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A Proposed Approach for Plastic Limit Determination Using the Drop-Cone Penetrometer Device

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Abstract

The drop-cone method, in which a 30° cone of mass 80 g is allowed to penetrate into a soil sample at any moisture contents, was used to determine the plastic limit for more than 160 natural samples representing a wide range of soil type with different values of liquid limit ranging from 25 to 75%.

Using the drop-cone penetrometer device, the moisture content corresponding at any penetration value is sufficient to generate the empirical formula to determine the plastic limit. The calculated values, from formula or chart, were close to the exact, tested, values. Hence, it is suggested to redefine the plastic limit as, the difference between the moisture content corresponding to the penetration of the drop-cone of 20 mm and that corresponding to any penetration divided by plastic factor corresponding to that penetration in which the product then subtracted from the liquid limit.

The plastic factor can be determined from plastic factor-penetration curve. The advantages of such new method is that the test is more closely related to soil behaviour, less subjective, at least as reproducible as the Casagrande test and may be carried out simultaneously with the liquid limit test.

الخلاصـــــة

إن أستخدام طريقة المخروط الساقط (والذي هو عبارة عن مخروط مائل بزاوية ٣٠ درجة يسقط سقوطا حرا بوزن ٨٠ غم على نموذج التربة) لاستخراج قيمة حد اللدونة تم بحثها في هذه الدراسة على ١٦٠ نموذج طبيعي ممثلة تشكيلة منوعة من الترب المختلفة بقيم حدود سيولة يتراوح من ٢٥ الى ٧٥%.

إن قيم المحتوى الرطوبي المقابل لقيم الاختراق بأستخدام جهاز المخروط تم صياغتها بشكل معادلات رياضية تجريبية لاستخراج قيم حد اللدونة حيث بينت النتائج تقارب واضح بين القيم الحقيقية (المفحوصة بالطريقة القياسية العادية) وبين القيم المحسوبة بأستخدام (المعادلات الرياضية او المنحنيات المرسومة).

يمكن تعريف حد اللدونة المحسوب بطريقة المخروط الساقط بأنه الفرق ما بين المحتوى الرطوبي المقابل لاختراق ٢٠ ملم في المخروط والمحتوى الرطوبي المقابل لاي اختراق يتم قياسه مقسوما على معامل اللدونة المقابل لهذا الاختراق والمستخرج من المعادلات المحسوبة او المنحنيات حيث يطرح الناتج من قيمة حد السيولة. إن فائدة استخدام هذه الطريقة الجديدة تتمثل في سهولة وبساطة استعمالها من جهة و إمكانية استخراج قيمة حد اللدونة بشكل ضمني (أني) أثناء استخراج قيمة حد السيولة من جهة اخرى.

1. The Atterberg Limits Concepts

Early interest in the various modes by which a fine soil interact with moisture content let to the development of the soil consistency concept. Largely through the work of Atterberg and

Casagrande, the Atterberg limits and related indices have become characteristics of assemblages of soil particles. The Atterberg limits have been correlated with properties such as swelling, shrinkage, compressibility, permeability and shear strength [1].

Actually, the plastic limit is an important property of fine-grained soils. The standard thread-rolling method for determining the plastic limit has long been criticized for requiring considerable judgments from the operator. This paper is aimed at developing a new simple method using the drop-cone method to predict the plastic limit with less human error and can be carried out simultaneously with the liquid limit test.

1-1 Shrinkage Limit

The shrinkage limit which is the lowest water content at which the sample can remain in a saturated state has been an important parameter in the identification of structural state of clay-water-electrolyte systems. Kingery and Fracl [2], conducted experiments with solutions of different surface tensions, obtained by the addition of different surface active material to water. Their results have shown that the amount of shrinkage from any given water content decreases linearly with decreasing surface tension. De Jong and Warkentine [3] studied the influence of texture on shrinkage. Though surface tension has been believed to be the cause of shrinkage, after theoretical and experimental studies of Sridharan and Venkatappa Rao [4], have shown that shrinkage limit is governed by the contact stress at particle contact and (or) between particles, as defined by the modified effective stress concept.

Methods of shrinkage limit determination are detailed elsewhere.

1-2 Liquid Limit

The liquid limit of the clays is regarded as the water content at which sufficient free water is present to allow clay particles to slip one another under certain applied force and then retain these new positions [5].

Earlier studies on the liquid limit behavior shows many correlations with many engineering properties. The liquid limit of kaolinite has been considered from the mechanistic point of view. Casagrande [6] deduced that the liquid limit corresponded approximately to the water content at which a soil has shear strength of about 0.025 kg/cm^2, while Norman [7] reported strength of the order of 0.02 kg/cm^2 at the liquid limit. The pore water tension at the liquid limit is about 0.004 kg/cm^2 [8]. For the effective stress corresponding to this negative pore pressure and an angle of friction of 30^o, the shear strength due to internal friction was computed by Seed et. al. [9] to be approximately 0.0025 kg/cm^2. It was concluded that the net interparticle attractive forces must account for the greatest proportion of strength at liquid limit. The net attractive forces between clay particles are in turn related to the surface activity of the clay component. The greater the surface area, the greater the attractive intensity and the higher the liquid limit.

Sridharan et. al. [1] studied the liquid limit of kaolinitic soils. They found that there is no correlation between liquid limit of these soils and their percentage clay size, exchangeable caution content, and diffuse double layer thickness. However, an increase in liquid limit was accompanied by an increase in shrinkage limit and sedimentation volume.

Liquid limit can be determined using the drop-cone penetrometer device, where the cone is permitted to fall freely for a period of 5 seconds. The water content corresponding to a cone penetration of 20 mm defines the liquid limit. The sample preparation is similar to the cup method except that the sample container in the fall cone test has a different shape and size as shown in **Fig.(1)**.

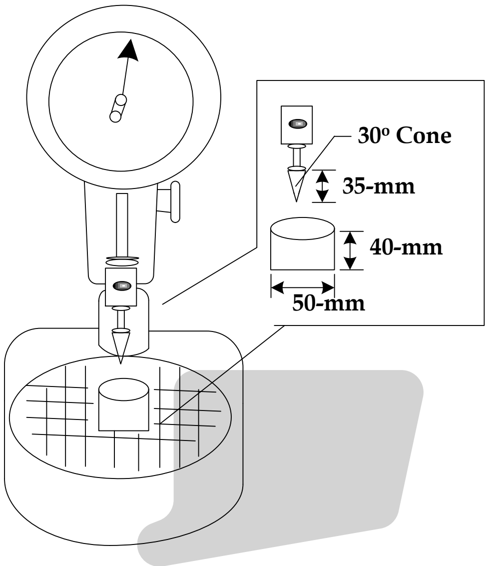

Figure (1) Drop-cone Penetrometer device

Four or more tests at different water contents are also required because of the difficulty of achieving the liquid limit from a single test. The results are plotted as water content versus penetration and the best fit straight line linking the data points is drawn. The liquid limit is read from the plot as the water content on the liquid state line corresponding to a penetration of 20 mm. However, a one point method may also be adopted to determine the liquid limit value and can be found in details elsewhere.

1-3 Plastic Limit

The physical mechanism for plastic limit is much less understood than liquid limit. According to Young and Warkentin [10] the plastic limit is a measure of cohesion of the soil particles to cracking when the sample is worked. The cohesion between particles or units of particles must be sufficiently low to allow movement between particles to slide past each other and yet sufficiently high to allow the particles to maintain the new mould position. In other words it may be stated that plastic limit is a measure of the water content of the soil when it approaches a particular shearing resistance and it is the amount of water which must be added to a soil in order to wet all the surfaces and to fill the small pores. At this water content, the particles will slide past one another on application of force, but there is still sufficient cohesion to allow them to retain shape.

Obviously, the plastic limit represents the moisture content at which the skeleton changes from the fabric to the plastic consistency. It represents the minimum moisture percentage at which the soil can be puddle. As mentioned, orientation of particles and their subsequent sliding over each other take place at this point, since sufficient water has been added to provide a film around each particle; or there is sufficient water to satisfy the requirements for the development of the highly rigid adsorbed layers plus a slight excess for lubricating purposes. The moisture content of this limit depends upon the amount and nature of the colloidal material present.

In fact, the standard thread-rolling method is used to determine the plastic limit value which has long been criticized for requiring considerable judgments from the operator. This research explores the possibilities of performing a new simple method using the drop-cone penetrometer device for the plastic limit determination with less human error and can be carried out simultaneously with the ordinary liquid limit test using the drop-cone penetrometer device.

2. Factors Affecting the Atterberg Limits

Baver et. al. [11] summarized the factors affecting the Atterberg limits values as:

- **Clay Content:** as known plasticity is a characteristic of the fine soils. Atterberg, 1911, 1912 (cited by Baver et. al., 1984), showed that an increase in the percentage of clay causes plastic limits to be higher on the moisture scale and increase in plasticity index. On the other hand, it is conducted from the previous studies that the effect of decreasing clay content is the rapid lowering of the liquid limit and the consequent decrease in the plasticity index. Skempton (cited by Baver et. al., 1984), showed that the plasticity index was related to the percentage of less than 2-μm clay in different clay systems.
- **Nature of Clay Mineral:** Atterberg, 1911, 1912, in his original investigation on plasticity showed that only those minerals that have a platy or sheet like structure exhibit plasticity. Quartz and feldspar, whose crystals are made up of, linked tetrahedral, are non-plastic. In contrast, kaolinite, talc, montmorillonite, biotite and others whose crystal lattices are built up in sheets are plastic. These differences are attributed to a greater surface and increased contact in the case of plate-shaped particles. Also, the type of clay mineral has a tremendous influence upon the adsorption of water by the colloidal system.
- **Nature of exchangeable Cations:** Baver, 1928 (cited by Baver et. al., 1984), stated that the exchangeable cations have considerable influence upon soil plasticity.

1. Na-Saturated soils exhibit the lowest plastic limit and the highest plasticity index.
2. K-saturated soils show the lowest plasticity index and the lowest liquid limit.
3. Ca-saturated soils show plastic and liquid limit generally higher than those of K and Na-systems.

4. Mg-saturated soils also show plastic and liquid limit generally higher than those of K and Na-systems and they have slightly higher plasticity indexes than those saturated with Ca.
5. H-saturated soils fluctuate considerably.

- **Organic Mater Content:** presence of the organic matter would lower of the plasticity limits on the moisture scale, without a really significant effect upon the plasticity index. Oxidation of the organic matter with hydrogen peroxide causes a lowering of liquid and plastic limits.

3. Experimental Work

3-1 Materials

Representative soils recovered from a depth 1.0- 8.0 m below ground surface and from various locations (mainly in southern of Iraq) were used in this work. The soils used represent various clayey soil types (CL, CH, ML and MH) in accordance with the USCS. The soil specimens were air-dried and ball milled to pass through a 425 μm. More than 160 specimens were prepared for this purpose. Ordinary liquid limit tests are performed using the drop-cone penetrometer device, and the standard thread-rolling method is used to determine the plastic limit.

Therefore, In order to eliminate the human errors that may occur in such tests one professional operator has done all these tests. The procedure described by Head [12] was adopted for the experimental work carried out in this study.

4. Results of Tests

Figure (2) shows the water content of samples tested for liquid limit prediction using the cone-drop penetration method as a function of their penetration. No systematic variation emerges in any group (i.e. LL < 35%, LL 35-50% or LL > 50%). However, as it well-known, for one sample such relations showing linear variation of water content with penetration. This may be attributed to the identity of effecting factors influencing the Atterberg limits when we test the same sample. On the other hand the natural soils which have been subjected to physical and chemical weathering and other depositional processes, have a wide range of physico-chemical and mechanical properties. Consequently, natural soils do not only represent an assemblage of solid system, the properties of which depend on the composite effects of several interacting and interrelated factors.

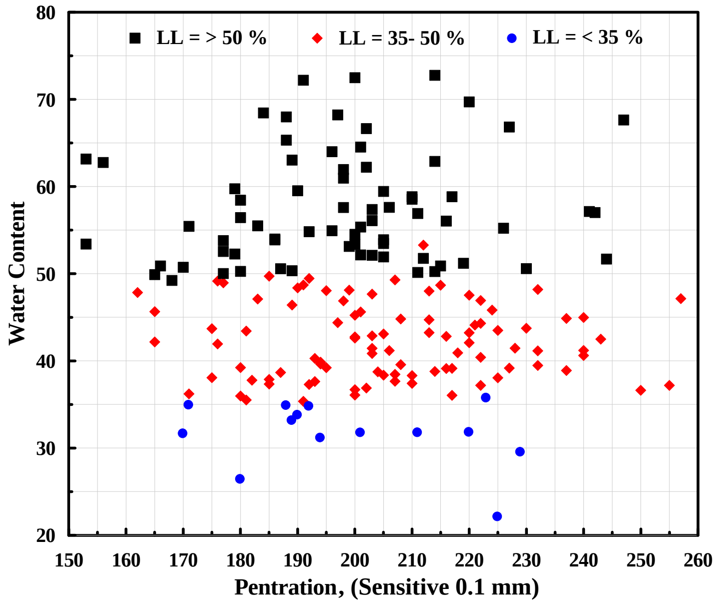

Figure (2) Plots of water content of samples of different values of liquid limit as a function of their penetration using cone-drop method

Figure (3) shows the relationship between the plastic factor and penetration. The plastic factor can be defined as the difference between the moisture content corresponding to the penetration of the drop-cone of 20 mm (i.e. liquid limit) and the water content for any penetration divided by plasticity index as given in equation (1). The numerator should be taken always as a positive value, since; when the penetration exceeds 20 mm the water content is grater than liquid limit value.

$$P_f = \frac{|LL - wc|}{PI} \qquad \text{.......... (1)}$$

where:

P_f: Plastic Factor.

LL: Liquid limit value (Using the Cone-Drop method, i.e. water content corresponding to 20 mm cone penetration).

Wc: Water content corresponding to any penetration.

PI: Plasticity Index value (LL – PL).

Figure (3) can be presented using empirical equations to give a relation between the plastic factor and penetration. However, the value of plastic factor can be defined using set of three equations depending on soil plasticity to be low, moderate or high. It can be seen that the plastic limit may be predicted value simultaneously with liquid limit determination using the Drop-Cone method, where, the plastic factor can be formulated as shown in **Table (1)**, where P is the penetration.

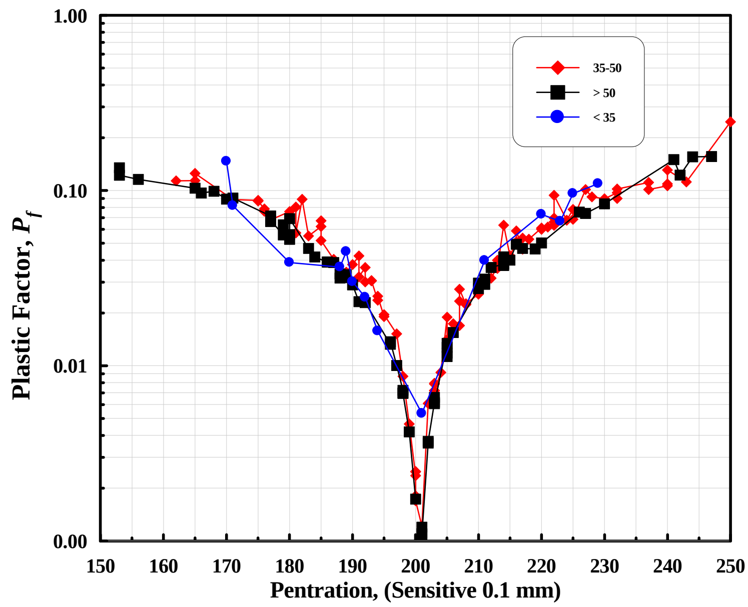

Figure (3) Plots of plastic factor as a function of penetration using drop-cone method

Table (1) Plastic factor equation corresponding to liquid limit value and penetration

	Penetration (0.1 mm)	Equation	Correction Factor R
Soil of Low Plasticity LL < 35 %	< 200	$P_f = -0.0489802 \ln(P) + 0.259569$	0.974922
	> 200	$P_f = 0.76557 \ln(P) - 4.05707$	0.95237
Soil of Moderate Plasticity LL = 35 – 50 %	< 200	$P_f = -0.580719 \ln(P) + 3.08374$	0.948379
	> 200	$P_f = 0.646245 \ln(P) - 3.42452$	0.955632
Soil of High Plasticity LL > 50 %	< 200	$P_f = -0.491875 \ln(P) + 2.61027$	0.981389
	> 200	$P_f = 0.733705 \ln(P) - 3.89492$	0.972702

Hence, the plastic limit value can be calculated as:

$$\mathbf{PL = LL - \left(\frac{LL - wc}{P_f}\right)} \quad \text{.......... (2)}$$

The penetration values that used in the equations of **Table (1)** are in (mm $\times 10$) [i.e. 20 mm = P value of 200 , 15 mm = P value of 150].

Figures (4), **(5)**, and **(6)** show the plots of tested versus predicted values of plastic factor using the equations presented in **Table (1)**. It can be seen that there is a close agreement between the calculated and predicted plastic factor. However, large number of soil used for tests with different random effects of factors affecting Atterberg limits may lead to some scatters. Generally, such expected error is routinely overcame since two or three attempts are required to determine the liquid limit value and the results of these attempts can be employed simultaneously to find the plastic limit value. The harmonic average from these attempts is used as a final plastic limit value.

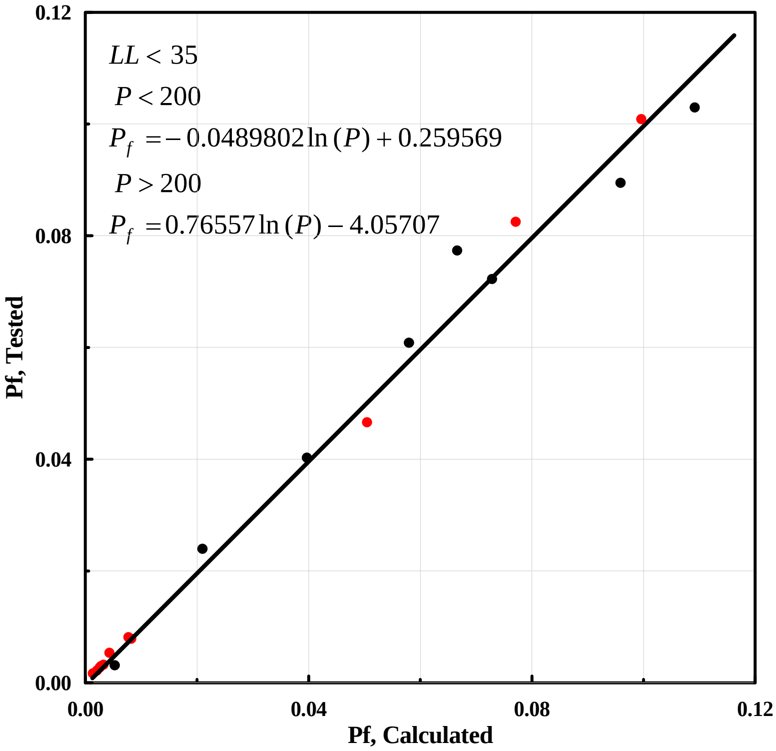

Figure (4) Plots of tested value of plastic factor versus the predicted value using the equations presented for soils of low plasticity (LL<35%)

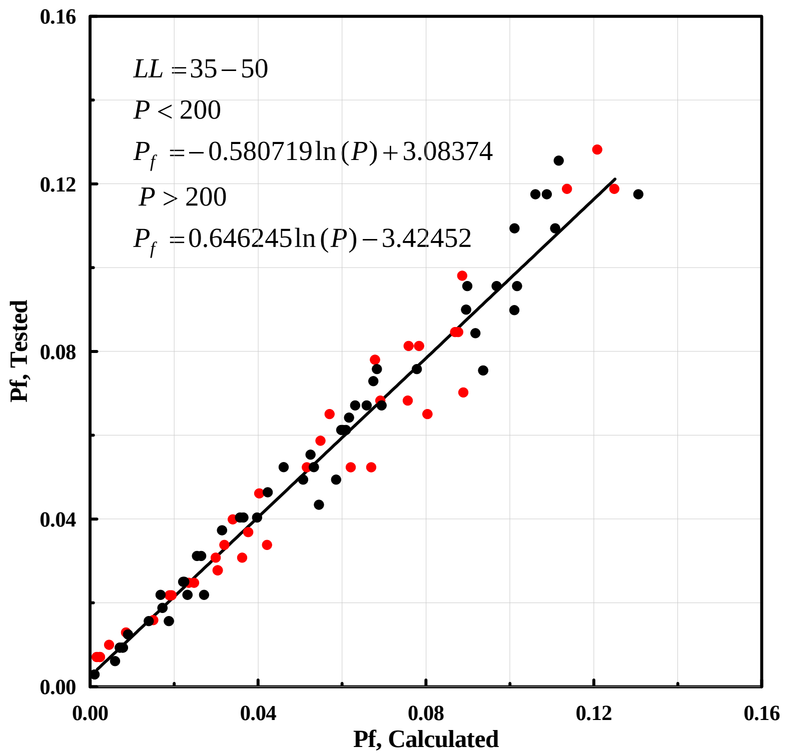

Figure (5) Plots of tested value of plastic factor versus the predicted value using the equations presented for soil of moderate plasticity (LL=35-50%)

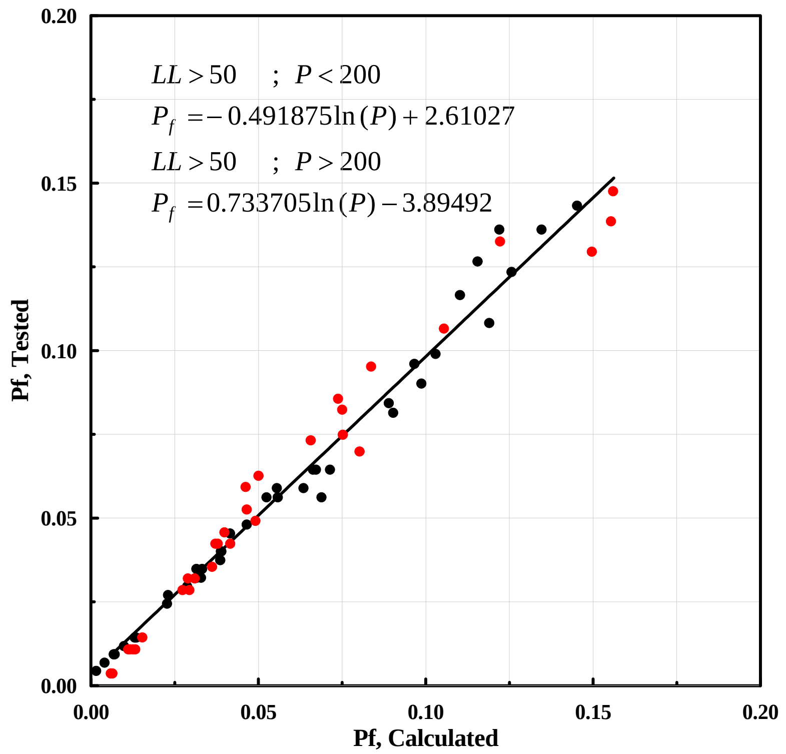

Figure (6) Plots of tested value of plastic factor versus the predicted value using the equations presented for soil of high plasticity (LL > 50%)

5. Conclusions

The use of Drop-Cone method in predicting the plastic limit value simultaneously with liquid limit value has been investigated in this study and the following conclusions may be drawn:

1. The penetration of cone has no correlation with the water content when using large number of samples representing different natural soils having a wide range of physico-chemical and mechanical properties.
2. The penetration of cone can be correlated with the plastic factor (the difference between the liquid limit and the water content at any penetration divided by plasticity index) to give a homologous frond shape around penetration of 20 mm.
3. Using the Drop-Cone method for plastic limit determination, emerges a new formula for determining the plastic limit which is given in this paper and according to which the plastic limit is a function of liquid limit and the plastic factor, P_f.
4. In order to predict the plastic limit value the plastic factor must be calculated which is a function of liquid limit and the penetration of the drop-cone corresponding to specific water content. This can be done simultaneously when trying to determine the liquid limit value and the harmonic average from at least three or four attempts is used as a final plastic limit value.

6. References

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