containing little or no fines) or DIRTY (containing appreciable fines) by estimating the percentage of grains not visible to the naked eye. If the soil is obviously clean and pervious, the final classification will be either:

WELL-GRADED GRAVEL (GW) if there is a good representation of all particle sizes, or

POORLY-GRADED GRAVEL (GP) if there is an absence of intermediate particle sizes or an excess of one size.

If the soil is obviously dirty and relatively impervious, the final classification will be either SILTY GRAVEL (GM) if the fines have no or low plasticity, or

CLAYEY GRAVEL (GC) if the fines are of low to medium plasticity.

Sand – If it was determined that the soil would finally be placed in one of the SAND groups, the same procedure would be applied as for gravels except that the word SAND replaces GRAVEL in the groups and the Symbol S replaces G. Thus, the obviously clean sands will be classified as either:

WELL-GRADED SAND (SW) or

POORLY-GRADED SAND (SP)

and the obviously dirty sands will be classified as SILTY SAND (SM) if the fines have no or low plasticity, or

CLAYEY SAND (SC) if the fines are of low to medium plasticity.

Coarse-Grained Soils – Descriptive information for coarse-grained soils may include:

(a) Typical name.
(b) Maximum size of particles, percentage of cobbles and boulders which are not included in the classification.
(c) Approximate percentage of gravel, sand and fines.
(d) Description of average size of sand or gravel; whether coarse, medium or fine according to the groups as follows:

Coarse gravel	– 75 mm to 26.5 mm
Fine gravel	– 26.5 mm to 4.75 mm
Coarse sand	– 4.75 mm to 2.00 mm
Medium sand	– 2.00 mm to 425 μm
Fine Sand	– 425 μm to 75 μm

(e) Description of the shape of the grains; rounded, subrounded, angular, subangular. (See Figure 2.)
(f) The surface coatings, cementation, and hardness of the grains and possible breakdown when compacted.
(g) The colour and organic content.
(h) Plasticity of fines.
(i) Geologic origin or formation, if known.
(j) Group symbol.

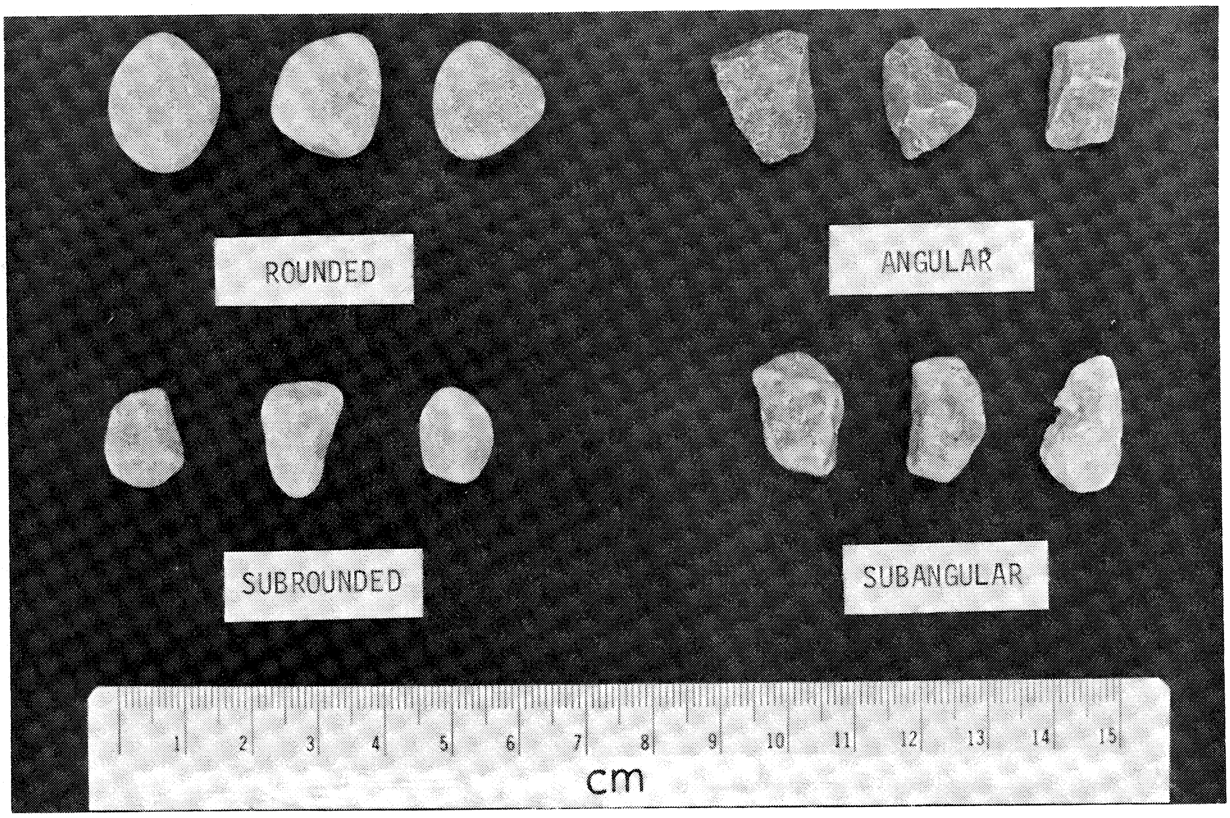


Figure 2. Typical Shapes of Gravels

(2.4) Visual Procedure for Fine-Grained Soils

If it has been determined that the soil is predominantly fine-grained (smaller than 75 μm), it is further identified according to its plasticity characteristics. The manual tests for dry strength, dilatancy, and toughness are performed as described below, and the results of these tests will determine which of the nine (9) standard group terminologies will apply. The same procedures are used to identify the fine-grained fraction of coarse-grained soils to determine whether they are silty or clayey.

(2.4.1) Manual Tests

The tests for identifying fine-grained soils in the laboratory are performed on that fraction of the soil finer than 425 μm. Therefore, the first step in classifying these soils in the field is to select a representative sample and remove by hand as much of the large particle size material as is practical. Then prepare three small specimens by moistening until they can easily be rolled into a ball. Perform the tests listed below, carefully noting the behaviour of each soil pat during each test. Operators with considerable experience find that it is not necessary in all cases to prepare all three pats. For example, if the soil contains dry lumps, the dry strength can be readily determined without preparing a pat for this particular purpose.

(a) Dry Strength (crushing resistance)

Air dry one of the prepared specimens. Then determine its resistance to crumbling and powdering between the fingers. This resistance, called "dry strength", is a measure of the plasticity of the soil and is influenced largely by the colloidal fraction contained. The dry strength is designated as "slight" if the dried pat can be easily powdered, "medium" if considerable finger pressure is required, and "high" if it cannot be powdered at all.

High dry strength is characteristic of clays. Silts possess "none to slight" dry strength.

Note: The presence of high-strength water-soluble cementing materials, such as calcium carbonates or iron oxides, may cause high dry strengths. Non-plastic soils, such as caliche, coral, crushed limestone, or soils containing carbonaceous cementing agents, may have high dry strengths, but this can be detected by the effervescence caused by the application of dilute hydrochloric acid (see acid test below).

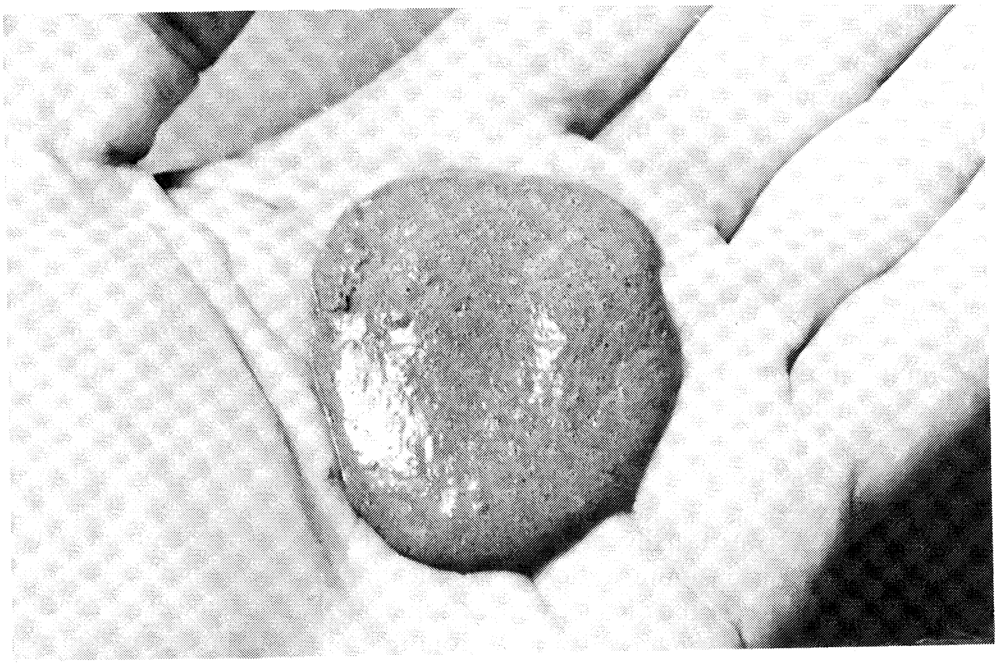
(b) Dilatancy (reaction to shaking)

Add enough water to nearly saturate one of the soil pats. Place the pat in the open palm of one hand and shake horizontally striking vigorously against the other hand several times. Squeeze the pat between the fingers. The appearance and disappearance of the water with shaking and squeezing is referred to as "reaction" (Figure 3). This reaction is called "quick" if water appears and disappears rapidly, "slow" if water appears and disappears slowly, and "no reaction" if the water condition does not appear to change.

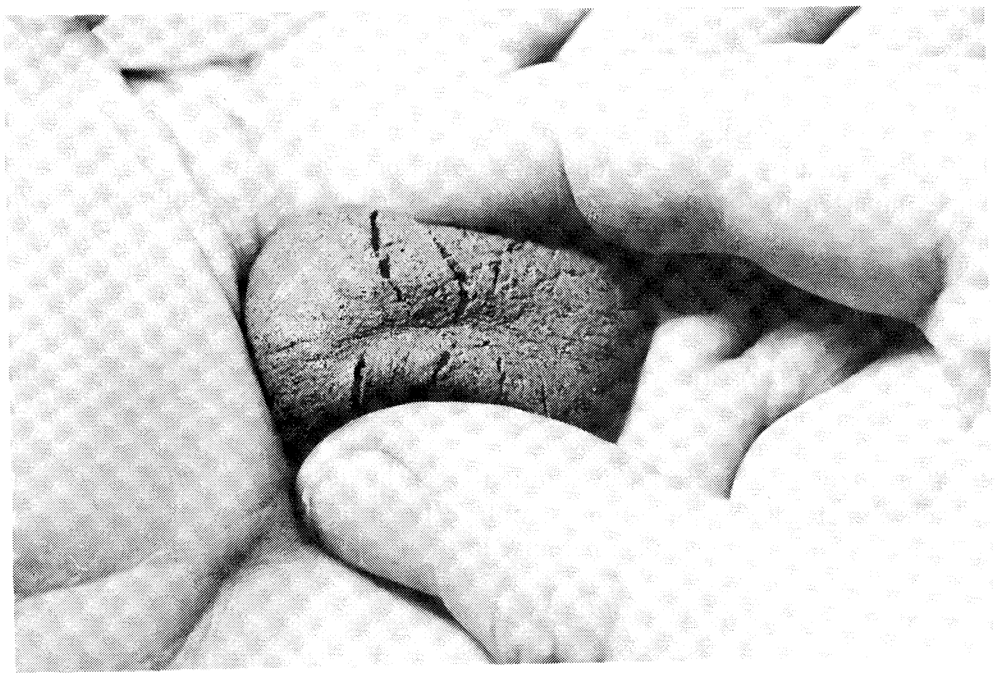
Fine clean sands give the quickest reaction, while plastic clays have no reaction. Silts usually show "slow to quick" reaction.

(c) Toughness (consistency near plastic limit)

Mould one of the prepared specimens into a pat having the consistency of putty. If too dry, water must be added and if too sticky the specimen should be allowed to partially dry. Roll the pat on a smooth surface or between the palms into a thread about 3 mm in diameter. Fold and reroll the thread repeatedly to 3 mm diameter so that its moisture content is



(a) Reaction to shaking



(b) Reaction to squeezing

Figure 3. Test for Dilatancy

gradually reduced until the 3 mm thread just crumbles (Figure 4). The moisture content at this time is called "the plastic limit", and the resistance to moulding at the plastic limit is called the "toughness". After the thread crumbles, the pieces should be lumped together and a slight kneading action continued until the lump crumbles. If the lump can still be remoulded slightly drier than the plastic limit and if high finger pressure is required to roll the thread between the palms of the hands, the soil is described as possessing "high toughness".

"Medium toughness" is indicated by a medium tough thread, and a lump formed of the threads slightly below the plastic limit will crumble; while "slight toughness" is indicated by a weak thread that breaks easily and cannot be lumped together when drier than the plastic limit. The thread will be soft and spongy. Nonplastic soils cannot be rolled into a thread of 3 mm diameter at any moisture content.

(d) Organic Content and Colour

Fresh, wet organic soils usually have a distinctive odour of decomposed organic matter. This odour can be made more noticeable by heating the wet sample. Another indication of the organic material is the distinctive dark colour. Dry, inorganic clays develop an earthy odour upon moistening, which is distinctive from that of decomposed organic matter.

(e) Additional Identification Tests

Acid Test – This test, using dilute hydrochloric acid (HC1), is primarily a test for the presence of calcium carbonate. Two or three drops of the acid solution on soil or rock will cause effervescence if the material contains calcium carbonate. For soils with high dry strength, a strong reaction indicates that the strength may be due to calcium carbonate as a cementing agent, rather than colloidal clay. The results of this test should be included in the soil description, if pertinent.

Shine – This is a quick supplementary procedure for determining the presence of clay. The test is performed by rubbing a lump of dry or slightly moist soil with the thumb. A shiny surface imparted to the soil indicates highly plastic clay, while a dull surface indicates silt or clay of low plasticity.

Grit – Silts feel gritty to the teeth, clays do not.

Stickiness – Clays are sticky. Silts are not. Silts can be readily dusted from the hands after drying. Clays cannot be readily dusted off.

Miscellaneous – Other criteria undoubtedly can be developed by the individual as he gains experience in classifying soils. For example, differentiation between some of the fine-grained soils depends largely upon the experience in the "feel" of the soils.

(2.4.2) Silts and Clays of Low Plasticity (Symbol L)

The following three groups in this category are commonly thought of as soils possessing low plasticity. Various combinations of results of the manual identification tests indicate which grouping is proper for the soil in question.

(a) INORGANIC SILT (ML) normally possesses no dry strength, quick dilatancy, and no toughness.

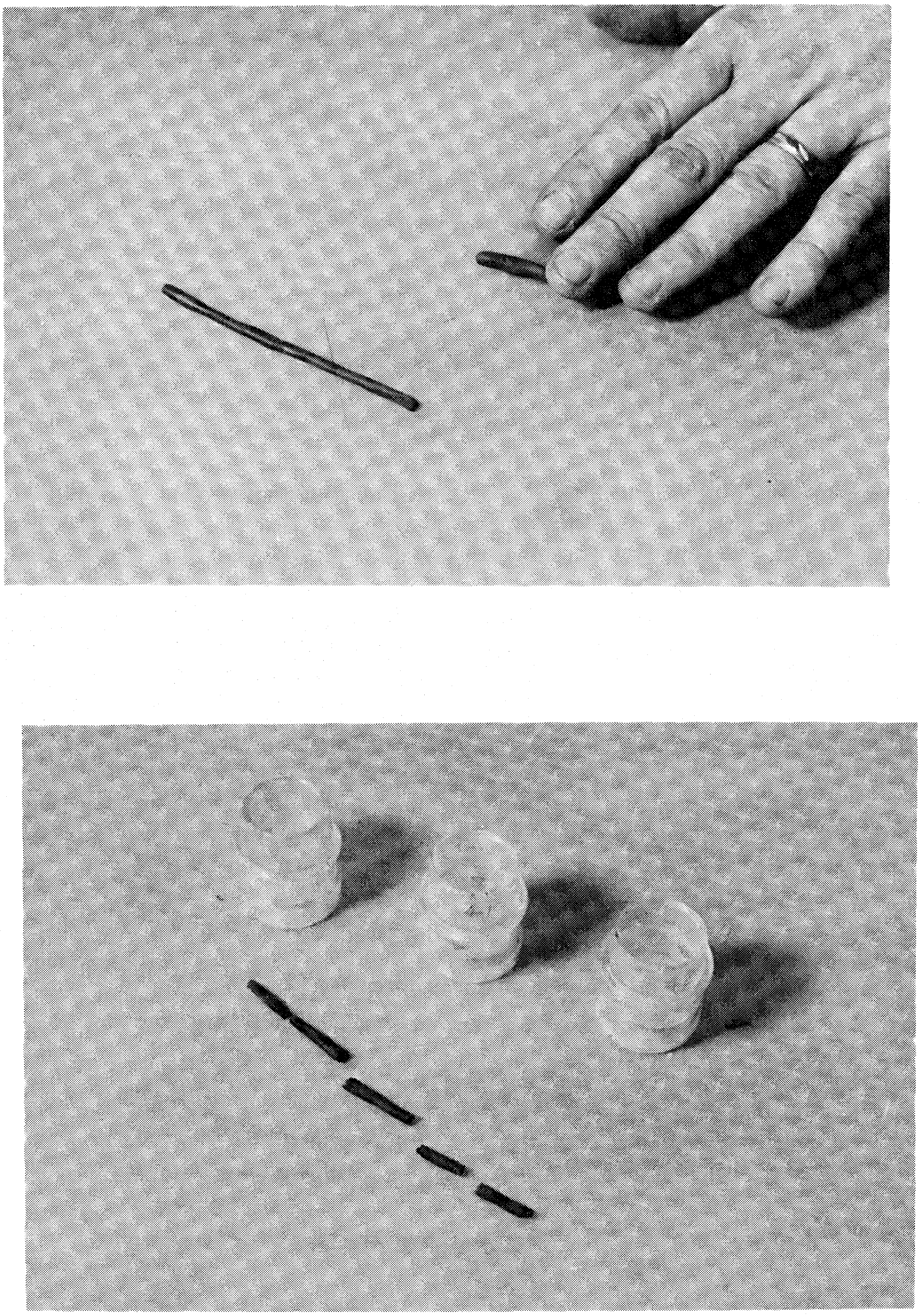


Figure 4. Test for Plastic Limit

(b) INORGANIC CLAY (CL) usually has medium to high dry strength, none to very slow dilatancy, and medium toughness.
(c) ORGANIC SILT OR CLAY (OL) generally has slight to medium dry strength, slow dilatancy and slight toughness. Organic matter must be present in sufficient amounts to influence the soil properties in order for a soil to be placed in this group.

(2.4.3) Silts and Clays of Intermediate Plasticity (Symbol I)

(a) INORGANIC SILT (MI) has "none to slight" dry strength, slow to quick dilatancy, and slight toughness.
(b) INORGANIC CLAY (CI) usually has high dry strength, no dilatancy, and medium to high toughness.
(c) ORGANIC SILT OR CLAY (OI) generally has slight to medium dry strength, very slow dilatancy and slight toughness. Organic matter must be present in sufficient amounts to influence soil properties in order for a soil to be placed in this group.

(2.4.4) Elastic Silts and Fat Clays (Symbol H)

(a) INORGANIC SILT (MH) is generally very absorptive, has slight to medium dry strength, "none to slow" dilatancy, and medium toughness. Some inorganic soils (such as kaoline which may be a clay from a mineralogical standpoint) possessing medium dry strength and toughness will fall in this group.
(b) INORGANIC CLAY (CH) always possesses high to very high dry strength, no dilatancy, and usually high toughness.
(c) ORGANIC SILT OR CLAY (OH) normally has medium to high dry strength, none to very slow dilatancy, and slight to medium toughness. Organic matter must be present in sufficient amounts to influence soil properties in order for a soil to be placed in this group.

2.5 Visual Procedure for Highly Organic Soils (Symbol Pt)

Highly organic material is readily identified by colour, odour, spongy feel and it may be fibrous or amorphous. These materials are not broken down further.

Partly organic soils tend to have the properties of their inorganic component but will exhibit high compressibility in relation to their organic content. These soils are further identified based on their inorganic components using the procedures described above.

Fine-Grained and Organic Soils – Descriptive information for remoulded fine-grained soils may include:

(a) Typical name.
(b) Amount and maximum size of coarse grains.
(c) Colour and organic content.
(d) Natural moisture content, drainage conditions.
(e) Plasticity characteristics.
(f) Geologic origin or local name, if known, (e.g. Glacial Till, Leda Clay).
(g) Group Symbol.

2.6 Guide for Field Description Procedure

In the field the soil may be described using the following steps. Abbreviations (see Table 1 in the Appendix) are used for pavement structure investigations owing to the numerous borehole logs required for this type of work.

1st Step: Decide whether the sample is predominantly coarse-grained, fine-grained or organic. In borderline cases dual descriptions may be used.

2nd Step: Identify the principal component based on grain size if coarse-grained, or on behaviour if fine-grained, and use as a noun in the soil description.

Example: *Medium sand (Med Sa)*
Clay (Cl)

3rd Step: Identify the second component. Does it have a substantial effect on the total sample (in the range of 10% - 15% of the total mass of a coarse-grained material).

If yes, use it as an adjective preceding the noun in the soil description.

Example: *Silty fine sand (Si F Sa)*
Silty fine sand to fine sandy silt (Si F SA-Sa F Si)
Silty clay (Si Cl)

If no, treat as in step 4.

4th Step: Are there minor components which still have a significant effect on the sample?

If yes, identify by using the word "with--".

Example: *Silty fine sand with gravel (Si F Sa with Gr)*
Sand with silt (Sa with Si)

5th Step: Are there components which have only a minor effect on the sample?

If yes, identify by using the word "trace–".

Example: *Silty fine sand trace of clay (Si F Sa Tr Cl)*
Silty fine to medium sand with gravel trace of clay (Si F-Med Sa with Gr Tr Cl)
Coarse sand trace of silt (Co Sa Tr Si)

6th Step: Describe the colour of the soil.

Example: *Grey silty sand (Gry Si Sa)*

7th Step: Describe the moisture content. The field moisture content may be defined as; dry, moist or wet.

Dry: a dry soil has a moisture content well below optimum ($w < w_{opt}$)

Moist: a soil with a moisture content at or near optimum ($w \approx w_{opt}$)

Wet: a soil with a moisture content well above optimum ($w > w_{opt}$)

Saturated: denotes the moisture condition of a soil below the water table. It may be below, at or above the optimum moisture content.

Example: *Grey silty sand, moist (Gry Si Sa, moist)*

2.7 Description of Foundation Soils

The in-place condition of soils which are to be utilized as foundations for structures assumes primary importance in soil classification. Borehole logs of foundation explorations and descriptions of undisturbed samples, therefore, must emphasize such in-situ conditions of the soil. It is necessary for the classifier to present a complete word picture describing the soil as it exists in-situ, in addition to placing it in the proper group. The following properties should be described for foundation soils in addition to those properties listed earlier.

(1) Permeability or drainage properties in the natural condition.
(2) Structure (stratified, flocculent, honeycomb, etc.).
(3) Type and degree of cementation.
(4) Degree of compactness or denseness.

For fine-grained soils the consistency in undisturbed and remoulded states should also be described.

The consistency of a cohesive, and the denseness of a non-cohesive soil in the field, are usually determined by Field Vane Tests or Standard Penetration Tests respectively.

Consistency – Is described on the basis of undrained shear strength (c_u)* as follows:

Consistency	**c_u (kPa)**
Very soft	0 – 12
Soft	12 – 25
Firm	25 – 50
Stiff	50 – 100
Very stiff	100 – 200
Hard	> 200

Denseness – is described as indicated by Standard Penetration Test 'N' values as follows:

Denseness	**'N' (Blows/0.3 m)**
Very loose	0 – 5
Loose	0 – 10
Compact	10 – 30
Dense	30 – 50
Very dense	> 50

The principal engineering properties of the various soil groups are tabulated in the Appendix.

*c_u is the symbol for apparent cohesion, which, in an undrained condition with saturated cohesive soils, is also called "undrained shear strength". Shear strength at failure $\tau_f = c_u + \sigma \tan \phi_u$; but in the undrained case $\phi_u = 0$, thus $\tau_f = c_u$

Chapter 3

LABORATORY CLASSIFICATION OF SOILS

Laboratory classification will, in general, be applied to those materials taken from natural deposits. All processed materials, and some materials from natural deposits will be tested and classified under the provisions of MTC Specification Division 10 for aggregates (e.g., HL1 and 3, Granular 'B', etc.).

Precise delineation of the soil groups may be obtained in the laboratory by means of grain-size analysis and Atterberg limits. For foundation or slope stability investigations, these tests are carried out as a matter of course together with other extensive testing, such as the measurement of strength and compressibility.

Laboratory tests may also be used as training for field personnel to improve their ability in estimating grain size percentage and degree of plasticity.

3.1 Test Apparatus

Descriptions of the apparatus required may be found in the following test methods described in the MTC Laboratory Testing Manual:

LS-700 Method of Dry Preparation of Soil ...
LS-600 Method of Preparation of Aggregates ...
LS-703 Method of Test for Liquid Limit of Soils ...
LS-704 Method of Test for Plastic Limit ...
LS-602 Method of Test for Sieve Analysis ...
LS-702 Method of Test for Particle Size Analysis ...

3.2 Test Samples

Test samples shall be prepared as follows:

(a) The sample as received from the field shall be thoroughly dried in air or a drying oven not exceeding 60°C if it is predominantly fine-grained. Predominantly coarse-grained material may be dried in an oven at 110 ± 5°C.

(b) The dried sample is separated into fractions on a 4.75 mm sieve if it is predominantly sand, silt or clay and on a 26.5 mm sieve if it has a substantial portion larger than 26.5 mm. The coarse portions are sieved in each case and the masses retained on each sieve recorded.

(c) Samples passing the 4.75 mm sieve are split and one portion is ground in a mortar with a rubber pestle and passed through a 2.00 mm sieve. The mass of material passing the 2.00 mm sieve may be split further to produce one sample for particle size analysis and one sample to be ground further to produce sufficient material passing the 425 μm sieve for Atterberg limit or organic tests.

(d) Samples passing the 26.5 mm sieve are placed in the Gilson sieving apparatus to obtain the grain-size distribution for particles from 19.00 mm to 4.75 mm. The material passing the 4.75 mm sieve is split to obtain a representative sample for the sieve analysis of the medium to fine sand.

(e) When all the tests have been completed, the grain-size distribution curve is plotted and the classification procedure may be carried out.

3.3 Procedure for Classification of Coarse-Grained Soils

(a) Classify the material as gravel (G) if 50% or more of the fraction retained on the 75 μm sieve is larger than 4.75 mm.

(b) Classify the material as sand (S) if more than 50% of the fraction retained on the 75 μm sieve is smaller than 4.75 mm.

(c) If less than 5% of the sample passes the 75 μm sieve, compute the coefficient of uniformity (C_U) and the coefficient of curvature (C_C) as explained under Section (1.3).

(d) Classify the sample as well-graded gravel (GW) or well-graded sand (SW), if C_U is greater than 4 for gravel and greater than 6 for sand, and C_C is between 1 and 3. Classify the sample as poorly-graded gravel (GP) or poorly-graded sand (SP) if either the C_U or C_C criteria are not satisfied.

(e) If more than 12% of the sample passes the 75 μm sieve, the liquid limit and plasticity index of the pass 425 μm portion should be determined.

(f) Classify the sample as silty gravel (GM) or silty sand (SM) if the results of the limit tests show the fines to be silty i.e., below the A-line or with plasticity index (I_P) less than 4. Classify the sample as clayey gravel (GC) or clayey sand (SC) if the results of the limit tests plot above the A-line and the plasticity index (I_P) is greater than 7.

(g) If the fines are intermediate between silt and clay, i.e., plot on or close to the A-line and with plasticity index (I_P) in the range of 4-7 (the hatched area in the plasticity chart), the sample should be given a borderline classification, such as GM-GC or SM-SC.

(h) If 5 to 12% of the sample passes the 75 μm sieve, the material should be given a borderline classification based on gradation and plasticity characteristics, such as GW-GC or SP-SM. In doubtful cases, the rule is to favour the less plastic classification.

Example: *a gravel with 10% fines, a C_U of 20, a C_C of 2 and a plasticity index of 6 would be classified as GW-GM rather than GS-GC.*

3.4 Procedure for Classification of Fine-Grained Soils

(a) If results of Atterberg limit tests plot above the A-line and the plasticity index is greater than 7, classify the sample as clay of high plasticity (CH) if the liquid limit is above 50; intermediate plasticity (CI) if the liquid limit is between 35 and 50 and low plasticity (CL) if the liquid limit is below.

(b) If results of Atterberg limit tests plot below the A-line or the plasticity index is less than 4, classify the sample as silt of high plasticity (MH) if the liquid limit is above 50; intermediate plasticity (MI) if the liquid limit is between 35 and 50 and low plasticity (ML) if the liquid limit is below 35.

(c) If the sample has a dark colour and an organic odour when moist and warm, the results of Atterberg limit tests plot below the A-line or the plasticity index is less than 4, classify the sample as organic clay or silty-clay of high plasticity (OH) if the liquid limit is above 50 and intermediate plasticity (OI) if the liquid limit is between 35 and 50. If the liquid limit is less than 35, classify the material as organic silt or organic silt with sand (OL).

(d) If the organic content is in doubt, a determination should be made by oxidation or reduction. If this cannot be carried out, Atterberg limit tests should be performed on natural, air-dried or oven-dried soil. Marked differences in the liquid limit or plasticity index would indicate a high organic content.

(e) If the results of Atterberg limit tests fall close to or on the A-line or in the hatched area of the plasticity chart ($w_L < 30\%$; $I_P = 4-7\%$) the sample should be classified as borderline such as CL-ML or CI-MI.

(f) If the plot of the liquid limit versus plasticity index falls close to or on the vertical line of 35 or 50% liquid limit, the sample should be given a borderline classification such as CI-CH, MI-MH, CL-CI or ML-MI. In doubtful cases, the rule is to favour the more plastic classification.

Example: *a fine-grained soil with a liquid limit of 50 and a plasticity index of 22 would be classified as CH-MH rather than CI-MI.*

REFERENCES

1. AASHTO. Washington, D.C. (1978), *Manual on Foundation Investigations* (pp B-26 to B-36).

2. ASTM. (1978), *Annual Book of ASTM Standards. Part 19.* D 653 (Reapproved 1973); D-2487 (Reapproved 1975); D 2488 (Reapproved 1975).

3. Ministry of Transportation and Communications, Ontario (1977), *Geotechnical Metric Guide* (Revised edition).

4. Ministry of Transportation and Communications, Ontario (1979), *Laboratory Testing Manual.*

5. National Research Council of Canada (1955), *Guide to the Field Description of Soils for Engineering Purposes.*

6. Road Research Laboratory. Great Britain (1954), *Soil Mechanics for Road Engineers.* Chapter 4.

7. Soil Mechanics Bureau. N.Y. State DOT. (1978), *Soil Description Procedure.*

8. U.S. Department of the Interior. Bureau of Reclamation. Denver, Colorado, (1963), *Unified Soil Classification System.*

APPENDIX

ABBREVIATIONS FOR BORING AND TEST DATA

Amor	— Amorphous	Grn	— Green	I_P	— Plasticity Index
Asph	— Asphalt	Grey	— Grey	PSty	— Polystyrene
BR	— Bedrock	Hi	— Highly	Poss	— Possible
Blk	— Black	HM	— Hot Mix	PST	— Prime & Surface Treated
Bl	— Blue	Lt	— Light	Quant	— Quantity
Bld(y)	— Boulder (y)	Liq	— Liquid	Reinf	— Reinforced
Blds	— Boulders	w_L	— Liquid Limit	RF	— Rock Fill
BU	— Break Up	Matl	— Material	Sa	— Sand
Br	— Brown	Max	— Maximum	Sat	— Saturated
Cl	— Clay	MDD	— Maximum Dry Density	Sh Rk	— Shot Rock
Co	— Coarse	MWD	— Maximum Wet Density	Si	— Silt(y)
Cob	— Cobbles	Med	— Medium	Sl(y)	— Slight(ly)
Comp	— Compact	Mod	— Moderate	D_R	— Relative Density
Conc	— Concrete	Mott	— Mottled	Stks	— Streaks
Contam	— Contaminated	Mul	— Mulch	Surf	— Surface
Cord	— Corduroy	NFP	— No Further Progress	Temp	— Temperature
Cr	— Crushed	NFP (Blds)	— No Further Progress (Boulders)	Tps	— Topsoil
Dk	— Dark	Num	— Numerous	Tr	— Trace
Decomp	— Decomposed	Occ	— Occasional	Unreinf	— Unreinforced
E	— Earth	w_{opt}	— Optimum Moisture Content	Varv	— Varved
Fib	— Fibrous	Ora	— Orange	VF	— Very Fine
w	— Field Moisture Content	Org	— Organic	WT	— Water Table
F	— Fine	Org M	— Organic Mattter	Weath	— Weathered
Fr Wat	— Free Water	Ob	— Overburden	Wd(y)	— Wood(y)
FB	— Frost Boil	Pavt	— Pavement	Yel	— Yellow
FH	— Frost Heave	Pedo	— Pedological		
Gran	— Granular	Pen Mac	— Penetration Macadam		
Gr	— Gravel(ly)	w_P	— Plastic Limit		

SUSCEPTIBILITY TO FROST HEAVING

HSFH — High
BSFH — Borderline
LSFH — Low

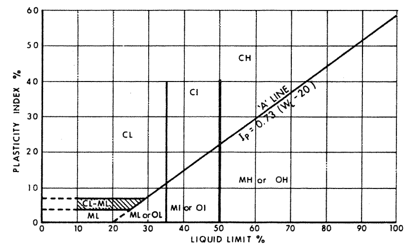
M.T.C. SOIL CLASSIFICATION

FIELD IDENTIFICATION PROCEDURES (EXCLUDING PARTICLES LARGER THAN 75 mm AND BASING FRACTIONS ON ESTIMATED MASS)			GRP. SYMB.	TYPICAL NAMES	INFORMATION REQUIRED FOR DESCRIBING SOILS	LABORATORY CLASSIFICATION CRITERIA	
COARSE GRAINED SOILS MORE THAN HALF OF MATERIAL IS LARGER THAN 75 µm — **GRAVELS** MORE THAN HALF OF COARSE FRACTION IS LARGER THAN 4.75 mm	CLEAN GRAVELS (LITTLE OR NO FINES)	WIDE RANGE IN GRAIN SIZE & SUBSTANTIAL AMOUNTS OF ALL INTERMEDIATE PARTICLE SIZE	GW	WELL GRADED GRAVELS, GRAVEL-SAND MIXTURES; LITTLE OR NO FINES	GIVE TYPE; NAME, IF NECESSARY; INDICATE APPROX. % OF SAND & GRAVEL; MAX. SIZE; ANGULARITY, SURFACE CONDITION, & HARDNESS OF THE COARSE GRAINS; LOCAL OR GEOLOGIC NAME & OTHER PERTINENT DESCRIPTIVE INFORMATION; & SYMBOL IN PARENTHESIS.	DETERMINE PERCENTAGES OF GRAVEL & SAND FROM GRAIN SIZE CURVE. DEPENDING ON PERCENTAGE OF FINES (FRACTION SMALLER THAN 75 µm) COARSE GRAINED SOILS ARE CLASSIFIED AS FOLLOWS: LESS THAN 5% GW, GP, SW, SP; MORE THAN 12% GM, GC, SM, SC; 5% TO 12% BORDERLINE CASES REQ. USE OF DUAL SYMBOLS	$C_u = \frac{D_{60}}{D_{10}}$ GREATER THAN 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ BETWEEN ONE AND 3
		PREDOMINANTLY ONE SIZE OF A RANGE OF SIZES WITH SOME INTERMEDIATE SIZES MISSING	GP	POORLY GRADED GRAVELS, GRAVEL-SAND MIXTURES; LITTLE OR NO FINES			NOT MEETING ALL GRADATION REQUIREMENTS FOR GW
	GRAVEL WITH FINES (APPRECIABLE AMOUNT OF FINES)	NON-PLASTIC FINES (FOR IDENTIFICATION PROCEDURES SEE ML BELOW)	GM	SILTY GRAVELS, POORLY GRADED GRAVEL-SAND-SILT MIXTURES			ATTERBERG LIMITS BELOW A-LINE, OR I_p LESS THAN 4 — ABOVE A-LINE WITH I_p BETWEEN 4 AND 7 ARE BORDERLINE CASES REQUIRING USE OF DUAL SYMBOLS
		PLASTIC FINES (FOR IDENTIFICATION PROCEDURES SEE CL BELOW)	GC	CLAYEY GRAVELS, POORLY GRADED GRAVEL-SAND-CLAY MIXTURES			ATTERBERG LIMITS ABOVE A-LINE WITH I_p GREATER THAN 7
SANDS MORE THAN HALF OF COARSE FRACTION IS SMALLER THAN 4.75 mm (75 µm IS ABOUT THE SMALLEST PARTICLE VISIBLE TO THE NAKED EYE)	CLEAN SANDS (LITTLE OR NO FINES)	WIDE RANGE IN GRAIN SIZES & SUBSTANTIAL AMOUNTS OF ALL INTERMEDIATE PARTICLE SIZES	SW	WELL GRADED SANDS, GRAVELLY SANDS; LITTLE OR NO FINES	FOR UNDISTURBED SOILS ADD INFORMATION ON STRATIFICATION, DEGREE OF COMPACTNESS, CEMENTATION, MOISTURE CONDITIONS & DRAINAGE CHARACTERISTICS.		$C_u = \frac{D_{60}}{D_{10}}$ GREATER THAN 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ BETWEEN ONE AND 3
		PREDOMINANTLY ONE SIZE OR A RANGE OF SIZES WITH SOME INTERMEDIATE SIZES MISSING	SP	POORLY GRADED SANDS, GRAVELLY SANDS: LITTLE OR NO FINES			NOT MEETING ALL GRADATION REQUIREMENTS FOR SW
	SANDS WITH FINES (APPRECIABLE AMOUNT OF FINES)	NON-PLASTIC FINES (FOR IDENTIFICATION PROCEDURES SEE ML BELOW)	SM	SILTY SANDS, POORLY GRADED SAND-SILT MIXTURES			ATTERBERG LIMITS BELOW A-LINE OR I_p LESS THAN 4 — ABOVE A-LINE WITH I_p BETWEEN 4 AND 7 ARE BORDERLINE CASES REQUIRING USE OF DUAL SYMBOLS
		PLASTIC-FINES (FOR IDENTIFICATION PROCEDURES SEE CL BELOW)	SC	CLAYEY SANDS, POORLY GRADED SAND-CLAY MIXTURES			ATTERBERG LIMITS ABOVE A-LINE WITH I_p GREATER THAN 7

IDENTIFICATION PROCEDURES ON FRACTION SMALLER THAN 425 µm

FINE GRAINED SOILS (MORE THAN HALF OF MATERIAL IS SMALLER THAN 75 µm)		DRY STRENGTH (CRUSHING CHARACTERISTICS)	DILATANCY (REACTION TO SHAKING)	TOUGHNESS (CONSISTENCY NEAR PLASTIC LIMIT)	GRP. SYMB.	TYPICAL NAMES	INFORMATION REQUIRED FOR DESCRIBING SOILS
SILTS AND CLAYS	LIQUID LIMIT LESS THAN 35%	NONE	QUICK	NONE	ML	INORGANIC SILTS & SANDY SILTS OF SLIGHT PLASTICITY, ROCK FLOUR	GIVE TYPE; NAME, IF NECESSARY, INDICATE DEGREE & CHARACTER OF PLASTICITY, AMOUNT & MAXIMUM SIZE OF COARSE GRAINS, COLOUR IN WET CONDITION, ODOUR, IF ANY, LOCAL OR GEOLOGIC NAME & OTHER PERTINENT DESCRIPTIVE INFORMATION & SYMBOL IN PARENTHESIS.
		MEDIUM TO HIGH	NONE TO VERY SLOW	MEDIUM	CL	SILTY CLAYS (INORGANIC), GRAVELLY CLAYS, SANDY CLAYS, LEAN CLAYS	
		SLIGHT TO MEDIUM	SLOW	SLIGHT	OL	ORGANIC SILT OF LOW PLASTICITY, ORGANIC SANDY SILTS	
	LIQUID LIMIT BETWEEN 35% AND 50%	NONE TO SLIGHT	SLOW TO QUICK	SLIGHT	MI	INORGANIC COMPRESSIBLE FINE SANDY SILT WITH CLAY OF MEDIUM PLASTICITY, CLAYEY SILTS	FOR UNDISTURBED SOILS AND INFORMATION ON STRUCTURE, STRATIFICATION, CONSISTENCY IN UNDISTURBED & REMOULDED STATES, MOISTURE & DRAINAGE CONDITIONS.
		HIGH	NONE	MEDIUM TO HIGH	CI	SILTY CLAYS (INORGANIC) OF MEDIUM PLASTICITY	
		SLIGHT TO MEDIUM	VERY SLOW	SLIGHT	OI	ORGANIC SILTY CLAYS OF MEDIUM PLASTICITY	
	LIQUID LIMIT GREATER THAN 50%	SLIGHT TO MEDIUM	SLOW TO NONE	MEDIUM	MH	INORGANIC SILTS, HIGHLY COMPRESSIBLE MICACEOUS OR DIATOMACEOUS FINE SANDY SILTS, ELASTIC SILTS	
		HIGH TO VERY HIGH	NONE	HIGH	CH	CLAYS (INORGANIC) OF HIGH PLASTICITY, FAT CLAYS	
		MEDIUM TO HIGH	NONE TO VERY SLOW	SLIGHT TO MEDIUM	OH	ORGANIC CLAYS OF HIGH PLASTICITY	
HIGHLY ORGANIC SOILS		READILY IDENTIFIED BY COLOUR, ODOUR, SPONGY FEEL & FREQUENTLY BY FIBROUS TEXTURE			Pt	PEAT & OTHER HIGHLY ORGANIC SOILS	

USE GRAIN SIZE CURVE IN IDENTIFYING THE FRACTIONS AS GIVEN UNDER FIELD IDENTIFICATION



PLASTICITY CHART
FOR LABORATORY CLASSIFICATION OF FINE GRAINED SOILS

BOUNDARY CLASSIFICATIONS: SOILS POSSESSING CHARACTERISTICS OF TWO GROUPS ARE DESIGNATED BY COMBINATIONS OF GROUP SYMBOLS. FOR EXAMPLE GW-GC, WELL GRADED GRAVEL-SAND MIXTURE WITH CLAY BINDER

TYPICAL NAMES OF SOIL GROUPS	GROUP SYMBOLS	PERMEABILITY WHEN COMPACTED	STRENGTH WHEN COMPACTED	COMPRESSIBILITY WHEN COMPACTED	WORKABILITY AS A CONSTRUCTION MATERIAL	SCOUR RESISTANCE	SUSCEPTIBILITY TO SURFICIAL EROSION	SUSCEPTIBILITY TO FROST ACTION	DRAINAGE CHARACTERISTICS
WELL-GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES	GW	PERVIOUS	EXCELLENT	NEGLIGIBLE	EXCELLENT	MEDIUM	NEGLIGIBLE	NEGLIGIBLE	EXCELLENT
POORLY GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES	GP	VERY PERVIOUS	GOOD	NEGLIGIBLE	GOOD	MEDIUM	NEGLIGIBLE	NEGLIGIBLE	EXCELLENT
SILTY GRAVELS, POORLY GRADED GRAVEL-SAND-SILT MIXTURES	GM	SEMI-PERVIOUS TO IMPERVIOUS	GOOD	NEGLIGIBLE	GOOD	LOW TO MEDIUM	SLIGHT	SLIGHT	FAIR TO SEMI IMPERVIOUS
CLAYEY GRAVELS, POORLY GRADED GRAVEL-SAND-CLAY MIXTURES	GC	IMPERVIOUS	GOOD TO FAIR	VERY LOW	GOOD	MEDIUM	SLIGHT	NEGLIGIBLE TO SLIGHT	PRACTICALLY IMPERVIOUS
WELL-GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES	SW	PERVIOUS	EXCELLENT	NEGLIGIBLE	EXCELLENT	LOW TO MEDIUM	SLIGHT	NEGLIGIBLE	EXCELLENT
POORLY GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES	SP	PERVIOUS	GOOD	VERY LOW	FAIR TO GOOD	LOW TO MEDIUM	MODERATE	NEGLIGIBLE TO SLIGHT	EXCELLENT
SILTY SANDS, POORLY GRADED SAND-SILT MIXTURES	SM	SEMI-PERVIOUS TO IMPERVIOUS	GOOD	LOW	FAIR	LOW	MODERATE	SLIGHT TO MODERATE	FAIR TO SEMI IMPERVIOUS IMPERVIOUS
CLAYEY SANDS, POORLY GRADED SAND WITH SOME CLAY MIXTURES	SC	IMPERVIOUS	GOOD TO FAIR	LOW	GOOD	VERY LOW TO LOW	MODERATE TO SLIGHT	NEGLIGIBLE	PRACTICALLY IMPERVIOUS
INORGANIC SILTS AND SANDY SILTS OF SLIGHT PLASTICITY, ROCK FLOUR	ML	SEMI-PERVIOUS TO IMPERVIOUS	FAIR	MEDIUM	FAIR	VERY LOW	SEVERE	SEVERE	FAIR TO POOR
INORGANIC CLAYEY SILTS OF LOW PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, LEAN CLAYS	CL	IMPERVIOUS	FAIR	MEDIUM	GOOD TO FAIR	LOW TO MEDIUM	SLIGHT TO MODERATE	MODERATE TO SEVERE	PRACTICALLY IMPERVIOUS
ORGANIC SILTS OF LOW PLASTICITY	OL	SEMI-PERVIOUS TO IMPERVIOUS	POOR	MEDIUM	FAIR TO POOR	VERY LOW TO LOW	SEVERE	SEVERE	POOR
INORGANIC COMPRESSIBLE SILTS OF MEDIUM PLASTICITY	MI	SEMI-PERVIOUS TO IMPERVIOUS	FAIR	MEDIUM TO HIGH	FAIR TO POOR	LOW	MODERATE	MODERATE TO SEVERE	FAIR TO POOR
INORGANIC SILTY CLAYS OF MEDIUM PLASTICITY	CI	IMPERVIOUS	FAIR TO POOR	HIGH	FAIR	LOW TO MEDIUM	SLIGHT	MODERATE TO SEVERE	SEMI IMPERVIOUS TO PRACTICALLY IMPERVIOUS
ORGANIC SILTY CLAY OF MEDIUM PLASTICITY	OI	SEMI-PERVIOUS TO IMPERVIOUS	POOR	HIGH	POOR	VERY LOW TO LOW	SEVERE	MODERATE TO SEVERE	POOR TO PRACTICALLY IMPERVIOUS
INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SANDY OR SILTY SOILS, ELASTIC SILTS	MH	SEMI-PERVIOUS TO IMPERVIOUS	FAIR TO POOR	HIGH	POOR	VERY LOW	MEDIUM	SEVERE	POOR
INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS	CH	IMPERVIOUS	POOR	HIGH	FAIR TO POOR	LOW TO MEDIUM	SLIGHT TO NEGLIGIBLE	NEGLIGIBLE	PRACTICALLY IMPERVIOUS
ORGANIC CLAYS OF HIGH PLASTICITY	OH	IMPERVIOUS	POOR	HIGH	POOR	LOW	MODERATE	NEGLIGIBLE TO SLIGHT	PRACTICALLY IMPERVIOUS
PEAT AND OTHER HIGHLY ORGANIC SOILS	Pt	—	—	—	—	LOW	SEVERE	—	FAIR TO POOR

ENGINEERING PROPERTIES OF SOILS

Appendix C
Embankment Settlement Criteria for Design (July 2010)

EMBANKMENT SETTLEMENT CRITERIA FOR DESIGN

July 2 2010

SUBJECT: **EMBANKMENT SETTLEMENT CRITERIA FOR DESIGN**

PURPOSE: To provide direction and generic criteria for post construction settlements for new embankments, transitions, and for embankment widenings. The criteria are intended to provide guidance in developing targets for embankment performance during the design phase. The criteria should be reviewed and designs customized on a project specific basis.

BACKGROUND: An embankment refers to the materials placed within the side slopes, below subgrade, and above the original ground, excavated base or theoretical bottom as identified during design.

Embankment settlements are attributable to movements and changes that occur within the underlying native soils due to embankment loading. Settlements can also occur within the embankment fill.

The main types of settlement of native soils include:

1. Elastic compression
2. Primary consolidation
3. Secondary consolidation (creep)

The total settlement is the sum of these settlements.

The magnitude of these settlements is a function of the applied loading, the thickness of the compressible layer and the physical, mechanical and compressibility properties of the soil.

Elastic compression is distinguished from primary consolidation and secondary consolidation in that the settlements are immediate in nature occurring during the construction period or shortly thereafter. Primary and secondary consolidation settlements are time dependent.

Settlements within the embankment fill can occur due to its own weight. Care must be taken to properly compact embankments to reduce settlements associated with fill density changes. Settlements within granular fills generally occur during construction. Settlements within cohesive fills are time dependent and can occur following construction.

Settlements in rock fill can occur due to weathering, particle breakage and particle reorientation. These settlements are partially elastic and partially time dependent.

Differential settlement between any two points is the primary concern when assessing embankment settlement performance. When differential settlements exceed limits as governed by the flexibility of the pavement structure, asphalt cracking and distortions will occur. Differential settlement limits are required to ensure adequate transitions and to avoid unacceptable surface distortions.

Generic performance criteria for highway embankments, including asphalt pavement and slopes, are necessary to ensure safety, rideability and to optimize initial construction and post construction maintenance cost. Performance requirements will also improve provincial design consistency and provide general guidance for foundation engineers. Due engineering diligence is required to define the embankment performance criteria during detail design and to customize the selection on a project specific basis. The requirements for major highways are more stringent than secondary highways or roadways.

For the purpose of establishing settlement design criteria, the following Pavement Design Life has been assumed:

- 20 years following the construction of the pavement structure for King's highways,
- 15 years following the construction of the pavement structure for secondary highways, and
- 15 years following the construction of embankments beneath surface treated and gravel surfaces.

During detail design, the designer shall recognize that post construction maintenance such as milling and shaving and paving can be carried out before the end of design life

This document does not apply to structures. For structures, refer to the applicable design requirements of the Canadian Highway Bridge Design Code (CAN/CSA-S6-00).

POLICY:

Section 1: Settlement Design Criteria

Gravel shoulders of paved or surface treated roads can be readily restored to design crossfall by grading/addition of gravel. For paved and surface treated roads, the settlement criteria apply only to the paved or surface treated portion of the road. Designs shall account for the loss of shoulder width due to settlement and subsequent restoration of the road to design profile, by including an overbuilding of the embankment where appropriate.

1.1 New Embankments

Maximum permissible post-construction settlements for new embankments are provided in Table 1.1. Refer to Figure 1.

Total settlements are defined relative to both the longitudinal profile of the traffic lanes of the roadway, and transversely across the top of the roadway surface.

Differential settlement rates are also applicable to both the longitudinal and transverse directions across the top of the roadway.

Table 1.1: Post-Construction Settlement Criteria For New Embankments

	Maximum Limits During Pavement Design Life	
	Total Settlement (mm)	Differential Settlement Rate
Non-Compressible Soils	50	200:1
Freeways on Compressible Soils	100	200:1
Non-Freeways On Compressible Soils	200	100:1
Surface Treated and Gravel on Compressible Soils	300	50:1

The values in Table 1.1 are recommended maximum permissible values for settlements. Each embankment shall be designed to satisfy these maximum values. Alternative foundation designs shall be developed and compared based on the advantages, disadvantages, costs, and risk/consequences. Alternatives that exceed the maximum settlement values should be considered when the initial construction costs of the alternatives are high, compared to the cost of surface repairs to correct the longitudinal and transverse profile of the surface. Typically, the embankment design selected shall be the preferred alternative that satisfies the maximum settlement values and is the most cost effective, considering both initial construction and anticipated maintenance costs.

1.2 Transition/Tapers

A smooth transition between elements such as a bridge abutment, existing embankment or other structure constructed on non-compressible soils and the new embankment shall be taken into consideration during design. The transition point is the point where an element that will have post-construction settlement intersects an element that will not have post-construction settlement. Refer to Figure 2.

In order to control the differential settlements both in the longitudinal and transverse directions between different ground treatment areas such as areas of compressible soils adjacent to areas of non compressible soils and also to afford acceptable transitions in areas of backfill and approach embankments to structures in areas of compressible soils consideration has to be given to transitions in these areas. Accordingly, embankments adjacent to bridge/culvert structures or to different ground treatment areas shall be designed with appropriate transitions and tapers in the longitudinal direction.

The total and differential post-construction settlement limits are shown in Table 1.2. The designer shall consider these limits and the varying profile grade to design an appropriate transition.

The settlement at structure/embankment interface shall not create any abrupt step deeper than 5 mm

Table 1.2: Post-Construction Settlement Criteria for Transitions

	Maximum Limits During Pavement Design Life			
Distance From Transition Point	0-20 m	20-50 m	50-75 m	>75 m
Freeways	25	50	75	100
Non-Freeways	25	50	100	200
Surface Treated and Gravel	25	75	150	300

1.3 Embankment Widening

Post-construction settlement of the widened embankment shall comply with the limits in Table 1.3. Refer to Figure 3. The differential settlement rate is applicable to both new widened embankment and also the differential settlement rate between the existing and the new embankment.

Table 1.3: Post- Construction Settlement Criteria for Embankment Widening

	Maximum Limits During Pavement Design Life	
	Total Settlement (mm)	Differential Settlement Rate
	50	200:1

Freeways		
Non-Freeways	75	100:1
Surface Treated and Gravel	100	50:1

The settlement across the widened embankment shall transition uniformly from the widening point (existing highway embankment rounding) to the new embankment rounding such that surface drainage is not impeded.

Section 2: Other Considerations

The design, construction and maintenance of embankments must ensure that post-construction deformations do not at any time:

- impair or compromise pavement support; or
- cause pavement to exceed, or fail to satisfy the pavement performance requirements

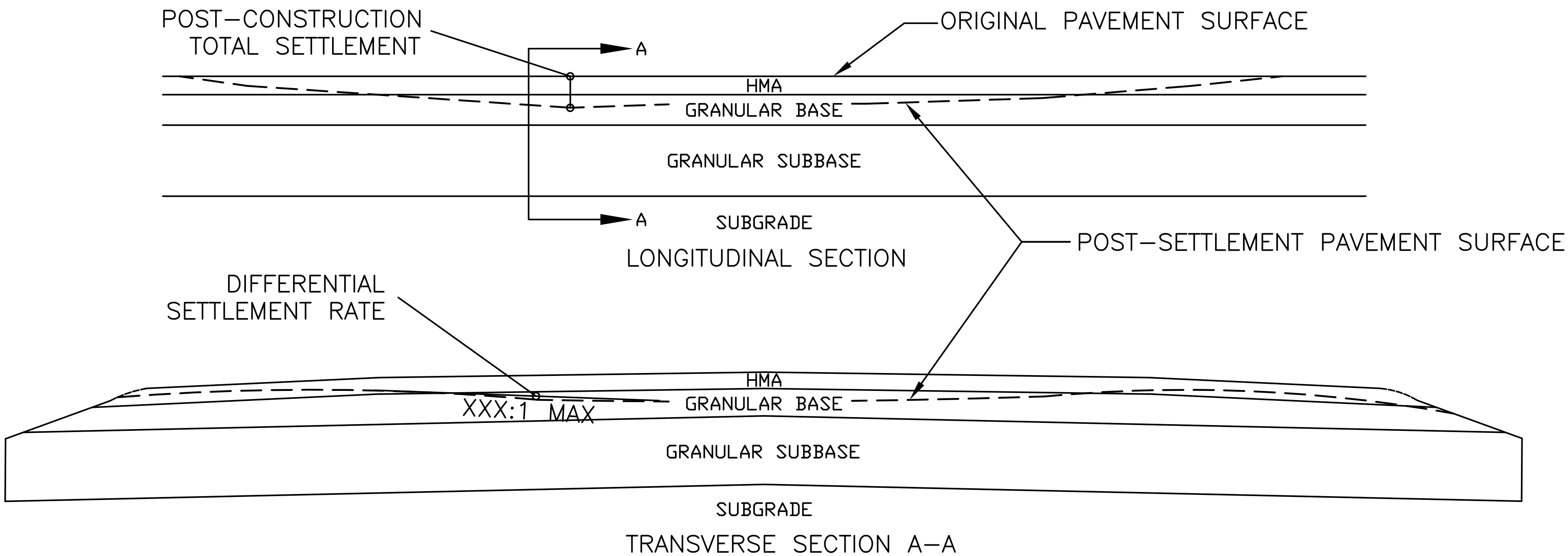
Where rigid (concrete) pavement is designed or possible by contract alternative bidding, the embankment settlement shall not result in joint faulting greater than slight (Reference Ministry of Transportation Manual for Condition Rating of Rigid Pavements, SP-026 (1995), and OPSD 551.010).

Any movement must not cause the cross-section profile to deform to an extent that would compromise surface runoff and subsurface drainage.

Embankment settlements and lateral movements of the subsoils must not adversely impact on existing structures, earthworks or services in a manner that compromises the serviceability and/or structural integrity of the existing structures, new structures, earthworks or services.

Refer to the project specific Foundations Engineering terms of reference for details regarding embankment settlement analysis and parameters for design.

Instrumentation to monitor settlement is generally required where the foundation conditions are high complexity and/or for construction safety purposes. Typically, monitoring of post-construction settlement is by observation. Where a problem is suspected, a ground survey and comparison with as-constructed elevations may be carried out.



NOTES:

1. SETTLEMENT DESIGN SHALL MEET THE TABULATED LIMITS.

2. FOR PAVED AND SURFACE TREATED ROADS, LIMITS SHALL APPLY ONLY TO THE PAVED OR SURFACE TREATED PORTION.

3. POST–CONSTRUCTION SETTLEMENT PERIODS ARE:
   - 20 YEARS FOR KING'S HIGHWAYS AND FREEWAYS
   - 15 YEARS FOR SECONDARY HIGHWAYS (500 SERIES AND HIGHER NUMBERED HIGHWAYS)
   - 15 YEARS FOR SURFACE TREATED AND GRAVEL HIGHWAYS

	SETTLEMENT LIMITS	
	TOTAL (mm)	DIFFERENTIAL
EMBANKMENT ON NON–COMPRESSIBLE SOILS	100	200:1
FREEWAYS ON COMPRESSIBLE SOILS	100	200:1
NON–FREEWAYS ON COMPRESSIBLE SOILS	200	100:1
SURFACE TREATED AND GRAVEL ON COMPRESSIBLE SOILS	300	50:1

NOT TO SCALE

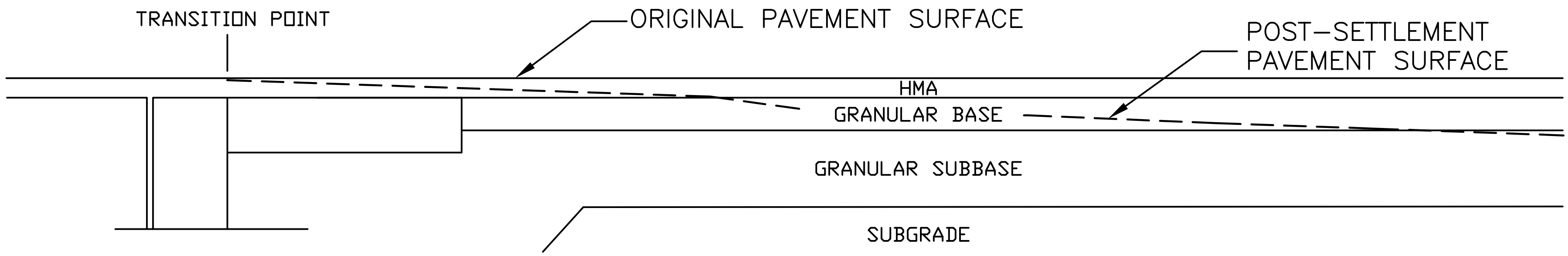
SETTLEMENT DESIGN CRITERIA

MARCH 2010

NEW EMBANKMENTS

Ontario

FIGURE 1



LONGITUDINAL SECTION

NOTES:

1. POST-CONSTRUCTION SETTLEMENT IN TRANSITION ZONE SHALL NOT EXCEED THE TABULATED LIMITS.

2. CRITERIA FOR TOTAL AND DIFFERENTIAL SETTLEMENT SHALL NOT EXCEED LIMITS IN FIGURE 1.

3. THE TRANSITION POINT IS THE POINT BETWEEN TWO DIFFERENT GROUND TREATMENT ZONES, INCLUDING STRUCTURE ZONE.

4. FOR PAVED AND SURFACE TREATED ROADS, LIMITS SHALL APPLY ONLY TO THE PAVED OR SURFACE TREATED PORTION.

5. POST-CONSTRUCTION SETTLEMENT PERIODS ARE:
   - 20 YEARS FOR KING'S HIGHWAYS AND FREEWAYS
   - 15 YEARS FOR SECONDARY HIGHWAYS (500 SERIES AND HIGHER NUMBERED HIGHWAYS)
   - 15 YEARS FOR SURFACE TREATED AND GRAVEL HIGHWAYS

	SETTLEMENT LIMITS (mm)			
DISTANCE FROM TRANSITION POINT	0–20 m	20–50 m	50–75 m	> 75 m
FREEWAYS	25	50	75	100
NON-FREEWAYS	25	50	100	200
SURFACE TREATED AND GRAVEL	25	75	150	300

NOT TO SCALE

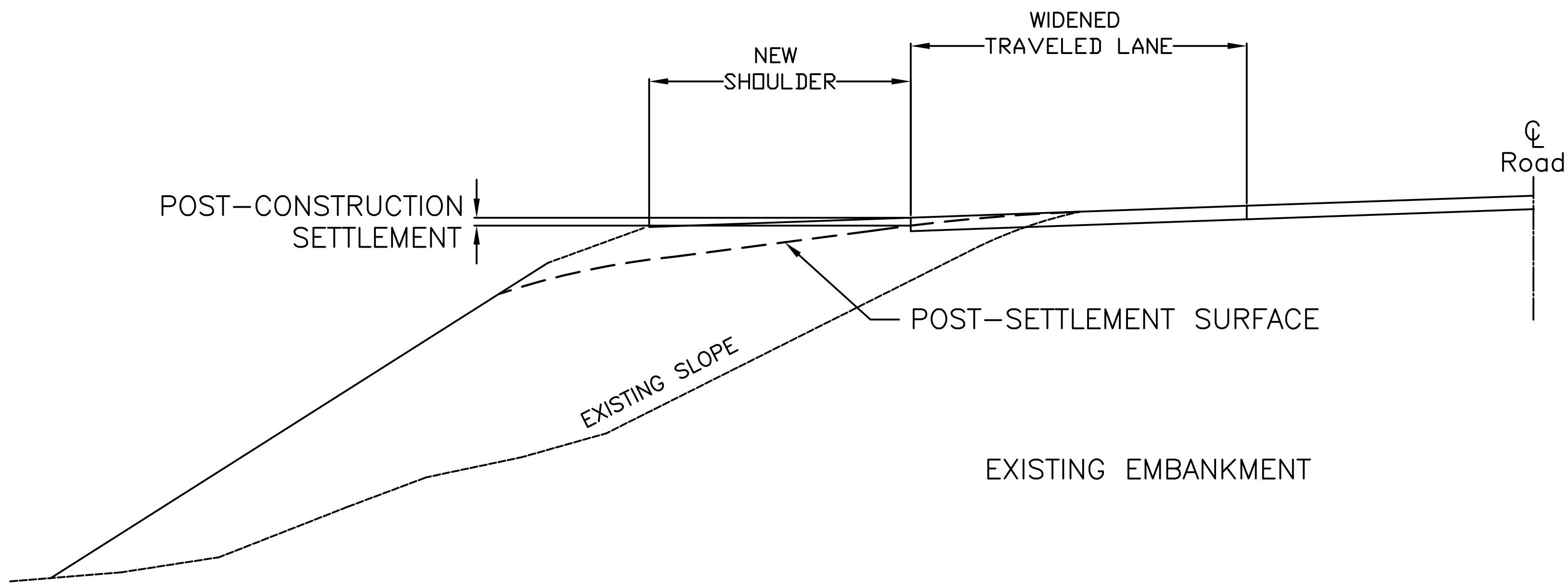
POST-CONSTRUCTION SETTLEMENT LIMITS

MARCH 2010

LONGITUDINAL TRANSITIONS

Ontario

FIGURE 2



NOTES:

1. POST-CONSTRUCTION SETTLEMENT SHALL NOT EXCEED THE TABULATED LIMITS.

2. LIMITS SHALL APPLY ONLY TO PAVED PORTION OF ROAD.

2. POST-CONSTRUCTION SETTLEMENT PERIODS ARE:
   - 20 YEARS FOR KING'S HIGHWAYS AND FREEWAYS
   - 15 YEARS FOR SECONDARY HIGHWAYS (500 SERIES AND HIGHER NUMBERED HIGHWAYS)
   - 15 YEARS FOR SURFACE TREATED AND GRAVEL HIGHWAYS

	SETTLEMENT LIMITS	
	TOTAL (mm)	DIFFERENTIAL
FREEWAYS	50	200:1
NON-FREEWAYS	75	100:1
SURFACE TREATED AND GRAVEL	100	50:1

POST-CONSTRUCTION SETTLEMENT LIMITS	MARCH 2010	Ontario
EMBANKMENT WIDENING		
	FIGURE 3	

NOT TO SCALE

Appendix D
Selection of Geotechnical Resistance Factors for Deep Foundations and Embankments
(March 2020)

HIGHWAY STANDARDS BRANCH

PROVINCIAL ENGINEERING MEMORANDUM

Material Engineering and Research Office (MERO) #2020-01, March 23, 2020

This memorandum provides guidance to foundation designers for the selection of geotechnical resistance factors for deep foundations and embankments.

Implementation

This memorandum is effective as of the date of issue.

Background

The selection of geotechnical resistance factors is a critical component in foundation engineering analysis. Optimization of these factors is required to achieve the desired performance of the foundation and geotechnical system and to produce cost effective designs for the service life of the structure or embankment (e.g. 75 years).

Limit states are classified as either ultimate limit states (ULS) or serviceability limit states (SLS). Foundations and geotechnical systems shall be designed to satisfy the ULS and SLS requirements as specified in Section 6.4 of the CHBDC.

At the ULS, the design shall be such that the factored ultimate geotechnical resistance is equal to or greater than the effect of factored loads for a given ULS.

At the SLS, the design shall be such that factored serviceability geotechnical resistance shall be equal to or greater than the effect of factored loads for a given SLS.

Factored ultimate and serviceability geotechnical resistances used in the design shall provide acceptable performance of the foundation and geotechnical system and the supported structure at all limit states.

The factored ultimate geotechnical resistance is determined by multiplying the ultimate geotechnical resistance by:

1. ψ = consequence factor given in Clause 6.5.2
2. φ_{gu} = ultimate geotechnical resistance factor given in Clause 6.9

The factored serviceability geotechnical resistance is determined by multiplying the serviceability geotechnical resistance by:

1. ψ = consequence factor given in Clause 6.5.2
2. φ_{gs} = serviceability geotechnical resistance factor given in Clause 6.9

The ULS and SLS consequence factor, ψ, are given in Table 6.1 in Clause 6.5.2. Consequence factors are given for high, typical and low consequence levels.

Table 6.2 in Clause 6.9 provides geotechnical resistance factors for various applications for both ULS and SLS for varying degrees of understanding. Factors with precision of two decimal places have been determined by rigorous reliability assessment. Factors with precision of one decimal place (the SLS factors) are applicable to the current code, but are under development and need further study to refine their accuracy.

Sound engineering judgement is relied upon in making recommendations in geotechnical engineering. This judgment is achieved as a result of experience allowing the gap to be bridged between theory and practice. The comprehensive system of consultant selection and review prevalent at the MTO reassures that this judgement and experience will be applied in the selection of specific and relevant resistance factors for MTO projects.

Policy

Geotechnical Resistance Factors shall be in accordance with Section 6.9 of the CHBDC and Table 6.2 in Section 6.9.1 of the CHBDC. When approved by MTO, the exceptions tabulated in Table 1 below can be used:

Table 1 – Geotechnical Resistance Factors

Application	Limit State	Test Method/Model	Degree of Understanding		
			Low	Typical	High
Deep Foundations	Compression(φ_{gu})	Static Test	0.50	0.65	0.75
	Tension	Static Test	0.40	0.55	0.65
	Lateral	Static Test	0.45	0.55	0.60
Embankment Fills	Global stability – temporary (φ_{gu})	Analysis	0.7	0.75-0.8	0.80-0.85
	Global Stability - permanent(φ_{gu})	Analysis	0.6	0.65-0.7	0.7-0.75
	Settlement	Analysis	1.0	1.0	1.0
		Test	N/A	N/A	N/A

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Manager, MERO

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Appendix E
Guidelines for Foundation Engineering – Tunnelling Specialty For Corridor Encroachment Permit Application

Guidelines for Foundation Engineering – Tunnelling Specialty
For Corridor Encroachment Permit Application

General

These guidelines specify MTO requirements for the Foundation Engineering – Tunnelling Specialty component of submissions from proponents of development within the Ministry of Transportation's (MTO) corridor permit control area. The Foundation Engineering – Tunnelling Specialty component of submissions is a requirement for the permit application only and does not cover all the design requirements.

All applications containing tunnelling proposals shall be forwarded to the regional Geotechnical Section for review. Applications containing Low Complexity tunnelling proposals will typically be reviewed by the regional Geotechnical Section. The Geotechnical Section will forward applications involving Medium and High Complexity tunnelling proposals to the Foundation Section of the Structures Office for review.

Foundations Engineering consultants that are registered in the MTO consultant acquisition system (RAQS) at complexity ratings identified in Table 1 are eligible to provide Foundations Engineering services for this project. Alternatively, the proponents may propose a Foundations Engineering consultant that is not registered in RAQS, in which case, the proponent must submit sufficient documentation to demonstrate that the consultant's qualifications meet or exceed the RAQS complexity requirements. The submission for RAQs exemption shall demonstrate that the proponent has successfully completed tunnelling/trenchless projects on projects of similar scope and complexity. The proponent shall submit a minimum of three (3) Foundation Investigation and Design Reports on projects of similar scope and complexity produced in the last five (5) years. The proponent shall submit any supplementary engineering and construction experience to demonstrate their qualifications.

For Engineering Materials Testing and Evaluation, the consultant shall be qualified for Soil and Rock testing of complexity level at least equal to that identified for this project.

Please refer to Table 1 on Page 2 for the Foundation Engineering Complexity of Work guideline.

Table 1: Complexity ratings for tunnelling specialty services

Excavation Diameter (ø)	≤ 300 mm		1 m ≥ ø > 300 mm		2 m ≥ ø > 1 m		ø > 2 m
Design Cover* (m)	≥ 1.5 m	< 1.5 m	≥ 3 ø and > 1.5 m	< 3 ø or < 1.5 m	≥ 3 ø	< 3 ø	N/A
King's Highway	**Low**	**Medium**	**Low**	**Medium**	**Medium**	**High**	**High**
400 Series Freeway	**Low**	**High**	**Medium**	**High**	**High**	**High**	**High**

* Design cover is the proposed vertical distance measured from the lowest ground elevation to the crown of the tunnel

Site Investigation, Field Testing and Monitoring

General

This section describes requirements for site investigation, field/laboratory testing and monitoring programs for a proposed tunnelling projects. For low complexity projects, some or all of these requirements may not be necessary. Foundation field investigation, laboratory analyses and monitoring for low complexity projects with an excavation diameter of 300 mm or less will generally only be required on an exception basis. The applicant's Foundation Engineering service can contact MTO Geotechnical staff for clarification regarding appropriate levels of investigation, testing and monitoring.

Field Testing

A minimum of one borehole is required at each end of tunnel crossing. The boreholes shall be located outside but within two metres of the tunnel's excavated footprint.

Spacing between the boreholes shall not exceed 50 m. In case of larger spacing between the boreholes, additional boreholes shall be advanced except where significant traffic disruptions might occur and where consistent conditions are evident.

Boreholes shall be advanced to 3 tunnel diameters (excavated diameters) below invert. If bedrock is encountered earlier, the borehole shall advance to at least 3 m below the invert of tunnel into the bedrock.

The investigations, if required, shall be supplemented with additional and deeper boreholes to verify consistent conditions and existence of boulders within critical foundation zones.

Sampling and testing, consisting of Standard Penetration Test, thin wall tube sample, rock cores, and MTO Field Vane Test where appropriate, shall be conducted to develop a comprehensive subsurface model. Semi-continuous sampling at 0.75m (2.5ft) intervals is required within overburden; whereas, sampling interval of 1.5m (5.0ft) is required below the tunnel invert.

Where encountered, the bedrock-soil interface shall be determined by geological definition and not the by the material properties.

All aspects of implementation of means of subsurface investigations including, but not limited to, planning, licensing, construction, maintenance, abandonment, and reporting, shall be in accordance with Ministry of the Environment Regulation 903 and its amendments (the water well regulation under the OWRA).

Boreholes and piezometer tubes shall be backfilled with a suitable bentonite/cement mixture. Test pits shall be backfilled with suitable material and either re-vegetated or otherwise protected from erosion. Temporary open holes shall be adequately covered. Holes in roads shall be backfilled as required to prevent future settlement and acceptably patched where pavement surfaces have been damaged. Backfilling requirements shall be described in the Foundation Investigation and Design Report.

Where encountered, artesian groundwater conditions shall be sealed. Details of the artesian condition and the sealing operation shall be included in the Foundation Investigation Report.

Fieldwork, including any Traffic Protection Plans required, shall be carried out in accordance with the Occupational Health and Safety Act.

Traffic Control in accordance with Ontario Traffic Manual Book 7 shall be provided during the course of any field investigations. However, where significant traffic disruptions might occur, boreholes may be relocated or numbers reduced with MTO's approval.

The locations and ground surface elevations of all boreholes, test pits and soundings shall be surveyed and referred to fixed reference points and data. Locations are to be identified by co-ordinates (Northing and Easting). The vertical accuracy of survey readings shall be within 0.1m; whereas, horizontal accuracy shall be within 0.5m.

The site investigation shall be of sufficient scope to verify design assumptions and to provide the contractor with adequate subsurface information for design and construction planning.

Sufficient subsurface (factual) information is required to determine the vertical and horizontal extent of subsurface materials (including both soil and rock) and their pertinent engineering properties and groundwater conditions.

Subsurface information is usually acquired by advancing boreholes, laboratory testing of soil samples and rock core samples, performing in-situ tests such as standard penetration tests, dynamic cone tests, and piezocone tests (CPTU) and test pits.

Minimum Laboratory Testing Requirements

Laboratory testing shall consist of routine testing of 25% of samples. One routine lab test is defined as natural water content plus Atterberg Limits plus grain size distribution tests. Complex laboratory testing is defined by all other tests including compressive strength, shear strength, consolidation, permeability and triaxial testing. Laboratory testing requirements shall be supplemented with additional routine and complex tests if required to verify strata boundaries and properties and behaviour of critical subsurface zones.

A minimum of one (1) soil chemical test shall be conducted at maximum of 100 m spacing. A soil chemical test includes pH, water soluble sulphate, sulphide, chloride, resistivity and electrical conductivity analyses.

Borehole Log Preparation and Foundation Drawing

Borehole log sheets, figures and drawings shall be prepared in accordance with MTO standards. The Foundation Drawing shall consist of a plan showing the locations of all borings, test pits and soundings and various stratigraphical longitudinal profiles and stratigraphical cross-sections at each tunnel structure foundation element and groundwater levels.

Requirements for the Foundation Investigation and Design Report

A Foundation Investigation and Design Report shall consist of the factual subsurface information (including the field and laboratory test information) and the recommendations required for foundation design.

Service Provider services shall be in accordance with the most recent editions of the Canadian Highway Bridge Design Code (CHBDC), and the 'Guideline for Professional Engineers Providing Geotechnical Engineering Services' published by the Professional Engineers of Ontario.

The designated principal contact identified for Foundations Engineering services by MTO shall sign, and where required, seal, all submissions and correspondence that are submitted to MTO.

The report shall be signed and sealed by two professional engineers, registered with the Professional Engineers of Ontario, representing the consulting firm; one of them shall be the firm's designated principal contact for MTO's Foundations Engineering projects.

The Foundation Investigation component of the report shall contain:

- Site Description - including topography, vegetation, drainage, existing land use, and structures.
- Investigation Procedures - including site investigation and lab testing procedures.
- Description of Subsurface Conditions - including soil, boulders, rock and groundwater conditions.
- Miscellaneous Section - that identifies the name of the drilling company, the laboratory where testing was performed, the persons who carried out the field supervision, and those who wrote and reviewed the report.

The Foundation Design component of the report shall present discussion and recommendations for design. The Service Provider shall analyse field data and test results and make comprehensive and practical recommendations pertaining to temporary, interim and permanent conditions at the Project.

The Service Provider shall identify and evaluate all reasonable and appropriate alternatives for the proposed tunnel crossing. Alternatives may include, but not limited to, jack & bore, pipe jacking using TBM, pipe ramming, micro-tunnelling, utility tunnelling using TBM (two pass system), Horizontal Directional Drilling (HDD)and cut and cover methods.

The Service Provider shall identify and present overview assessments of the advantages, disadvantages, relative costs and risks/consequences of alternative tunnelling methods in a table. The report should conclude a preferred alternative from foundation engineering and cost effectiveness perspective.

In the development and design of the preferred alternative, the Service Provider shall, as applicable, address:

- impacts on the land use and property, traffic and transportation, and environment,
- length and diameter constraints
- control of face stability
- capability of boulder excavation
- evaluation of temporary and permanent support
- alignment control
- estimated settlements and heave and management of these deformations

- special access and egress requirements for TBM's and other similar equipment such as those used for the Jack & Bore method including recommendations for vertical shafts and jacking pits;
- shored and un-shored alternatives for open-cut excavation;
- groundwater control & dewatering;
- the long-term stability of the tunnel;
- relative costs; and
- traffic management and contractor access for each alternative.

If borehole logs available from previous projects are included to meet the requirements of field investigations then the accuracy of subsurface information from these boreholes remains the responsibility of Service Provider except in situations where MTO specify the use of previous boreholes. Borehole logs from previous studies that are appended to the report shall be reformatted to meet the MTO's requirements.

The final foundation recommendations shall detail the geometric, material and strength properties of the new tunnel crossing plus the liner, bedding and backfill requirements, and slope and embankment restoration requirements. The invert elevation should be assessed in view of the subsurface conditions and the anticipated open face stability control.

The Service Provider is responsible for developing contract documents sufficient to implement the design. This typically includes:

- Contract specifications for materials and specialized construction activities, and
- Recommendations for methods of overcoming anticipated construction problems, in particular, those relating to dewatering, boulder excavation, alignment control and the stability of excavations and embankments.

The Service Provider shall develop a detailed instrumentation and monitoring program that meets the requirements of these guidelines. (see Appendix for typical settlement monitoring guidelines).

The Service Provider is responsible for preparing Traffic Control Plans, Traffic Protection Plans and to obtain approvals and an Encroachment Permit from the Ministry, which are required for lane closures necessary to install the settlement monitoring points.

The tunnelling Service Provider shall ensure that the foundations engineering component of the project is adequately reflected in the design drawings, specifications and related contract documents.

Written confirmation is required from the Proponent and the tunnelling Service Provider that the design package submitted to MTO have been reviewed by the tunnelling Service Provider and that all recommendations have been satisfactorily incorporated in the contract package.

APPENDIX: SETTLEMENT MONITORING GUIDELINES - TUNNELING

The purpose of settlement monitoring is to prevent damage to existing utilities and highway structures along the tunnel alignment. Ground settlement include settlement due to lost ground and dewatering/drainage.

Daily visual monitoring of the road surface and shoulders shall be carried out for any evidence of movements (e.g. cracks, bulges, heaves, depressions, ponding, etc.)

Instrumentation Arrays

All measurement points shall be installed and surveyed before the start of excavation to establish benchmarks/baseline.

Surface Monitoring Points

Surface monitoring points will be installed to cover the whole length of the tunnel with in the right of way under the jurisdiction of MTO (Figure 1).

Surface monitoring points will be located at not greater than 5m intervals along the tunnel alignment. The surface monitoring will be identified using paint marks on the pavement. Surface monitoring points installed on the unpaved right of way shall be founded below frost penetration depths. The interval and/or marking of the points should be changed with MTO's approval where traffic disruptions might occur.

The final instrumentation plan should be finalised when Contractor's proposed construction method is available.

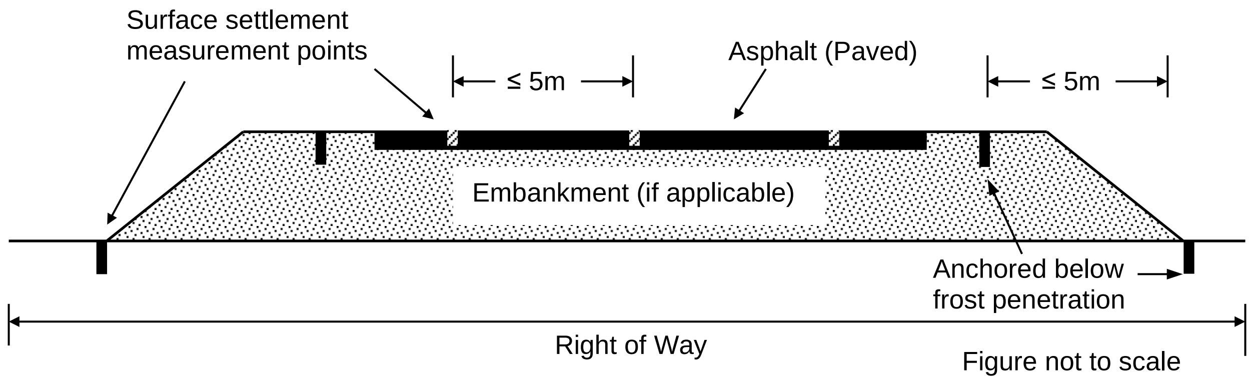

Figure 1: Typical configuration of surface settlement monitoring points along the tunnel alignment.

Condition Survey

A condition survey for the pavement will be carried out prior to commencement of construction and documented for the purpose of requirement of restoration. The condition survey shall document visible flaws such as cracks, distortions and deviations, heaves, and depressions. This surface survey will be completed during the installation of the monitors and again once the tunnel has been completed.

Reading Frequency

An average of at least two readings shall be taken to establish the initial conditions.

The reading and collection of data from the surface monitoring points shall be read and recorded by the Contractor during the construction period and after construction for period of at least 2 weeks provided that further settlement has stopped.

A minimum of three (3) sets of reading be taken daily, provided that movements are within anticipated limits. Otherwise, the frequencies should increase according to a pre-planned interval.

Monitoring of movements is required during work stoppages, such as during non-operation period (off-shifts) or weekends. A minimum of three (3) sets of readings should be taken daily.

Measurements of the monitoring points shall be reported promptly to MTO for review.

Data Collection and Data Transfer

A procedure is required to be established in consultation with MTO so that the monitoring data and the interpreted data will reach all parties as soon as necessary. The contract administrator/Service Provider and the Contractor should interpret monitoring data as needed for the purpose of on-going construction. The Foundation Engineer should be contacted for technical support to the prime Service Provider in the interpretation of ground movements and review of the Contractor’s response when Review and Alert Levels are reached.

Criteria for Assessment

The acceptable surface settlement (or heave) will be according to criteria as specified below.

Baseline Reading – A baseline reading of the instrumentation shall be taken prior to commencement of the work. An average of at least two initial readings shall be recorded as baseline reading.

Review Level – A maximum value of 10 mm relative to the baseline readings is suggested for this project. If this level is reached, the method, rate or sequence of construction, or ground stabilization measures should be reviewed or modified to mitigate further ground displacements.

Alert Level – A maximum value of 15mm relative to the baseline readings is suggested for this project. If this level is reached, the Contractor shall cease construction operations and to execute pre-planned measures to secure the site, to mitigate further movements and to assure safety of public and maintain traffic.

Review of Contractor's Proposed Method

MTO, the Proponent's prime Service Provider and Foundation Engineer should review the Contractor's proposed method of construction. The proposed method should include a description of the potential loss of ground, and calculation of the maximum settlement in relation to the Contractor's procedure and equipment, alternative/remedial measures when review level of measurement is reached; and contingency/remedial measures when alert level of measurement is reached.

Contractor's Responsibility for Restoration and Warranty Provision

In addition to the monitoring program to assess the adequacy of the construction method to control potential ground movements and groundwater, the Contractor is responsible for reinstatement (such as surface paving) should movements or other surface distress occur, and provide a reasonable warranty period acceptable to MTO. Remedial measures shall be approved by MTO; however, MTO maintains the right to perform the maintenance at the proponent's expense.

Construction Monitoring

The Proponent shall retain a RAQS qualified Geotechnical Service Provider – Medium Complexity to supervise the installation of surface settlement points on site and to provide direction, technical input and field inspection on this project.

Appendix F
MTO Guideline for Rock Fill Settlement and Rock Fill Quantity Estimate (September 2010)

MTO Guideline for Rock Fill Settlement and Rock Fill Quantity Estimates

September 14, 2010

SUBJECT: **ROCKFILL SETTLEMENT AND ROCK FILL QUANTITY ESTIMATES**

PURPOSE: To provide direction for estimating settlements and quantity of rock fill used for the construction of new embankments. The criteria are to provide guidance for estimating settlement within rock fill (within the embankment proper exclusive of the settlement of the native subsoil) of new embankments; and outlining the information that should be provided for use in the estimation of the quantity of rock fill that may be required for construction. The criteria apply to strong, granitic-type rock fills (placed above and below original ground surface) that are up to 15 m in total thickness. The criteria should be reviewed and the designs modified for thicker/higher rock fill embankments and/or for weaker types of rock fill on a project specific basis.

BACKGROUND: If rock fill is used for the construction of embankments, there will be settlement due to compression of the rock fill. In highway embankments, settlement of rock fill during and after construction occurs as a result of re-arrangement of rock particles under load and as a result of crushing of rock particles at point contacts.

The magnitude of settlement of the rock fill depends on the following factors:

- type of rock/strength of particles;
- size and shape of rock particles;
- gradation of rock fill;
- total height/thickness of rock fill (stress level); and,
- method of construction and sequence of placement (including, lift thickness, compactive effort, and state of packing).

The magnitude of the short-term settlement (i.e. within about 1 year following completion of construction to full height) and long-term settlement (i.e. after 1 year, over the life of the embankment) of rock fill depends on amongst other variables the method of placement (compacted versus dumped) as discussed below.

Compacted Rock Fill

Where possible, rock fill should be placed in a controlled manner (i.e. not end dumped) in accordance with Special Provision 206S03. Blading, dozing and 'chinking' the rock to form a dense, compact mass will be required to minimize voids and bridging and should be used to construct rock fill embankments above the existing groundwater table. Rock size shall be controlled in accordance with SP206S03.

Dumped Rock Fill

If rock fill embankments are constructed by end dumping rock fill (for cases where Special Provision 206S03 cannot be applied) or when backfilling sub-excavated areas below the groundwater table by end dumping rock fill with little or no control on the lift thickness and compactive effort, the settlement of rock fill placed in this uncontrolled manner will be greater than that of compacted rock fill.

POLICY:

Section 1: Performance - Recommendation for Design

For rock fill embankments, both the short-term and long-term settlement of the fill should be considered in the design. Further, both the compacted and un-compacted portions of rock fill in the embankment should be considered when estimating the magnitude of settlement. In all cases, the total height of the rock fill embankment will be measured from the base of the rock fill.

1.1 Short-Term Rock Fill Settlement

For rock fill embankments constructed over a non-compressible subgrade, the percentages in Table 1.1 should be used for estimating the short-term settlement of the embankment.

Table 1.1: Short-Term Rock Fill Settlement

Height of Rock Fill, H (m)	Short-Term Settlement (m)	
	Compacted Rock Fill	Dumped Rock Fill
Up to 5	0.5%·H	1.0%·H
>5 to 10	0.75%·H	1.5%·H
>10 to 15	1.0%·H	2.0%·H

Short-term is defined as 1 year after the rock fill embankment is constructed to full height. Approximately 90% of the short-term settlement may be expected to be complete within 6 months following construction to full height (including surcharge, if applicable).

1.2 Long-Term Rock Fill Settlement

For rock fill embankments constructed over a non-compressible subgrade, the percentages in Table 1.2 should be used for estimating the long-term settlement of the embankment.

Table 1.2: Long-Term Rock Fill Settlement

Height of Rock Fill, H (m)	Long-Term Settlement (m)	
	Compacted Rock Fill	Dumped Rock Fill
Up to 15	0.1%·H	0.2%·H

Long-term is defined as being after 1 year following construction to full height, over the life of the embankment.

1.3 Rock Fill Embankments over a Compressible Subgrade

For rock fill embankments constructed over a compressible subgrade, the estimated settlement of the embankment must include the compression of the rock fill (short-term and long-term, as described in Section 1.1 and 1.2) plus the settlement of the compressible foundation soils.

Section 2: Guidelines for Estimating Rock Fill Quantities for Construction

Each fill material has its own unique quantity requirements that are dependent upon the type of material used. For the appropriate embankment fill item, the designer determines the quantity of material for backfill and embankment construction by considering the following:

- neat lines of the embankment;
- embedment of fill material into the founding stratum;
- settlement during construction of the underlying founding stratum;
- settlement during construction of the un-compacted fill material;
- settlement during construction of the compacted fill material; and,
- construction loss of material below the water line.

For each swamp crossing and high fill area, the Foundation Investigation and Design Report should include the following estimates:

- estimated max. embedment of fill into the founding stratum (m);
- estimated max. settlement of the founding stratum during construction (m); and
- estimated max. settlement within the fill itself (both compacted and un-compacted) (m)

The estimates of maximum embedment and foundation soil settlement during construction are to be considered by the designer when estimating the quantity of fill required for construction. To account for the settlement of rock fill during construction, the rock fill quantity should be estimated using the standard bulking factor(s) currently recommended by MTO.