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Determination of liquid limit by the Fall Cone method

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Note

Keywords
Atterberg limits
Casagrande
Consistency
Fall Cone

Abstract

The knowledge of soil characterization parameters allows identification and classification of materials. Also, indicates the soil behavior in front of stress and deformation. The aim of this paper was to evaluate the methods available for determining the liquid limit by the Casagrande device and Fall Cone equipment. The classic method of Casagrande was developed by Arthur Casagrande in 1932 and the Swedish Fall Cone was developed by Geotechnical Commission of the Swedish State Railways in 1915. To guarantee the representativeness of the evaluation, 31 Brazilian soil samples from different origins were tested (marine, residual, colluvium and tailings). In order to understand the behavior of the samples and evaluate the applicability of the Swedish Fall Cone method were determined other geotechnical properties as a percentage of fines, specific gravity and plastic limit. The results show that the values obtained with the Casagrande method are slightly lower than with the Fall Cone equipment. It was observed a coherent correlation between the methods for liquid limits values less than 80 % with a corresponding coefficient of determination R^2 of 0,9453. Above this moisture content, it was not possible to verify any correlations between the methods applied.

1. Introduction

For a long time, geotechnical engineering was based on past experiences through a succession of experiments without any real scientific definition. Concerns about soils study and its properties began in the mid-eighteenth century when problems of foundation in older constructions emerged, as is the case of the famous Tower of Pisa in Italy (Das, 2012). The knowledge of soils consistency is relevant, because demonstrate the soil behavior before stress and deformation, influencing on soil penetration resistance and compaction and affecting hydraulic conductivity.

Plasticity is a property of soils that consists of the ability of the soils to be or not molded, under a certain moisture condition, without volume variation. The plastic properties of a soil depend on the water content, the form of the particles and its chemical and mineralogical composition (Lambe & Whitman, 1969).

In 1908, Albert Atterberg published research with the first result about soil plasticity and its several moisture contents and in 1911, explained cohesive soils consistency defining liquid limit, plastic limit and contraction limit. Arthur Casagrande, in 1932, deepened his research on Atterberg's papers and developed the liquid limit device, used until today in laboratories.

The Swedish Fall Cone method was developed between 1914 and 1922 as a fast, simple and accurate method to determine the undrained shear strength, sensitivity of clays and liquid limit, which has encouraged several countries to choose it as a standardized equipment (Karlsson, 1981). The variation of the method between the countries is given by the type of cone applied with different masses and opening angles. The use of the cone to determine liquid limit had the objective of reducing the influence of factors that negatively affected the results obtained with the Casagrande method (Spagnoli, 2012).

Several studies have been made comparing the Fall Cone equipment and the Casagrande apparatus (*e.g.*, Garneau & Le Bihan, 1977; Leroueil & Le Bihan, 1996; Nini, 2014; Spagnoli, 2012; Wood, 1982). However, there is no single standardized test, as there are several methods for estimating a liquid limit with the Fall Cone.

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The aim of this paper is to demonstrate that Swedish Fall Cone can be an alternative method to determine liquid limit, being a practical, fast and with less interferences of the operator in the procedure when compared with the determination by Casagrande apparatus. To evaluate the validity of the liquid limit determination using the Swedish Fall Cone method in this article, the liquid limit of samples was determined using this method and comparing the obtained values and dispersion associated with each determination for Casagrande method. It was intended to indicate the differences between one method and another in order to correlate the methods and it was evaluated if the results obtained with the Swedish Fall Cone are consistent when compared with the Casagrande method.

2. Materials and methods

In order to achieve a greater coverage in the results of the present article, it was select samples from different locations in Brazil (state of Rio de Janeiro, Amapá, Pará and Minas Gerais) and with various geotechnical characteristics (marine, residual, colluvium and tailings), totaling 31 samples.

Soil characterization tests are in general simple tests and relatively fast with international validity and few variations between the methods used in the different countries. These tests have major importance in the study of soils, since they are the beginning in the identification of the material and its later classification, providing important data in the determination of the engineering characteristics of the sample. In the present study were performed the traditional characterization tests (grain size distribution, specific gravity and Atterberg limits) to gain an understanding of the soil properties. All the characterization tests were performed according the Brazilian standards recommendations.

The Casagrande apparatus is composed of a brass shell and a rigid rubber base. This brass shell is struck at the base by a crank. The procedure and apparatus are specified in the Brazilian standard ABNT NBR 6459 (ABNT, 1984). The liquid limit devices specified at the Brazilian, American ASTM D 4318 (ASTM, 2017) and British BS 1377-2 (BSI, 1990) Standards are similar, but there are variations at the details. The American and Brazilian devices have a rubber base, different from the device of the BS proposal (Head, 2006). Therefore, the tests result from the three type of devices may not be well matched. The procedures established by the standards are similar.

The execution of the test begins with the preparation of the sample, in order to obtain a homogeneous paste. Part of the mixture is transferred to the shell of the equipment, molding so that the central region has a thickness of the order of 10 millimeters. With a chisel, a groove opens in its central part, dividing the soil mass into two parts. The consistency of this first paste should close the groove with about 25 blows. The closure occurs at a distance of approximately 12.7 millimeters along the base of the groove. In the graphical representation of the test, the values of moisture content are plotted in the axis of ordinates in arithmetic scale and the number of strokes in the abscissa axis in logarithmic scale. The liquid limit corresponds to the moisture content equivalent to 25 blows.

The equipment of the Swedish Cone consists of a metal cone of a certain mass with a certain angle suspended vertically only with the tip of the cone touching the surface of the sample. When released, the cone falls freely by its own weight on the soil sample, so the final depth of penetration is measured. The equipment is represented in the Figure 1.

In the research presented here, it was worked with the Swedish standard definition SS 027120 (SSC, 1990) and Karlsson's recommendations (Karlsson, 1981) considering that the liquid limit is defined as the moisture content in which a cone with opening angle of 60° and mass of 60 g penetrates 10 mm in the soil. Unlike the Casagrande apparatus, there is no single procedure and equipment for Fall Cone, there are variations in weight and dimensions depending on the standard consulted. For instance, the British Cone standardized by British Standard BS 1377 (BSI, 1990) has a weight of 80 g and an opening angle of 30°, the liquid limit is determined at a 20 mm penetration. The Chinese Cone uses a penetration of 17 mm, it has a weight of 76 g and opening angle of 30°. There is no Brazilian standard available to regulate the liquid limit test using the Cone yet, but some studies have been made by Silveira (2001) and Queiroz de Carvalho (1986).

Figure 1. Fall Cone, 2015.

For the graphical representation, a graph is constructed with the values of moisture content in the axis of the ordinates and the values of the penetration in millimeters in the abscissa axis, both in arithmetic scale, as shown in Figure 2.

3. Results and discussions

The soil samples were numbered from 1 to 31. Three samples did not have enough material to perform specific gravity and distribution size analysis. The Table 1 presents the sample identification with the related origins and the results of characterization tests. The Table 1 also presents the soil samples classification according to Unified Soil Classification System (USCS) as CL (clays of low plasticity), CH (clays of high plasticity), ML (silts of low plasticity), MH (silts of high plasticity) and SC (clayey sands). Three samples (13, 14 and 15) were left unclassified due to lack of material to perform the classification tests.

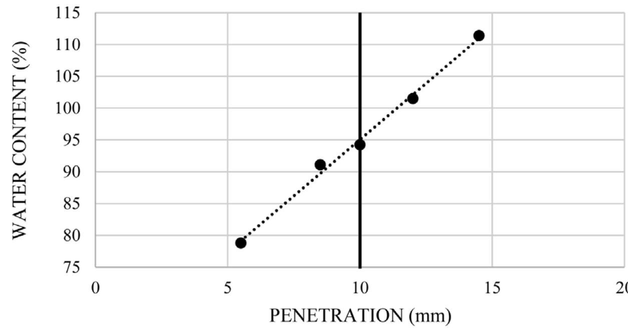

Figure 2. Graphic representation of liquid limit by the Fall Cone method.

Table 1. Sample identification and properties of soils tested.

Sample	Origin	Gs – Specific Gravity	Percentage of fines (%)	Liquid limit (%)	Plastic limit (%)	USCS classification	Activity (%)
1	Marine	2.737	93.7	75	39	MH	38.42
2	Marine	2.759	99.0	100	36	CH	64.65
3	Marine	2.708	81.2	64	26	CH	46.80
4	Marine	2.712	88.4	86	36	CH	56.56
5	Marine	2.722	91.5	54	24	CH	32.79
6	Colluvium	2.631	97.0	110	53	MH	58.76
7	Aluminum ore - Tailing	2.698	31.5	18	10	SC	25.40
8	Aluminum ore - Tailing	2.750	88.8	49	25	CL	27.03
9	Marine	2.645	91.5	54	16	CH	41.53
10	Marine	2.635	77.0	63	12	CL	66.23
11	Marine	2.533	71.5	51	9	CL	58.74
12	Marine	2.651	77.7	89	12	CH	99.10
13	Marine	-	-	33	14	-	-
14	Marine	-	-	83	-	-	-
15	Marine	-	-	54	15	-	-
16	Colluvium	2.836	62.9	49	23	CL	41.34
17	Marine	2.485	100.0	94	27	-	67.00
18	Residual	2.837	63.0	34	21	CL	20.63
19	Marine	2.523	100.0	56	28	CH	28.00
20	Residual	2.697	51.0	30	16	CL	27.45
21	Residual	2.660	70.0	41	20	-	30.00
22	Residual	2.689	61.0	52	27	CH	40.98
23	Residual	2.695	68.0	47	20	CH	39.71
24	Residual	2.621	40.0	40	24	SC	40.00
25	Residual	2.776	63.0	51	29	MH	34.92
26	Residual	2.609	65.0	40	22	SC	27.69
27	Residual	2.707	61.0	48	28	ML	32.79

Table 1 (cont.)

Sample	Origin	Gs – Specific Gravity	Percentage of fines (%)	Liquid limit (%)	Plastic limit (%)	USCS classification	Activity (%)
28	Residual	2.644	74.0	43	22	CL	28.38
29	Residual	2.642	80.0	48	24	CL	30.00
30	Residual	2.631	56.0	24	12	CL	21.43
31	Residual	2.830	61.0	32	17	CL	24.59

Table 2 shows the results of liquid limits obtained with the Casagrande and Swedish Fall Cone apparatus, as well as the R^2 values achieved in each test. Due to the amount of material available, not all samples were able to have all the tests performed. But this factor does not influence the evaluation because the fundamental tests - the liquid limit at the two methods - were tested.

The average R^2 values and dispersion values for the Fall Cone method were 0.975 which reveals a good test result and a coherent application for the samples tested. For a better analysis of the liquid limit data and further analysis, a graph was constructed in which in the abscissa axis are the values of liquid limit (LL) using the apparatus of Casagrande and in the axis of the ordinates the values using the Fall Cone. The trendline was fixed at the origin to represent an ideal correlation. The graph is presented at the Figure 3.

The first evaluation that can be done is that the Fall Cone method and Casagrande apparatus generally give different values for the liquid limits, as already proven by some researches (Wood, 1982; Leroueil & Le Bihan, 1996; Crevelin & Bicalho, 2019). And when comparing the values between Casagrande and Fall Cone methods, for most samples, it is noticed that the higher values were obtained with the Fall Cone.

In this graph, the tendency line was considered through the origin (45 degrees), which would imply a perfect correlation between the methods, but it was noticed a dispersion of the points as the moisture increased. Evaluating the data up to a Casagrande liquid limit value of 80 %, the R^2 value is 0.9453, considering the values with LL > 80 %, the R^2 is 0.1485, which shows an increase in the dispersion of the values. This suggests that results can be divided into two groups, with a liquid limit of 80 % as the separation point, however the quantity of tests with LL > 80 % was small (Figure 3, samples 2, 4, 6, 12, 14 and 17). No correlation was observed between the differences between the methods and the properties of the soils tested.

In compliance with previous studies available in the geotechnical literature, there is a certain tendency for Casagrande values to be lower than those obtained by Fall Cone for lower liquid limits and higher than Cone values for higher liquid limits. According to Sridharan & Prakash (1998), this differentiation of the values between the appa-

Table 2. Liquid limit results.

Sample	Liquid limit (%)		R^2 - Casagrande	R^2 - Fall Cone
	Casagrande	Fall Cone		
1	75	80	0.998	0.969
2	100	95	0.985	0.995
3	64	61	0.99	0.978
4	86	76	0.996	0.996
5	54	57	0.997	0.955
6	110	107	0.995	0.998
7	18	23	0.987	0.959
8	49	58	0.989	0.976
9	54	57	0.957	0.986
10	63	63	0.991	0.988
11	51	50	0.952	0.947
12	89	97	0.936	0.999
13	33	34	0.965	0.955
14	83	98	0.966	0.970
15	54	59	0.988	0.990
16	49	58	0.942	0.989
17	94	82	0.986	0.989
18	34	38	0.985	0.970
19	56	63	0.994	0.926
20	30	33	0.944	0.954
21	41	44	0.998	0.962
22	52	57	0.994	0.978
23	47	54	0.964	0.979
24	40	41	0.994	0.973
25	51	60	0.985	0.988
26	40	53	0.990	0.993
27	48	57	0.993	0.979
28	43	52	0.997	0.965
29	48	52	0.973	0.994
30	24	31	0.978	0.967
31	32	36	0.994	0.969

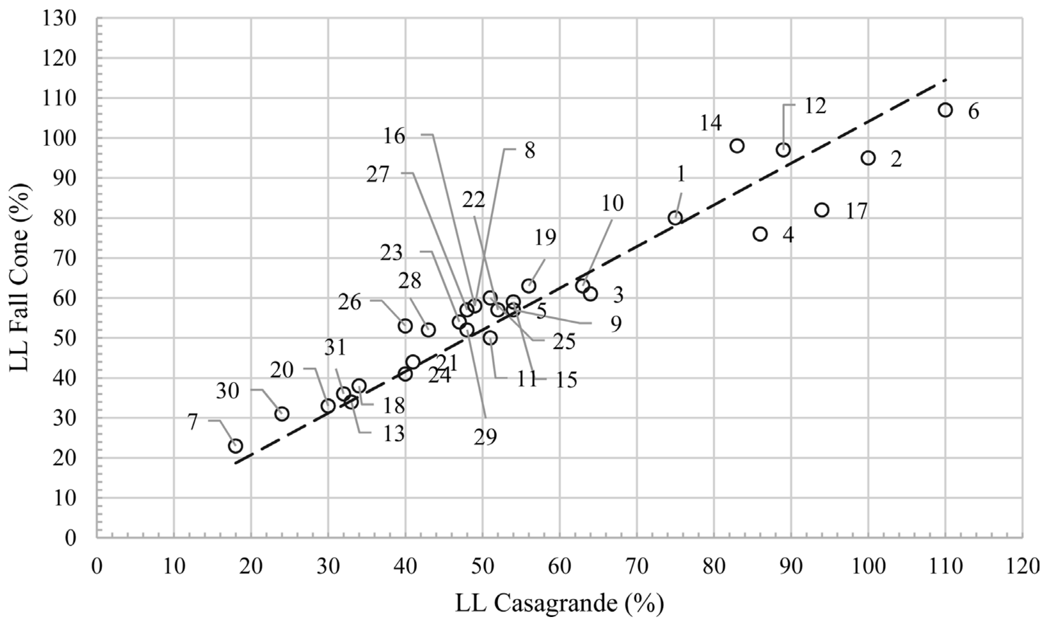

Figure 3. Comparison between Fall Cone method and Casagrande device.

ratus of Casagrande and Swedish Fall Cone is related to the dominant clay mineral and its proportion contained in the clay fraction. Other authors, such as Leroueil & Le Bihan (1996), agree that the clay minerals are an important factor, but should not be the only one to be considered.

In order to explain this difference in behavior, the content of organic matter and the type of clay mineral were determined. Regarding organic matter, the maximum value found was 9,8 %, therefore the samples did not present a significant amount of organic content that could have influenced on the behavior of the test results. Another attempt to identify the existent clay minerals, the points were plotted on a chart - index of plasticity x percentage of the clay fraction - proposed by Lambe & Whitman (1969), as shown at Figure 4. As maximum and minimum values of percentage of clay fraction are, respectively, 100 % and 31.5 % and in the case of plasticity indices, 77 and 12. According to these values and approaching a corresponding area, it is noted that the clay minerals present in the samples are illite and kaolinite. The values of activity of the samples (Table 1) also show inactive clays (A < 0.75) and normal clays (A between 0.75 and 1.25). As described by Sridharan & Prakash (1998), the mechanisms controlling the kaolinitic soils are different than montmorillonite soils and usually, the Cone

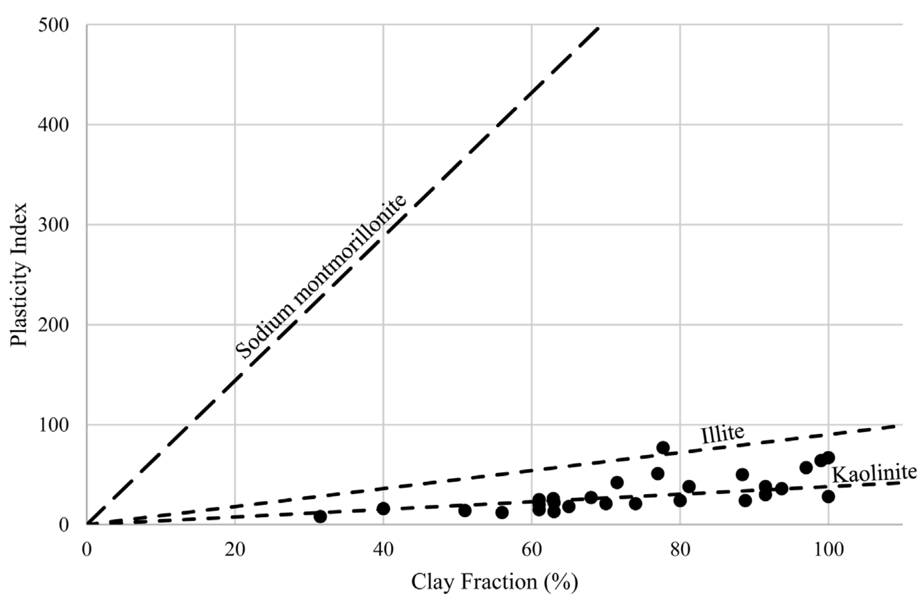

Figure 4. Plasticity index *vs.* clay fraction (Lambe & Whitman, 1969).

method gives a higher liquid limit than the Casagrande device for kaolinitic soils. For these authors, the dominant clay mineral type and its proportion in the clay content are in charge of the variations between the results of the Casagrande and Cone tests. The data obtained do not permit to confirm or discard this assumption, the most part of the materials presents low activity and apparently the same kind of clay minerals.

According to Head (2006), the mechanics of the Fall Cone test depend directly on the static shear strength of the soil, as the Casagrande procedure includes a dynamic component not associated with shear strength in the same way for all soils. By the liquid limit definition, the obtained value is influenced by the point at which the soil begins to gain a detectable shear strength, about 1.7 kN/m^2. For Bicalho et al. (2014), the difference of values between the methods is related to the mechanics of the test and its correlation to estimate the undrained shear strength and the clay content of the samples.

One of the likely explanations for the variation of the values between one method and another can be explained by the differences between behavior to obtain the results. For the execution of a test point in the Casagrande apparatus the groove must close at 12.7 millimeters, in other words, the ground behaves as if in a “dynamic slope stability” test where each stroke generates an acceleration and causes the “slope” to move until the groove closes (Haigh, 2012). In the Swedish Fall Cone, the execution of a test point is done by touching the tip of the cone on the surface of the soil sample and when the cone is released and a quasi-static penetration in millimeters is measured, there is more direct measurement of cone penetration in soil. This behavior may be a more consistent explanation for the justification of differences than the individual assessment of materials.

4. Conclusions and recommendations

This study presented an experimental analysis of the performance of Fall Cone device as an alternative method to determine the liquid limit. The main limitation associated with this method is the lack of an apparatus and methodology internationally adopted. Therefore, the procedure of the test was followed as recommended by Karlsson (1981) and the Swedish Standard, which uses a cone with mass of 60 g and 60° opening angle cone. The current study evaluated 31 soil samples from various regions of Brazil and different geotechnical properties. Besides the execution of liquid limit at Casagrande’s method, other tests as the plastic limit, percentage of fines, and specific gravity were determined to expand the database and identify possible deviations.

The Fall Cone test is simpler to perform and factors such as operator influence, trial run time and calculation are smaller than Casagrande. In addition, the Fall Cone method avoid some inconveniences generated by Casagrande device, such as dispersion of the results, small differences in the apparatus, distribution of material in the shell, observation of the slot closure and incorrect homogenization time. Analyzing the individual results, the Fall Cone method obtained acceptable outcome and presents a suitable application for the samples tested. Comparison of the values between Fall Cone and Casagrande shows that the methods present a good correlation in liquid limits of up to 80 % and above this value the differences increase, which relates to the obtained in other studies (Bicalho, 2014; Head, 2006; Leroueil & Le Bihan, 1996). For liquid limit until 80 %, the difference between the method is about 5 %, above 80 % the differences between the values of liquid limit obtained increases to 8 %.

No direct correlation was observed between the soils properties and the differences observed between the methods, however, the quantity the tests with LL > 80 % was reduced. Most of the soils tested present low activity; therefore, it is necessary to investigate further the influence of different clay minerals in the results and correlations between the two methods.

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