Evaluation of Soft Clay Properties by the Screw Plate Test

Paramètres des Argiles Molles à la Plaque Helicoïdale

A.P.S. SELVADURAI Associate Professor of Civil Engineering, Carleton University, Ottawa, Ontario, Canada
T.J. NICHOLAS Engineer, Golder Associates, Ottawa, Ontario, Canada

SYNOPSIS This paper summarizes the results of a field testing programme which was devoted to in situ evaluation of undrained deformability and strength characteristics of a soft clay by the screw plate test. The results of forty screw plate tests carried out at the Gloucester test fill site are statistically evaluated to generate spatial averages of undrained geotechnical parameters for the tested soil region.

INTRODUCTION

Extensive deposits of glacially derived marine and lacustrine silts and clays are encountered in regions of Eastern Canada and in the Scandinavian countries. The accurate estimation of the mechanical properties of these sensitive soil deposits is in itself an important aspect of geotechnical engineering. It is generally recognized that routine sampling techniques introduce considerable disturbance errors in the laboratory estimates for the strength and deformability characteristics of such sensitive cohesive soils. Detailed accounts of the factors which contribute to such disturbance effects are documented in the researches of Crawford and Burn (1962), Bjerrum (1964), Soderman et al. (1968), Hanna and Adams (1968), Eden (1970), LaRochelle and Lefebvre (1970) and Raymond et al. (1971). Eden (1970) suggests the use of block samples as a means for minimizing the degree of sample disturbance. With this factor in mind efforts have been made (Domaschuk, 1977; Lefebvre and Poulin, 1979) to develop techniques of obtaining large diameter block samples directly from boreholes. The development of techniques is still at its early stages and the procedures involved are by no means routine. In any event the degree of disturbance associated with these "undisturbed" sample retrieval procedures constitutes an unknown factor. Therefore, where possible, recourse must be made to calibrate the laboratory parameters with equivalent results obtained from in situ tests.
The self boring pressuremeter and the screw plate test are two such in situ tests which have potential application in the estimation of deformability and strength characteristics of soft sensitive clays. Accounts of pressuremeter testing of Champlain Sea clays are reported by Roy et al. (1975) and Eden and Law (1980). Similarly, the screw plate testing of Scandinavian soft clays are reported by Janbu and Senneset (1973), Schwab (1976), Schwab and Broms (1977) and Berg and Olssen (1978).

This paper summarizes the results of screw plate tests conducted in the soft clay deposit located at the Gloucester test fill site. This site has been the subject of extensive geotechnical studies (Bozozuk and Leonards, 1972; Lo et al. 1976). A complete statistical analysis of forty screw plate tests conducted at this site is presented. Spatial average values of the undrained modulus (E_u) and undrained shear strength (c_u) are estimated via theoretical relationships developed by Selvadurai and Nicholas (1979) and Selvadurai and Szymanski (1980). In addition, the experimental results obtained by Berg and Olssen (1978) in connection with screw plate tests carried out on Gothenburg Clay are briefly examined.

THEORETICAL DEVELOPMENTS

Many of the early applications of the screw plate test were primarily concerned with the in situ testing of granular soil deposits. The methods used for the interpretation of these test results usually involved empirical assumptions. Such empiricism is, of course, not uncommon in the treatment of settlement and deformations in granular soils (Sutherland,1975; Burland, 1977). When dealing with screw plate tests conducted in cohesive soil media it is instructive to reassess the performance of the screw plate test by appeal to simplified theories of material behaviour such as linear elasticity and ideal plasticity. These theories are by no means complete descriptions of the complex mechanical properties of soils. They provide useful first approximations for the mechanical behaviour of cohesive soils at working stress and ultimate stress levels. Furthermore, the distinct advantage of using such theories is that the test parameters derived from separate in situ tests, such as the screw plate test or the pressuremeter test, permit comparison. With this in mind theoretical analyses were carried out to determine the undrained response of the screw plate test. Complete accounts of these developments are given by Selvadurai and Nicholas (1979), Selvadurai and Szymanski (1980) and Selvadurai et al. (1980). The influence of factors such as screw plate dimensions, its relative flexibility, adhesion at the plate - soil interface, disturbance due to driving action, depth of penetration, etc., were given due consideration. The following theoretical relationships were developed for the estimation of E_u and c_u.

The undrained elastic modulus (E_u) can be determined from the load (P) displacement (w) curve observed in a screw plate test, via the following relationship:

$$E_u = \{0.60 \text{ to } 0.75\} \frac{pa}{w} \qquad (1)$$

where a is the radius of the screw plate and $p = P/\pi a^2$ is the average stress acting at the soil - plate interface.

Similarly, the undrained shear strength (c_u) can be determined from the ultimate or failure load (P_{ult}) observed in a screw plate test via the following relationship:

$$c_u = \frac{p_{ult}}{\{9.00 \text{ to } 11.35\}} \qquad (2)$$

where $p_{ult} = P_{ult}/\pi a^2$.

The bounds contained in the theoretical estimates (1) and (2) stem from uncertainties with regard to the physical conditions (interface adhesion, disturbance, etc.) which constitute unknown factors in each test. The most probable engineering estimates for E_u and c_u would roughly correspond to the arithmetical average of the two bounds.

FIELD INVESTIGATIONS

The screw plate test

Detailed accounts of the screw plate device developed at Carleton University are given by Selvadurai et al. (1980) and Nicholas (1980). The screw plate used in the investigation was approximately 0.295 m in diameter. In contrast to the conventional screw plate test (see, e.g., Janbu and Senneset, 1973; Schwab, 1976) the apparatus used in this investigation has a tripod frame which is supported by three reaction anchors (Fig. 1). This apparatus avoids the use of a cumbersome horizontal beam which is required for the application of the loads in the conventional apparatus. Also, there is a greater distribution of the anchoring loads which prevents its interaction with the test region. The load is measured by a proving ring and the displacements at the proving ring level are monitored by dial gauges and a reference beam. The actual displacement of the screw plate is calculated by taking into account the shaft compression. A priming load is maintained to provide continuity in the individual sections comprising the loading shaft. These sections (of highly polished stainless steel) were liberally treated with silicone grease to minimize adhesion and frictional effects.

The Gloucester test fill site

Briefly, the soil profile at the Gloucester test fill site consists of a surface crust terminating abruptly at a depth of approximately 1.8 m with the lower 0.9 m composed of a medium stiff fissured clay. The crust rests on a soft silty clay layer of thickness approximately 0.75 m containing organic matter. The underlying grey silty marine clay extends to a depth of approximately 18 m. A more complete account of the index properties of the various strata, together with their in situ undrained shear strength characteristics, may be found in the article by Bozozuk and Leonards (1972).

The test procedure

Screw plate tests were performed at 12 locations at the Gloucester test fill site at depths of approximately 2.3 m and 4.1 m. The test locations are shown in Figure 2. The initial metre of organic matter was removed by an 0.2 m diameter hand auger to facilitate driving of the screw plate. The screw plate was driven manually to the desired depth. A probable ultimate load for the screw plate was established a priori by using the shear strength data given by Bozozuk and Leonards (1972) and the relationship (2). The screw plate was subjected to a maximum load not greater than one third of this ultimate value. Each load increment within this range was maintained for a period of 2 mins. Within these stress ranges the cohesive soil did not exhibit any accelerated creep effects. Two loading and unloading cycles were obtained for the working stress range. In the third loading cycle the screw plate was loaded until failure was observed. The occurrence of failure was usually accompanied by accelerated creep.

Test results

Undrained modulus values: A typical load-displacement curve obtained from a screw plate test conducted at the Gloucester test fill site is shown in Figure 3. The first cycle of these load-settlement curves indicates the possibility of the occurrence of some disturbance due to smearing action of the driven plate or bedding errors in the test plate. The second and subsequent cycles (Fig. 3) of each screw plate test are used for the determination of the undrained deformability characteristics. Several elastic moduli values can be estimated from any stress-strain or load displacement curve. For consistency and for purposes of comparison with other results we shall record here only initial tangent modulus values. These values are inferred from the slope of line of best fit to the initial (approximately linear) set of points (Fig. 4). Points which indicate anomalies or obvious recording errors are excluded. The Table 1 shows the results for the undrained moduli values as estimated from the second loading cycle. The histograms associated with the results are shown in Figure 5. Results similar to these can be derived for the third loading cycle and for the combination of all three unloading cycles. Details of the statistical analyses are given by Nicholas (1980) and will not be repeated here.

Table 1

Test No:	Undrained Modulus E_u			
	2.3 m depth		4.1 m depth	
	$0.6 \frac{pa}{w}$	$0.75 \frac{pa}{w}$	$0.6 \frac{pa}{w}$	$0.75 \frac{pa}{w}$
1	8.55	10.70	11.60	14.50
2	4.39	5.49	-	-
3	8.45	10.60	8.89	11.10
4	8.90	11.10	5.28	6.60
5	6.47	8.09	4.35	5.44
6	6.75	8.44	4.62	5.78
7	7.37	9.21	6.22	7.77
8	7.94	9.92	6.06	7.58
9	-	-	-	-
10	5.17	6.47	4.40	5.50
11	6.13	7.67	5.61	7.01
12	5.95	7.44	6.47	8.01

[The omitted values are due to malfunctions of the anchors; all values are in $kN/m^2 \times 10^3$]

The following summarizes the mean values of the undrained modulus as determined from the loading ($\bar{E}_u$) and unloading ($\bar{E}_{ur}$) curves at the two depths.

The statistical estimates are derived by assuming a Student's T distribution and a 95% confidence interval.

Depth 2.3 m

$\bar{E}_u$(2nd cycle) = {7.78 ± 0.82} x 10^3kN/m^2

$\bar{E}_u$(3rd cycle) = {7.61 ± 0.80} x 10^3kN/m^2

$\bar{E}_{ur}$(all cycles) = {8.77 ± 0.81} x 10^3kN/m^2

Depth 4.1 m

$\bar{E}_u$(2nd cycle) = {7.15 ± 1.23} x 10^3kN/m^2

$\bar{E}_u$(3rd cycle) = {7.35 ± 1.09} x 10^3kN/m^2

$\bar{E}_{ur}$(all cycles) = {7.62 ± 0.65} x 10^3kN/m^2

Undrained shear strength values: As has been observed by Schwab (1976) and Schwab and Broms (1977), the effect of sinkage of the screw plate makes the failure load less discernable. To obtain an accurate estimate of the failure load it is convenient to adopt a modified load-settlement representation wherein the average stress is plotted in a log scale and the screw plate settlement is expressed as a percentage of the plate radius. A failure load can then be defined as either a peak value of this modified plot or the pressure at which the slope of this curve changes abruptly (Fig. 6). The Figure 7 shows the histograms of results derived for the c_u values at the two depths. The Table 2 summarizes the limits of the undrained shear strength as obtained from screw plate tests conducted at the Gloucester test fill site.

Table 2

Test No:	Undrained Shear Strength c_u			
	2.3 m depth		4.1 m depth	
	$\frac{p_{ult}}{9.0}$	$\frac{p_{ult}}{11.35}$	$\frac{p_{ult}}{9.0}$	$\frac{p_{ult}}{11.35}$
1	7.01	5.55	10.10	8.00
2	8.05	6.38	-	-
3	11.10	8.80	14.00	11.10
4	-	-	11.10	8.80
5	8.80	7.00	11.10	8.80
6	12.50	9.90	9.90	7.90
7	10.10	8.04	-	-
8	10.10	8.04	11.10	8.80
9	-	-	-	-
10	12.20	9.70	14.00	11.10
11	9.70	7.70	12.20	9.70
12	12.20	9.70	12.20	9.70

[The omitted values are due to malfunction of the anchors; all values are in kN/m^2]

The following summarizes the average undrained shear strength values ($\bar{c}_u$) at the two depths inferred from the test data by assuming a Student's T distribution and a 95% confidence interval.

Depth 2.3 m

$\bar{c}_u$ (3rd cycle) = {9.13 ± 0.92} kN/m^2

Depth 4.1 m

$\bar{c}_u$ (3rd cycle) = {10.53± 0.90} kN/m^2

The ratio E_u/c_u

Several investigators including Ladd (1964), Bjerrum (1964), Raymond et al. (1971) and Eden (1970) have observed that the ratio E_u/c_u generally remains constant for relatively undisturbed soils and tends to decrease with increasing sample disturbance. A range of values for the ratio E_u/c_u can be evaluated from the results presented earlier in connection with screw plate tests conducted at the Gloucester test fill site. These results are summarized in Table 3.

Summary of Test results - Gloucester test fill site

Finally, it is of interest to compare the average results derived from a statistical evaluation of the screw plate tests conducted at the Gloucester test fill site with the results for the undrained shear strength and deformability characteristics as determined from in situ vane tests and laboratory tests. The laboratory undrained moduli values were determined from triaxial tests conducted with specimens obtained from block samples and high quality NGI and Osterberg samplers (Bozozuk and Leonards, 1972; Lo et al., 1976). A comparative summary is given in Table 3. (The screw plate values of E_u correspond to the second loading cycle.)

Table 3

Comparison of Screw Plate Test Results for the Undrained Strength and Deformability Parameters - Gloucester Test Fill Site

	Depth	Screw plate test	Previous studies*
E_u(kN/m^2)	2.3 m	(7.8±0.8)x10^3	(8.0 to 10.0)x10^3
	4.1 m	(7.2±1.2)x10^3	(11.0 to 13.0)x10^3
c_u(kN/m^2)	2.3 m	(9.13 ± 0.9)	10.0
	4.1 m	(10.53 ± 0.9)	19.6
E_u/c_u	2.3 m	660 to 922	630
	4.1 m	541 to 854	630

*Bozozuk and Leonards (1972); Lo et al. (1976)

Screw plate tests in Gothenburg Clay

Berg and Olssen (1978) have presented an interesting study concerning the application of the screw plate test in the estimation of deformability characteristics of a Gothenburg clay. It is of course difficult to calculate the geotechnical properties of the clay without access to the actual field data; the initial portion of the load-settlement curve must be especially carefully examined to determine the undrained modulus value. A very approximate estimate of E_u can be obtained by examining the curves given in Figures 5b and 5.2b for screw plate tests conducted with an 18 cm diameter screw plate at depths of 4 m and 6 m respectively. These results together with the theoretical relationship (1) yield the following estimates of the undrained modulus : $E_u \simeq 6.6 \times 10^3$ kN/m^2 at a depth of 4 m to $E_u \simeq 7.0 \times 10^3$ kN/m^2 at a depth of 6 m. The undrained shear strength on the other hand can be estimated reasonably accurately from the results given by Berg and Olssen (1978). The theoretical result (2) when applied to the test results given in Figures 5b and 5.2b give the following : $c_u \simeq 17.5$ kN/m^2 at a depth of 4 m to $c_u \simeq 18.0$ kN/m^2 at a depth of 6 m. The undrained shear strength values in this 2 m region as estimated from vane tests vary between 15 kN/m^2 to 18 kN/m^2.

CONCLUSIONS

On the basis of extensive theoretical studies two relationships have been proposed whereby the in situ undrained deformability and shear strength characteristics of cohesive soils can be estimated from load-displacement curves derived from screw plate tests. To verify the accuracy of the proposed relationships extensive field studies were conducted with the screw plate test at the Gloucester test fill site. The results for the undrained parameters obtained from the screw plate test compare favourably with equivalent results derived from laboratory tests on high quality soil samples. Further screw plate testing is necessary to clearly establish the accuracy of the proposed theoretical relationships. Such a testing programme should be extensive enough to cover not only efficient undisturbed sample recovery procedures but also a variety of in situ testing devices such as the screw plate test and self boring pressuremeter tests.

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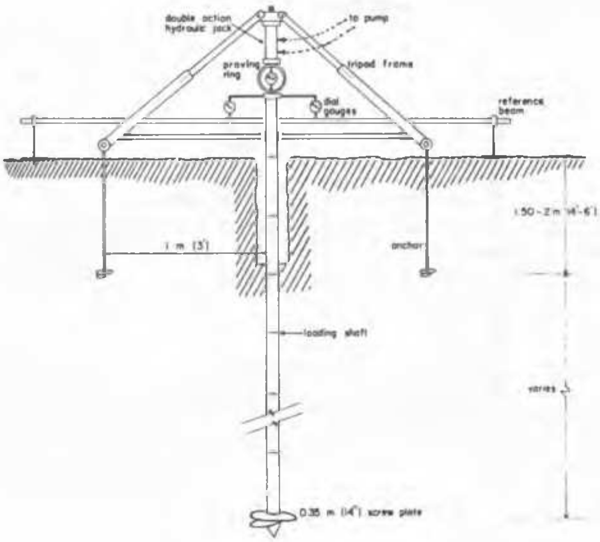

Fig. 1 The Carleton University screw plate apparatus.

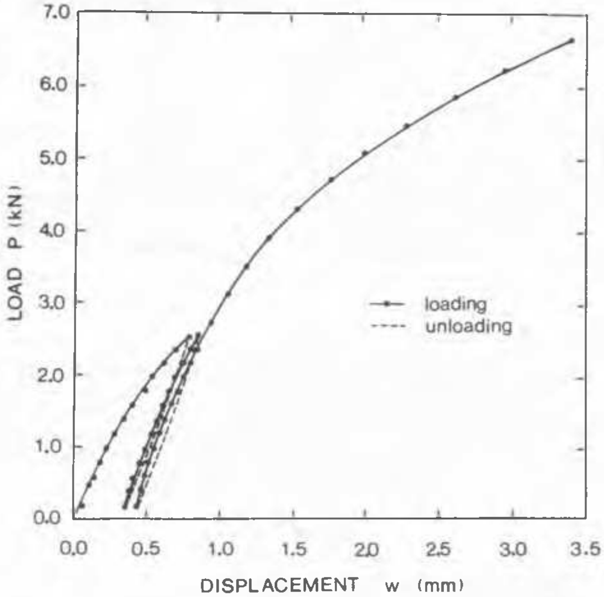

Fig. 3 Typical load(P)-displacement(w) curve for a Screw Plate Test - Gloucester Test Fill Site

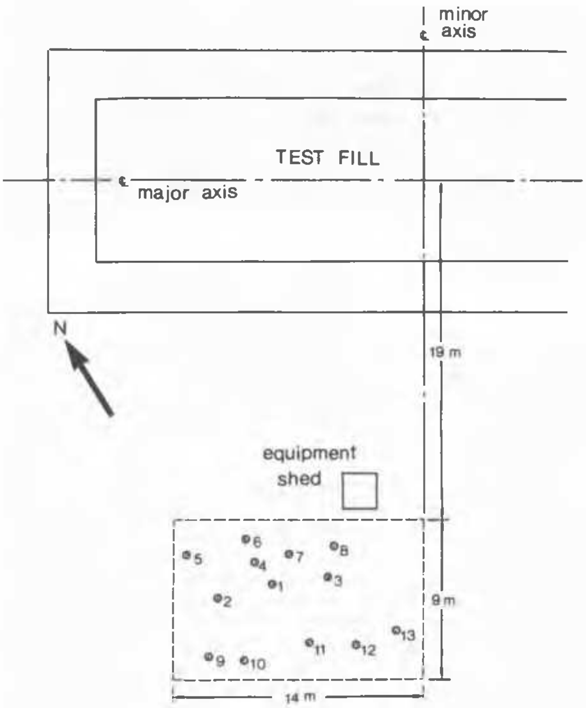

Fig. 2 Location of the Screw Plate Tests Gloucester Test Fill

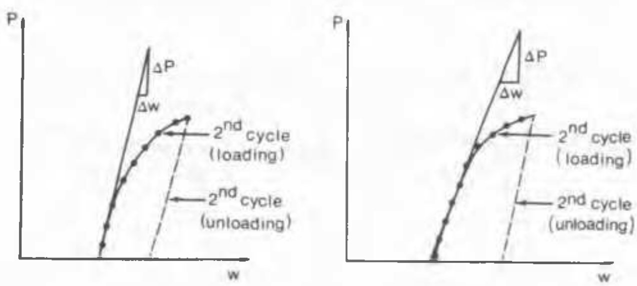

Fig. 4 Characteristic features of the load-displacement curves used in the estimation of E_u

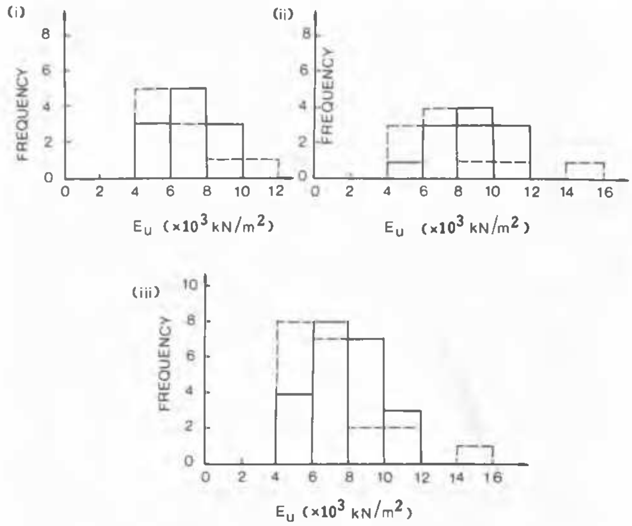

Fig. 5 Histograms for E_u values:

(i) E_u based on Eq'n(1) and factor 0.60

(ii) E_u based on Eq'n(1) and factor 0.75

(iii) E_u based on Eq'n(1) and factor 0.60 to 0.75

—— depth 2.3 m ---- depth 4.1 m

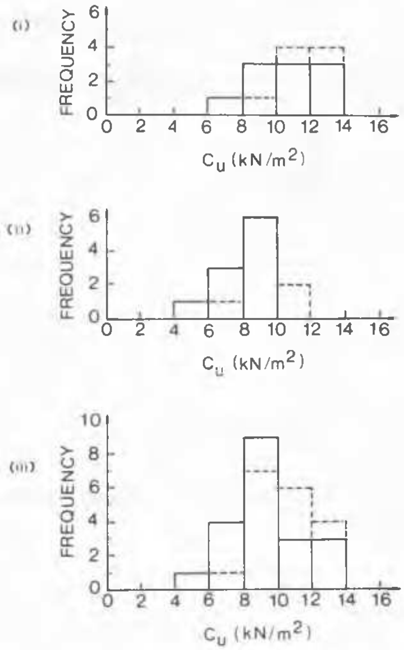

Fig. 7 Histograms for C_u values:

(i) C_u based on Eq'n (2) and factor 9.00

(ii) C_u based on Eq'n (2) and factor 11.35

(iii) C_u based on Eq'n (2) and factor 9.00 to 11.35

—— depth 2.3m ---- depth 4.1m

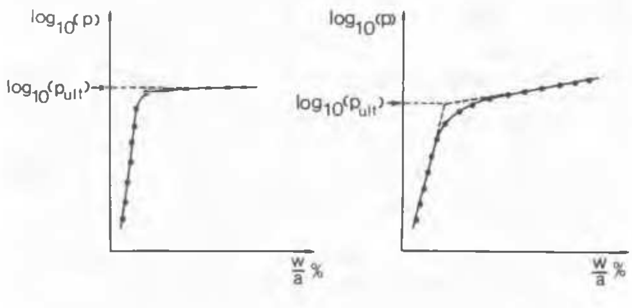

Fig.6 Estimation of limit pressure in a screw plate test