Does long-term storage of clay samples influence their mechanical characteristics?

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Complete List of Authors: Abdellaziz, Mustapha; Universite de Sherbrooke, Génie Civil Hussien, Mahmoud; Assiut University, Civil Engineering; Sherbrooke University, Civil Engineering Chekired, Mohamed; Institut de recherche d’Hydro-Quebec Karray, Mourad; Universite de Sherbrooke, Génie Civil
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Does long-term storage of clay samples influence their mechanical characteristics?

Mustapha Abdellaziz, Mahmoud N. Hussien, Mohamed Chekired, Mourad Karray

Mustapha Abdellaziz. Department of Civil Engineering, Université de Sherbrooke, Sherbrooke, Québec, Canada, Mustapha.Abdellaziz@USherbrooke.ca

Mahmoud N. Hussien. Department of Civil Engineering, Faculty of Engineering, Université de Sherbrooke, Sherbrooke, QC, Canada, Mahmoud.Nasser.Ahmed@USherbrooke.ca; Department of Civil Engineering, Faculty of Engineering, Assiut University, Assiut, Egypt, mahmoudnasser2002@aun.edu.eg

Mohamed Chekired. Researcher, Institut de Recherche d'Hydro-Québec, Varennes, Québec J3X 1S1, Canada, Chekired.Mohamed@ireq.ca

Mourad Karray. Department of Civil Engineering, Université de Sherbrooke, Sherbrooke, Québec, Canada, Mourad.Karray@USherbrooke.ca

Abstract: The prime objective of this study is to assess the influence of long-term storage on the physical and mechanical characteristics of clay samples. Samples from two different clays were sealed and stored in a temperature and humidity-controlled room at the geotechnical laboratory of the Université de Sherbrooke for up to 27 years. The stored clay samples were tested before and after long-term storage and the results compared in this note. The comparison showed that even with long-term storage, the majority of the physical and mechanical characteristics of the samples were preserved.

Résumé: Le but de cet article est d’évaluer l’effet d’une longue durée d’entreposage sur les propriétés géotechnique des échantillons d’argiles. L’article présente les résultats de plusieurs essais géotechniques réalisés sur des échantillons qui ont été entreposés durant une longue période dans une chambre humide avec des conditions de température et d’humidité contrôlées. Deux argiles ont été scellé et entreposé dans le laboratoire de géotechnique de l’Université de Sherbrooke pour une durée allant jusqu’à 27 ans. Les résultats des essais géotechniques réalisés dans cette étude montrent que même avec une longue durée d’entreposage, les échantillons conservent la majorité de leurs propriétés physiques et mécaniques.

Keywords: Storage, quality sample, sensitive clay, sampling method, sealing sample.
1. **Introduction**

Storage and conservation of intact clay samples is an important step in geotechnical laboratory work. Most of the available storage techniques of intact samples are employed for a relatively short term and their validity for long term storage is not well assessed. The effect of storage and conservation on geotechnical properties has been discussed by several authors. Eden (1965) found that a high storage temperature generally induces an increase of sample strength and a decrease of water content. Bozozuk (1976) reported: “the grain size analysis and Atterberg limits of sensitive marine clay do not appear to be affected significantly by long periods of storage, even though the samples change color frequently, indicating that some chemical changes have occurred”. Lessard and Mitchell (1985) attributed the changes in soil sample characteristics to changes in pore water chemistry. They reported: “Any sample stored in the laboratory will eventually undergo significant changes in pore water chemistry and in geotechnical properties”. Lessard and Mitchell (1985) concluded that the effect of storage is to increase the remoulded shear strength and liquid limit (LL) and to decrease the sensitivity, liquidity index, and pH. They did not report any effects on the water content, plastic limit, and undisturbed shear strength. Lessard and Mitchell (1985) recommended a constant temperature of 4 °C to reduce organic matter oxidation to a minimum. In contrast to Lessard and Michell (1985), La Rochelle et al. (1986) reported that it is possible to prevent ageing during the storage of clay samples by using an adequate sealing technique. They recommended using a wax compound made of a mixture of 50% paraffin and 50% Vaseline instead of paraffin wax. Graham and Lau (1988) pointed out that drainage conditions during storage
could significantly affect the undrained shear strength. L’Heureux and Kim (2014) observed that the undrained shear strength and preconsolidation pressure decreased with the period of storage, which they attributed to factors such as migration of pore fluid and associated changes in stress distribution, moisture loss, and chemical effects, as well as temperature and humidity changes. The latter factors (i.e., temperature and humidity changes) can be well-controlled. Most of the early studies on the influence of the storage period on the properties of stored soil samples were limited to a maximum storage period of 8 years. This study provides an assessment of the influence of long-term storage on the characteristics of samples of sensitive Eastern Canadian clays stored for up to 27 years. The stored clay samples were tested before and after long-term storage, and the results are compared herein. Details of the sampling and storage techniques as well as interpretation of the results obtained are provided.

2. Experimental methodology

Soil specimens

Two sensitive post-glacial clays from Eastern Canada were used in this study: Saint-Hilaire clay and Matagami clay. Saint-Hilaire is a marine clay from the Champlain Sea while Matagami is a lacustrine varved clay deposited in the post-glacial lake Barlow-Ojibway (Quigley 1980), (Locat and Lefebvre 1981). Saint-Hilaire clay was sampled in 2001 as a part of a research project (Lefebvre and Burnotte 2002). Matagami clay was sampled in 1991 by Compagnie Nationale de Forage et Sondage as a part of a geotechnical campaign in the region of Matagami. Some samples were tested in the same year they were taken, and the rest were preserved in the humid room at the Université de Sherbrooke under controlled temperature and humidity conditions. In 2018, a second
series of tests were carried out on the stored samples to assess the influence of long-term storage on their characteristics. Figures 1 and 2 are photos taken in 2018 of a Matagami and Saint-Hilaire clay samples tested in this study.

**Sampling and conservation methods**

Sampling was carried out using the large diameter Sherbrooke sampler or the stationary piston sampler ELE100 (Tanaka et al. 1996). The Sherbrooke sampler was developed at the Université de Sherbrooke in 1979 to minimize stress and overall disturbance related to the sampling of sensitive clays (Lefebvre and Poulin 1979). Samples were 250 mm in diameter and 350 mm in height (Lefebvre and Poulin 1979). The stationary piston sampler is 101 mm in diameter and 500 mm in height. At the laboratory, the blocks of Saint-Hilaire clay sampled by the Sherbrooke sampler were identified and cut into small blocks of about 120 mm in height each using a steel wire cutter. For the Matagami clay samples, the stationary piston sampler was used and the samples removed from the tube with a hydraulic extruder and cut with a steel wire cutter into small samples 120 mm in height. The sealing technique was almost identical to the technique proposed by La Rochelle et al. (1986). The samples were wrapped in ordinary plastic sheet and then painted with a wax compound prepared from a mixture of 50% paraffin and 50% Vaseline. The wax coating was at least 0.2 inch thick as recommended by Hvorslev (1949). The blocks of Saint-Hilaire clay were deposited on a plywood board previously prepared by painting the upper surface with a wax compound, covering it with a layer of plastic sheet and then painting on another layer of wax compound. The blocks were then stored in a humid room at 97% humidity and approximately 7°C. The humid room is equipped with alarm system that alert about the change of humidity and temperature.
samples were stored in a wood frame construction within the room. The temperature and humidity conditions did not change during the storage period.

**Tests procedures and apparatus**

The tests carried out in this study include: Atterberg limits ($W_{Lc}$, $W_p$, $W_n$), Oedometer, fall cone (for sensitivity), undrained triaxial, and direct simple shear tests. The standards followed for plastic limits, liquid limit, sensitivity and oedometer tests were ASTM D-4318, BNQ-2501-092, BNQ-2501-110 and ASTM D-2435, respectively. A direct simple shear test procedure was carried out following the procedures proposed by Bjerrum and Landva (1966) for tests carried out on the NGI-DSS apparatus. The procedure proposed by Chekired et al. (2015) for tests carried out in the simple shear T$_x$SS apparatus. Note that wire-reinforced membrane was used for the tests in 1991 and in 2018.

The same procedures for the original undrained triaxial testing were used for the present tests, as follow: soil specimens of 72 mm in height and 36 mm in diameter were carefully cut from the block samples and placed in the triaxial cell. The specimens were saturated by applying back pressure until they reached a Skempton factor $B$ of 0.95. After saturation, the specimens were consolidated to similar effective stresses before and after storage. An axial load was then applied to shear the samples in strain-controlled mode with a strain rate of 0.008 mm/min. The acquisition equipment used in 2018 gave a more continuous record in contrast to the manual acquisition equipment used in the 1991 and 2001 tests.

3. **Results and discussion**

Table 1 summarises the tests program and table 2 presents the Atterberg limits of clay tested in 1991, 2001 and 2018 for the two clays: Matagami (depth 8.6 m and 9.6 m) and
Saint-Hilaire (depth 4.5 m). It can be seen from table 2 that the liquid limit ($w_{l,c}$) and plastic limit ($w_p$) values before and after storage are similar. These results compare well with the conclusions of La Rochelle et al. (1986) that the liquid limit and plastic limit can be preserved unaltered for a long period with an adequate storage method. For natural water content, some disparity was observed in the results, which may be attributed to the variability of the soil. The measurements show some decrease in the average value of $w_n$, but the decrease does not exceed 5% for both types of clay.

Table 3 presents the results of the fall cone tests. It can be seen that the measurements of the undisturbed and remoulded shear strength are almost similar. Figure 3 presents the oedometer test results for samples extracted from a depth between 4 m and 6 m. The preconsolidation pressures $\sigma'_p$ obtained in 1991, in 2001, and in 2018 are approximately the same. The compression and recompression indexes obtained from these tests are also similar. The compression index $C_c$ is 2.2 for Saint-Hilaire clay and 1.1 for Matagami clay. The recompression index $C_r$ is 0.013 for Saint-Hilaire and 0.011 for Matagami clay. However, the initial void ratio $e_0$ shows some disparity for the tests on Saint-Hilaire clay and a decrease of 0.05 for the 2018 tests on Matagami clay. Figure 4 presents the results of six consolidated undrained triaxial compression tests on Matagami clay, two of them carried out in 1991 on samples extracted from two different depths (8.6 m and 9.6 m) and four performed in 2018 on soil samples extracted from the same depths. The stress-strain curves in Fig. 4a show a some decrease (around 5-10%) in the peak shear strength for the 2018 tests, while the axial deformation at the peak shear strength increased from 1% in 1991 to 2-3% in 2018. The stress-strain curves show some decrease of the secant modulus $E_{50}$. Figure 4-a also shows that the clays have almost the same shear strength at
large deformations. Figure 4-b demonstrates that there is a small difference between the excess pore pressure-deformation curves obtained in 1991 and 2018. The curves of excess pore pressure-deformation also show that steady-state conditions \( \frac{dt}{dt} = 0 \) and \( \frac{du}{dt} \) = 0, (Roscoe et al., 1958)) were not reached in either series of tests. The stress paths (Fig. 4-c) confirm that there is a small reduction in the peak shear strength of soil samples tested in 2018, while the residual shear strengths are almost the same. It should be noted that the pairs of triaxial tests carried out in 2018 for the two depths give almost the same results. The results of the direct simple shear tests on Matagami clay samples are presented in Fig. 5. The pore pressure of DSS tests carried out in 1991 were calculated from the change in the equivalent vertical stress as proposed by Bjerrum (1966). In contrast, the 2018 tests constitute a direct measurement of the pore pressure generated during shearing. The stress-strain curves (Fig. 5a) show a some decrease (around 2 kPa) in the peak shear strength of Matagami clays tested in 2018. The stress-strain curves show also some decrease of the secant modulus \( G_{50} \) for the tests carried out in 2018. At large deformation, the 2018 test gives approximately the same shear strength as the 1991 tests. The curves of the pore pressure ratio (or equivalent change in vertical stress) shown in Fig. 5b indicate that the 2018 tests generated approximately the same pore pressure as the 1991 tests.

4. Conclusion

Experimental results assessing the effects of long-term storage and conservation of clays samples in controlled humid room were presented and discussed. The tests were carried out on two clays: Saint-Hilaire and Matagami clays sampled in 1991 and 2001, respectively. The samples were sealed using plastic sheet and a wax compound prepared
from a mixture of paraffin and Vaseline. The samples were stored until 2018 in a room at 97% humidity and about 7°C. The clays were tested in the year of sampling and again in 2018 to compare the effects of storage. The results of tests conducted, including Atterberg limit, oedometer test, triaxial CIU and DSS tests, showed that there was an appreciated long-term conservation of the following properties: liquid limit, plastic limit, sensitivity, preconsolidation pressure, compression index, recompression index, development of pore pressure and large deformation shear strength. However, a reduction of 5-10% in peak shear strength and an increase in axial deformation at the peak shear strength from 1% to 2-3% in triaxial undrained tests were observed. These results indicate that the conservation method followed in this study can preserve the main physical and mechanical properties of intact clays.
5. List of notations

\( w_n \): Natural water content

\( w_p \): Plastic limit

\( w_{Lc} \): Liquid limit

\( I_L \): Liquid index

\( PI \): Plastic index

\( C_u \): Undisturbed shear strength

\( C_{ur} \): Remolded shear strength

\( S_t \): Sensitivity

\( B \): Skempton factor

\( \sigma'_p \): Preconsolidation pressure

\( C_c \): Compression index

\( C_r \): Recompression index

\( E_{50} \): Secant young modulus at 50% of strength

\( G_{50} \): Secant shear modulus at 50% of strength
References


CAN/BNQ 2501-092, 2006a. Soil Determination of Liquid Limit by the Fall Cone Penetrometer and Determination of Plastic Limit. Canadian Standards Association (CSA) and Bureau de Normalisation du Quebec (BNQ), National Standard of Canada, Ottawa, ON.

CAN/BNQ 2501-110, 2006b. Soils Determination of Undrained Shear Strength and Determination of Sensitivity of Cohesive Soils using the Fall Cone Penetrometer. Canadian Standards Association (CSA) and Bureau de Normalisation du Quebec (BNQ), National Standard of Canada, Ottawa, ON.


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Figure 5: Direct simple shear test results: (a) stress-strain curves, (b) pore pressure ratio curve.
Table 1: Test programs before and after the storage

<table>
<thead>
<tr>
<th>Test</th>
<th>Depth (m)</th>
<th>Date of test-1</th>
<th>Date of test-2</th>
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<tbody>
<tr>
<td>Matagami clay</td>
<td></td>
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</tr>
<tr>
<td>Atterberg limit</td>
<td>8.6 – 9.6</td>
<td>October 1991</td>
<td>March 2018</td>
</tr>
<tr>
<td>Oedometer</td>
<td>5.6</td>
<td>October 1991</td>
<td>February 2018</td>
</tr>
<tr>
<td>Triaxial CIU</td>
<td>8.6 – 9.6</td>
<td>February 1991</td>
<td>February 2018</td>
</tr>
<tr>
<td>Direct simple shear</td>
<td>5.6- 5.7</td>
<td>January 1991</td>
<td>April 2018</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>3.4-3.5</td>
<td>October 1991</td>
<td>September 2018</td>
</tr>
<tr>
<td>Saint-Hilaire clay</td>
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<td></td>
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</tr>
<tr>
<td>Atterberg limit</td>
<td>4.5</td>
<td>2001</td>
<td>February 2018</td>
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<tr>
<td>Oedometer</td>
<td>4.4-4.9</td>
<td>2001</td>
<td>February 2018</td>
</tr>
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</table>

Table 1: Physical properties of the clays before and after storage

<table>
<thead>
<tr>
<th>Test</th>
<th>Matagami clay (depth 9.6 m)</th>
<th>Matagami clay (depth 8.6 m)</th>
<th>Saint-Hilaire clay (depth 4.5 m)</th>
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<tr>
<td>Test date</td>
<td>1991</td>
<td>2018</td>
<td>1991</td>
</tr>
<tr>
<td>Water content (%)</td>
<td>71 – 72</td>
<td>64 – 68</td>
<td>85 – 92</td>
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<tr>
<td>Liquid limit (%)</td>
<td>53</td>
<td>51</td>
<td>69</td>
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<tr>
<td>Plastic limit (%)</td>
<td>24</td>
<td>24</td>
<td>28 – 30</td>
</tr>
<tr>
<td>Plastic index (%)</td>
<td>29</td>
<td>27</td>
<td>41 – 39</td>
</tr>
<tr>
<td>Liquid index</td>
<td>1.65 – 1.62</td>
<td>1.62 – 1.40</td>
<td>1.56 – 1.41</td>
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</table>

Table 3: Results of the fall cone test before and after storage

<table>
<thead>
<tr>
<th>Test</th>
<th>Matagami clay (Depth 3.4 m)</th>
<th>Matagami clay (Depth 5.8)</th>
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<tr>
<td>Test date</td>
<td>1991</td>
<td>2018</td>
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<tr>
<td>Cu (kPa)</td>
<td>29.16</td>
<td>28.6</td>
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<tr>
<td>Cur (kPa)</td>
<td>1.13</td>
<td>1.24</td>
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<tr>
<td>St</td>
<td>25.8</td>
<td>23.1</td>
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