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Comparison In Undrained Shear Strength Between Low And High Liquid Limit Soils

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Abstract

The evaluation of undrained shear strength is very important in geotechnical engineering. This study compares undrained shear strength values of low and high liquid limit soils determined by Fall Cone method and Laboratory Vane Shear Apparatus, based on 16 soil samples with varying liquid limits. The liquid limit of the samples is determined by Casagrande Method and Fall Cone Method. All tests are performed by the same person and same equipments to avoid operator and equipment error. The results indicate that the rate of decrease of undrained shear strength of high liquid limit soils at higher water content is less compared to that at lower water content.

Keywords: *Liquid limit, plastic limit, fall cone, undrained shear strength, water content.*

1. Introduction

The liquid limit (LL or W_L) is the water content at which a soil is practically in a liquid state, but has infinitesimal resistance against flow. It is the factor used in classification of fine-grained soils, and it also relates to their engineering properties. The concept of liquid limit was first introduced by a Swedish agriculturist Albert Atterberg in 1911. There are two main methods that has been adopted world widely in practice to determine the liquid limit of fine-grained soils: the Casagrande method suggested by Arthur Casagrande (1932), and the Fall cone method originally suggested by the Geotechnical Commission of Swedish State Railways (GCSSR) between 1914 and 1922. Later Hansbo [4] presented a very thorough study of the relationship between cone penetration 'h_L' and strength 'C_u' for different cone angles. Several methods based on the same principles have been developed and standardized in different countries since that time.

The experimental studies reported in this literature (e.g. Casagrande [3], Norman [10], Wood and Wroth [16]) have shown that it was reasonable to assume that soil can be assigned a unique undrained strength, when it is remoulded at liquid limit. The consistency limit can be regarded as a water content associated with states of strength of a soil in remoulded saturated condition.

When the Casagrande method (Wilson, Seed & Peck [15]) is used for determining liquid limit, there is a systematic variation of strength with liquid limit. Wasti and Bezirci [14] demonstrated that the undrained shear strength varies at Casagrande liquid limit between 0.5kPa and 5.6kPa with an average of 2.15kpa. Similarly Youssef et. al. [17] obtained a straight line when the water content and the undrained shear strength was plotted on a log-log scale, the values of shear strength vary from 2.4kN/m^2 to 1.3kN/m^2 with a mean value of 1.7kN/m^2. This variation of undrained shear strength with liquid limit can be attributed to the dynamic nature of the test associated with the Casagrande apparatus where deformation of the soil is induced by its own weight. This method has been affected by other factors like the tendency of the soil to slide in the cup rather than flowing plastically due to hard rubber base. The judgment of the operator is another factor as the operator should be very efficient in providing the required revolutions. In the Fall cone test the deformation of the soil is caused by the weight of the cone and is independent of the self weight of the cone and hence its water content. Therefore in the Fall cone test there is no variation of the strength behavior of high liquid limit soils strength with variation in liquid limit values.

Youssef et. al. [17], Sharma, B. and Bora [12], obtained a linear relationship between undrained shear strength and water content for natural soil samples. But in case of high liquid limit soil the linear characteristic of undrained shear strength and water content invalidates.

In this study Vane shear test and Fall cone test are performed to reassess the water content-undrained shear strength behaviour of high liquid limit soils. The undrained shear strength of 16 soil samples obtained from various locations of North Eastern region of India are determined using both the methods. In addition the liquid limit of all these samples are determined and compared by both Fall cone and Casagrande method.

2. Test samples

All the soil samples used in this study are collected from North Eastern region of India. The basic properties are shown in table 2. Sixteen soil samples are tested which include eight alluvial soil samples, four bentonite samples and four artificial soil samples.

The artificial soil samples are prepared by mixing bentonite and fine grained soil samples at different proportions as summarized in table 3.

3. Test method

The liquid limit of these soil samples are determined by using 60gm 60^0 cone, plastic limits are determined by 400gm 30^0 cone and to investigate medium consistency soil 100gm 30^0 cone is used. Additionally liquid limits and plastic limits are also determined by Casagrande method and conventional thread rolling method according to IS: 2720, Part-5 standard (Indian Standard- Method of Test for Soils, 1985). Specific gravity has been determined according to IS: 2720 (Part-3, 1980).

Table 2. Physical properties of soil tested

Soil Samples	Casagrande method			Cone method			Specific	IS: Classification
	W_L(%)	W_p(%)	I_p(%)	W_L(%)	W_p(%)	I_p(%)	Gravity(G_s)	(IS:1948-1970)
1	71.6	31.25	40.35	75.2	29.7	45.5	2.62	CH
2	58.5	24.66	33.84	58	18.6	39.4	2.63	CH
3	63.4	28.85	34.55	64	28.6	35.4	2.63	CH
4	56.7	28.4	28.3	56.9	23.4	33.5	2.6	CH
5	35.7	18.37	17.33	39.1	17.1	22.0	2.62	CI
6	32.6	20.3	12.3	34.9	21.0	13.9	2.6	CL
7	43.5	23.78	19.72	45.8	23.8	22.0	2.61	CI
8	41.5	20.11	21.39	43.1	21.0	22.1	2.64	CI
Artificial-1	198	25.87	166.1	162	27.2	140.3	2.71	CH
Artificial-2	173	27.3	153	145	27.0	118.2	2.69	CH
Artificial-3	166	19.67	137.3	145	22.0	116.0	2.72	CH
Artificial-4	171	20.51	142.4	142	25.1	117.9	2.7	CH
Bentonite-1	322	27.78	288.2	250	30.8	231.2	2.71	CH
Bentonite-2	324	36.1	287.9	248	40.4	227.6	2.73	CH
Bentonite-3	310	22.58	287.4	245	29.5	215.5	2.7	CH
Bentonite-4	314	42.73	271.2	240	47.2	212.8	2.71	CH

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Table 3. Proportions of artificial soil samples

Artificial Samples	Proportion of Bentonite Soil (%)	Proportion of Alluvial Soil (%)
Artificial-1	50% of bentonite-2	50% of sample-3
Artificial-2	50% of bentonite-2	50% of sample-2
Artificial-3	50% of bentonite-1	50% of sample-5
Artificial-4	50% of bentonite-3	50% of sample-7

The tests are carried out from a range of water content beginning from lower than plastic limit state to greater than the liquid limit of the soil. Undrained shear strength of these soil samples were determined by fall cone method using Hansbo's equation [4] and by laboratory vane shear apparatus according to and IS: 2720 (Part-30, 1980) over the same range of water contents. All tests were performed by the same person and same equipments to avoid operator and equipment error.

4. Soil test results and discussions

4.1. Liquid limit and Plastic limit

The plastic limit of the soils by Fall cone method are found to range from 17.1% to 29.7% for alluvial soil samples, 22.0% to 27.2% for artificial soil samples and 26.0% to 47.2% for bentonite soil samples. The plastic limits as determined by thread rolling method range from 18.37% to 31.25% for alluvial soils samples, 19.67% to 27.3% for artificial soil samples and 22.58% to 42.73% for bentonite soil samples.

The liquid limits of the alluvial soil samples as determined by the Fall cone method ranges from 34.9% to 75.2%, 167.5% to 145% for artificial soil samples and 240% to 250% for bentonite soil. The liquid limit values as determined by Casagrande apparatus range from 32.6% to71.6% for alluvial soil samples, 166% to 198% for artificial soil samples and 310% to 324% for bentonite soil samples.

A comparison has been made between the liquid limits obtained by fall cone method and casagrande method for all the alluvial soil samples together with artificial and bentonite soil samples as shown in figure.1. The results of Wasti and Bezirci [14] are also included in the comparison.

It has been observed that at lower water content i.e. for all alluvial soil samples the liquid limit values obtained by Casagrande method agrees well with fall cone method. But as liquid limit increases the curve deviates more from 45^0 line and much higher limits were obtained by Casagrande method. Similar trend of deviations were also observed by Wasti and Bezirci. The authors has concluded that the deviation of liquid limit values at higher limits shows a trend toward increasing depth of cone penetration with increasing Casagrande liquid limit. Similar conclusions were also made by Koumoto and Houlsby [8], Kumapley and Boakye [9] and Japanese Geotechnical Society [6] where h_L increases with W_L.

But to simply increase the depth of penetration of high liquid limit soils at liquid limit and to throw the points near the 45^0 line so that the Fall cone liquid limit agrees well with Casagrande liquid limit is not the true solution.

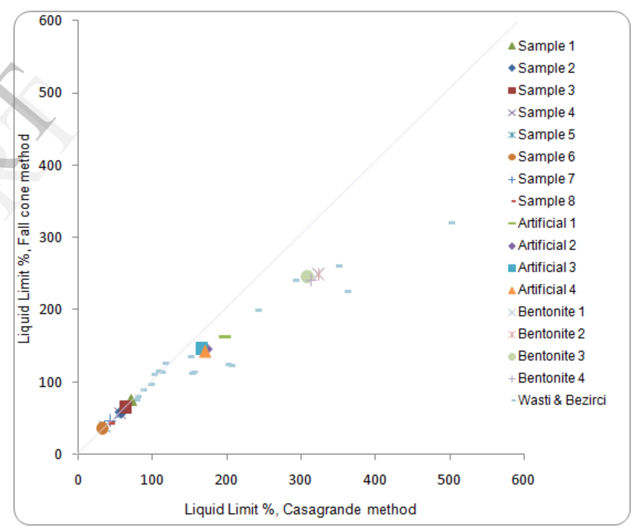

Figure 1. Comparison of test methods in defining the liquid limit of studied soil samples.

4.2. Undrained shear strength

The undrained shear strength values obtained at different water content for the soil samples by the Laboratory vane shear test and the Fall cone test are shown in figure. 2. A constant decrease of undrained shear strength values with increase in water content is clearly obtained for all alluvial soil samples by both fall cone and laboratory vane shear test in a log-log plot (figure 2.a).

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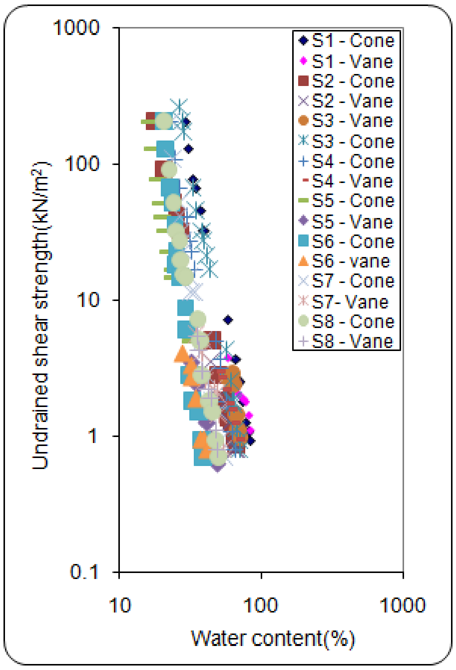
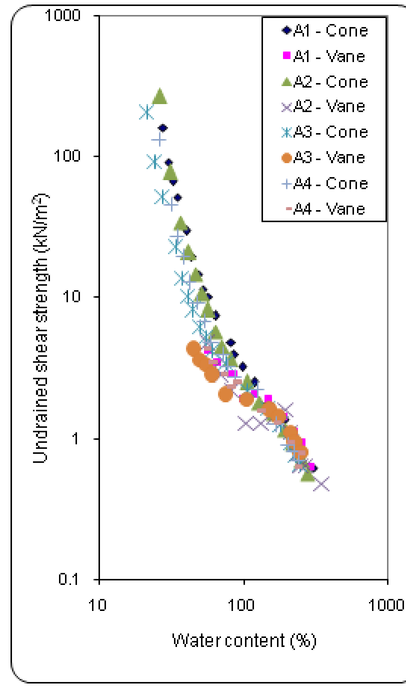


(a)



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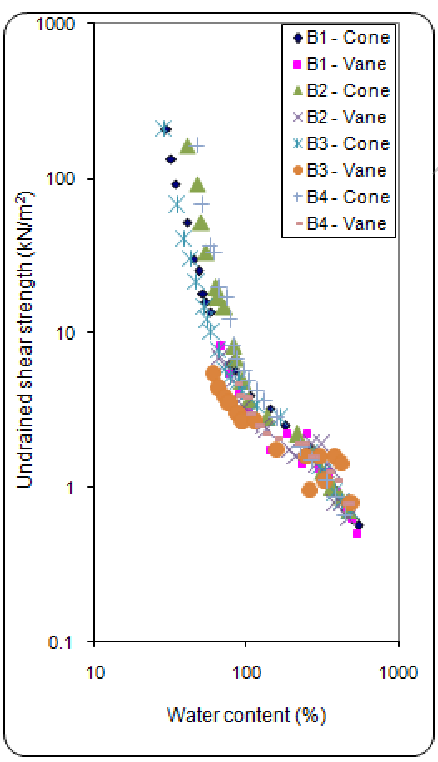

(b)

Figure 2. Relationships between undrained shear strength and water content: a) for alluvial soils, b) for bentonite soils; and c) for artificial soils

But for high liquid limit soils i.e. for artificial and bentonite soil samples at lower water content a constant decrease of undrained shear strength with water content is obtained, whereas at higher water content reduced rate of decrease of undrained shear strength with increasing water content is observed (figure 2.b & 2.c). A comparison has been made between the undrained shear strength values at cone liquid limit and at Casagrande liquid limit by fall cone method and laboratory vane shear apparatus as shown in table 3. The undrained shear strength values determined by fall cone method were obtained by using Hansbo's equation [4]. Therefore at fall cone liquid limit of the soil a constant value of undrained shear strength of 1.7kN/m^2 is obtained, and similar results are found with laboratory vane shear method. But for high liquid limit soil a lesser value of undrained shear strength is obtained at Casagrande liquid limit.

Table 3. Undrained shear strength at fall cone liquid limit and casagrande liquid limit as determined by cone and vane shear apparatus

Soil Samples	Undrained shear strength by Vane Method (kN/m2)		Undrained shear strength by Fall Cone method (kN/m2)	
	At fall cone liquid limit	At Casagrande liquid limit	At fall cone liquid limit	At Casagrande liquid limit
1	1.8	2	1.7	2.15
2	1.65	16	1.7	1.6
3	2	2.2	1.7	1.8
4	1.75	1.8	1.7	1.69
5	1.6	2.5	1.7	2.8
6	1.8	2.6	1.7	3.25
7	2	2.45	1.7	2.3
8	1.7	2.01	1.7	1.98
Artificial-1	1.6	1.28	1.7	1.3
Artificial-2	1.55	1.2	1.7	1.35
Artificial-3	1.55	1.3	1.7	1.4
Artificial-4	1.58	1.2	1.7	1.25
Bentonite-1	1.6	1.2	1.7	1.25
Bentonite-2	1.7	1.25	1.7	1.25
Bentonite-3	1.55	1.2	1.7	1.3
Bentonite-4	1.7	1.3	1.7	1.25

5. Conclusion

The main conclusions obtained in this study are summarized as follows:

1) Casagrande liquid limit agrees well with fall cone liquid limit for low liquid limit soil samples. As liquid limit increases i.e. for high liquid limit soils Casagrande liquid limits were found to be much higher than fall cone liquid limits. It is nearly 65% to 75% more in bentonite soil samples and 20% to 30% more in case of artificial soil samples.

2) Casagrande apparatus yield higher value of liquid limit compared to fall cone method in high liquid limit soils. This higher value of liquid limit results in lower value of undrained shear strength by both fall cone method and laboratory vane shear apparatus at Casagrande liquid limit. Hence the conclusions made by Koumoto and Houlsby [8], Kumapley and Boakye [9] and Japanese Geotechnical Society [6] to increase the depth of penetration at cone liquid limit for high liquid limit soils breaks down.

3) The reduced rate of decrease of undrained shear strength of high liquid limit soils at higher water content may be due to the extremely large specific surfaces and the properties of adsorbed water layer with the mineral skeleton which is different from those of ordinary water i.e. the neutral silicates layer readily take up polar water molecules giving rise to hydrogen bonding (Kemper, W. D., Maasland, D. E. L. and Porter, L. K. [7]) which is not easily broken. However, more research efforts are needed to further look into it.

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