Validity Assessment of Cone Penetrometer To Estimate Liquid Limit and Optimum Moisture Content in Soil Compaction

Ravindu Weerasinghe
Department of Civil Engineering
General Sir John Kotelawala
Defense University
Rathmalana, Sri Lanka
ravindushashipriya5@gmail.com

Sehan Seneviratne
Department of Civil Engineering
General Sir John Kotelawala
Defense University
Rathmalana, Sri Lanka
hansajasehan@gmail.com

Thushara A. Madanayaka
Department of Civil Engineering
General Sir John Kotelawala
Defense University
Rathmalana, Sri Lanka
madanayaketa@kdu.ac.lk

***Abstract*—This research article presents a comprehensive study aimed at validating the Cone Penetrometer Method as an alternative to the traditional Casagrande Method for liquid limit determination in geotechnical engineering. The main objective of this study was to assess the accuracy and reliability of the Cone Penetrometer Method and establish a relationship for estimating optimum moisture content using the Cone penetrometer method. A series of laboratory tests were conducted on a range of soil samples, with comparisons drawn between liquid limit results obtained using the above two methods. Accordingly, an equation for Optimum Moisture Content was derived using Liquid limit values of cone penetrometer method.**

Keywords—Liquid limit, casagrande, cone penetrometer, optimum moisture content

I. INTRODUCTION

The determination of liquid limit and optimum moisture content is of paramount importance in geotechnical engineering and construction practices. Evaluation of liquid limit is based on two methods: cone penetrometer and Casagrande method. Casagrande method is the typical and widely used method for measuring Liquid limit; however, there are several limitations in the Casagrande method has several drawbacks, including high operator dependence, the need to predict the amount of groove closure, the difficulty of cutting a perfect groove, a slow pace of operation, a low degree of repeatability, and so on ([1, 2, 4, 5, and 6]). In addition, there is a noted difficulty of adopting Casagrande method to estimate the liquid limit in low plasticity soil due to the fall of the soil particles towards the groove ([7]). Considering all the above, liquid limit estimation using cone penetrometer appears to be an alternative option. However, several researchers ([9], [3], [8]) have pointed out that the liquid limit values found by the cone penetrometer method (LL_{CONE}) and the liquid limit values found by Casagrande method (LL_{CAS}) are not comparable to a good level of accuracy. Therefore, as the first part of this study, the validity assessment of liquid limit estimation using cone penetrometer test has been carried out.

Furthermore, it has been understood that liquid limit may relate to some soil properties applied in civil engineering. Optimum moisture Content (OMC) in soil compaction is one of the most applied soil parameters in construction industry; however, determination of optimum moisture content for soil compaction requires significant effort, time and soil material. Therefore, as the second part of this study an effort has been made to develop a possible relationship between optimum moisture content and liquid limit values estimated from cone penetrometer method as a simple and fast way of determining optimum moisture content for a preliminary level of analysis.

II. VALIDITY ASSESSMENT OF CONE PENETROMETER METHOD AND CASAGRANDE METHOD FOR LIQUID LIMIT DETERMINATION

A. Experimental Procedure

First, in accordance with ASTM guidelines, the suitability of the cone penetrometer for the determination of liquid limit was evaluated using five soil samples that were collected in different locations in and around Colombo in the Western province of Sri Lanka.

All soils samples were categorized using the Unified Soil Classification System (USCS) before the start of the experiments. The liquid limit of each soil sample was then determined using the Casagrande apparatus method, which is described below. After each soil had been sieved using a 0.425 mm (No. 40) sieve, the sample was first mixed with the necessary volume of water and a spatula was used to transfer a portion of the moist soil sample into a metal cup. As seen in Figure 1, the groove opening was subsequently created in the Casagrande method in accordance with ASTM D4318 using a particular grooving tool. In here tests of groove closure were conducted at various blow counts. Water content samples were taken from the precise position of the closure after each groove closure event, and they were then put in containers to be measured for moisture content. After that, the containers with relevant specimens were weighed and put inside an oven. Those specimens were taken out of the oven and precisely weighed after 24 hours. After calculating the moisture content of each specimen, the results were plotted against the total number of blows. Based on the graph, the water content that corresponds to 25 blows is the specimen's liquid limit.

Fig. 1. Determination of liquid limit using Casagrande method

As per the ASTM 3441-16 cone penetrometer method, the apparatus for determining the liquid limit consists of a 35 mm long, 30°stainless steel cone penetrometer and a sliding shaft with a combined mass of 80 g. The soil being tested is combined with water to make a thick, homogeneous paste, which is then let to stand for a complete day. Next, a portion of this paste is poured into a cylindrical metal cup that has been smoothed at the rim and measures 55 mm in internal diameter by 40 mm in depth.

With the cone securely held in its support, the cone is carefully lowered until it lightly touches the surface of the soil in the cup. The cone is then released and allowed to penetrate the soil for 5 seconds before being tested for depth of penetration (Fig. 2). The test is repeated until a consistent penetration value is attained, which is when the average of two values is within 0.5 mm of each other or three values are within 1.0 mm of each other. This entire process is repeated at least four times with the same soil sample while slowly increasing the water content, ensuring that penetration values fall within a 15 mm to 25mm range.

The recorded cone penetrometer values are plotted against the corresponding water content, and a straight line is drawn to best fit the data points. The liquid limit is determined as the water content at which the cone penetrates to a depth of 20 mm. The recorded cone penetrometer values are plotted against corresponding Casagrande values. Then a straight line is drawn to fit data points.

Fig. 2. Determination of liquid limit using cone penetrometer method

B. *Data Analysis*

Soil classification

Fig. 3 shows Particle size distribution (PSD) curves of five soil samples. Using PSD curves, 10% of passing (D10), 30% of passing (D30) and 60% of passing (D60) of each soil were determined and then coefficient of uniformity (Cu) and Coefficient of Curvature (Cc) were calculated using equations 1 and 2 listed below.

$$C_u = \frac{D_{60}}{D_{10}} \quad (1)$$

$$C_c = \frac{(D_{30})^2}{D_{60} * D_{10}} \quad (2)$$

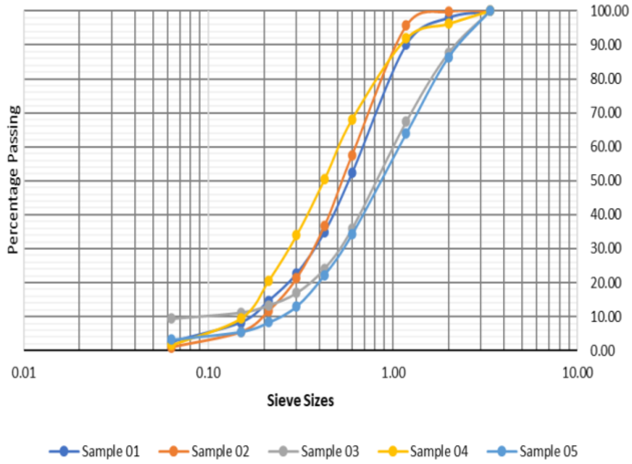

Figure 3: Particle size distribution of samples

As per the Unified Soil Classification System (USCS) all five samples are classified, and the results are shown in Tab. 1. Accordingly, all five samples are classified as poorly graded sands (SP).

TABLE 1. IMPORTANT VALUES OF SOIL CLASSIFICATION OF SAMPLES

	Sample 01	Sample 02	Sample 03	Sample 04	Sample 05
D10	0.18	0.2	0.078	0.16	0.26
D30	0.38	0.38	0.51	0.28	0.51
D60	0.7	0.61	1.02	0.51	1.02
Cu	3.8	3.05	13.07	3.18	3.92
Cc	1.14	1.18	3.27	0.96	0.98
Soil Type	SP	SP	SP-SC	SP	SP

Liquid limit analysis

The estimated liquid limit values for five samples using Casagrande method (LL_{CAS}) and cone penetrometer (LL_{CONE}) method are shown in Tab. 2.

Fig. 4 shows the comparison of liquid limit values estimated from both methods.

TABLE 2. LIQUID LIMIT VALUES FOR SOIL SAMPLES

Sample	Soil type	LL_{CAS}	LL_{CONE}
01	SP	19	21
02	SP	12	13
03	SP-SC	28	29

04	SP	17	19
05	SP	31	32

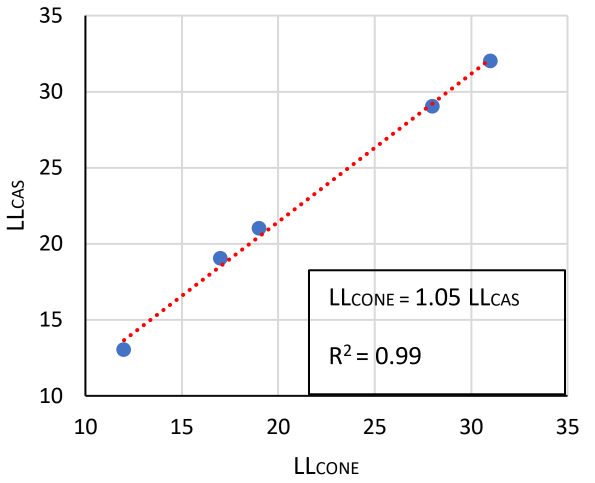

Fig. 4. Correlation of liquid limit values of cone penetrometer method and casagrande method

From Tab. 2, it is observed that LL estimated using cone penetrometer is slightly higher compared to the values taken from Csasagrande method. However, the variation range remains within 3–12 % limiting to the average deviation about to 5%. Therefore, it can be concluded that LL estimated from Cone penetrometer is also comparable to the values from Casagrande method to reasonable degree of accuracy.

Also in this study, equation 3 is proposed relating LL_{CAS} and LL_{CONE} as per the graph shown in Figure 4. Here, the relevant $R^2 = 0.99$ confirms the best matching of LL_{CAS} and LL_{CONE}.

$$LL_{CONE} = 1.05\, LL_{CAS} \qquad (3)$$

III. Simplified Method for Estimating Optimum Moisture Content of Soil Compaction

A. Experimental Procedure

The optimum moisture content for soil compaction was determined using the same five samples that were previously discussed. Optimum moisture content and the highest dry density that can be attained with a certain compaction effort are the key findings of the standard Proctor compaction test. During the procedure, the link between the soil's density and moisture content will be discovered. The compaction effort measured in the field and the one intended for this lab test are similar.

As per ASTM D1557, 2.5kg rammer is dropped from 300mm to compact soil in the mould. Compaction was proceeded for three layers. The maximum dry density and their related optimum moisture content were found by mixing soil with various water contents to reach the desired dry density. The study aimed to investigate potential relationship between five soil types by plotting the predicted optimum moisture content values against relevant liquid limit values obtained using the cone penetrometer.

In this study, optimum moisture content values estimated for five soils were plotted against relevant liquid limit values obtained from cone penetrometer method for developing a possible relationship between them.

B. Data Analysis

Fig. 5 shows the proctor compaction curve developed for all five cases and from which optimum moisture content values for each case were determined.

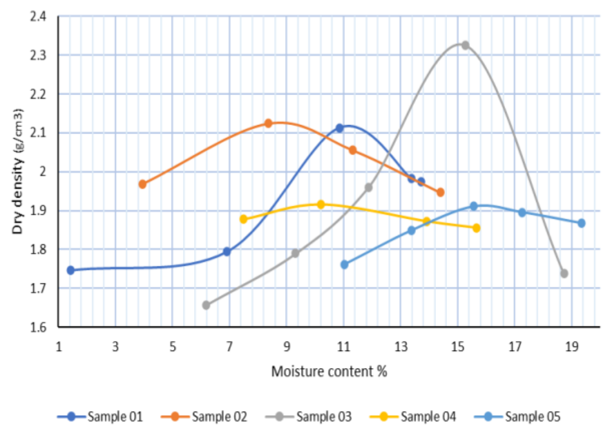

Fig. 5. Proctor curves of samples

The derived optimum moisture content values of five samples and corresponding liquid limit values obtained from cone penetrometer method are shown in Tab. 3.

TABLE 3. OPTIMUM MOISTURE CONTENT AND LIQUID LIMIT VALUES OF SAMPLES

SAMPLE	LL_{CONE}	OMC
01	21	11
02	13	09
04	19	10
05	32	16

The comparison of optimum moisture content values and corresponding liquid limit values are plotted in Fig. 6.

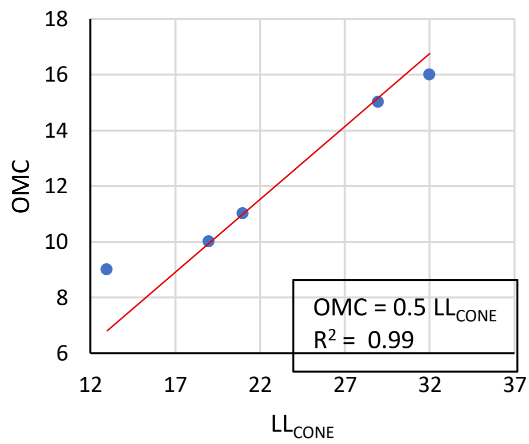

Fig. 6: Correlation between LL_{CONE} and OMC

As shown in Fig. 6, it is clearly shown that OMC relates well with the LL $_{CONE}$ to a good level of accuracy being the R^2 = 0.99. Equation 4. below shows the developed relationship from which OMC can be estimated just using the LL $_{CONE.}$

$$\boldsymbol{OMC = 0.5\, LL_{CONE}} \qquad (4)$$

IV. CONCLUSION

Based on performed experimental laboratory testing, the following conclusions can be finalized.

When the results were examined in relation to liquid limit estimation from Casagrande technique and cone penetrometer technique, it can be concluded that both methods provide approximate values reporting the variation range between limiting to the average variation only to 5%. Also, findings indicated that, overall, the Casagrande technique consistently yielded lower values compared to the cone penetrometer method. Additionally, a correlation between LL_{CAS} and LL_{CONE} has been introduced, as shown in equation 3. relating LL $_{CONE}$ and LL $_{CAS}$.

Even though previous researchers have pointed that LL_{CAS} and LL_{CONE} are not comparable, in this study we can conclude that LL_{CAS} and LL_{CONE} are comparable to good level of accuracy. As discussed above, the average variation limiting only to a 5% The authors believe that this degree of precision aligns with practical application in geotechnical engineering applications. Hence, the cone penetrometer emerges as a viable alternative for promptly, easily, and efficiently determining liquid limit with a reasonable level of accuracy.

In comparison with the Casagrande method, cone penetrometer method is easier, quicker, and simpler to perform.

Based on the data depicted in Figure 6, a correlation exists between LL_{CONE} and OMC. Consequently, it is feasible to derive a straightforward formula for estimating OMC based on LL_{cone} data for soil samples as shown in equation 4. Simply, it can be concluded that OMC is only a half of the liquid limit estimated from the cone penetrometer test. Further, in the case of unavailability of experimental data for LL $_{CAS}$, the authors suggest using equation 3 to estimate LL $_{CONE}$ using the LL $_{CAS}$ and then apply equation 4 to find out OMC.

In summary, from the proposed solutions above, optimum moisture content value can be determined just using liquid limit value obtained either Casagrande or cone penetrometer method without conducting standard Proctor compaction test. This facilitate much of the money, time, effort and material savings and is much useful for finding preliminary level approximation value of OMC very quickly.

However, in this study, all tested five samples are poorly graded sands and therefore, the direct applicability of proposed solutions is limiting to the same soil type (poorly graded sands). But authors suggest that the same procedure can be carried out to other soil types and there is possibility of generating similar relationship to estimate OMC using liquid limit values to a good level of accuracy.

FUTURE RECOMMENDATIONS

The similar relations can be developed furthermore to other soil types using the same procedure outlined above enabling a faster way of estimation OMC for any soil type just using liquid limit values.

REFERENCES

[1] Sowers, G., Vesić, A., & Grandolfi, M. (1960). Penetration tests for liquid limit. Paper presented at the Papers on Soils 1959 Meetings.

[2] Sherwood, P., & Ryley, M. (1970). An investigation of a cone-penetrometer method for the determination of the liquid limit. Géotechnique, 20(2), 203-208.

[3] Sivapullaiah, P. V., & Sridharan, A. (1985). Liquid limit of soil mixtures. Geotechnical Testing Journal, 8(3), 111-116.

[4] Hanks, A. (1981). Measurement of the liquid limit of soils using the cone penetration method: The Office.

[5] Medhat, F., & Whyte, I. (1986). An appraisal of soil index tests. Geological Society, London, Engineering Geology Special Publications, 2(1), 317-323.

[6] Leroueil, S., & Le Bihan, J.-P. (1996). Liquid limits and fall cones. Canadian Geotechnical Journal, 33(5), 793-798.

[7] Mishra, A. K., Ohtsubo, M., Li, L., & Higashi, T. (2011). Controlling factors of the swelling of various bentonites and their correlations with the hydraulic conductivity of soil-bentonite mixtures. Applied Clay Science, 52(1-2), 78-84.

[8] Wasti, Y., & Bezirci, M. (1986). Determination of the consistency limits of soils by the fall cone test. Canadian Geotechnical Journal, 23(2), 241-246.

[9] Budhu, M. (1985). The effect of clay content on liquid limit from a fall cone and the British cup device. Geotechnical Testing Journal, 8(2), 91-95.

[10] Hrubesova, E., Lunackova, B., & Brodzki, O. (2016). Comparison of Liquid Limit of Soils Resulted from Casagrande Test and Modified Cone Penetrometer Methodology. In Proceedings of the Sustainable Development of Civil, Urban and Transportation Engineering Conference. Publisher: VŠB-Technical University of Ostrava, Faculty of Civil Engineering