DETERMINATION OF PLASTIC LIMIT USING CONE PENETROMETER

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ABSTRACT
The plastic limit is the minimum water content at which soil starts to show plastic behaviour. Any fine grained soil having natural water content close to its plastic limit is expected to have high shear strength and low compressibility. The standard thread-rolling method for determining the plastic limit has long been criticized for requiring considerable judgments from the operator. Cone penetrometer is usually used for determining the liquid limit of a soil. In this study, effort has been given towards using Cone Penetrometer to determine the plastic limit in a way to overcome the inconsistent results. Two approaches have been suggested. Firstly, tests have been done on soils of eight locations to find a specific penetration value using standard Cone Penetrometer whose corresponding water content in the penetration vs water content curve can be marked as the plastic limit of that soil. Secondly, a modified load is used in Cone Penetrometer to determine Plastic Limit. The advantages of such new procedure is that the test is more closely related to soil behaviour, less subjective, at least as reproducible as the Casagrande test and can be carried out in the same manner as determining liquid limit.

Keywords: Plastic limit; cone penetrometer; penetration value

INTRODUCTION
Plastic limit is defined as the moisture content at which the soil crumbles when rolled into threads of 3.2 mm (about 1/8 inch) in diameter by hand on a ground glass plate. However, there are several criticisms on this test since the operator is required to judge the state of crumbling and the 3-mm diameter of the thread. If full saturation and incompressibility are assumed, plasticity theory indicates that the soil yield stress will be a function of a number of parameters such as-

(1) The pressure applied to the soil thread,
(2) The geometry, i.e. the contact area between hand and thread,
(3) The friction between the soil, hand and base plate,
(4) The rate of rolling etc.

None of these variables is controlled easily and consequently the traditional plastic limit test does not provide a direct measurement of soil strength. For this reason our research was done. There are many advantages of this work. Some are mentioned below:

(1) It is not dependent on user's sensitivity,
(2) Can be done simultaneously with liquid limit test,
(3) Since the result is obtained by interpolating from water content vs penetration curve, the result is more precise and accurate.

In this research, it has been tried to take an initiative to determine the plastic limit using "Cone Penetrometer" which is normally used to determine the Liquid Limit of soil. The objectives of this research are stated below:

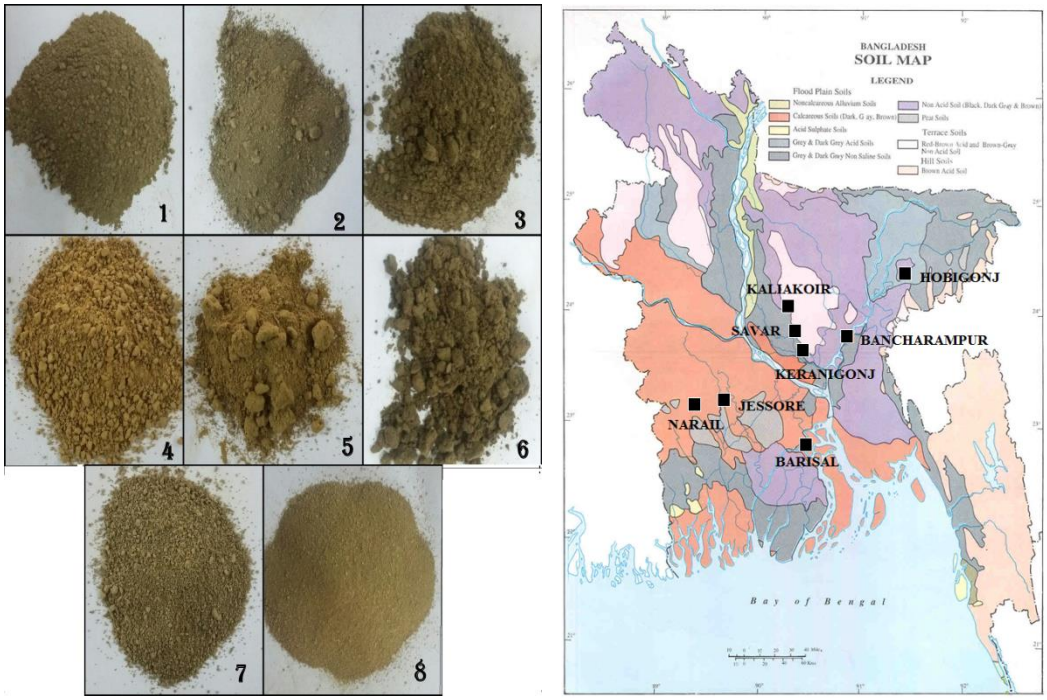
(1) To determine plastic limit using a modified load (240 gm where 30gm cone and 210gm load).
(2) Another was to determine a specific penetration value with the regular cone (80 gm) whose corresponding water content in the water content vs penetration graph can be stated as the 'Plastic Limit' of that soil.

METHODOLOGY

Soils from four different locations of Bangladesh have been collected and a series of laboratory investigations were performed in the Geotechnical Laboratory of BUET. Tests were done following the corresponding ASTM standards and BS standards.

Study Areas

To make the research more precise soils have been collected from eight different locations of Bangladesh. These locations are-
(1) Barisal, (2) Keranigonj, (3) Bancharampur, (4) Kaliakoir, (5)Hobigonj, (6)Narail, and (7)Jessore (8)Savar.



(a) (b)

Fig. 1:(a) Soil samples collected from: **(1)** Barisal, **(2)** Keraniganj, **(3)** Bancharampur, **(4)** Kaliakoir, **(5)** Hobigonj, **(6)** Narail, **(7)** Jessore, and **(8)** Savar and (b) locations shown on Bangladesh Soil Map

Hand Rolling Method

The plastic limit of each soil sample is determined using hand rolling method (ASTM Standard D 4318). About 30 gm of soil passing through 425 micron sieve is mixed with distilled water and left for a suitable maturing time. A ball is formed with about 5 gm of soil paste and rolled into a thread of 3 mm diameter on a glass plate with the fingers of one hand. This procedure of mixing and rolling is repeated till the soil starts crumbling at a diameter of 3 mm. The rate of rolling should be between 80 to 90 strokes per minute to form a 3mm dia. The water content of the crumbled portion of the thread is determined. The test is repeated at least thrice to get the average water content. This average water content is called the plastic limit.
Following are the two methods which are proposed here.

Proposed Method 1

This method is used to determine a specific penetration value corresponding to whose water content can be marked as the Plastic Limit of that soil.

Experimental Set-up

The experimental set-up is exactly similar to the liquid limit test. Neither the load nor the dimensions of the set up is changed.The British fall cone apparatus (BS 1377, British Standard Institution, 1990); manufactured by Wykeham Farrance, Inc; with a 30 degree cone and weighing 0.785 N (80 gm) was used during the experimental investigation. The fall cone apparatus includes a specimen cup of 55 mm in diameter and 40 mm in height. Fig. 2(a) shows the schematic diagram of the experimental set-up.

Procedure

At first, the soil samples were dried in air. If clods were there in soil sample, they were broken with the help of wooden mallet. It has to be ensured that the soils were fine enough. Then sieving was done. The soil samples were passed through #200 IS standard sieve. The plastic limit of each soil sample was known. Each soil should be mixed with water exactly by the percentage of the plastic limit. Distilled water was used to make the soil paste.

After making the soil sample it was taken in the mould and the mould is filled to the top. The top surface was made horizontal and taken care that too much hollow was not present in the sample. It should also be kept in mind that soil sample should not be pressed too much. Then it was placed below the cone and the load is dropped for 5 seconds. That penetration value was that noted. Fig. 2(b) shows the photograph of the experimental set-up.

Proposed Method 2

The load used for this test should be 240 gm. The load of the cone is 30 gm. So the modified load should be of 210 gm. Mild steel has been used to make the load. For inserting it in the cone penetrometer a small section has been cut off and the height is adjusted according to it.

The experimental set-up and procedure is exactly the same as the Liquid Limit Test using cone penetrometer apart from the load used for it. In Liquid Limit Test, 80 gm load is used for penetration where in Plastic Limit Test 240 gm load is used. It is based on the measurement of penetration into the soil of a standardized cone of specific mass. The plastic limit is defined as the water content of the soil which allows the cone to penetrate exactly 20 mm during that period of time. Because it is difficult to obtain a test with exactly 20 mm penetration, the procedure is performed multiple times with a range of water contents and the results are interpolated from water content vs penetration graph. Fig. 2(c) shows the custom made load and Fig. 2(d) shows the schematic diagram of the load.

Fig. 2: (a) schematic diagram of the experimental set-up; (b) photograph of the test set-up; (c) The modified load and (d) schematic diagram of the load (dimensions in cm)

RESULTS AND DISCUSSIONS

After collecting the samples from different locations, various tests were performed on the soils such as: specific gravity test, sieve analysis, hydrometer analysis, liquid limit test etc. Grain size curves has been obtained by sieve analysis and hydrometer analysis. The curves for all soil samples are shown in Fig. 3 and the results are shown in tabular form in Table 1.

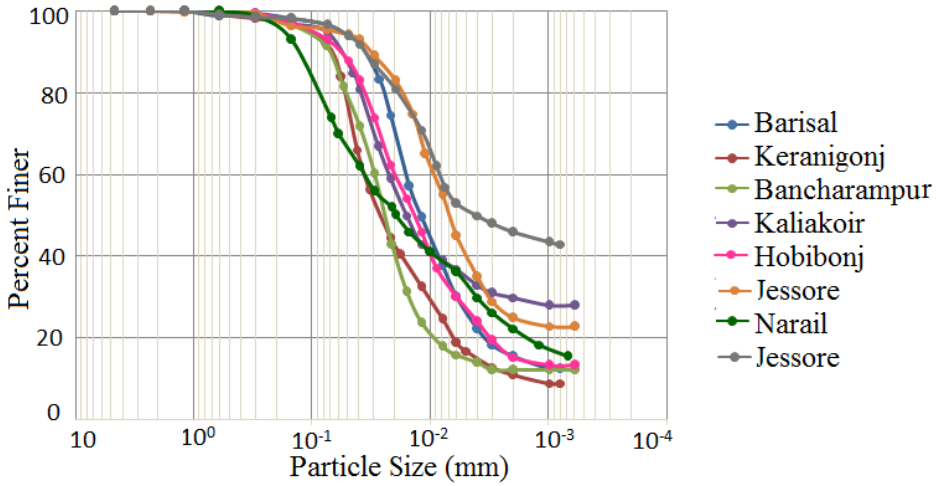


Fig. 3: Grain size curves of eight soil samples collected

Table 1: Grain size, soil classification and liquid limit

Name of the region	G_s	% Passing # 200 sieve	Sand (%)	Silt (%)	Clay (%)	Soil Classification (USCS)	Liquid Limit (%)
Barisal	2.64	96.8	3.2	71.0	15.5	CL	34
Keraniganj	2.72	85.6	1.0	88.0	11.0	CL+ML	23
Bancharampur	2.83	95.5	1.0	52.5	46.5	ML	37
Kaliakor	2.64	94.8	5.2	64.8	30.0	CL	36
Hobiganj	2.55	93.1	6.9	77.7	15.4	CL	31
Narail	2.71	88.9	1.2	66.8	32.0	ML	35
Jessore	2.57	95.5	3.9	71.1	25.0	CL	36
Savar	2.62	80	2.0	41.0	57.0	CL	49

Plastic Limit Obtained Using Modified Load and Penetration Values

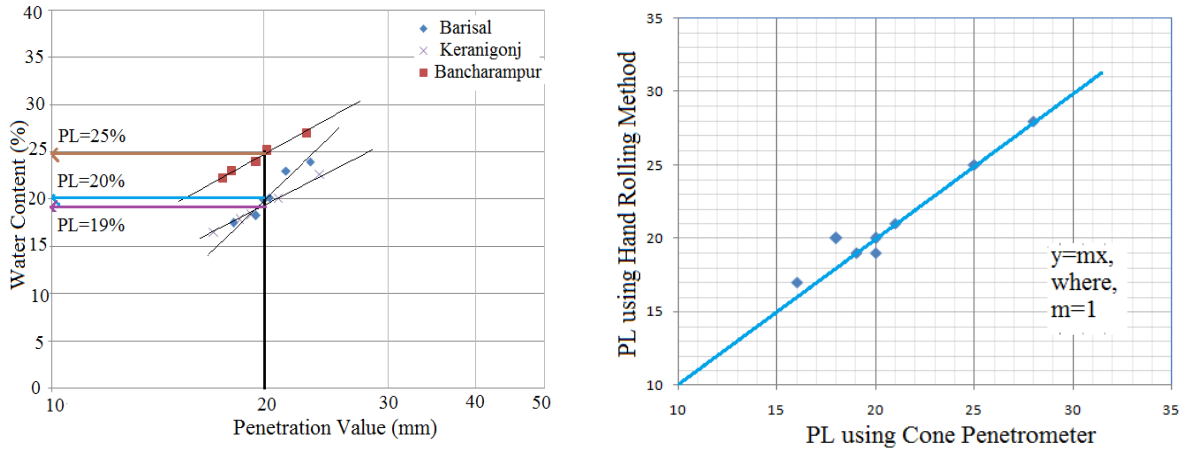
Method 1:

The predetermined plastic limit values using the Hand Rolling Method are used to determine the penetrations values. Table 2 depicts the penetration values obtained using cone penetrometer.

Method 2:

The water content corresponding to 20mm penetration is said to be the Plastic Limit of that soil. For three soils: Barisal, Keranigonj and Bancharampur, plastic limits are shown in the Fig. 4(a). Other values are obtained in the same process. Table 2 depicts are values of other five soil samples.

A correlation can be shown between the plastic limit values obtained in the hand rolling method and Cone Penetration's modified load method in Fig. 4(b). Since the values obtained in two methods are almost the same or near to each other, the plotted graph of plastic limit by hand rolling vs plastic limit by Cone Penetrometer is a straight line passing through the origin.



(a) (b)

Fig. 4: (a) Plastic Limit of Barisal, Keranigonj and Bancharampur soil with modified load and (b) correlation of plastic limits determined using Hand Rolling and Cone Penetrometer method

Table 2: Plastic limit of 8 soils using Hand Rolling and Cone Penetrometer (Method 1) and Penetration values found by Cone Pnetrometer (Method 2)

Name of the Locations	Method 1		Method 2	
	Values of Penetration (mm)	Average Penetration Value (mm)	PL (Hand Rolling Method) (%)	PL(Cone Penetrometer) (%)
Barisal	12.9	13 (approx.)	18	20
Keraniganj	13		19	19
Bancharampur	12.8		25	25
Kaliakor	12.3		16	17
Hobiganj	13.1		20	20
Narail	13.5		28	28
Jessore	11.6		21	21
Savar	Not obtained		20	19

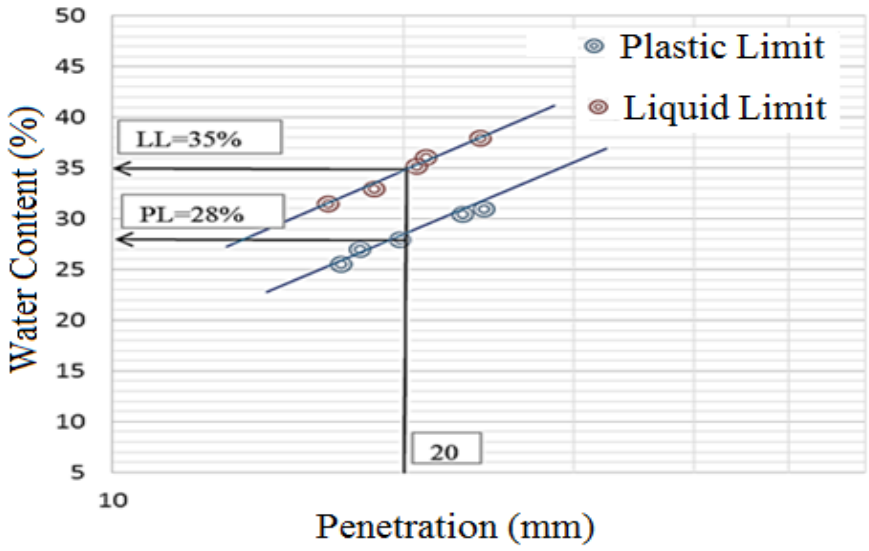


Fig. 5: Combined graph for liquid limit and plastic limit using Cone Penetrometer (for Narail soil)

Plastic Limit is determined by 240 gm load and Liquid Limit is determined using 80 gm load. If the water content vs penetration curves for both are plotted in the same graph, we can see that they are

parallel to each other. The vertical difference between these two lines is the Plasticity index of this soil. Fig. 5 shows the liquid limit and plastic limit curves for the soil sample of Narail. The other soil samples also give similar graphs.

Following observations are made:

(1) The penetration values are nearly 13 mm for 6 soil samples-Barisal, Keranigonj, Bancharampur Kaliakoir, Narail and Hobigonj. It can be said that without modifying the load, the plastic limit values can be obtained from the penetration at nearly 13 mm.
(2) The study was done on eight soil samples. Among them six soil samples gave quite similar penetration values where in case of Savar soil sample we could not hydrate it with Plastic Limit to do the test. This is because there is a large difference between the liquid limit (49%) and plastic limit (20%) of this soil.
(3) This study was done only on eight soil samples. Use of more soil samples can give more precise and accurate results.
(4) Use of modified load for determining plastic limit is quite and accurate process and less operator dependent.
(5) When the plastic limit obtained by Hand Rolling method and Cone Penetrometer are plotted in plain graph, they give a straight line passing through the origin.

CONCLUSIONS

Findings of this research are summarized below:

(1) The specific penetration values obtained from different type of soils for determining plastic limit is nearly 13 mm. That means in the water content vs penetration graph from liquid limit test, water content corresponding to 13 mm penetration can be said the plastic limit.
(2) The penetration value of Jessore soil is quite far from the value 13mm.
(3) The penetration value of Savar soil sample could not be obtained because it did not make a proper soil paste to perform the test.
(4) The plastic limit values obtained by Cone Penetrometer by modifying the load were almost the same as the values obtained by Hand Rolling Method.

The accuracy of measuring plastic limit of fine grained soil has been debatable. The study proposed new techniques to determine the plastic limit which has rich significance on the soil characteristics. The results produced from these methods were compared to the results from standard method stated in (ASTM Standard D 4318) Hand Rolling method. It is apparent that method which is less operator dependent produce least variability and is expected to be more feasible means of measuring Plastic Limit of soil.

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