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Determination of Shear Viscosity of Clay Soil Using Gravity Cone Apparatus

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Abstract: *In soil mechanics the shear strength of soil is a result of friction and interlocking of particles, and it gives the magnitude of shear stress that a soil can sustain. Knowledge of shear viscosity plays a vital role in understanding the viscous resistance in the dynamic penetration through the soils for applications in geotechnical field such as cone penetrometers landslides and jacked piles. The intention of this study is to apply viscous flow (hydrodynamics) principles to soils at critical state with the main purpose of understanding the effects of viscous soil resistance on penetrating shafts or objects in clay and also post failure features during movement of mud slides.*

Keywords: *Fall cone, Kaolin, Liquidity Index, Shear Strength, Shear Viscosity*

I. INTRODUCTION

In soil mechanics the shear strength of soil is a result of friction and interlocking of particles, and it gives the magnitude of shear stress that a soil can sustain .In geotechnical engineering applications Coulomb's friction hypothesis (1776) is considered as a basis to determine the failure stress. It is clear that when failure on a slip plane is initiated, Coulomb‟s equation gives the information on the soil strength. However, there is a certain class of problems in geo engineering which comprise post-failure soil response. In such response there is no distinct failure plane but the associated soil mass flows like a fluid after reaching critical state (failure). Such problems include mudslides and soil flow around penetrating rigid bodies such as the shaft surface of a jacked pile, a sleeve of a cone penetrometer or the installation of spud-can footings for offshore structures in soft clays.

A potential approach to analyze viscous drag is to use hydrodynamics principles of creeping flow also called stokes law (is a type of fluid flow where adjective inertial forces are small compared with viscous forces.).To compute the viscous drag shear viscosity of soil will be the inherent parameter in a hydrodynamics method. A potential test known as fall cone test is used to determine the shear viscosity of soil at low water contents, which is used to measure the index and shear properties of fine grained soils(clays).

II. LITERATURE REVIEW

S.P.Mahajan and **M.Budhu** (2009) conducted a test on shear viscosity of clays using the fall cone test in which kaolin of liquid limit (47%) and plastic limit (30%) was used as test samples in their experiment. Tests were conducted on soil specimens with water contents ranging from 35.8% to 65.7%.

Youssef et al (1965) showed the relation of shear strength (determined with a 20mm x 10mm laboratory vane) with moisture content for 26 different soils from United Arab Republic and points corresponding to liquid limit.

Sherwood and **Ryley (**1970) provided a graph (fig 2:2)showing cone penetration of 300mm, 80gf cone with moisture content for 25 soils mostly from UK and indicate the Cassagrande liquid limit.

Hansbo (1957) made an extensive study of cone penetration testing using four different cones (600 cones-10gf: 600 cones-60gf:300 cones-100gf: 300 cones-400gf) to correlate the penetrations of these cones.

Locat and **Demers** (1988) conducted an analysis on Viscosity, yield stress, remoulded strength, and liquidity index relationships for sensitive clays in which the viscometer which they adopted for the experiment is a rotational rheometer and that run in a steady state conditions.

In 1982, **Edgers** and **Karlsrund** made a note on the critical role of the viscosity of the soil mass in submarine and sub aerial slide dynamics. Thus it can be concluded that flow behavior can be quite complex and flow behavior varies on the soil type, pore-water salinity, mineralogy, and water content.

The fall cone test consists of a solid metal cone that freely penetrates a soil mass placed in a standard size cup. The depth of cone (tip) penetration is used to determine the liquid and plastic limits (Wroth and Wood, 1978; Wood, 1982; Budhu, 1985; Zreik et al., 1995; Feng, 2000) and the undrained shear strength (Hansbo, 1957; Houlsby, 1982; Wood, 1985; Shimobe, 2000; Koumoto and Houlsby, 2001) of finegrained soils. Shear strengths greater than 0.075 kPa and corresponding LI less than 1.7 (Wroth and Wood, 1978) can be effectively measured using the fall cone test.

III. LABORATORY EXPERIMENTATION

The soil used in this experiment was kaolin and all the basic properties of kaolin such as Natural Moisture Content, Gradation Analysis, Specific Gravity, Compaction Characteristics, pH and also elemental analysis are carried out. The basic properties of soil sample obtained from the tests are tabulated as shown.

S.No	Properties	Test soils
1	**Natural Moisture content (%)**	1.5
2	**Gradation analysis:** Coarse sand (%) Medium sand (%) Fine sand (%) Silt (%) Clay (%)	 - - 02 38 60
3	**Specific gravity**	2.65
4	**Atterberg limits:** Liquid limit (%) Plastic limit (%) Liquidity index (%) Shrinkage limit (%)	 46.30 27.69 18.60 26
5	**Soil Classification**	CI
6	**Compaction characteristics:** Max dry density(g/cm3) Optimum moisture content (%)	 1.46 26.5
7	**pH**	7.2

Table 1: properties of soil sample

A clay sample of liquid limit (LL %) and plastic limit (PL %) of 47% and 30% respectively, was used for the test samples. Dry soil was mixed with distilled water to achieve the desired water content and stored in an air tight container for 24 hours. The wet soil was then thoroughly mixed and placed in the soil cup for the experiment to be conducted. Water content of the soil sample placed in the soil cup was measured. Tests were performed on soil samples with water contents in the range 35.8 % to 65.7 %. The total mass of the cone assembly (cone, shaft and LVDT) was 93 grams.

A standard cone of apex angle, 30^o and height, 35 mm, was used for the test. The procedure used for conducting the tests is similar to the conventional fall cone test. A computer data acquisition system recorded the times and penetrations at a frequency of 1 kHz as shown in Fig.1. For soil states near the plastic limit, additional masses of 50 grams and 150 grams were added to increase the depth of penetration. However, to record continuous data of penetration (h) with time (t), the dial-needle measurement assembly was replaced by a calibrated linear variable displacement transformer (LVDT) and computer data acquisition system. The voltage data measured by the LVDT was sent to a data acquisition system.

Figure 1: Modified fall cone apparatus

IV. METHODOLOGY

When a fall cone penetrates soil, the soil just below and adjacent to the cone tip reaches CS and flows around the cone as illustrated in Figure 4.5. The soil mass at CS behaves like a yield stress fluid as discussed in previous chapters. The equation of motion of a cone at any penetration depth, h, in the soil is

$$ma = mg - F\tau h^2$$

Where m is mass of the cone, a is acceleration of the cone at depth, h, g is the acceleration due to gravity, τ is the (dynamic) shearing resistance and F is the non-dimensional cone resistance factor (Houlsby, 82; Koumoto and Houlsby, 2001) expressed as

$$F = \pi N_{ch} \tan^2(\theta)$$

Where N_{ch} is the modified bearing capacity factor of the cone, which accounts for the soil heave around the cone, and θ is the half cone angle. For a 30^0 (i.e. $\theta = 15^0$) semi rough cone, the value of N_{ch} is 7.457 (Koumoto and Houlsby, 2001).

When the free fall motion of the cone is initiated, its acceleration decreases from an initial value, g, due to the soil resistance. At a certain depth of penetration, h_{eq}, the acceleration of the cone becomes zero, i.e. the net force on the cone is zero.

In this investigation, this depth is referred to as the dynamic equilibrium position. The cone thereafter decelerates further finally coming to rest at h_f. The velocity of the cone increases from the zero (beginning of test) and reaches a maximum value at h_{eq}. Thereafter, the velocity reduces until the cone finally comes to rest. The additional viscous stress due to cone motion causes the dynamic equilibrium (h_{eq}) to be achieved at penetration depth lesser than the theoretical equilibrium depth, h_s.

If the dynamic shear resistance at this point of equilibrium in a fall cone test is estimated, the viscous component can be extracted by subtracting the static component. From Equation, the dynamic equilibrium condition (a = 0) is

$$ma = mg - F\tau h_{eq}^2$$

Using values from above equations, the viscous component of shear resistance is expressed as

$$\mu_p \dot{\gamma} = \left(\tau^{\frac{1}{2}} - \tau_{cs}^{\frac{1}{2}}\right)^2 = \left[\left(\frac{W}{Fh_{eq}^2}\right)^{\frac{1}{2}} - \left(\frac{KW}{h_f^2}\right)^{\frac{1}{2}}\right]^2$$

V. RESULTS AND DISCUSSION

Fall cone procedure is followed as per BS 1377, British standard Institution, 1990 a standard cone of apex angle 30^0 is used and a calibrated potentiometer is connected to the top of the shaft and a data logger is connected to obtain penetration continuously with time. Soldering of potentiometer is done with the help of Quantum^x manual.

The total mass of the cone assembly is 87g including the cone and the shaft .Fall cone test is conducted in which LI changes from 0.29 to 2.00 (with a total weight of 87g).Tabulated test results(few readings only) of sample 1 is shown in table 2 in which LI=0.4 with addition of weight 389.76g (i,e. total of476.76g).

Time ins	Measured penetration in mm	Corrected penetration in mm	dp	dt	Avg p	dp/dt
0	-0.05016	0				
0.01	-0.05013	3.03E-05	3.02941E-05	0.01	1.5147E-05	0.003029
0.02	-0.05014	1.97E-05	-1.0639E-05	0.01	2.4974E-05	-0.00106
0.03	-0.05015	5.08E-06	-1.4577E-05	0.01	1.2366E-05	-0.00146
0.04	-0.05021	-5.3E-05	-5.8126E-05	0.01	-2.399E-05	-0.00581
0.05	-0.05032	-0.00016	-0.00010565	0.01	-0.0001059	-0.01056
0.06	-0.05037	-0.00021	-4.746E-05	0.01	-0.0001824	-0.00475
0.07	-0.0504	-0.00024	-3.6307E-05	0.01	-0.0002243	-0.00363
0.08	-0.05038	-0.00022	2.39424E-05	0.01	-0.0002305	0.002394
0.09	-0.05035	-0.00019	2.88226E-05	0.01	-0.0002041	0.002882
0.1	-0.05036	-0.0002	-1.5173E-05	0.01	-0.0001973	-0.00152

Table 2: Tabulated test results obtained for sample

Cone penetration versus time is plotted (in which test number 1 which is used as a representative of all other samples for further discussions and the graphs plotted). Fig.2 and 3 provides penetration versus time graph and velocity versus penetration graph respectively. Velocity is obtained by differentiating the polynomial (penetration versus time) and those values were used to calculate the shear viscosity.

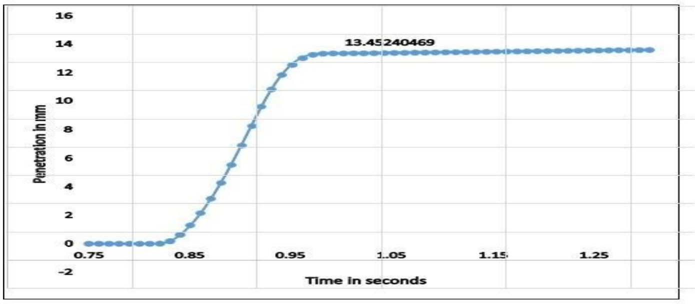

Figure 2: Penetration versus time relationship of the test

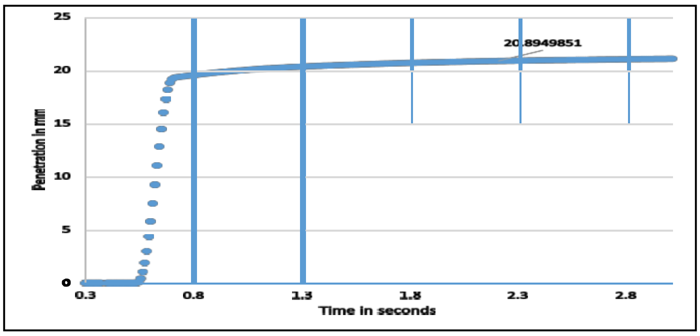

Figure 3: Velocity of the cone test

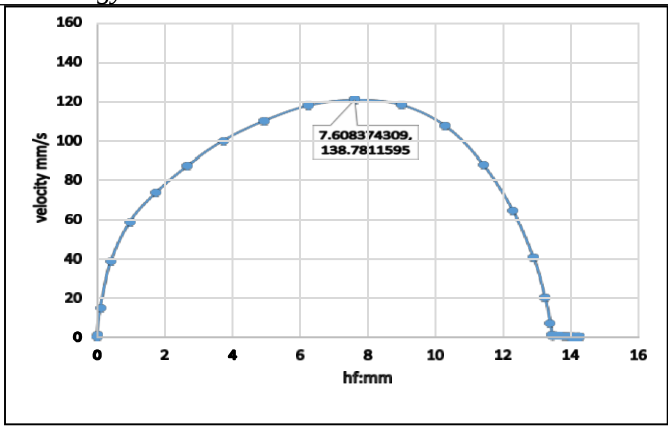

Figure 4: Penetration versus time relationship of the test

Test data of cone penetration:

s.no	h_f(mm)	h_{eq}(mm)	LI	total weight(g)	weight N	τ_{cs}(kPa)	τ (kPa)	Ÿ(sec)	μ(Pas)
1	13.46	7.61	0.4	476.76	4.68	34.35638	48.04526	2.932822	401.1263
2	19.77	12.56	0.4	686.01	6.73	22.90094	25.36354	2.419941	28.2222
3	23.75	15.23	0.4	898.601	8.81	20.77305	22.58136	2.207885	18.89424
4	24.37	14.24	0.41	1118.39	10.97	24.56672	32.1633	2.179618	242.3071
5	29.1	21.58	1.06	476.76	4.68	7.350409	5.974712	1.994627	34.33409
6	29.08	23.3	1.05	686.01	6.73	10.58468	7.370165	1.995313	142.319
7	20.9	10.16	0.56	476.76	4.68	14.24967	26.95457	2.353613	866.2101
8	27.8	17.23	0.56	686.01	6.73	11.58183	13.47778	2.040731	37.25561
9	19.63	10.44	0.52	476.76	4.68	16.15314	25.52812	2.428555	448.8687
10	24.43	14.19	0.53	686.01	6.73	14.99753	19.87121	2.17694	162.3171

Table: 3 Results of Fall Cone Penetration

The results obtained for fall cone penetration (LI versus penetration depth). It provides a curve similar to the plot provided by Mahajan and Budhu (2009) i.e.an exponential curve is obtained. Similar to the findings of Mahajan and Budhu(2009) plotting shear viscosity versus liquidity index(log scale) in which the standard mass of the cone is increased with the help of discs (389.76g,599.01g,811.601g,1031.39g) shows that shear viscosity decreases with increasing LI.

The relationship between LI versus shear viscosity varies with the addition of weight (figure5:15).But all the data which follows an exponential function which again follows the similar pattern provided by Locat and Demers (1988) from viscometer data with sensitive clays having high liquidity index. The fall cone test conducted in this experiment varies a liquidity index ranges from 0.05 to2.

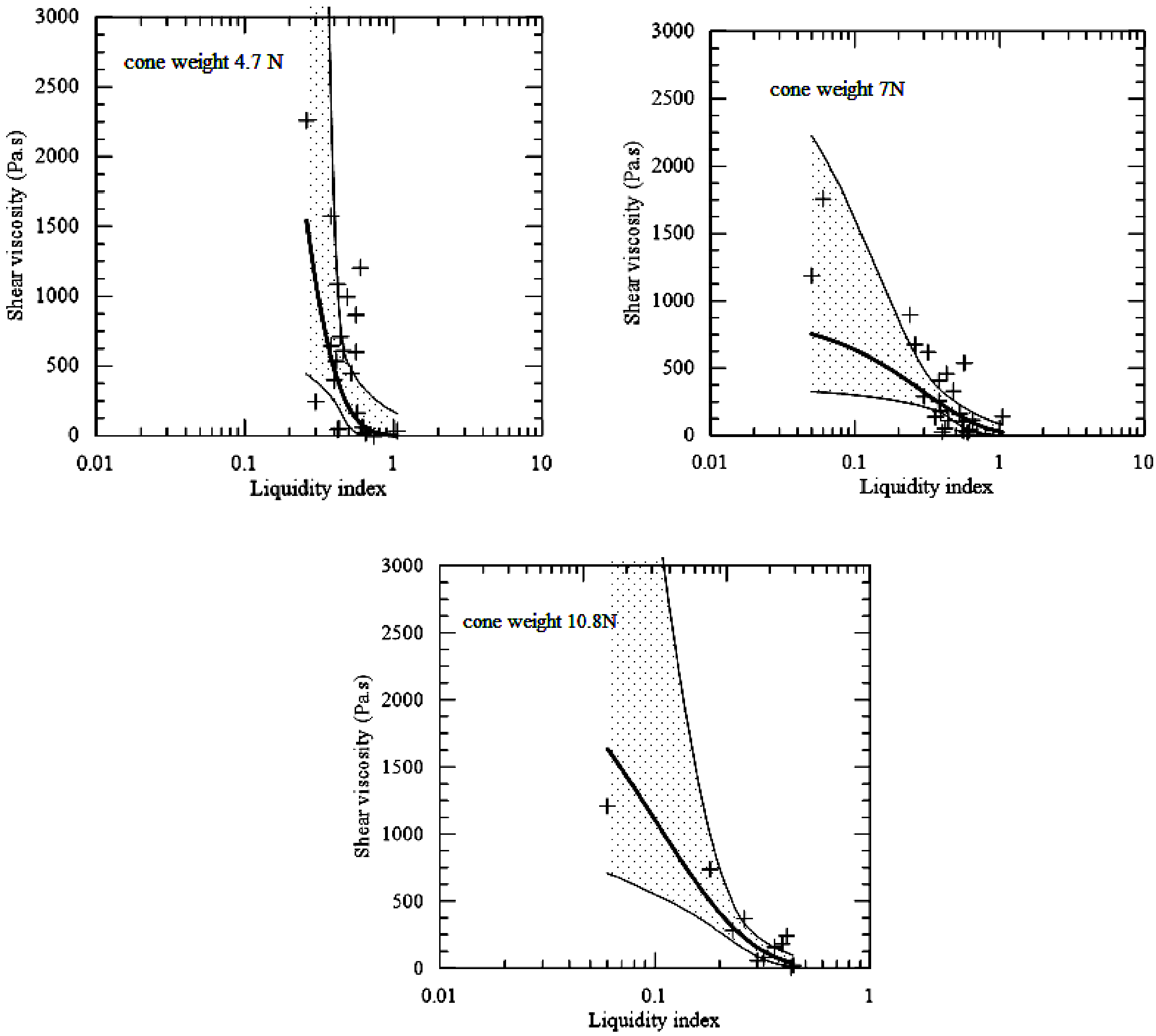

Fig. 5 The relationship between LI versus shear viscosity varies with change in weight(4.7 N,7N, 10.8N)

Conclusion

Standard methods of defining the viscosity of soil are not presently available. The shear viscosity has been investigated for clays with higher water contents to study soil flows in landslides using viscometers. Viscometers are difficult to operate on soils with low water contents. In this research, it is shown that a fall cone test can be used to determine the shear viscosity of clays at low water contents (LI < 2). Fall cone experiments were conducted using SOIL samples. Based on the reevaluated theory for the fall cone test (provided by Mahajan and Budhu) and experimental results, provided in this report leads to the following conclusions.

1. Thefallconetestisapromisingtooltoestimatetheshearviscosityofclaysanditfound to be a new theoretical approach based on hydrodynamics to study viscous resistance in soil penetration problems.
2. Advancementofthetheoryandexperimentalproceduresofthefallconetesttoestimate shear viscosity of clays at low water contents (up to LI=2).
3. The shear viscosity decreases exponentially with increases in LI.
4. Liquidity index varies exponentially with time and varies with weight.
5. Shear strength versus LI obtained from penetrations conducted on loading frame results and fall cone test are in good agreement.
6. Cone driving conducted on loading frame shows that the more the liquidity index the more will be the penetration.

7. Fall cone apparatus thus suggested to find out shear strength and shear viscosity since it is easy and rapid.

References

[1] Wells,A.F,(1984).Structure of Kaolins.Structural Inorganic Chemistry.Clarendon press,Oxford,1028pp.

[2] Ladd, CC, Foott, R, Ishihara, K, Schlosser, F and Poulos, HG. (1977).Stress- deformation and strength characteristics. International conference on soil mechanics and foundation engineering, 9, Proceedings, Vol. 2, pp 421-494.Tokyo.

[3] Mahajan, S., and Budhu, M., 2009, "Shear Viscosity of Clays Using the Fall Cone Test," Geotechnique, Vol. 59, No. 6,pp.539–543.

[4] Locat, J., and Demers, D., 1988, "Viscosity, Yield Stress,Remolded Strength, and Liquidity Index Relationships for Sensitive Clays," Can. Geotech. J., Vol. 25, No. 4, pp. 799–806.

[5] Wood, D. M., 1982, "Cone Penetrometer and Liquid Limit,"Geotechnique, Vol. 32, No. 1, pp.152–157.

[6] Hansbo,S.,1957,"A new Approach to the Determination of the Shear Strength of Clay by the Fall-Cone Test," Proceeding Royal Swedish Geotechnical Institute, Vol. 14, Royal Swedish Geotechnical Institute, Stockholm, pp.1–47.

[7] Koumoto, T., and Houlsby, G. T., 2001, "Theory and Practice of the Fall Cone Test," Geotechnique, Vol. 51, No. 8, pp.701–712.

[8] Harison, J. A. 1988. „„„Using the BS cone penetrometer for the determination of the plastic limits of soils.‟‟‟ *Geotechnique,* 38(3),433–438.

[9] Feng, T. 2004. "Using a small ring and a fall-cone to determine the plastic limit." *J. Geotech. Geoenviron. Eng.*, 130(6),630–635.

[10] Serge Leroueli and Jean-Pierre Le Bihan(1996) published a note on Liquid limits and fall cones , vol. 33, no. 5, pp. 793-798,1996.

[11] Bojana Dolinar and Ludvik Trauner(2005) - a technical note on impact of soil composition on fall cone test *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 131, No. 1, January 2005, pp.126-130.

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