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RESEARCH ARTICLE

Effect of Determination Method on the Liquid Limit of Quaternary Soils

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Abstract

The design process in geotechnical engineering has been vastly affected by Atterberg limits. There are wide variances in the results of liquid limit (LL) determined by different methods. It thought that the procedure used in the test is the primary source of these variances. The research reported in this paper was carried out to find the extent of the proper variance caused by the procedure used to determine the LL of quaternary soils. The effect of this variance on soil classification and activity (A) were included thoroughly. The LL was determined by six methods. They are the Casagrande hard-base and soft-base devices (multi-point and one-point method, and multi-point and one-point cone penetrometer methods. It was found that the index properties obtained from hard-base Casagrande device are differed significantly when compared with other methods. The variance noted was great enough to change LL and change the classification of soil from CL to CH and cause an error in computing A.

Keywords: Liquid limit, Cohesive soil, Quaternary soil, Activity, Classification, Cone penetrometer, Casagrande device

1. Introduction

In geotechnical engineering, the most common index limit that widely used in the classification of fine-grained soil is the liquid limit. Furthermore, numerous soil engineering properties, like permeability, undrained strength, swelling behavior, compressibility, cation exchange capacity, surface area, and liquefaction have been correlated, direct or indirect, with the value of the liquid limit [1-5]. The main approaches proposed to determine the value of soil liquid limit are the fall cone method and the percussion method [6-9]. In a number of countries, the determination of the liquid limit by fall cone is the standard method. However, the widely and most common method is the Casagrande method. The fall cone method is the definitive method in the United Kingdom, BS, while the alternative method is the method of Casagrande. While the recommend method according to the American Society for Testing and Materials, ASTM is the Casagrande method. In fact, there is an important difference between the Casagrande device adopted in each standard. The base of the device is relatively softer in BS 1377 [10] when compared with the ASTM device [1].

Research efforts, from different countries and using different soils, have been directed to study the effect of the mentioned difference, between ASTM and BS, on the values of soil liquid limit [11-21]. Different relationships have been proposed from these researches and showed that the conclusions of the experiments of them are widely varied.

The tests of a number of natural soils from some countries (e.g. Brazil and Canada) presented that the soil with low plasticity (liquid limit <50%) the Casagrande cup-device gives lower liquid limit than cone penetrometer, vice versa [15], [17], [22]. The contrast has been found for

artificial soils as per Sivapullaiah and Sridharan (1985) [13], Wasti (1987) [15], Shimobe, and Spagnoli (2019) [21]. The determination of the liquid limit of artificial soils using the ASTM Casagrande device gave higher values than the BS penetrometer device. The study of five natural soils from the United Kingdom tested using both Casagrande and cone devices, Whyte (1982) [12], concluded that the Casagrande liquid limit values were the higher in comparison to the cone-penetrometer. The liquid limit results obtained from experimental tests on a number of soils from different locations in Turkey revealed that LL from ASTM cup-device is always lower than that from the cone-penetrometer. Numerous natural soils tested using British cup-apparatus, American cup-apparatus, and BS cone-penetrometer revealed that the cone penetrometer gave a higher liquid limit than American cup-apparatus for soils LL < 70%. While the cone gave a lower liquid limit than BS Casagrande-apparatus for soils with LL > 40% [1]. Haigh and Vardanega (2014) [19] attributed the variation in liquid limit values to the variability of the devices used. They mentioned that the soils' variation has a low effect on the liquid limit values obtained from different practice codes.

From the previous researches the following could be noted:

- The effect of the testing method on the values of soils' liquid limit is clearly varied in the findings of the researches.
- The effect of the testing method on the values of soils' liquid limit is clearly varied in the findings of the researches.
- The researches that studied the relation between the liquid limit from the one-point method (from Casagrande device) and that from the cone penetrometer are limited.
- In spite of using the Casagrande device and the cone-penetrometer in Iraqi engineering laboratories, there is scarcity

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in researches studies on the effect of different testing procedures on the liquid limit of Iraqi soils. On the other hand, there is yet no correlation available between the liquid limit values of Iraqi soils obtained from different methods.

With the above points in mind the investigation described herein were undertaken.

2. Soils and experimental work

All the soil samples used in this study were collected from three provinces southern Iraq. They are clayey soils from Hilla, Dewaniya, and Nasiriyah provinces. The soil at these provinces is of a quaternary type. This type of sediment was resulted from interaction of the Euphrates River and the Tigris River, and covered the main parts of Mesopotamian Plain, Fig. 1 [23]. The samples were subjected to a series of physical and chemical tests to determine their basic properties. Table 1 gives the physical and chemical properties of the soils used, as shown, nearly all soils are predominated fine grains with little content of sulphite and chloride. The liquid limit of soils was determined by six deferent methods applied for each sample. The methods employed were the Casagrande (multi-point and one-point method) with the hard base device as specified by ASTM, the Casagrande (multi-point and one-point method) with the soft base device as in BS standards, and cone penetrometer (multi-point and one-point method) according to BS standards. However, these tests were conducted in the laboratories, the Nahrain University, Baghdad, Iraq.

Table 1. Some physical and chemical properties of Quaternary cohesive soil

Location	Fines	Sand	LL%	PL%	PI%	So ₃ %	Cl%
Hilla	87	13	30	19	11	0.05	0.04
Dewaniya	96	4	33	23	10	0.85	1.60
Hilla	94	6	36	16	20	0.42	0.80
Nasiriyah	91	9	39	20	19	0.75	0.04
Dewaniya	97	3	49	21	28	0.25	1.20
Nasiriyah	94	6	49	27	22	0.25	1.51
Dewaniya	92	8	51	24	27	0.3	0.85
Nasiriyah	99	1	53	23	30	0.52	0.24
Dewaniya	97	3	58	26	32	0.35	0.92

Figure 1. Location of collected samples

3. Results and discussions

3.1. Casagrande method –multipoint liquid limit

Casagrande (1958)[24] stated that the liquid limit (LL) determined from percussion-cup is affected by the properties of the device's base (the type of material, insulation from the supporting table, and its dimensions), the properties of the device's cup (vertical drop height, Material, weight, and dimensions), type of soil, and operator judgment. In particular, the device's base, has varied in various countries as shown by Casagrande [24]. He stated that the bases of different liquid limit apparatus (the United Kingdom and the United States) have significant differences in the hardness, the apparatus defined in ASTM has a relatively harder base than that defined in BS 1377 [10]. To investigate the effect of this matter, the liquid limit (LL) of the collected samples was determined by the procedure specified in ASTM D4318-00 using the two machines with bases as specified in ASTM and BS Standards, (see Fig. 2). It should be mentioned that, in all the cases, the same operator conducted the tests and the same part of the bench was used. In this way, the use of the machines on different benches and the variations due to operators can be eliminated.

Fig. 3 shows the results of the test. The values of the liquid limit of soil used in this paper ranged from (30.43) % to (59.87) % which indicated that the plasticity of the tested soils ranged from low to high. One could notice that with all the soils tested with the hard-base device, the value of liquid limit (LL) was 1 to 5% in terms of moisture content less than that obtained with the soft-base device (i.e. BS 1377 [10] device). This is compatible with the finding of Qzer [1]. This author stated that LL obtained by hard-base Casagrande device is down to 5% lower than these from soft-base device. However, one should expect that when the soft base device used the liquid limit values will be wetter, and weaker, than those from the hard base type.

Figure 2. Liquid limit devices, (a) hard base Casagrande device (Soil Test), (b) soft base Casagrande device (Wykeham Farrance), (c) BS cone penetrometer

Figure 3. Liquid limit from multi point method, ASTM and BS Casagrande device

3.2. Casagrande method –one point liquid limit

This method provides a quick means of determining LL of soil because only one water content measurement is required. It is widely used to obtain LL in geotechnical engineering laboratories in Iraq. In this method, the test is carried out as in multipoint LL test but the water content should be such that the number of blows for the closure of the groove is not less than 15 nor greater than 35 (according to BS standard), while in ASTM, the lower and upper limits for blows are 20 and 30 blows respectively (ASTM D4318-00 Method B [25]). In an investigation carried out by the US, "Waterways Experiment Station" on soils from lower Mississippi valley, it showed that if (W) is the liquid limit at (N) blows, then the liquid limit for 25 blows can be given by using the following expression:-

$$LL = W \left(\frac{N}{25} \right)^{0.121} \quad (1)$$

The formula of Waterways was developed to be applicable to the United Kingdom soils with fitting differ from that of Equation 1, Norman (1958) [6]. The formula used by BS is shown below:

$$LL = W \left(\frac{N}{25} \right)^{0.092} \quad (2)$$

Both Norman formula and Waterways were adopted as standards in determination of LL by one-point-method. ASTM used Waterways formula to determine the LL from a single the determination, while, BS standard adopted Norman formula as a one-point-method in the determination of the liquid limit. The flow lines slopes are different in BS and ASTM standards. In BS the slop is $\tan \beta = 0.092$, while in ASTM $\tan \beta$ is 0.121.

In order to investigate the effect of this factor on the values of the liquid limits of quaternary soils, a series of one-point limit liquid test was performed according to ASTM D4318-Method B [25]. The tests were conducted on the same samples used in the multipoint method using both the hard and the soft base devices. The effect of the base handiness on the LL values obtained from the one-point method is shown in Fig.4. It has appeared that the values of the one-point LL obtained from the soft-base device are greater than those obtained from the hard-base machine. On the other hand, Fig. 5 shows the effect of the flow lines slope ($\tan \beta$) on the one -point LL values obtained from both devices. It is shown, there are few differences obtained due to changing the flow line slop (0.092) to (0.121) for the same hardness value.

Figure 4. liquid limit from one point method, ASTM and BS Casagrande device

Figure 5. Effect of ($\tan \beta$) on the one point liquid limit values, (a) ASTM device, (b) BS device

3.3. Cone Penetrometer–multipoint method

Cone-penetrometer is another method to determine LL. This approach is considered more reliable in the determination of the LL limit than the Casagrande method. It was the preferred method in LL determination in many counties and, thus, it was used as a standard test method [26]. In this method, the penetration of cone (with specified weight and geometry) and the water content corresponding to it is measured [11].

The cone penetrometer was introduced by BS Institution (1975) [10] as the preferred method to determine the LL of soils [27]. In this standard, a cone of 80 g weight, 30° angle and 2 mm penetration has been adopted for the LL test as shown in Fig. 2. Nevertheless, in Iraq, both the cone penetrometer and Casagrande methods are used for the determination of the LL of soils. Skopek and Ter-Stepanian (1975)[28] and Littleton and Farmilo (1977) [22] stated that the values of LL determined from the cone penetrometer method are differed from those of Casgrandede method. In order to compare the differences, a series of cone-penetrometer test was carried out as described in BS 1377: (1975)[10]. The LL values obtained using the Casagrande-method (from the hard base and the soft base devices) and the fall-cone test are shown in Fig. 6 and Table 2. For both Casagrande Devices, the values of LL obtained with fall-cone are (2 to 8) % greater than those from the Casagrande method determined.

Table 2. Liquid limits from percussion method and cone penetrometer

Sample No.	LIHM	LLSM	LL cone
1	30.43	32.13	35.97
2	33.32	35.17	41.19
3	36.06	36.92	41.45
4	39.08	41.38	47.04
5	48.86	53.59	56.43

6	49.32	49.99	51.26
7	50.79	54.47	55.55
8	53.8	56.15	61.14
9	58.1	59.87	62.09

Figure 6. Liquid limits from cone and Casagrande devices (multi-point test).

3.4. Cone Penetrometer–one-point method

As stated by Head (2006)[29], the one-point cone-penetrometer method was suggested by Clayton and Jukes [27] as a less elaborate routine method of determining the LL of soils than the multipoint cone-penetrometer test. The device and material are the same that described in the standard procedure, but, a smaller soil quantity is required. Proper maturing and thorough mixing with water is just as important as in the standard test. The soil's water content should be adjusted so that a cone-penetration between (15 and 25) mm is obtained. Tables with factors are used to calibrate the obtained water content to obtain the LL of the soil. The factors of these tables are depended on the initial soil plasticity, low, medium or high plasticity. Clayton and Jukes (1978) [27] mentioned that the cone may reasonably be used in a one-point LL test, and this will provide a cheap and relatively accurate alternative to the Casagrande one-point method. The accuracy of this method was checked by calculating the values of liquid limit for the range of soils used in this study. The LL obtained using the Casagrande one-point method (from hard-base and soft-base devices) and the one-point fall cone test is shown in Fig. 7. The results indicated that the one-point-cone penetrometer gave a higher LL than one-point method with ASTM cup apparatus and BS Casagrande devices for all soils.

Figure 7. Liquid limits from cone and Casagrande devices (one-point tests)

3.5. Final Comparison of Methods

It can be concluded that the Casagrande hard-base device (American type) does not yield liquid limit values as those obtained by Casagrande soft-base device (British type) or obtained from BS cone-penetrometer. On the other hand, it is clear that LL determined from all these methods are susceptible to be in error as a result of variability

in devices adopted, and it is highly useful to correlate the LL obtained from American device with LL obtained from other devices. Based on least square principle, the results of LL from all the soil samples were compared statistically using linear-regression-analysis to determine the relationship between one method and another, (see Fig. 8. The coefficient of determination, R^2 , and regression line equations were computed for pairs of variables in turn. The resulting equations are presented below, while the coefficients of determination, R^2 , are given in Table 3.

$$LL_{HM} = 1.031 LL_{PM} - 7.361 \quad (3)$$

$$LL_{HM} = 1.006 LL_{PO} - 6.119 \quad (4)$$

$$LL_{HM} = 0.949 LL_{SM} + 0.176 \quad (5)$$

$$LL_{HM} = 0.947 LL_{SO} + 0.239 \quad (6)$$

$$LL_{HM} = 1.01 LL_{HO} - 0.272 \quad (7)$$

Despite the fact that the Coefficients of determination, R^2 , are significantly different, in some cases it is seen that there is a strong correlation between methods; the lowest R^2 is obtained for the Casagrande (hard-base device) multipoint method and cone-penetrometer (multipoint method). It is also to be noted that the regression-equations for all these tests are similar.

Table 3. Tensile coefficients of determination R^2

Test Method	R^2
Casagrande (Hard base) one point ($\tan \beta = 0.121$)	0.990
Casagrande (hard- base) multi point	0.953
Casagrande (soft) one point ($\tan \beta = 0.092$)	0.966
Casagrande (soft base) multipoint	0.985
Cone penetrometer (one point)	0.957
Cone penetrometer (multipoint)	0.957

Figure 8. Correlations between liquid limits, (a) Casagrande hard base and cone penetrometer, (b) Casagrande hard base and one-point cone penetrometer, (c) Casagrande hard and soft base devices, (d) Casagrande hard base device and one-point soft base device.

Comparing the overall difference in the LL results of each method of greater relevance. This can be assessed by taking the mean LL value of all results for each test and comparing these means. The mean values are shown in Table 4 and propose that the Casagrande-method (with soft-base device) overestimates the Casagrande method (with hard-base device) by approximately 5%, whereas, the cone- method overestimates the other methods by approximately (8 to 12) %. These results are in agreement with the results reviewed by Wasti [16] on fifteen natural soils from various locations in Turkey [1]. The differences in LL values are due to the mechanism of a test device used. In Casagrande-method, as opposed to cone-penetrometer method, it is assumed that the deformation of the groove sides is resisted by shearing-resistance of the soil, Investigators attributed the differences between the result of cone and Casagrande devices to the tendency of soil (of high LL) to exhibit low shear strength at the LL. The difference in LL values between the two devices is related to the behavior of clay under the different modes of deformation imposed by these devices. The soil in the cup-device imposed on a sudden shock loading as the cup impacts the base. The fall cone, however, imposed slow, relative to the cup, gradual static shear deformation over a five-second time period. The cone is an indirect strength test based on the resistance of the soil to the penetration of the cone.

Table 4. Mean of liquid limit values

Test Method				Mean of liquid limit results %
Casagrande method	Hard base device	Multipoint method		44.42
		One point method	$\tan \beta = 0.092$	44.21
			$\tan \beta = 0.121$	44.14
	Soft base device	Multi point method		46.63
		One point method	$\tan \beta = 0.092$	46.45
			$\tan \beta = 0.121$	46.47
	Cone method	Multipoint method		50.24
One point method		50.21		

On the other hand, Fig. 9 shows the values of LL from one-point and multi-point obtained from both all devices. It can be seen that, from the same devices, there is a little difference in the value of the LL of a soil that is determined by any method for the same device employed. Finally, one should be kept in mind that the index properties determined using the cone-penetrometer should not be expected to correspond precisely with index properties determined using other devices and procedures. Also, the same should be expected to index properties obtained from Casagrande methods with the soft base device and that of the hard type.

Figure 9. Liquid limit values from one-point and multi-point methods

3.6. Effect of method of test on the soil activity

Activity is the ratio of the plasticity index, PI, to the %finer than 0.002 mm [30]. To calculate the values of the activities of the soils used in this series of tests, the plastic limits and clay contents (particles less than 0.002 mm) were measured. Fig. 10 shows the variations in PI values resulting from the variance in LL values due to different methods of test. Examination to Fig. 10 reveals that, the maximum variance in PI is more than (8%) as a water content when the LL obtained from Casagrande hard-base and BS cone (one-point and multi-point method), while the effect of the difference in hardness of the base of the percussion cup on the PI is more than (4%). These variances in the values of PI causing an error in computing the activity of clay. The resulting error ranged from 3% to 15 % when the LL measured with the machine with the softer BS base, and from 19% to 42% when the LL measured with the BS cone apparatus. It can be concluded that, a small change in plasticity index could lead to an appreciable error in activity if the measurement were based on apparatus of the type used in this study

Figure 10. plasticity index from different liquid limit devices

3.7. Effect of method of test on soil classification

Casagrande (1932)[31] studied the relationship of the plasticity index (PI) to the liquid limit (LL) of different natural soils. According to his results, the plasticity chart was proposed as shown in Fig. 11. The plasticity chart provides information of great value uses to classify engineering fine-grained in standard classification systems like ASTM D2487 [32].

The LL and resulting PI for all soil tested in this paper are shown in Figure 11. The examination of this figure shows that the effect of the method of test on the classification of the soils is of most importance when the values of the LL of the tested soils fluctuated near 50%. For example, the soil sample, from Dewaniya tested with the American hard-base and the British soft type and BS cone found to have LL values equal to (48.86), (53.59), and (56.43) respectively. The PL of this sample is (21.21) and the content of material passing sieve No. 200 is

(97%). According to the "Unified Soil Classification System" this soil can be classified as follows:

Lean clay (CL) --- (LL from harder American base)

Fat clay (CH) --- (LL from softer British type and BS cone)

Soil index properties are used extensively by geotechnical engineers to discriminate between the different soil kinds within a broad category, e.g. clay will exhibit a wide range of engineering properties depending upon its composition. Classification tests to determine index properties will provide the geotechnical engineers with important information if the results are compared with empirical data with respect to the determined index properties. Thus, the effect of the variance presented in this paper on the classification of quaternary soil may present the misleading information that leads to different soil properties, and one should keep in mind that the behavior and properties of CL are different from those of CH. The difference between CL and CH behavior was stated by Head [29]. The permeability of CH soils is lower, they are more compressible, the time required to complete the consolidation in CH soils is higher. As for filling material, the compaction of CH soils is more difficult. The indications from LL and PL (from liquidity index) to the type clay in cohesive soils, the shear strength, and compressibility may widely be affected by the variance presented in this paper.

Figure 11. Plasticity chart.

4. Conclusions

The research reported in this paper was conducted to determine the extent of the proper variance caused by the procedure used in the LL test on quaternary soils. The following conclusions were found:

- There was a clear variance noted between the LL values determined from different methods. The Casagrande method (with hard-base device) underestimated the Casagrande method (with soft-base device) by approximately 5%, whereas, the cone-penetrometer method overestimated the other methods by approximately (8 – 12) % On the other hand, there was a strong correlation between the values of LL obtained according to ASTM D 4318-00 with those determined according to BS specifications.
- The variance noted was great enough to change LL values and move the classification of some samples from a CL to a CH and cause an error in computing the activity of soil.
- The index properties obtained from the Casagrande method with the hard-base device can differ significantly when compared with index properties determined using other types. The indications from LL to the type clay in cohesive soils, the shear strength, and compressibility may widely be affected by the variance presented in this paper.

Nomenclature

Y: The length of the specimen in vertical direction

Ip: plasticity index

LL: liquid limit

LL_{HMC}: liquid limit (Casagrande (Hard base) multipoint)

LL_{HO}: liquid limit (Casagrande (Hard base) one point)

LL_{PMC}: liquid limit Cone penerometer multipoint point))

LL_{PO}: liquid limit (Cone penerometer (one point))

LL_{SM}: liquid limit (Casagrande (soft base) multipoint)

LL_{SO}: liquid limit (Casagrande (soft base) one point)

PL: plastic limit

N: Number of blow

tan β : slope of the flow lines

W: water content

Declaration of Conflict of Interests

The author declares that there is no conflict of interest.

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