Characterisation of Champlain saline clay from Lachenaie using the Swedish fall cone

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ABSTRACT
This paper presents the results of Swedish fall cone tests and Casagrande liquid limit tests conducted on saline clay samples from Lachenaie, Quebec. The liquid limits values obtained with the Swedish fall cone and the Casagrande apparatus are shown to be equal. The influence on test results of using a Casagrande apparatus with an incorrect calibration of the fall height is evaluated. Using a blunt 60° cone is shown to have a negligible impact on determined liquid limit values. For stiff clays, a discrepancy between the measured undrained shear strength values obtained with the 100 g and 400 g cones was observed. Finally, the Swedish fall cone allows observing a correlation between thixotropic strength regain and sensitivity for the Lachenaie clay body.

RÉSUMÉ
Cet article présente les résultats d'une série d'essais exécutés avec le cône suédois et l'appareil de Casagrande sur des échantillons d'argile salée de Lachenaie. On montre que le cône suédois et l'appareil de Casagrande donnent les mêmes valeurs de limites de liquidité. Ces deux essais sont aussi utilisés pour montrer l'influence marquée d'une mauvaise hauteur de chute sur les résultats de la méthode de Casagrande. On montre ensuite que l'utilisation d'un cône de 60° dont la pointe est émoussée a peu d'impact sur la valeur obtenue de limite de liquidité et que les cônes de 100 g et 400 g donnent des résultats différents pour les argiles raides. Finalement, le cône suédois nous permet d'observer une corrélation entre la sensibilité et le regain de résistance dû à la thixotropie.

1 INTRODUCTION

During the past few decades, the Swedish fall cone has become increasingly important in the evaluation of clay mechanical properties. Its main advantage over the Casagrande apparatus is the possibility to study many problems linked with the clay intact and remoulded shear strengths. This paper presents the results of a few simple experiments conducted with the Swedish fall cone. These fall cone tests were part of an extensive testing program for the Lachenaie clay body. The results of this testing program are summarised in the companion paper of Duhaime et al. (2010). These authors show that the Lachenaie clay body is relatively stiff (high shear strength and preconsolidation pressure) and that its pore water has a high salinity (up to 20 g/L). The liquid limit values for this deposit are in the 40 to 78 % range. These values are within the 30 to 85 % range reported for the entire Champlain Sea basin (Leroueil et al. 1983; Windisch and Yong 1990)

The testing program for this paper involved 31 Swedish fall cone tests and 18 Casagrande liquid limit determinations. All Swedish fall cone tests included the measurement of the intact undrained shear strength (c_u), liquid limit (w_L) and sensitivity. For some samples, c_u was measured with both the 100 g and 400 g fall cones.

Our testing program allows five issues to be addressed. First issue, the w_L values obtained using the fall cone method are compared with those of the Casagrande method. Most of the authors who compared results for these two methods used arrays of artificial and natural clays having different geochemical and geotechnical properties (Figure 1). In this paper we verified this relationship for a specific clay body with saline pore water. The second issue covered in this paper is the magnitude of the w_L error obtained with an incorrect falling height for the Casagrande apparatus. This was achieved by comparing the cone-Casagrande relationships for both the right calibration and an incorrect calibration of the Casagrande apparatus. The third issue was to examine the effect of using a blunt 60° cone by comparing the w_L values obtained using either a new cone or a blunt one for three samples. The fourth issue was to compare, for stiff clays, the values obtained for the intact shear strength using the 100 g and 400 g cones. Finally, fifth issue, the influence of thixotropy on obtained w_L values (thixotropy being the time-dependent shear strength recovery after remoulding), was investigated by recording for each penetration the time elapsed after remoulding.

2 FALL CONE, LIQUID LIMIT AND SHEAR STRENGTH

Atterberg limits were introduced in 1911 by A. Atterberg for the caracterization of clays' properties, such as viscous flow, gripping to a metal spoon or limits of plastic state (Holtz and Kovacs 1981). The utilization of a fall cone penetrometer for the measurement of the liquid limit (w_L) was proposed by the Geotechnical Commission of the Swedish State Railways in the 1920's (Leroueil and Lebihan 1996). In 1932, Casagrande proposed an apparatus for the mesurement of w_L.

Both approaches to obtain the liquid limit (Casagrande method and Swedish fall cone) are used in the standards of many countries (Leroueil and Lebihan 1996). Some authors have established relationships between these two methods using clays from different countries (Littleton and Farmilo 1977; Belviso et al. 1985; Budhu 1985; Wasti 1987; Christaras 1991; Leroueil and Lebihan 1996). Figure 1 shows the general relationship obtained by these authors. Tests for each data points were performed with either the Canadian (CAN/BNQ) or British standards, which have been proved to provide similar results (Leroueil and Lebihan 1996). For w_L < 100%, the w_L values obtained with the fall cone and Casagrande methods are approximately equal (Wasti and Bezirci 1986). For some of the data points presented in Figure 1, the two methods give results which differ by more than 10%. However, the correlation is very good, especially if one considers that Figure 1 gathers data for clays having very different geochemical and geotechnical properties. With clays, such correlations are often only valid locally, when a specific type of clay is considered (Windisch and Yong 1990).

The fall cone and Casagrande methods give the same result because they are essentially evaluating the same soil property: remoulded shear strength (c_{ur}). The w_L value corresponds to the water content that will bring about a given consistency, a given remoulded shear strength. The fall cone has the advantage of giving an explicit c_{ur} value. By comparing fall cone penetrations with results from field vane tests, Hansbo (1957) found that Equation 1 can be used to define c_u or c_{ur}.

$$c_u = \frac{9.8\,K\,m}{P^2} \qquad [1]$$

Where c_u is given in kPa, K is an empirical constant related to the cone angle, m is the cone mass in g and P is the mean penetration in mm. Equation 1 is used in Standard CAN/BNQ 2501-110 to calculate the values of c_u and c_{ur} from penetration data.

The link between c_{ur} and w_L is less direct for the Casagrande apparatus. This method is thought to be influenced by the soil self weight (Sharma and Bora 2003). As a result, w_L corresponds to a range of c_{ur} values. For soils with w_L = 30%, c_{ur} is around 2.5 kPa at w_L whereas c_{ur} = 1.3 kPa at w_L for clays with w_L = 200% (Youssef et al. 1965). When evaluating w_L with the fall cone, a c_{ur} value at w_L of 1.7 kPa is usually assumed (Sharma et Bora 2003).

Another advantage of the fall cone is that it allows other properties to be measured concurrently with w_L. In their companion paper, Duhaime et al. (2010) use the fall cone to evaluate clay sensitivity (S_t), the ratio of c_u and c_{ur}. In the past, the fall cone test has also been used to study thixotropy (Lefebvre et Grondin 1978).

Mitchell and Soga (2005) define thixotropy as “an isothermal, reversible, time-dependent process occurring under conditions of constant composition and volume whereby a material stiffens while at rest and softens or liquefies upon remoulding”. Thixotropy was previously studied in the lab using the miniature vane-apparatus (Skempton and Northey 1952), the viscosimeter (Perret et al. 1996) and the triaxial shear test (Pusch 1982). Thixotropy is related to the time-dependent dissipation of the excess pore pressures generated during remoulding. The pore pressure decrease is thought to be connected with a reorganisation of the grain skeleton as different arrangements are stable during shearing (in this case remoulding) and at rest (Mitchell 1960; Osipov et al. 1984).

The shear strength regain is usually presented in a graph with the decimal logarithm of time elapsed since remoulding on the x axis and c_u or percentage shear strength regain on the y axis (Skempton and Northey 1952; Mitchell 1960; Lefebvre and Grondin 1978). This type of graphical representation does not usually allow a mathematical equation to be fitted on the data. Generally, it can only be said that c_u increases with time at a decreasing rate.

Inasmuch as intense thixotropy can easily be observed with the fall cone, it can also affect w_L determinations. Experienced soil mechanics technicians know that for very sensitive clay, the cone penetration decreases very rapidly after remoulding. Obviously, thixotropy also affects the w_L values measured with the Casagrande apparatus. However, the fall cone test usually lasts a longer time. This is especially true for very sensitive clays when the standard CAN/BNQ 2501-092 is used. In this case repeating penetrations within 0.3 mm often takes 2-3 minutes. On the other hand, at the liquid limit, the Casagrande test should always have roughly the same duration: 12 seconds if one follows standard CAN/BNQ 2501-090 and fulfills 2 revolutions per second. The main characteristics of these two standards will be introduced in section 3.1.1.

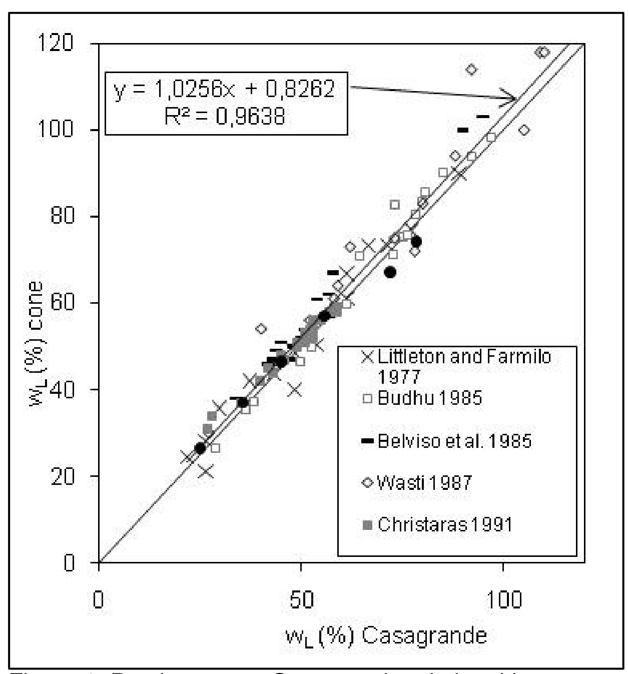

Figure 1. Previous cone-Casagrande relationships.

3 METHODOLOGY

Liquid limits tests were performed according to standards CAN/BNQ 2501-090 and CAN/BNQ 2501-092, which apply respectively to the Casagrande apparatus and the Swedish fall cone. Values of c_u and c_{ur} were determined following standard CAN/BNQ 2501-110.

A total of 31 samples from 11 boreholes located in Lachenaie, Quebec have been investigated. The samples were obtained using thin-walled samplers with a 3-inch diameter. Three sets have been completed. Set 1 was done with an incorrect calibration of the Casagrande apparatus: the cup's falling height was approximately 11 mm instead of 10 mm. Set 2 was achieved with a correct calibration and set 3 was performed to evaluate the impact of thixotropy on liquid limit determinations. For sets 1 and 2, both the 100 g and 400 g cones were used for the c_u determinations.

3.1 Standards

3.1.1 Liquid limit standards

For both the Casagrande and fall cone methods, the material passing the 400 µm sieve is used. The sample remoulding and testing are performed immediately after sampling or after having removed the paraffin coating used for sample conservation.

For the Casagrande method, remoulded clay is put in the cup of the apparatus. After levelling the clay surface, a groove is formed with a special tool. The lever is then turned so that the cup drops 2 times per second. The test ends when a 13 mm long section of the groove closes. The number of drops is recorded. After remoulding the clay, the test is done a second time at the same water content. If the number of drops is very close, the water content is determined and the average number of drops is recorded. This procedure is repeated for at least 3 points. A graph of the number of drops versus the water content is plotted. A straight line is fitted through the data and w_L is taken as the water content resulting in 25 drops.

When using the fall cone method, the remoulded sample is put in a cup. After having levelled the clay surface, a set of penetrations is obtained with the 60g/60° cone. When two penetrations between 7 and 15 mm and within 0.3 mm of each other are obtained, the clay is removed from the cup, remoulded and put back in the cup. Another set of penetrations is then acquired, again stopping when two penetrations within 0.3 mm are obtained. If the average of the two penetrations of the first set is within 0.3 mm of the average of the two penetrations of the second set, the point is considered valid, the average of the four penetrations is noted and the water content is determined. Three or four data points are obtained this way. The liquid limit is found by plotting penetration depths versus water contents. A straight line is fitted through the data points. The value of w_L is taken as the water content leading to a 10 mm penetration.

3.1.2 Undrained shear strength standard

Measurement of c_u is done on a fresh and plane surface of the undisturbed clay sample. The test has to be repeated at least 5 times on the same surface, the tested zones being spaced at least 10 mm apart. The mean square penetration ($\overline{P}^2$) is used in the calculations (Equation 2).

$$\overline{P}^2 = \frac{\sum P_i^2}{N} \qquad [2]$$

Where P_i values represent the individual penetrations and N is the number of penetrations. The user has to employ a 100 g cone with a 30° apex angle. If penetrations of less than 5 mm are obtained with this cone, a 400 g cone with a 30° apex angle must be used.

When sensitivity is to be measured, the value of c_{ur} at the natural water content (w_n) must be evaluated. Normally, a 60 g cone with an apex angle of 60° is used. For very sensitive clays, a 10 g cone with a 60° apex angle is used. After remoulding the sample, two series of at least three penetrations are taken. The averages of the two series must be within 0.3 mm of each other. The series with the highest average is used to calculate the mean square penetration.

The c_u and c_{ur} values are computed using Equation 1. The K values are respectively taken to be 1.0 and 0.3 for cones with apex angles of 30° and 60°.

3.2 Thixotropy

For set 3, fall cone tests were also conducted according to standards CAN/BNQ 2501-092 for w_L determinations and CAN/BNQ 2501-110 to evaluate clay sensitivity. A small change was introduced in order to quantify thixotropic behaviour. For each penetration, the time elapsed since remoulding (t) was recorded. In order to do so, a stopwatch was started at the end of remoulding, after having levelled the clay surface. After each remoulding, 4 or 5 penetrations were taken. For the last penetration, the t value was generally around 5 minutes.

No special efforts were made to keep the water content constant during the thixotropy test. The loss of water during the 4 or 5 minutes that the test lasted was found to be small (around 0.05 g for a 24.6 cm^2 clay surface). If we assume that the water evaporated from a thin layer at the clay surface, say 2 mm thick, this translate to a 0.5 % water content change at the surface. This water content change probably answers for a small portion of the shear strength gain. However, this gain is assumed to be much smaller than thixotropic regain.

For a test duration of about 5 minutes, the relationship between log(c_{ur}) and log(t) was found to be linear. Equation 3 was fitted to the test data.

$$c_u = A\,t^B \qquad [3]$$

Where *A* and *B* are constants depending on sample and water content, and c_{ur} is calculated using Equation 1. Results for a sample with intense thixotropy are presented in Figure 2. Data for three different water contents are shown. To compare the relative magnitude of thixotropy between samples, we defined a strength regain factor (*R*) which is equal to 10^B. *R* gives the strength regain per log cycle of elapsed time. In practice, it means that between the first (roughly t = 30 s) and last penetration (t = 300 s), the shear strength is multiplied by *R*.

Figure 2 shows that depending on the time elapsed since remoulding, different water contents can lead to c_{ur} = 1.7 kPa, the assumed consistency at w_L. Note that one can sometimes obtain a larger c_{ur} value by waiting 5 minutes than by decreasing water content by 3-4 %. To evaluate the range of w_L values that can be obtained, for each sample, the test data were used to calculate two values of w_L. A first value was calculated according to standard CAN/BNQ 2501-092: only the first two penetrations within 0.3 mm of each other were used. A second w_L value was calculated by fitting Equation 3 on the two sets of 4-5 penetrations obtained for each water content. Initial penetration values were obtained for each water content by substituting t = 30 s in Equation 3 and by solving Equation 1 for *P*. The *P* values hence obtained were plotted in the usual penetration versus water content graph to obtain w_L. This value is meant to give an idea of the w_L values obtained if we only use the first penetrations of each set.

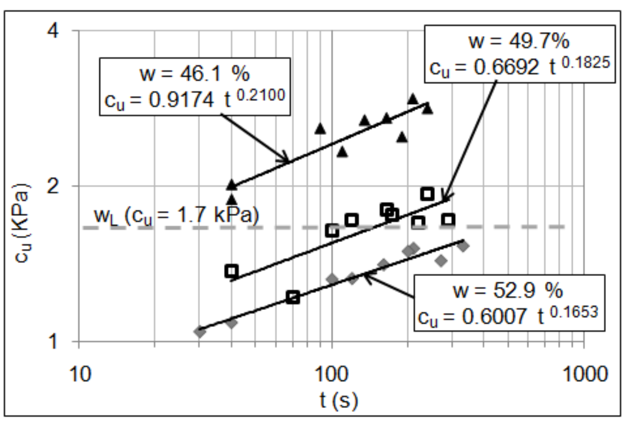

Figure 2. Results of the thixotropy test for a sample showing strong thixotropy (FP-08-07AB, depth 6.66 m).

4 RESULTS AND DISCUSSION

4.1 Fall cone-Casagrande Relationship for liquid limit

Results of sets 1 and 2 are shown in Table 1. Results of set 2 are shown in Figure 3 with background literature data. Results of set 1 are not used for the analysis of the cone-Casagrande relationship because of the incorrect calibration of the Casagrande apparatus: this topic is discussed in the next section.

Figure 3 shows good agreement between the w_L values of the fall cone and Casagrande methods. There is less spread in the Lachenaie experimental data points than in the general literature data. This indicates that the high salinity of the Lachenaie clay pore water has no influence on the cone-Casagrande relationship. Equation 4 gives the relationship that was obtained.

$$w_{L\ cone} = 0.8696\, w_{L\ Casagrande} + 8.9835 \qquad [4]$$

When w_L is in the 50 to 70 % range, both methods can be used with saline clays. We conclude that the Swedish fall cone can replace the Casagrande apparatus to measure w_L for the saline clays of Lachenaie.

4.2 Effect of a wrong calibration

Set 2 was performed with an incorrect falling height for the Casagrande apparatus' cup. Figure 4 shows the cone-Casagrande relationship for sets 1 and 2. Even if the falling height error for set 1 was small (11 mm instead of 10 mm), Figure 4 indicates that it had a direct influence on w_L determinations. A calibration error as small as 1 mm can generate an error varying between 8 to 14 % (approximately 6 % points w_L). An error of 6 % points w_L is higher than the precision of the test.

The authors of this paper have noticed that the falling height of the Casagrande apparatus can easily be incorrectly adjusted. Indeed, an inexperienced user can take the falling height as the maximum vertical distance between the lowermost point of the cup and the base. However, the standardized falling height of 10 mm applies to the maximum vertical distance between the base and the point of the cup that hits the base. This point does not correspond to the lowest point when the cup is up. This difficulty in the standardization of the Casagrande apparatus probably causes errors in many experimental programs. It is one of the reasons why the authors of this paper recommend the use of the Swedish fall cone to avoid this source of error.

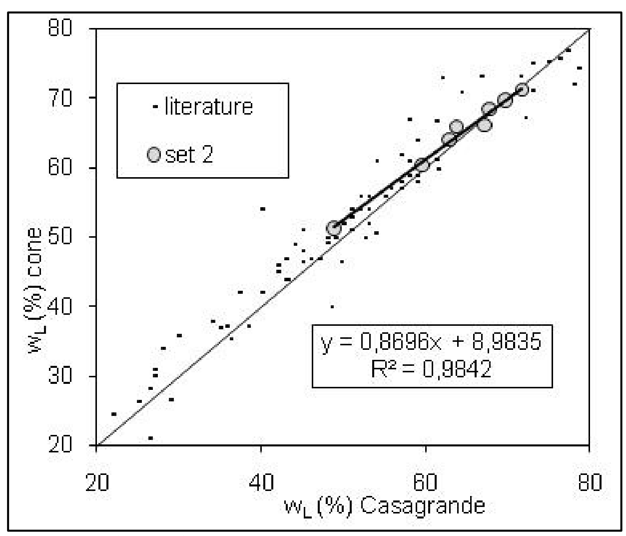

Figure 3. Cone-Casagrande relationship for set 2.

Table 1. Experimental results, sets 1 and 2

Set	Borehole	Depth (m)	w_L Casa. (%)	w_L cone (%)	c_u - 400g (kPa)	c_u - 100g (kPa)	c_{ur} (kPa)
1	FP-06-03R	5.58	60.9	70.7	40.60	42.27	2.55
1	FP-06-02R	20.35	54.3	62.1	56.66	60.43	4.71
1	FP-07-04R	7.32	61.4	67.1	78.29	89.59	9.27
1	FP-06-02R	8.65	58.5	66.1	40.81	52.03	2.42
1	FP-06-01R	18.03	58.5	63.2	43.52	44.83	3.46
1	FP-06-01R	21.42	42.3	48.6	59.94	80.01	7.11
1	FP-06-03R	6.25	59.6	65.3	28.30	34.59	3.60
1	FP-06-03R	17.58	64.0	68.5	54.95	59.96	4.31
1	FP-07-04R	6.66	50.5	58.6	74.72	83.86	9.75
1	FP-06-02R	6.22	58.3	64.3	43.68	42.61	2.39
1	FP-06-01R	3.48	-	66.1	34.11	40.46	2.01
2	FP-06-03R	3.72	62.9	64.0	31.84	31.78	1.61
2	FP-06-02R	3.66	59.6	60.3	34.17	30.92	3.37
2	FP-06-02R	15.99	67.8	68.4	82.47	97.98	7.00
2	FP-06-02R	2.29	69.7	69.7	40.63	43.88	6.10
2	FP-06-02R	11.16	63.7	65.8	41.25	46.18	2.88
2	FP-06-03R	6.71	67.2	66.1	31.34	32.60	2.70
2	FP-06-03R	14.17	71.8	71.1	46.31	45.55	2.94
2	FP-06-02R	23.43	48.9	51.3	53.93	68.33	5.33
2	FP-07-05AH	8.05	-	42.2	61.29	72.93	2.19
2	FP-07-05AB	11.05	-	44.8	54.81	72.89	0.75

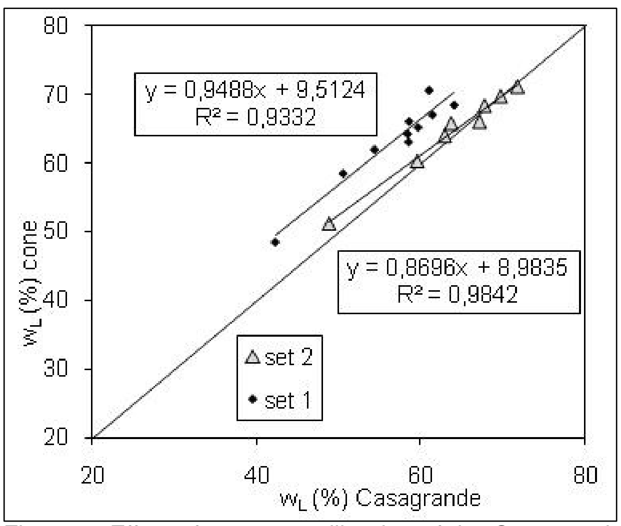

Figure 4. Effect of a wrong calibration of the Casagrande apparatus (set 1) on the cone-Casagrande relationship.

Even if the Casagrande apparatus was not correctly calibrated, the Swedish fall cone can be used to correct the erroneous results. It is suggested to perform a set of 10 liquid limits with various samples from the same location with both the fall cone and the incorrectly calibrated Casagrande apparatus. The results will provide a relationship similar to the one shown in Figure 4 that can be directly used to correct previous results.

4.3 Effect of using a blunt cone

An objective of the experimental program was to assess the necessity of buying a new cone if a cone is blunt. For that purpose, a severely blunt cone and a new cone were used to determine w_L for three samples. Figures 5 and 6 show the two cones.

Figure 7 superposes results for those two cones in the usual graph used to determine w_L. Only sample FP-06-02R (depth 23.43 m) is presented but the two other samples yielded similar graphs: the results for the blunt and sharp cones are similar. The regression lines are nearly superposed and the points are precisely aligned. The w_L values for the three samples and the two cones are presented in Table 2. The sharp and blunt cones give almost identical w_L values for the three samples. We can thus conclude that using a blunt cone for the determination of w_L does not generate a measurable error.

Figure 7 shows an example of the quality of the linear regression obtained with cone results. This is not always the case with the Casagrande method. This is another reason why the authors recommend using the cone over the Casagrande method.

Table 2. Liquid limit results with sharp and blunt cones

Sample	Depth (m)	w_L sharp (%)	w_L blunt (%)
FP-06-03R	6.71	66.05	66.49
FP-06-03R	14.17	71.14	71.12
FP-06-02R	23.43	51.28	51.45

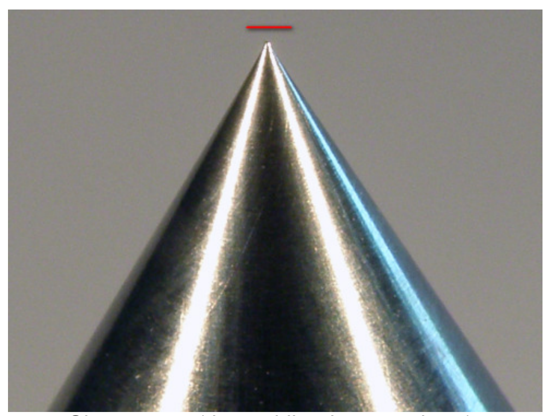

Figure 5. Sharp cone (the red line is 1 mm long)

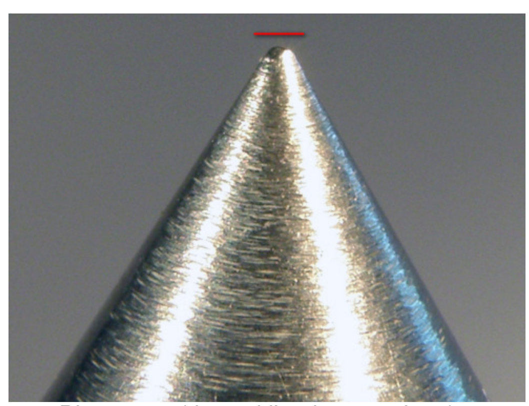

Figure 6. Blunt cone (the red line is 1 mm long).

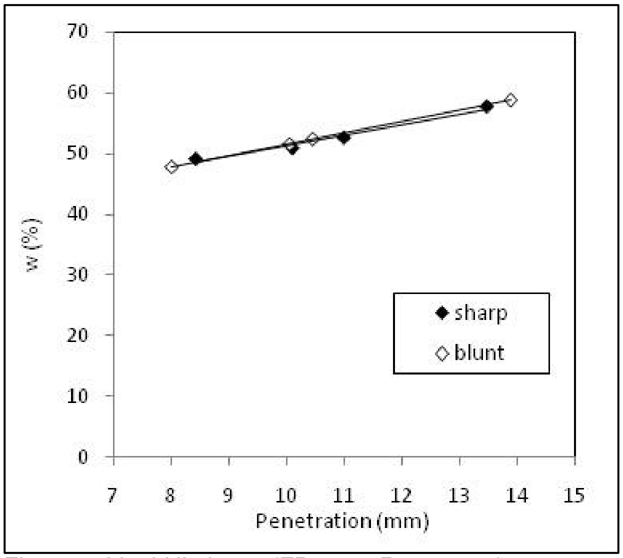

Figure 7. Liquid limit test (FP-06-02R, 23.43 m).

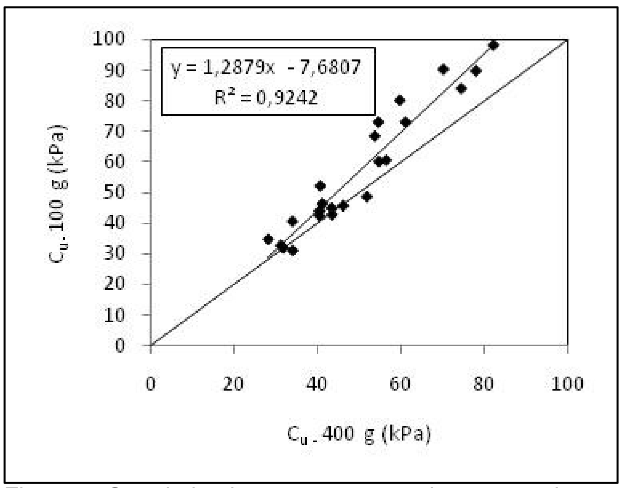

Figure 8. Correlation between 100 g and 400 g results.

4.4 Measurement of c_u with the 100 g and 400 g cones

The undrained shear strength experimental program was performed to evaluate the influence of using a 100 g or a 400 g cone to measure c_u. The standard CAN/BNQ 2501-110 states that the 400 g cone has to be used for stiff clays, when penetrations obtained with the 100 g cone are less than 5 mm. The samples presented in this paper should be tested with the 400 g cone as their mean penetration value is 4.23 mm and the maximum penetration is 5.63 mm. Tests were performed systematically with both cones to evaluate how different the measurements were.

Figure 8 shows the correlation between the c_u values obtained with the 100 g and 400 g cones. Equation 1 was used to calculate c_u. For stiffer clays, the c_u values for the 100 g and 400 g cones are markedly different. The c_u values measured with the 100 g cone are higher. This discrepancy can be explained by increased errors when penetrations are too low. If penetrations are lower than 5 mm, the cone apex crosses only the superficial crust of the sample. This crust is probably subjected to drying and solidification, thus increasing the measured strength. This phenomenon was also reported by Lu (1997), who noted that results are more consistent for penetrations of more than 4 mm.

This study validates the cone selection of the standard. In Figure 8, the 4 samples that have a shear strength lower than 39.2 kPa (corresponding to a penetration of 5 mm with the 100 g cone) are equally distributed around the 45° line. For stiffer samples, the higher the shear strength, the greater is the bias between the two cones' measurements. Therefore, the utilisation of the 400 g cone for stiff clays is essential to avoid overestimating c_u and S_t.

4.5 Thixotropy

For each sample, the magnitude of thixotropic strength regain, the *R* value, shows some variation with water content but, as opposed to Mitchell (1960) who found that thixotropy was more intense for *w* values between the plastic limit (w_P) and w_L, no specific trends were observed for the Lachenaie clay. For most samples, the log (c_{ur}) vs log (*t*) relationships for each water content were roughly parallel, as shown in Figure 2.

Table 3 presents results for the thixotropy tests. Even if there is no clear link between *w* and *R*, we interpolated the *R* value at a water content corresponding to the 30 s w_L by fitting a straight line through the *R* vs *w* data points. For some samples, we also calculated the *R* value at the natural water content (w_n) by recording the elapsed times during the remoulded part of the sensitivity test. The *R* values at w_L and w_n are similar. It should not come as a surprise as w_n is usually close to w_L in Champlain clays.

Figure 9 shows the regain factor *R* against sensitivity. As expected from soil mechanics technician lore, *R* is larger when sensitivity increases. This seems to be true whether we take *R* at the natural water content or at w_L. However, it does not seem to hold for the whole Champlain Sea basin. Some results for thixotropy experiments with samples covering the whole Champlain Sea basin were presented by Lefebvre and Grondin (1978). Figure 10 shows the *R* values calculated using their strength regain database for t < 5 minutes. The relationship between *R* and sensitivity is far more obscure in their case. Also, the thixotropy that we observed in Lachenaie's clay appears to be much more intense than elsewhere in the Champlain Sea basin. This could be due to some distinctive property of the Lachenaie clay body, perhaps its pore water salinity, or to some differences in testing methods.

Figure 11 shows how the w_L values calculated with the 30 s penetrations compare with the w_L values obtained by following Standard CAN/BNQ 2501-092. Following the Standard yields higher w_L values but the difference is generally small. Except for the sample with intense thixotropy which test results are presented in Figure 2, the difference between the two w_L values is always less than 5 %. For the case of Figure 2, the w_L values for 30 s penetrations and for the standard are respectively 46.5 %

and 50.1 %. Sample FP-07-05R (depth 9.51 m) shows that intense thixotropy does not always imply markedly different w_L values. This could be due to the fact that sensitive clays often have a low I_p (w_L-w_P). Since w_L and w_P correspond to fixed c_{ur} values (Sharma and Bora 2003), a low I_p implies that a small w change will result in a relatively large c_{ur} change. Thus one could get strong thixotropy and, consequently, *P* values at 30 s which differ markedly from the P values obtained by following standard CAN/BNQ 2501-092, but at the same time little water content change between the 3 points of a test. In other words, in a graph similar to the one presented in Figure 2, a low I_p clay showing strong thixotropy would have steep c_{ur} versus t relationships but with little water content change between them.

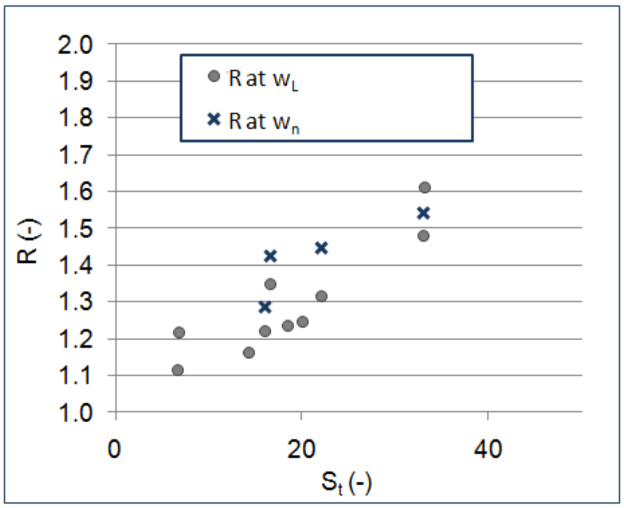

Figure 9 : Thixotropic strength regain versus sensitivity for some Lachenaie clay samples.

Table 3. Experimental results, set 3.

Borehole	Depth (m)	*R* w_n (-)	*R* 30 s w_L (-)	w_L (%) CAN/BNQ	w_L (%) 30 s	S_t (-)
FP-06-01AB	13.69	1.42	1.35	72.9	70.5	17
FP-06-01R	6.39	-	1.25	65.0	64.4	20
FP-07-04AH	4.40	1.29	1.22	66.8	65.7	16
FP-07-04R	12.75	-	1.11	46.9	46.9	7
FP-07-05R	9.51	1.54	1.48	54.7	53.8	33
FP-07-06R	13.12	-	1.22	41.2	40.8	7
FP-08-07AB	6.66	-	1.61	50.1	46.5	33
FP-08-07AH	3.63	1.45	1.31	63.8	61.5	22
FP-08-07R	7.78	-	1.16	41.6	41.2	14
FP-08-07R	3.37	-	1.23	59.6	58.8	19

5 CONCLUSION

For the saline clay of Lachenaie, the Casagrande and fall cone methods give equal w_L values. Figure 3 shows that the fit for the Lachenaie data is actually better than what was found in the literature. It is likely that the outliers found in the literature have some distinctive geotechnical or geochemical properties, or that the results were affected by an experimental bias.

For the fall cone, three sources of error were appraised. First, using a blunt 60° cone was found to have a negligible influence on w_L. Secondly, for the intact shear strength, the c_u values obtained with the 100 g and 400 g cones were found to be markedly different when the penetration with the 100 g cone was less than 5 mm. Finally, thixotropy was shown to have some impact on w_L measurements, albeit a small one (up to 4 % units). Even if thixotropy appears to be more important for sensitive clays, the w_L values obtained by using the penetration at 30 s or by following the standard do not differ by a greater margin for them.

On the other hand, for the Casagrande apparatus, the fall height was found to have a major influence on test results. A fall height error of 1 mm was found to result in a bias of up to 6 % units. This is one of the reasons why the authors recommend the fall cone technique over the Casagrande apparatus method.

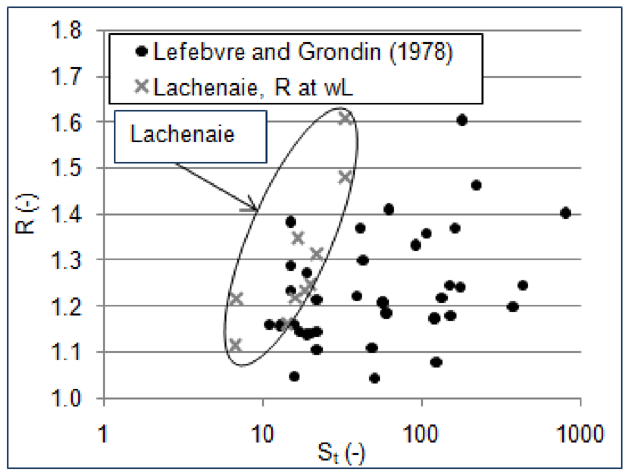

Figure 10 : *R* versus S_t for the Lachenaie clay body and for the whole Champlain Sea basin

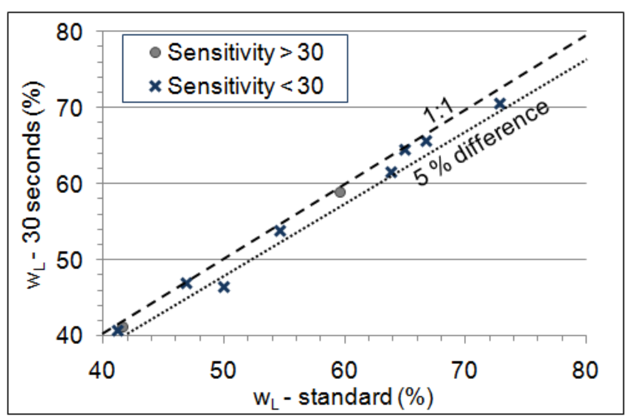

Figure 11 : w_L for first penetration and w_L done according to Standard CAN/BNQ 2501-092.

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