# A proposed reporting approach for Champlain Sea clays and other similar deposits

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ABSTRACT
This paper recommends the routine inclusion of profile-based geotechnical models, Liquidity Indices and Consistency Indices to supplement the more commonly used Plasticity Indices and Sensitivity values to characterize clay soils. Provincial transportation departments in Canada currently promote the use of the Unified Soil Classification System (USCS), where mineral soils are divided into fine-grained and coarse-grained soils; fine-grained soils are sub-classified as Silt or Clay; and, clays are further sub-classified on the basis of their degree of plasticity as being of low plasticity, of intermediate plasticity or of high plasticity with corresponding Group Symbols of CL, CI and CH. The intuitively incompatible CL classification for quick clays presents a risk of misunderstanding of the anticipated soil behavior since for other non-marine deposits the group symbol CL typically indicates more favorable soils when compared to the CI and CH clays. This paper also proposes the use of a group symbol modifier such as $CL_{-m}$ to reflect the non-standard predicted behavior of these soil types and the inclusion of a List of Risk and Methods of Interpretation to supplement the standard Lists of Abbreviations, of Symbols and of Terms currently included in geotechnical reports.

RÉSUMÉ
Cet article recommande l'inclusion systématique de modèles géotechniques basés sur les profils, les indices de liquidité et les indices de consistance pour complémenter les indices de plasticité et les valeurs de sensibilité, plus couramment utilisés pour caractériser les argiles. Les ministères des Transports provinciaux du Canada font actuellement la promotion de l'utilisation du Système unifié de classification des sols (USCS), où les sols minéraux sont divisés en sols à grains fins et à grains grossiers; les sols à grains fins sont sous-classés en silt ou en argile; et, les argiles sont en outre sous-classées sur la base de leur degré de plasticité comme étant de faible plasticité, de plasticité intermédiaire ou de plasticité élevée avec les symboles de groupe correspondants de CL, CI et CH. La classification CL, intuitivement incompatible pour les argiles liquides, présente un risque d'incompréhension du comportement attendu du sol puisque pour les autres dépôts non marins, le symbole de groupe CL indique généralement des sols plus favorables par rapport aux argiles CI et CH. Cet article propose également l'utilisation d'un modificateur de symbole de groupe tel que $CL_{-m}$ pour refléter le comportement prédictif non-standard de ces types de sols et l'inclusion d'une liste de risques et de méthodes d'interprétation pour compléter les listes standard d'abréviations, de symboles et des termes actuellement inclus dans les rapports géotechniques.

## 1 INTRODUCTION

This paper includes a review of the field behavior of sensitive marine clays and compares it to that of the more common lacustrine and glacio-lacustrine clays. It also includes a recommendation that USCS group symbols (CL, CI, and CH) should be modified in case of Eastern Canada marine clays. Figure 1 presents the typical profile of post-glacial marine clays within eastern Canada. A Champlain Sea clay deposit would typically include a surficial crust (consisting of stiffer and drier clay) that is underlain by a weaker and a more compressible clay layer (City of Ottawa, 2007). The thickness of the surficial crust is highly variable based on the location and can be up to several metres. However, in some locations, where the clay is overlain by a sand deposit, there may not be a crust and the near surface portions of the clay may be soft and compressible.

The lower portion of the clay is unweathered and it is typically soft to firm with local variations to the mineralogy and the depositional history (City of Ottawa, 2007). The presence of the post-glacial marine clays within eastern Canada generally poses several design and construction constraints. During significant seismic events, there is a risk that the ground motions can result in the formation of liquefiable shear planes within marine clay deposits. This applies mainly to areas where the clay is characterized as highly sensitive or quick (Lee, 1979).

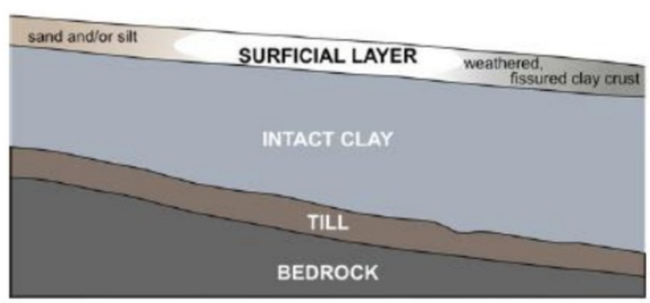


Figure 1. Typical soil profile within the Ottawa area (Lefebvre, 2017)

Figure 2 presents a sensitive clay flow which occurred in 1993 near Lemieux, Ontario. The failure involved 2.5 to 3.5 $Mm^3$ of sand, silt and clay which flowed into the South

Nation Valley, flooding 3.3 km of the valley bottom and impounding the South Nation River (Brooks et. al., 1994).

Figure 2. Lemieux landslide in June 1993 (Brooks et al. 1994)

The engineering issues associated with the field behavior of the post-glacial marine clay deposits within eastern Canada have been addressed in the geotechnical engineering investigation reports in several ways. It is crucial to highlight these issues in the reports using a standard procedure so that contractors can better understand the construction constraints associated with these deposits. The following sections present a recommended way for reporting these issues in the geotechnical investigation reports.

## 2 PROPOSED INSERT TO GEOTECHNICAL REPORTS

It is proposed that the geotechnical reports prepared for sites within post-glacial marine clay deposits would include a section preceding the borehole records. This section would include the following subsections.

### 2.1 Description

This section would include a generic description of the sensitive marine clays within Eastern Canadian (i.e. Champlain Sea, Goldthwait Sea and LaFlamme Sea clay deposits). It shall highlight that these deposits are typically highly compressible and can undergo significant settlements when subjected to new loads associated with site grade fills or foundations. A figure showing the distribution of these deposits such as the one presented in Figure 3 below may be presented in this subsection.


Figure 3. Extent of sensitive clays within Eastern Canada (City of Ottawa 2004)

### 2.2 Characterization

In this subsection, the available methods that can be used to characterize the sensitivity level of clay soils can be presented. Tables 1 and 2 summarize some of the key methods that can be used to assess the sensitivity degree of clay soils available in the literature. Table 3 presents a terminology that is typically being used to identify quick clays based on liquidity index (Lebuis et al. 1983 and Tavenas et al. 1983).

Table 1. Soil sensitivity levels (Canadian Geotechnical Society, 2006)

| Classification | Sensitivity ($S_t$) |
|---|---|
| Low sensitivity | $S_t < 2$ |
| Medium sensitivity | $2 < S_t < 4$ |
| Sensitive | $4 < S_t < 8$ |
| Extra-sensitive | $8 < S_t < 16$ |
| Quick clay | $S_t > 16$ |

Table 2. Remoulded shear strength for quick clays

| Classification | Remoulded Shear Strength, $S_{ur}$ (kPa) |
|---|---|
| Quick clay | $S_{ur} < 0.5$ |
| Susceptible to large retrogressive failures | $S_{ur} < 1.0$ |

Table 3. A terminology to identify quick clays using the liquidity index

| Classification | Liquidity Index (LI) |
|---|---|
| Quick | LI > 1.3 |
| Extra-sensitive | 1 < LI < 1.3 |
| Susceptible to large retrogressive failures | LI >1.2 |

For foundation designs, provincial transportation departments in Canada typically recommend the use of the Unified Soil Classification System (USCS), where mineral soils are divided into fine-grained and coarse-grained soils. Clays are sub-classified on the basis of their degree of plasticity as being of low plasticity, of intermediate plasticity, or of high plasticity with corresponding Group Symbols of CL, CI and CH. One of the key objectives of using the USCS is to predict the soil behavior and to provide a basis for soil parameter correlations.

However, using the CL classification for quick clays presents a risk of misrepresenting of the anticipated soil behavior in the geotechnical reports. For other non-marine deposits, the group symbol CL typically indicates favorable soils when compared to CI and CH clays. However, for Champlain Sea clays of low plasticity would be expected to have high liquidity index and high sensitivity. It is, therefore, proposed the use of a group symbol modifier such as $CL_{-m}$ to reflect the non-standard predicted behavior of these soil types and the inclusion of a List of Risk and Methods of Interpretation to supplement the standard Lists of Abbreviations, of Symbols and of Terms currently included in geotechnical reports as presented in Table 4 below.

Table 4. Proposed group symbol modifier for sensitive marine clays

| Classification | Description |
|---|---|
| $CL_{-m}$ | Post-glacial marine clay with low plasticity (often extra sensitive to quick) |
| $CI_{-m}$ | Post-glacial marine clay with intermediate plasticity (often extra sensitive) |
| $CH_{-m}$ | Post-glacial marine clay with high plasticity (often sensitive to extra sensitive) |

As an example, Figures 3 and 4 present the Plasticity Index and Liquidity Index profiles for a Champlain Sea clay deposit in Beauharnois, Quebec as documented in El-Dana et al. (2017). It can be noted that as the clay becomes less plastic with depth, the liquidity index increases. As noted earlier, when the liquidity index is greater than 1.5 the clay should be considered quick. This shows that the portion of the clay that is classified as intermediate plastic clay should be expected to pose more challenges to construction activities than the highly plastic portion.

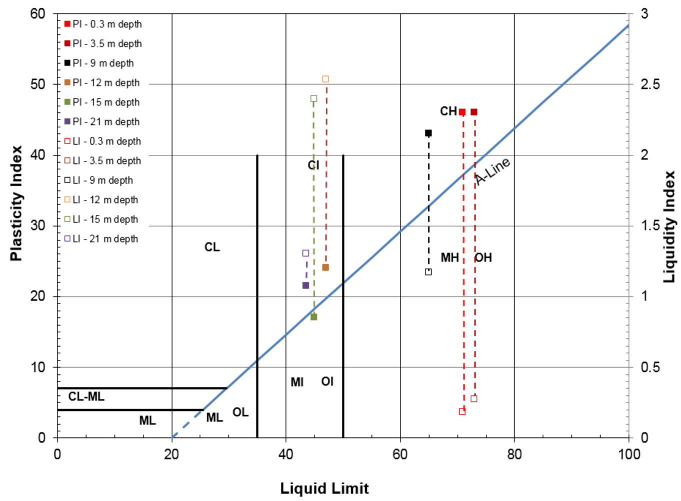


Figure 3. Plasticity Index and Liquidity Index for a Champlain Sea clay deposit in Beauharnois, Quebec

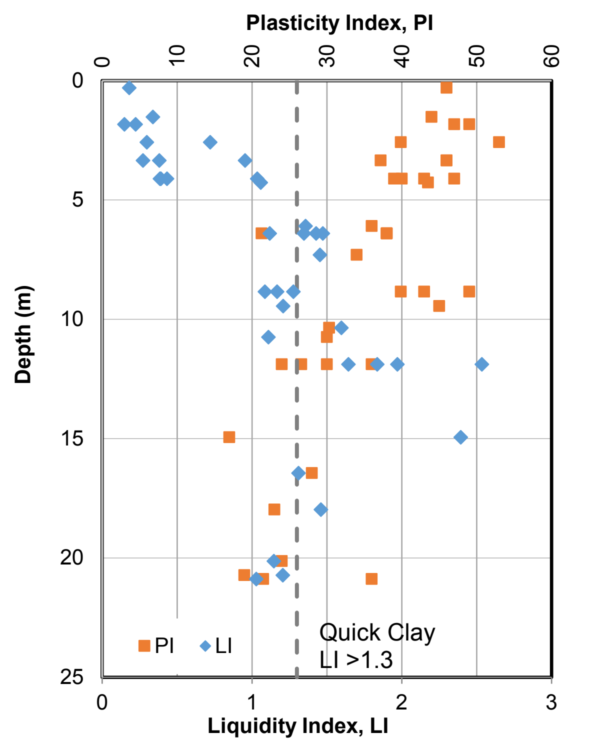


Figure 4. Plasticity Index and Liquidity Index versus depth for a Champlain Sea clay deposit in Beauharnois, Quebec

It is also noted that the Standard Penetration Test (SPT) N-values are generally being utilized to estimate the undrained shear strength of soils. For marine clays, the N-value based correlations may underestimate the undrained shear strength of the clay. It is, therefore, recommended that the sensitivity and the plasticity of marine clays be considered in the estimation of undrained shear strength from N-values.

### 2.3 Key Geotechnical Issues

The following key geotechnical issues associated with the presence of post-glacial marine clay deposits should routinely be discussed in the geotechnical reports. Including these issues in the proposed insert to the geotechnical reports is to standardize the reporting approach.

- Marine clays are prone to slope instability issues. Flow slides have developed within marine clays in the past. Specific areas near some watercourses within marine clay deposits are designated as hazard lands with development restrictions (Locat et al. 2017, Lefebvre, 2017 and Turmel et al. 2018).

- Sensitive marine clays can behave like a fluid when excavated and/or disturbed. These materials are not considered suitable for re-use and could require specialized handling procedures (e.g. drying) prior to transport off-site (Torrance, 2017 and Locat and St-Gelais, 2014).

- Large consolidation settlements can occur when the new loads exceed the maximum past loading conditions (i.e. the preconsolidation pressure) of marine clays. This includes any combination of the following loading scenarios, excessive foundation load, weight of site grading fills, and lowering of the water table (Torrance, 2017 and Locat and St-Gelais, 2014).

- Water extraction caused by trees may also result in extensive foundation damage to buildings supported on marine clays. Buildings with shallow foundations are more susceptible than those with basements that extend below the reach of tree roots. Clay shrinkage due to moisture extraction is particularly active during extensive dry periods. The risk of moisture extraction problems within marine clays is generally managed by planting trees a distance away from foundations of not less than their mature height and by using trees with a lower water demand (Silvestri et al. 1990, Silvestri et al. 1992, Silvestri et al. 1994, Silvestri, 2000).

- Marine clays are also subject to seasonal heaving associated with frost action. In the cases where clays have not previously been exposed to frost action the amount of heaving during the first few winters can be dramatic. The frost heaving process within these previously unexposed clays results in a net water extraction (or expulsion) from the soil matrix and an overall shrinkage of the clay within the frost depth which results in an overall lowering of the ground surface profile (Konrad, 1999, Eigenbrod, 1996 and Konrad, 1995).

- During significant seismic events, there is a risk that the ground motions can result in the formation of liquefiable shear planes within marine clay deposits. This applies mainly to areas where the clay is characterized as highly sensitive or quick (Lee, 1978).

## CONCLUDING REMARKS

- It is the authors' opinion that the behavior of Eastern Canadian clays is significantly different than other clay types and that the general use of the USCS group symbols can be misleading.

- It is suggested that a USCS group symbol modifier be used for marine clays (i.e., $CL_{-m}$, $CI_{-m}$ and $CH_{-m}$).

- It is the authors' opinion that the hazards associated with Eastern Canadian marine clays be systematically presented in all geotechnical reports where these clays are presented.

- The characterization of Eastern Canadian marine clays should routinely include presentations of Liquidity Index, remoulded shear strength values and sensitivity measurements to help identify hazardous conditions.

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