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Application of vane shear tools to assess the shear strength of remolded clay soil

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Abstract

The un-drained shear strength of soil is of great concern in certain geotechnical engineering applications. Several methods for determining this parameter exists. Among them, vane shear test (VST) is one of the easy and simple methods which are useful for very soft to firm clay to calculate the un-drained shear strength. A substantial discrepancy between shear strength at Atterberg limits proposed by different researchers, but it known that shear strength is constant at Atterberg limits. This research is try to find the shear strengths at plastic limit (PL) and liquid limit (LL) by laboratory vane shear tools to re-appraise the un-drained shear strength at two major Atterberg limits employing on a small scale of remolded soil sample of sylhet clay. Observation showed that the un-drained shear strength is lower in the range for plastic limit and slightly higher in the range for liquid limit as compared with previous works. This study revealed that for plastic clayey soil the shear strength is almost 50 kPa at plastic limit and 5.0 kPa at the liquid limit.

Keywords: Clayey soil, Liquid limit, Plastic limit, Shear strength, Vane shear test.

Introduction

The un-drained shear strength is necessary and very important parameter for the determination of the bearing capacity of foundations, dams, pile design[1], mass movement investigations of glacial deposits[2]. For instance, pile installation in place causes disturbances in the soil adjoining to the pile. For the design of offshore foundation systems[3], the un-drained and remolded strength profile of soft clay deposits is often required. Glacial deposits and quick clays often require the determination of the remolded strength particularly in mass movement investigations[2]. Engineers often take necessary design decisions without enough or poor quality soil strength data. In such cases, engineer may wish to evaluate the remolded soil strength as a lower bound value.

Laboratory vane shear test is easy a method for measuring the un-drained shear strength of cohesive soils at low shear strength for which unconfined tests cannot be performed. It is said that the shear strength are constant between liquid limit and plastic limit and at remolded state this is the threshold water contents for fine grained soils[4-5]. If the shear strength between plastic limit and liquid limit were fixed correctly, the un-drained shear strength of remolded soils at any water content at consistency limits can be found easily. In fine soils, strength decreases as the water content increases. The average value of shear strength at LL was 2.65 kPa which suggested Casagrande. Shear strength range from 0.5-5.6 kPa and 20-320 kPa at the LL and PL respectively. Excellent reviews of recent investigation on this topic can be found at Wroth[6], Whyte[7], Sharma and Bora[8] and Kayabali and Tufenkci[9]. Most of the researches have concluded that un-drained shear strength of remolded soils at liquid limit is around 1.6 to 1.7 kPa and plastic limit is around 110-170 kPa[9] mostly towards the lower bound.

Table-1: Un-drained shear strength at liquid limit[9].

References	Shear strength c_u (kPa)		Remarks
	Range	Average	
10	-	1.6	Whyte[7]
11	0.7–1.75	-	Soils with very different PI values
12	0.8–1.6	-	Apparatus used conforms to BSI standards
13	2.5	-	Whyte[7]
14	1.3–2.4	1.7	Utilized laboratory vane tests
15	1–3	-	Wroth and Wood[8]
16	0.5–4.0	-	Whyte[7]
8	-	1.7	The best estimate
17	1.1–2.3	-	Wroth and Wood[8]
7	-	1.6	Upon literature review
18	1.7–2.8	-	Sharma and Bora[6]
19	-	1.7	Sharma and Bora[6]
20	-	1.6	Upon literature review
6	-	1.7	Adopted as the best estimate

Table-1 and 2 presents un-drained shear strength (c_u) at liquid limit and plastic limit respectively. Based upon the common view that un-drained shear strengths of remolded soils at the plastic and liquid limits are 170 and 1.7 kPa, respectively the ratio between these two strengths is about 100[6,8,11,21-22]. For some Swedish clay, Whyte[7] suggested that this ratio was approximately 70; Karlsson[16] indicated that this ratio was between 50 and 100[9].

Table-2: Un-drained shear strength at plastic limit[9]

References	Shear strength c_u (kPa)		Remarks
	Range	Average	
10	-	110	Whyte[7]
11	85–125	110	Whyte[7]
23	30–320	115	Whyte[7]
24	20–220	110	Whyte[7]
7	25–280	130	Oral communication with Arrowsmith
8	-	170	The best estimate
20	-	110	Literature review
6	-	170	Cone penetration method

Materials and methods

The materials used in this study cover clayey soils around Kumargoan, Sylhet. The soil samples were collected based on the availability of clayey soil in surrounding area. From each site (such as roadsides, paddy field etc) large bags of soil sample were collected and then send to the laboratory. After oven dried all the soil samples were pulverized and halved. A part of soil sample was sieved through #200 sieves. For each soil sample about 500 gm of ready to use soil was kept for further use. For vane shear test soil sample mixed with pre-determined water content and fill the mold so that there is no void space in the mold.

According to American Society for Testing Materials (ASTM) standard the miniature vane shear test is used for the determination of shear strength of the fine grained soil[25]. The miniature vane shear apparatus (Figure-1) consists of four intersecting blade. This four-bladed vane were inserted into the soil and rotating it a constant rate. Take the dial reading to calculate the torque required to cause a cylindrical surface to be shared by the vane and from this torque calculated the shearing resistances of remolded soil. The torque was measured by a calibrated torque spring.

The vane consists of four rectangular blades which height is 12.7 mm and it is equal to the diameter. The diameter and length of the mold is 37.5 mm and 75 mm respectively. That's the specimen length to diameter ratio is 2. The vane was rotated at a uniform rate say 0.1^0/s or 6 degrees per minute. Torque applied until the soil fails. The torque measuring device was a spring. To carry out the test four torque springs with different stiffness was utilized. Vane blade was inserted in the soil at a depth of 10 mm from the top surface of soil specimen. The initial reading was taken.

$$c_u = \frac{M*1000}{K} \quad (1)$$

Where: c_u = soil vane shear strength in kPa, M = measured torque in N-mm, D = diameter of vane in mm and, H = height of vane in mm

Figure-1: Miniature vane shear apparatus[26]

Experiments started using the smallest coefficient of stiffness torque spring at the soil water contents slightly higher than the liquid limit followed by the determination of liquid limit and plastic limit of the soil sample. Prevent rotation of mold when the soil specimen was sheared. Using appropriate spring coefficient determines the un-drained shear strength of soil specimen. Progressively decreasing moisture contents following vane shear test were performed. The same torque spring was constantly used until the recorded rotation angle lower or equal to 90^0. Stiffer torque spring was used when the rotation angle above 90^0. This procedure continues for all soil samples. Two vane shear tests is conducted in each soil sample of five different water content between plastic limit and liquid limit where average value was picked up.

Results and discussion

The vane shear test results on each soil sample were plotted in Figure-2. Research results are expressed in the following empirical form.

$$y = pe^{-qx} \quad (2)$$

Where: y = un-drained shear strength of remolded soil sample, x = water content and p, q are expression constant.

The un-drained shear strength values of remolded soil samples corresponding to the plastic limit and liquid limit were computed by using the values of respective PL and LL in equation (2). Table-3 comprises the soil sample, liquid limit and plastic limit values and the coefficient of p, q, R^2. For each soil samples the un-drained shear strengths were computed at corresponding liquid limit and plastic limit values.

This research result reveals that there is an outstanding relationship between the water contents and un-drained shear strength of remolded soil. The regression coefficient of six soil samples is near to unity and it is around 0.96 to 0.99. However, un-drained shear strengths at liquid limit closer to the range which scatter mostly around 5 kPa and it is slightly higher than that of the previous investigations[9,18]. It also finds that the un-drained shear strengths at the plastic limits in the range which scatter around 50 kPa.

This result appears to be in conformity with the range of 20-320 kPa, reported by four other researches, Whyte[7], Skempton and Northey[11], Arrowsmith[24], Dennehy[23]. Figure-2 shows that the combined graph of six different samples. All samples give a similar pattern. Average un-drained shear strength is almost 50 kPa at PL and 5 kPa at LL. Shear strength decrease as the increase in water content and vice-verse. The samples show the similar values at the consistency limits though they have different values of plastic limit and liquid limit.

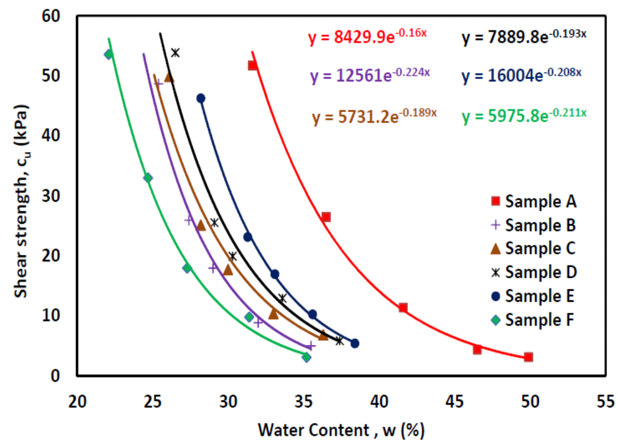

Figure-2: Shear strength vs water contents for all soil samples of miniature VSTs

Conclusion

The vane shear test offers great potential in determining the un-drained shear strength of remolded clay soil at varying water contents. Using laboratory vane shear technique, the average un-drained shear strength of the test soils was found about 5 kPa and 50 kPa at the liquid limit and plastic limit respectively. These values can be treated as quick and rough strength marker in any geotechnical application done by the investigated soil.

Table-3: Results summary obtained from VST

Sample	Liquid limit (LL)	Plastic limit (PL)	p	q	R^2	$c_{u\,(LL)}$ (kPa)	$c_{u\,(PL)}$ (kPa)
A	49.9	31.6	8429.9	0.160	0.994	2.87	53.70
B	35.5	25.4	12561	0.224	0.986	4.42	42.45
C	36.3	26.1	5731.2	0.189	0.962	5.67	41.31
D	37.4	26.5	7889.8	0.193	0.981	5.78	47.42
E	38.4	28.2	16004	0.208	0.998	5.43	45.38
F	35.2	22.1	5975.8	0.211	0.986	3.56	56.39

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