THE USE OF LOCALLY FABRICATED INSTRUMENTS FOR MEASUREMENT OF UNDRAINED SHEAR STRENGTH OF MUDS

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ABTRACT

A literature review of submarine mudslides has shown that six methods exist to measure the undrained shear strength, Cu, of muds. Instruments for two of these methods, namely: the pull out test instrument, using a cylinder, and the laboratory cone penetration test instrument, were fabricated locally.

Test results for deltaic mangrove mud sample locally known as 'chikoko' mud, using the locally fabricated instruments gave similar results with standard vane shear tests for Cu and therefore compare well.

1.0 INTRODUCTION

Since the vane test has been introduced in geotechnical practice, it has become the most widely used tool for measuring the undrained shear strength of clays and, consequently, the usual reference for stability analysis.

During the past 40 years, it became obvious that the vane test usually overestimates the undrained strength of soils. On the other hand, triaxial compression tests (CIU type) on good quality samples usually give higher values of undrained strength than those from vane tests. As a result, soil engineers lost confidence in the measured undrained strengths.

In a state-of-the-art paper, Schmertmann (1975) pointed out that many specialists, "no longer consider Cu_v as the correct Cu, but rather as an empirical strength index test. In his conclusions, he recommended continued use of the vane test while, at the same time, recommending development of other methods using the more fundamental effective stress behaviour concepts. For this purpose, undrained tests, in situ as well as in the laboratory should be interpreted by the effective stress analysis in order to get the three parameters, $\varnothing'$, C' and u, needed for an effective stress method, rather than getting the Cu needed for a total stress method.

However, at present the interpretation of undrained tests in terms of effective stresses is difficult, mainly because of difficulty in predicting pore pressures (Otoko 1987).

This paper presents a literature review of the existing methods of measuring the undrained shear strength, Cu of muds; and the use of two locally fabricated instruments for two of the methods to measure the undrained shear strength of a deltaic mangrove mud locally known as 'chikoko' and in order to evaluate their accuracy. The need to fabricate these instruments locally, arises from the fact that these instruments are not readily available and the fact that there is need to save cost on importing them at the current high foreign exchange rates.

1.1 UNDRAINED STRENGTH, Cu, OF MUDS

Apart from the difficulty of predicting pore pressures in interpretation of undrained tests in terms of effective stresses, there is also the additional difficulty that muds generally are too soft to allow samples to be taken and tested in conventional triaxial or direct shear apparatuses (Tsui 1972; Mitchell et al 1972). Therefore stability analysis of submarine mud slopes in the Niger Delta has to be calculated in total stress terms. Such knowledge of the stability against sliding where offshore installations are going to be located is of primary consideration. (Wright and Dunham 1972).

In 1998, flooding study in the Niger Delta, Nigeria, by Mosunmolu Ltd. Lagos, sponsored by the World Bank, Federal Environmental Protection Agency and the Niger Delta Environmental Survey shows that submarine mudslides are powerful agents of degradation of submarine slopes of the Niger Delta. Submarine mudslides are also reported to cause destruction of offshore installations such as oil platforms, pipelines, and communication cables (Arnold 1967; Bea 1971, Bea and Arnold 1973; Demars et al 1977, Bea and Audibert 1980); and muds characterised by high water contents such as the chikoko mud are most at risk (Bea and Audibert 1980; Richards and Parks 1976; Prior and Coleman (1978; Schapery and Dunlap 1978).

A literature review of submarine mudslides has shown that six methods exist to measure the undrained strength, Cu, of muds either in the field or in the laboratory. These methods are: (a) the vane shear test (Schapery and Dunlap 1978; Tsui 1972; Mitchell et al 1972; Kraft Jr. et al 1976 ; Chaney and Demars 1985), (b) the cylinder-strength meter test (Vellejo and Tarvin 1982) (c) the sphere-strength meter test (Johnson 1970, Hampton 1970) (d) the cone penetration test (Hirst et al 1972; Rodin 1975; Ladd, et al 1977; Chaney and Demars 1985, (e) the pullout test using a cylinder (Reese and Casbarian 1968; Lim 1974; Ghazzalli and Lim 1975) and (f) the mudslide profile method (Vallejo 1986).

2.0 DESCRIPTION OF THE TWO LOCALLY FABRICATED INSTRUMENTS

(a) The Pull out test using a cylinder

Details of the pull out test method is fully described by Reese and Casbarian (1968), Lim (1974) and Ghazzalli and Lim (1975). The instrument was fabricated and set up as presented in Fig.1(a) and 1(b). Fundamentally, a cylinder of known weight and dimensions is buried to a certain depth in a mud sample of Liquidity Index greater than unity. Then the force, F, needed for the pulling out of the cylinder slowly and steadily is measured. Non dimensional analysis of the results to obtain Cu of the mud is then carried out using Fig. 2 (after Reese and Casbarian 1968). F is the pullout force, L is the length of the cylinder used, D. is the diameter of the cylinder used, Cu is the undrained shear strength of the mud sample, and H is the depth of the centre of the cylinder from the mud surface. Thus knowing F, L, D and H, and using Fig. 2 the value of the Cu of the mud can easily be obtained.

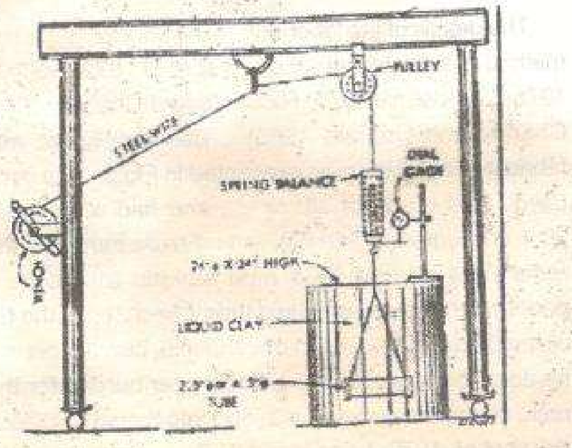

Fig 1 (a) The pullout test up (after Ghazzali and Lim 1975)

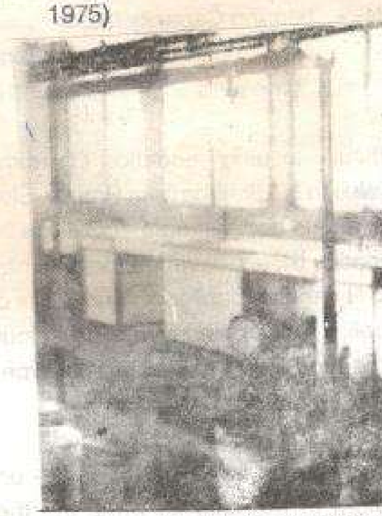

Fig 1(b) The pullout test set up (photo)

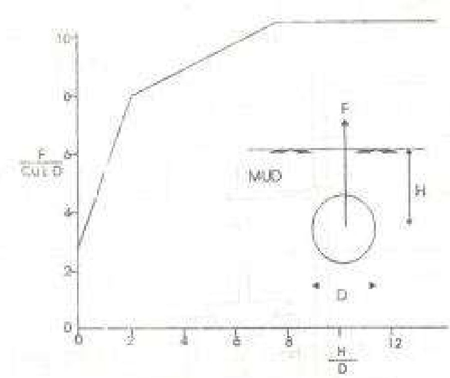

Fig. 2 A non-dimensional analysis plot of the pullout test results (after Reese and Casbarian 1968)

b. The laboratory penetrometer test

The details of the laboratory cone penetrometer test method is fully described by Hirst et al 1972; Rodine, 1975; Ladd et al, 1977; Richards and Chaney, 1980; Chaney and Demars 1985). The instrument was fabricated and set up as presented in Fig.3. The cone used was made of aluminum and had a tip angle 2θ = 60 degrees (See Fig. 3a) Fundamentally, the resistance offered by a mud sample to the cone penetration is measured and then correlated to the Cu of the mud by the use of conventional, bearing capacity equation (equation 1) with no over burden for the case of shallow cone penetration into the mud surface (Hirst et al, 1972; Ladd et al 1977).

$q_c = CuN_c$ ....(1)

where q_c = measured cone resistance
N_c = bearing Capacity factor
Cu = undrained shear strength of the mud

The difficulty in using equation (1) above, is in assigning value to N_c. Starting from Prantle, Skemphon, Mayerhof, Fellnius and Terzaghi's solutions based on bearing capacity thoeries, various values have been assigned to N_c ranging between 5 and 70 for cohesive saturated soils (∅ = 0), and N_c has been found to be related to the type of soil tested and the type of cone used Ladd, et al, 1977).

For the laboratory investigation of the undrained shear strength of the chikoko mud, the theoretical analysis developed by Rodine

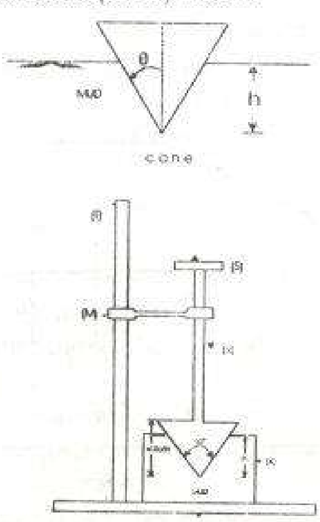

Fig. 3 (a) The laboratory cone penetration test

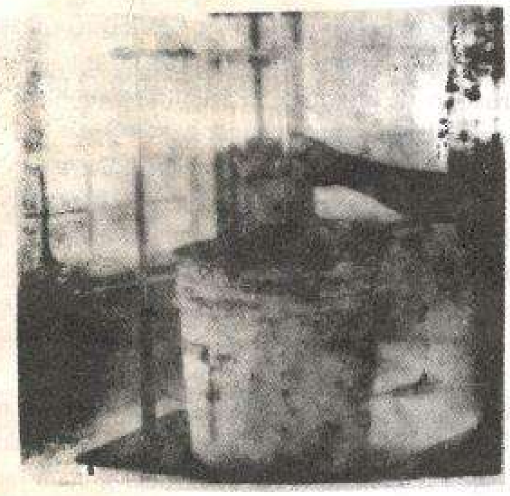

Fig. 3 (b) The Laboratory cone penetration test **(photo)**

(1975) was used. Rodine's analysis based on the slip-line approach of plasticity theory, gives the force F needed to shallowly penetrate a mud sample a distance h (fig. 3) as:

$$F = Cu\pi h^2 \tan\theta \; [0.5 + 1.5 \cot\theta + Cu$$

$$x\,(1 + \pi/_2 + 2\theta) + (\gamma\pi h^3 \tan^3\theta \cot\theta) .... (2)$$

Where θ = one half of the angle made by the sides of the cone

γ = unit weight of the mud.

1.0 DESCRIPTION OF THE STANDARD VANE SHEAR TEST

As previously described, the vane shear test is extensively used for measuring Cu, in practice, inspite of its obvious limitations. It consists of a rod at the end of which are four rectangular paddles at right angles to each other (Fig. 4).

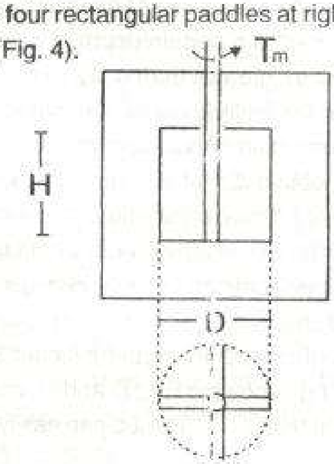

Fig. 4 (a) The vane shear apparatus

Fig. 4 (b) The vane shear apparatus (photo)

The torque resistance to rotation of the vane in the soil is used in equation (3) to obtain the undrained shear strength, Cu, of the cohesive soils.

$$Cu = \frac{2T}{\pi D^2 H (1 + D/3H)} \quad .... (3)$$

Where T = Torque
H = Height of the blades
D = Diameter of the blades

Usually, a cylindrical failure surface is assumed in vane shear tests. However, due to the fluidity of the muds, the failure surface induced by the vane cannot rigorously be represented as that of a cylinder (Johnson 1965). Also, during the rotation of a vane-like apparatus in múds, collisions and adhesions between clay particles take place which causes the particles to aggregate resulting in changes in the mud's undrained shear strength (Krone 1963, 1976).

4. LABORATORY TESTING OF MUD SAMPLES

Although artificially prepared mud samples can be made from kaoline clay, calgon and distilled water (Hampton 1970, Rodine and Johnson 1976, and Vallejo 1981, 1984), the chikoko mud used for this work was not prepared artificially, but instead was brought relatively undisturbed from Chinda waterside, Port Harcourt, to the soil laboratory of the Rivers State University of science and Technology, Port Harcourt. Classification tests on the samples showed the following characteristics:

Natural water content = 198.6%
Liquid limit = 54.8%
Plastic limit = 33.1%
Plasticity index = 21.7%
Liquidity index = 7.6
Specific gravity = 2.42
Bulk density = 11.9 kN/m^3
Clay fraction = 51.0%

The Chikoko mud was tested using the two fabricated instruments designed to obtain the Cu of muds. The mud was tested at its natural moisture content first; and then tested at subsequent moisture contents after air drying it intermittently, which represents moisture contents of 198.6%,181.5%, 174.8.%, 167.5% and 158.9%.

4.1 THE VANE SHEAR TEST RESULTS

The vane shear apparatus was used to determine the Cu of the mud at various moisture contents shown in table 1; against which results from the fabricated instruments were compared. The vane was rotated at a rate of about 10 degrees per minute. The Cu values determined for the mud samples using the vane and equation (3) are shown in Table 1 and figure 5.

Table 1:
Values of the Cu obtained from laboratory Tests (including % difference from vane results).

Moisture Content (%)	Undrained shear strength, Cu		
	Vane (kpa)	Pullout (kpa)	Cone (kpa)
198.6	6.60	6.57 (-0.5%)	6.45 (-2%)
181.5	6.88	6.75 (-2%)	6.67 (-3%)
174.8	7.61	7.56 (-0.7%)	7.48 (-2%)
167.5	8.48	8.31 (-2%)	8.27 (-2%)
158.9	9.56	9.43 (-1%)	9.39 (-2%)

4.2 THE PULLOUT TEST RESULTS

For the pullout test, the chikoko mud sample was placed in a cylindrical container. The cylinder of known weight and dimensions was buried to a certain depth in the mud. The force needed to slowly pull the cylinder out of the mud was obtained from a string-pulley-weight system (fig. 1a and 1b). The Cu values determined for the mud samples using the pullout test and the Reese and Casbarian (1968) plot shown in fig. 2 are shown in Table 1 and figure 5.

4.3 THE CONE PENETROMETER TEST RESULTS

The Cone Penetrometer apparatus fabricated locally and described in fig. 3 was used to determine in the laboratory the Cu of the Chikoko mud sample. Using the depth of penetration of the mud as a result of a known force F and equation (1), the Cu of the mud sample was determined in the laboratory. The results of the laboratory tests are shown in Table 1 and fig. 5

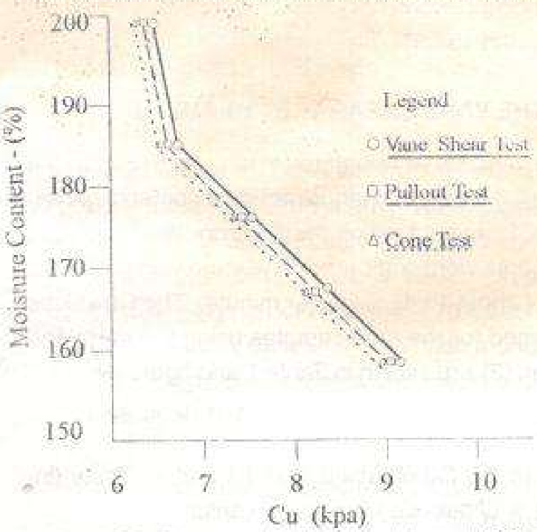

Fig. 5. Moisture content - Cu relation of Chikoko mud.

5.0 ANALYSIS OF THE RESULTS

Analysis of the results of Cu of the mud samples using the fabricated instruments depicted in Table 1 and figure 5 shows that the results from the fabricated instruments compare well with the results from the standard vane shear test; although the vane shear test results was all the time slightly higher than those from the fabricated instruments. One requirement associated with the vane shear test is that the failure surface for soil strength determination is that of a cylinder with dimensions equal or slightly greater than those of the vane blades (Arman et al, 1975). This requirement seems not to apply to muds (due to their fluidity) when they are tested by the vane. Not meeting the above requirement seems to be reflected in the slightly higher values obtained for the Cu of the muds tested.

Generally, the Cu of muds seems to be very sensitive to changes in their water content. Table 1 and figure 5 show increasing values of Cu as the moisture content of the mud decreases.

6.0 CONCLUSIONS

A literature review of submarine mudslides has shown that six methods exist to measure the undrained shear strength, Cu, of muds. These methods are: the vane shear test, the cylinder - strength meter test, the sphere-strength meter test, the cone penetrometer test, the pullout test using a cylinder, and the mudslide profile test. Instruments for two of these methods, namely: the pullout test instrument, using a cylinder, and the laboratory cone penetrometer test instrument, were fabricated locally, and used to measure the undrained shear strength of chikoko mud, in order to evaluate their accuracy. Results obtained indicate the following:

a) Table 1 and figure 5 show that the results from the fabricated instruments compare well with the results from the standard vane shear test; although the vane shear test results was all the time slightly higher than those from the fabricated instruments. This is probably because, the requirements in the vane shear test theory seem not to be met when applied to muds.

b) The undrained shear strength of muds seems to be very sensitive to changes in water content. Results show that undrained shear strength increased with decrease in moisture content.

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