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June 9th 2010

Abstract

The Casagrande Cup method has been the preferred method of finding the liquid limit in Denmark for many years. It is however stated by the Danish Standards Association, that the Fall Cone test, is to be preferred when possible. The comparability of the Casagrande and the Fall Cone method has been shown in numerous papers. However the comparability is still fairly undocumented on the plastic danish tertiary clay, like the Søvind Marl. Based on a serie of tests carried out on Søvind Marl, the liquid limit from the Casagrande Cup and the Fall Cone apparatus are compared.

The Loss on Ignition on non organic materials has been suggested as a new and fast way to classify clay and determine the plasticity index up to an I_p of 60 %. A serie of tests using traditional means, the Casagrande Cup, and Loss on Ignition have been carried out, and the results are compared, to assess whether this method can be used on Søvind Marl.

Keywords: Søvind Marl, Liquid limit, Plasticity index, Casagrande, Fall Cone, Loss on Ignition

1 Introduction

The Atterberg limits plays a great role in assessing and classifying clays. Atterberg divided the behavior of clay into types, depended on the water content of the clay, the Atterberg limits. The plasticity of clay is a property in clay that allows wet clay to be molded into a given shape when pressure is applied. The plastic limit, w_P , is the water content, at which

the clays consistency changes from semi-solid to plastic. The liquid limit, w_L , is the water content at which the consistency changes from plastic to liquid. The plasticity index, I_P , is given as the difference between the liquid limit and the plastic limit. The definition of the Atterberg limits can be seen in figure 1.

Classification of clay is done by a plasticity chart. The plasticity chart for the Søvind Marl can be seen in figure 7. The Søvind Marl falls outside the normal range of the plasticity chart, which goes up to a liquid limit of 100 %. The Søvind Marl is therefor classified as a very high plasticity clay.

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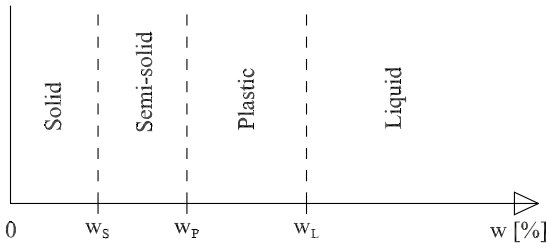


Figure 1: Atterberg limits of clay. After [Ovesen, 2006]

The liquid limit has in Denmark traditionally been determined by use of the Casagrande percussion cup method. This method is however very dependent on the apparatus and the person operating it, resulting in variations of the results. Hansbo (1957) showed through a series of tests that the Fall Cone Apparatus could be used as a quick and easy way to find the strength of soils. Wroth and Wood (1978) found that the liquid limit test establishes the water content, at which the clay has a certain undrained shear strength. They suggested, based on series of tests, that the liquid limit corresponds to a fall depth of 10 mm when using a cone weighing 60 g and having an angle of 60°.

Wasti (1987) compared liquid limits in the range between 27 % and 110 %, found by using the Casagrande and the Fall Cone method, of 15 soils from different locations in Turkey. The correlation found was given by:

$$w_L(FC) = 1.0056 \cdot w_L(C) + 4.92 \quad (1)$$

where $w_L(FC)$ and $w_L(C)$ is the liquid limit found by respectively the Fall Cone method and the Casagrande method.

The plastic properties of clay is, among other things, dependent on its ability to bind water to the crystal structure. Most clay material is primarily platy hydrous aluminum silicates.

These silicates contains OH-groups and large amounts of water of crystallization. A description of the clay minerals in the Søvind Marl can be found in *Chloride concentration and pHs influence on the Atterberg limits of Søvind Marl* [Grønbech et al., 2010].

Stockmarr (2008) suggest that the plasticity index up to an I_P of 60 % is proportionally to the Loss on Ignition. When the clay is heated to 550 °C, the crystal structure of the clay minerals is disintegrated, and the water of crystallization and the combined OH-groups is liberated. The clay carbonates is considered stable up to 600 °C, and should therefor not be affected by the heating. Stockmarr also linked the Loss on Ignition with the classification of the clay as can be seen in table 1.

Table 1: Classification based on Loss on Ignition. [Stockmarr, 2008]

L.o.I	Classification
< 1 %	Sandy clay or silt or sand
1 % – 2.2 %	Medium plasticity clay
2.2 % – 4.2 %	High plasticity clay
> 4.2 %	Very high plasticity clay

In Eurocode 7 DS/CEN ISO/TS 17892-12 it is stated that the Fall Cone penetration method is the preferred method of determining the liquid limit, compared to the Casagrande Cup method. [Danish Standards Association, 2004]. It is wanted to find if this comparability of the two methods also applies to clays with a very high liquid limit, such as the Søvind Marl.

In this paper the correlation between liquid limit found by the Fall Cone and the Casagrande method is assessed. Additionally a comparison of the plasticity index found by traditional methods and Loss on Ignition is made, for an assessment of the usability of the method on Søvind Marl.

2 Geological description of Søvind Marl

All of the samples of clays tested in this paper is Søvind Marl from Århus Harbor. Søvind Marl is a tertiary sediment. The tertiary clays in Denmark is located in a belt from Mors in the north west over Århus and the western and southern parts of Fuen to Lolland, as it can be seen in figure 2, where Århus is marked.



Figure 2: The Eocene plastic clay in Denmark. Århus is marked with \circ . [Thøgersen, 2001]

The climate of the Eocene periode was in Denmark tropical or subtropical, and the sediments of the periode are all deposited in the ocean of the time. The changes in the characteristic of the sediments is due to the changes in the water level and the degree of living organisms of the time. The sediments changes from limestone in the earlier deposits to clays and silt in the latest deposits. Through the Eocene layers around 180 layers of ashes from volcanic eruption can be found, evidence of a great and

long lasting geological change. Above the layers of ashes a plastic clay is found, where up to 90 % of the particles has a grain diameter less the $2 \mu\text{m}$. In Århus Søvind Marl is located to depths of 70 m and has a very high concentration of lime. The lime concentration varies from very light, 1 %, to highly limy, 65 %. The lime comes from coccoliths that lived when the Søvind Marl was deposited [Okkels, 2008].

Based on the coccoliths the age of the Søvind Marl at the location in Århus is determined. The coccoliths are all from the NP zone 15 and 16, estimating the age of the Søvind Marl to be between 40.5 and 46 million years old. It was determined that all the samples was from the Middle Eocene age, and thus the oldest part of the Søvind Marl Formation. The lowest sample, from a depth of 69 m, is estimated to be located at the transition from the lower Little Belt Clay Formation to the Søvind Marl Formation. The formations is located in a correct stratigraphically order, with no overlapping. [Thomsen, 2008]

3 Methods

Three methods have been use to determine the plasticity Index of the Søvind Marl. And there are found pro and cons with them all.

The tests done by the Casagrande Cup and the Fall Cone Apparatus is both done by gradually adding more de-ionised water. Therefor these experiments are carried out simultaneously on the same material. Whereas the Loss on Ignition is done on a separat, yet identical, sample of the material.

Casagrande method

The Casagrande Cup tests are carried out as described in *Manual for laboratory tests* [Danish Geotechnical Society, 2001], on an apparatus with a base of bakelite and a brass cup, figure 3, as the standard is in Denmark. The liquid limit is defined as the water content at which the groove closes over a distance of 12 mm after 25 strokes at a rate of 2 strokes per second.

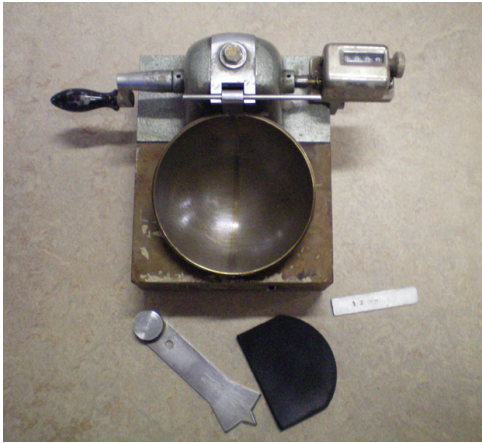


Figure 3: The Casagrande Cup apparatus used for the tests.

The Casagrande Cup is a well known method, which has been used all over the world for many years. The results obtained by this method is however very dependent on the person operation the Casagrande Apparatus, thus making it hard to replication the results when the same test is carried out on the same material, but by a different person. The factors dependent on the operator includes the rate at which the cup is dropped, judgement on when the sample is touching over a distance of 12 mm, the placement of the sample in the cup and the making of the groove. Other factors that might influence the results is the materiale and state of the base and the cup, variations in the vertical drop of the cup, the fundaments

stability and the grooving tool. [Prakasha, 2002]

Fall Cone Method

The Fall Cone tests are carried out as described in *Manual for usage of Fall Cone Apparatus to determine the Liquid Limit* [Grønbech, 2010]. A Geonor Fall Cone Apparatus without a timer and with a 60 g/60° cone were used, figure 4. The water content corresponding to a fall depth of 10 mm is described as the liquid limit.

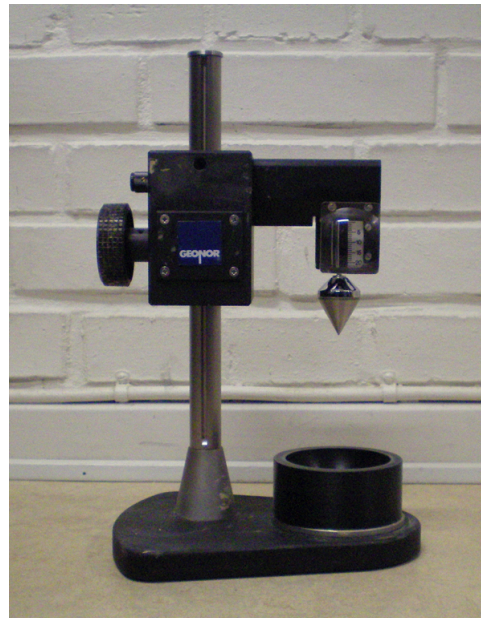


Figure 4: The Fall Cone apparatus used for the tests.

The Fall Cone is widely known throughout the world, and the accepted standard in many countries. The Fall Cone has the advantage over the Casagrande cup that the operation of the apparatus is not affected by the operator, and the results are thereby comparable independent of the user. When using the Fall Cone Apparatus, one should be aware of the state of the cone, since a worn cone can affect the fall depth, and thereby the results of the liquid li-

mit. Air pockets trapped in the clay can also influence the fall depth.

For both the Casagrande cup and the Fall Cone method, the clay should be homogenized and the water content brought to a level close to yet under the liquid limit, which is a time-consuming process. The homogenizing of the clay is a very important part of finding the liquid limit, and should be done carefully. Not homogenizing the clay sufficient or mixing air in the clay can have a great influence on the outcome of the liquid limit.

The plastic limit is found by rolling the clay on a glass plate into stings with a diameter of 3 mm before they crumbled as described in DS/CEN ISO/TS 17892-12 [Danish Standards Association, 2004].

Loss on Ignition method

The tests with Loss on Ignition on the clay is carried out as described in DS/EN 12879 [Danish Standards Association, 2001].

Finding the plasticity index of a clay using the Loss on Ignition, is a new and fairly untested method. Stockmarr (2008) proposed a correlation between the Loss on Ignition and the plasticity index:

$$I_P = 12.5 \cdot L.O.I(\%) - 2.5 \quad (2)$$

where L.O.I(%) is the Loss on Ignition in percent.

Finding the plasticity index by means of the Loss on Ignition, is an easy and simple method, completely independent of users or apparatus. There are however factors that increase the Loss on Ignition, but do not increase the plasticity of the clay, like non plastic organic ma-

terial, such as plant material, and other non plastic materials, like rust.

The Loss on Ignition method is not considered usable on clays which have been subject to diagenesis processes like chemical, biological or physical changes.

4 Results

The liquid limit, by the Casagrande and the Fall Cone method, is found on 23 clay samples from two places on Århus Harbor, L*H 9 and L*H 11, to depths of respective 49 m and 69 m.

The liquid limits over the depth can be seen in figure 5. The liquid limit from L*H 9 can also be seen in table 2.

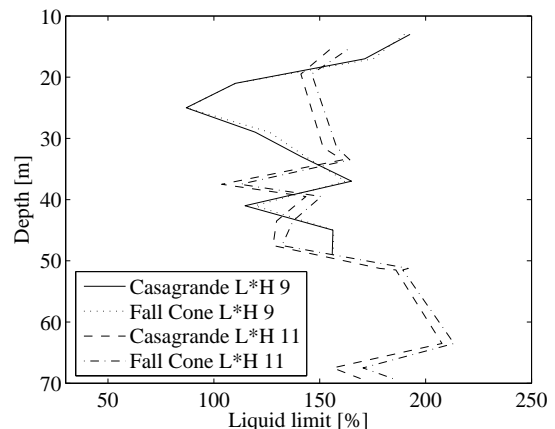


Figure 5: The liquid limits found by respectively the Casagrande and the Fall Cone method for L*H 9 and L*H 11.

It is shown in figure 5 that the liquid limit found by the two methods gives similar results and follows the same pattern. A comparison of the liquid limit found by the two methods can be seen in figure 6.

The relation between the liquid limit of the Søvind Marl in the range of 80 % to 215 %

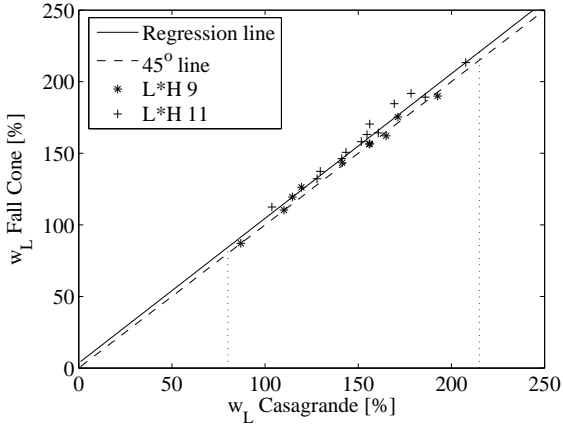


Figure 6: The relation between the liquid limit found by Casagrande method versus Fall Cone method. The dotted line marks the range of the liquid limit.

found by the two methods in figure 6 can be described by using linear regression analysis using the least squares method as:

$$w_L(FC) = 1.0106 \cdot w_L(C) + 3.49 \quad (3)$$

The found relation shows, that the liquid limit found by the two methods correlates very well.

The plasticity chart of the Søvind Marl can be seen in figure 7, where the A-line is described by equation 4.

$$I_P = 0.73 \cdot (w_L - 20) \quad (4)$$

All the samples lie above the A-line, equation 4, and from a w_L of 86 % and higher, this classifies the Søvind Marl as a very high plasticity clay. The dashed line in figure 7, marks the normal range of the plasticity chart. The plasticity of the Søvind Marl is therefore well outside the normal classification range of clay.

The plasticity index is found for 10 samples of clay from drilling L*H 9 from Århus Harbor.

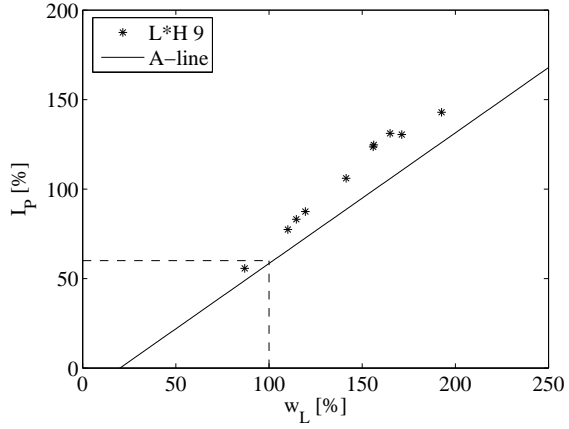


Figure 7: Plasticity chart of Søvind Marl from L*H 9. The A-line comes from equation 4.

The liquid and plastic limits, the Loss on Ignition and the plasticity index can be seen in table 2. The same plastic limit is used when finding the plasticity index from both the Fall Cone and the Casagrande method, since the Danish Standard Association only stipulates one method to determine the plastic limit.

The plasticity index from all three methods can be seen over the depth in figure 8.

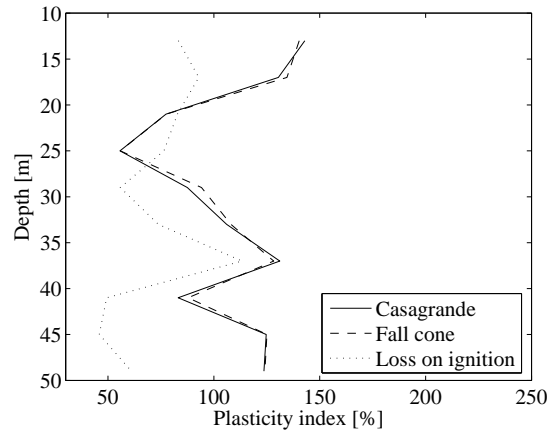


Figure 8: Plasticity index found using Casagrande method, Fall Cone method and Loss on Ignition.

It is clear from 8 that there is no clear correla-

Table 2: The liquid and plastic limit, the Loss on Ignition and the plasticity Index of the 10 samples from L*H 9.

Depth [m]	Casagrande			Fall Cone		Loss on Ignition	
	w_P [%]	w_L [%]	I_P [%]	w_L [%]	I_P [%]	L.o.I [%]	I_P [%]
13	49.7	192.6	142.9	190.0	140.3	6.86	83.3
17	40.8	171.3	130.4	175.3	134.5	7.63	92.9
21	32.8	110.2	77.4	110.3	77.5	6.82	82.8
25	31.3	87.0	55.7	87.1	55.8	6.32	76.5
29	32.1	119.6	87.5	126.3	94.2	4.66	55.8
33	35.3	141.4	106.1	143.4	108.1	6.11	73.8
37	33.9	165.0	131.1	162.2	128.3	9.26	113.3
41	31.6	114.7	83.1	119.4	87.9	4.15	49.4
45	31.5	156.2	124.7	156.6	125.1	3.87	45.9
49	32.3	155.9	123.6	156.4	124.1	5.09	61.1

tion between the Loss on Ignition and the plasticity index for these samples of Søvind Marl. I_P for Søvind Marl can therefore not be determined by Loss on Ignition.

We can see from figure 7, that the Søvind Marl is a very high plasticity clay. This can also be seen when the Loss on Ignition of the Søvind Marl, table 2, is compared to the classification based on the Loss on Ignition proposed by Stockmarr, tabel 1.

(1987), equation 1, suggesting that the use of the Fall Cone offers satisfactorily results when used on Søvind Marl. The results of the Fall Cone method had a little higher liquid limit than the results from the Casagrande method, as can be seen from equation 3, but the difference is shown to be almost constant independent of the liquid limit and of such little magnitude that the difference is negligible. The liquid limit of Søvind Marl can therefore be considered equal independent of the method.

5 Discussion

$$w_L(FC) \approx w_L(C) \quad (5)$$

The purpose of this paper is to compare and assess the liquid limit of the plastic tertiary clay Søvind Marl found by Casagrande Cup and Fall Cone method, as well as the plasticity index found using these methods and the Loss on Ignition.

First the liquid limits were found using the Casagrande and Fall Cone methods, figure 5. It was shown that the results of the two methods has a good correlation. The findings in this paper correspond well with the findings of Wasti

The plasticity index of the Søvind Marl from L*H 9 is also attempted to be found by the Loss on Ignition, as suggested by Stockmarr (2008). The plasticity index from the Loss on Ignition is compared to the plasticity index found by the Casagrande and the Fall Cone methods. It is found that for Søvind Marl with I_P in the range of 55 % to 145 % there is no correlation between the Loss on Ignition and the plasticity index. There is a good relation between the Loss on Ignition and the classification of the Søvind Marl. Loss on Ignition can

therefor be use as a simple method to classify the plasticity of the Søvind Marl.

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