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INTERPRETATION OF FULL DISPLACEMENT PRESSUREMETER TEST

UNE NOUVELLE METHODE D'ANALYSE POUR LE TEST DU PRESSIONMETRE DE DEPLACEMENT PLEIN

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The full displacement pressuremeter (FDP) is found suitable for practical engineering applications. A new method for analyzing the FDP test is proposed. Because of the installation of FDP, an annulus of disturbed soil is formed. This disturbed annulus is divided into layers with different modulus. The disturbance index is calculated by using the generalized Lame's solution. This new method can obtain the information of the whole pressuremeter testing process including the "installation expansion" and the "probe expansion".

This method is implemented in a computer program. Graphics output of the results can be produced. FDP tests and self-boring tests were conducted at two uniform silty clay sites. For both sites, results of shear modulus from FDP tests interpreted by the proposed method showed excellent repeatability. The values of shear modulus from FDP tests also agrees very well with those from the self-boring pressuremeter tests.

INTRODUCTION

The use of in-situ tests to complement laboratory tests is becoming more and more important in geotechnical engineering (Jamiolkowski et al. 1985, Meigh et al. 1987). Compared with other in-situ tests, the pressuremeter test has one special attraction in that theoretically, the boundary conditions are well defined and controlled during the test (Baguelin et al. 1978, Mair and Wood 1987).

A full displacement pressuremeter (FDP) is used in this study. It is a pressuremeter fitted with a conical tip to ease the pushing of the device to the desired depth. It is fully mechanical, requiring no electronic instrument nor power supply. It is, therefore, completely portable and simple to use. It can be used both for offshore and onshore investigations.

Some researchers have used FDP tests in sand and clay. This study involves testing in silty clays. In the following sections, a new method of analysis is proposed. The repeatability of FDP results interpreted using the new method is investigated. Also, the results of shear modulus interpreted by the proposed method are compared to those of the self-boring pressuremeter tests.

THE FDP DEVICE

The FDP device used in this study is composed of two parts, a 60° conical tip similar to the standard static penetrometer cone, and a pressuremeter probe.

The probe is consisted of a cadmium plated steel tube on which is mounted a rubber membrane with a protective metallic sheath. The membrane with the sheath is held in place using two tapered metal rings and two lock nuts. The probe is fitted with quick connectors at both ends. One accepts the tubing leading from the pressure-volume control unit and the other, the saturation tubing. The conical tip is screwed onto the base of the probe. The top of the probe is fitted with an adaptor which accepts EX drill rod. The total length of the probe is 580 mm and its deflated diameter is 35.2 mm which is slightly less than the diameter of a standard static penetrometer cone.

INSTALLATION OF FDP DEVICE

The installation process is illustrated in Figure 1. The soil around the tip of the FDP device is divided into three areas: A, B, and C. During the penetration of the tip, soil in areas C and B mainly experiences lateral movement, which can be modelled by cylindrical expansion. This process is called "installation expansion" hereafter. Not all the soil is expanded laterally. Part of the soil in area A would be pushed downwards. The soil at the surface of the tip and the probe will experience severe shearing movement and remoulding. The neighbouring soil will also be affected by the shearing. Consequently, an annulus of disturbed soil is formed around the probe after the installation.

The exact soil state resulted from the "installation expansion" is not clearly known. One way to account for this state is to introduce an initial equivalent diameter, d_{eq}. It is an imaginary initial diameter of the hole which, when expanded to the diameter of the probe, gives the same soil state as the one caused by the installation expansion. This is illustrated in Figure 1.

One known effect of installation expansion is the pressure surrounding the probe is higher than the initial in-situ value. For FDP test, the test data or the curve is obtained after the installation has completed. The cylindrical expansion process actually started before the recording of the test data. The test data, or the volume - pressure curve represents only the information of the second phase of cylindrical expansion. This is consistant with the obervation that the values of measured initial horizontal pressure from the FDP tests are higher than those from the self-boring pressuremeter tests.

ANALYSIS OF DISTURBANCE EFFECTS

Several people have studied the disturbance effects of the Menard pressuremeter tests (Baguelin et al. 1972, 1978, Ladanyi 1974, and Sayed 1988). In their studies, only one layer of disturbed soil was considered. For the FDP test, however, the installation method is different from the Menard type or the self-boring type. The soil around the FDP probe is not disturbed by drilling, but by the mixed actions of shearing and expansion. Therefore one layer of disturbed soil does not adequately reflect the real situation around the pressuremeter.

The installation of the FDP device is similar to the penetration of a cone penetrometer. The most relevant information is how the soil is disturbed and to what extent. Mlynarek et al. (1982) conducted a model test of static cone penetration in clay. Figure 2a (redrawn from the original figure) shows their result of the deformed shape of the clay around the probe. The disturbance is greatest at the surface of the probe and decreases with distance away from the probe.

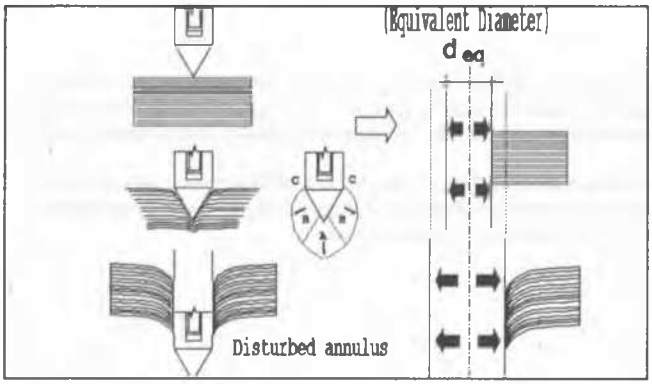

Figure 1. Installation of full displacement pressuremeter device

The above consideration suggests that the characteristics of the disturbed annulus is not uniform. Therefore the annulus should be characterized by layers of material with different modulus values. The reduction of the modulus depends on the degree of disturbance, which is related to the vertical movement of the soil (Figure 2a). The variation of the modulus therefore can be assumed to follow the pattern of the vertical movement (Figure 2c). The equation for the shear modulus G can be written as:

$$G=G_0[1-(1-\alpha)\frac{R_0^2}{r^2}] \tag{1}$$

where r = radius, G_0 = the shear modulus of the undisturbed soil, α = G_1/G_0 at r = R_0, where G_1 is the shear modulus of the soil at the soil/pressuremeter interface.

For numerical solution, the annulus is divided into layers of different thicknesses. Layers are thinner near the probe than those farther away from the probe. The inner radius (R(i)) of the i^{th} layer is given by:

$$R(i)=\frac{R_0}{N+1}(N+i^2) \tag{2}$$

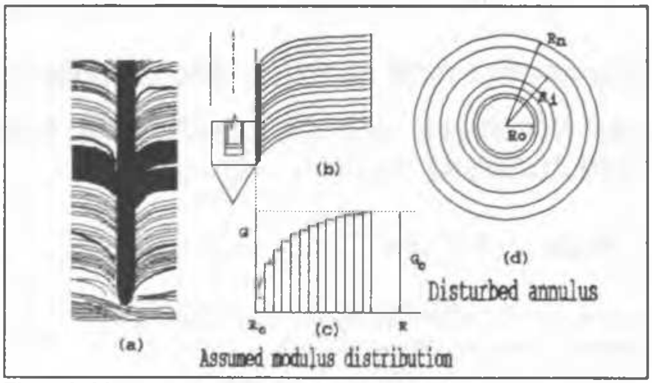

Figure 2. Model tests and assumptions for the disturbed annulus

where N > 5.

As suggested by Wroth (1984), the unloading reloading path is in elastic range if the unloading magnitude does not exceed $2S_u$, where S_u is the undrained strength. This elastic behaviour can be used to study the degree of disturbance.

The generalized Lame's solution is used for solving the problem of n layers of cylindrical annulus (Sayed et al. 1987). The matrix form of the equation is:

$$[D]\{x\}=\{b\} \tag{3}$$

where [D] is the stiffness matrix, {b} is the radial pressure vector. With different pressures of P1 and P2, the corresponding strain $\epsilon_{\theta,1}(1)$ and $\epsilon_{\theta,1}(2)$ can be calculated and the apprent modulus G_{ap} is obtained by:

$$G_{ap}=\frac{P2-P1}{2(\epsilon_{\theta,1}(2)-\epsilon_{\theta,1}(1))}=\frac{G_1(P2-P1)}{2M}=\frac{\alpha G_0(P2-P1)}{2M} \tag{4}$$

where M is a constant determined from {x}, and subscript 1 refers to parameters associated with the first layer, (1) and (2) corresponding to P1 and P2, respectively. The disturbance index I_p is defined as:

$$G_{ap}=G_0(1-I_p) \tag{5}$$

then

$$I_p=1-\frac{G_{ap}}{G_0}=1-\frac{\alpha(P2-P1)}{2M} \tag{6}$$

A computer program is compiled to calculate I_p. The ratio of α is assumed to be 0.1. Evidence in support of this number is given by Wang (1993). The calculated I_p is shown in the table below:

ν	0.3	0.4	0.499
I_r	0.512	0.487	0.45

The Possion's ratio for undrained condition is taken as 0.499. The results show that the disturbance index is not very sensitive to the change of Poisson's ratio.

EVALUATION OF PRESSURE-STRAIN RELATIONSHIP

For an ideal pressuremeter test where the soil is not disturbed, the initial starting pressure on the curve should equal to the initial in-situ horizontal pressure. The initial slope would be equal to the unload-reload slope, which is a function of the shear modulus. Accordingly, the following assumptions are made for the FDP:

1. The pressuremeter testing starts from an equivalent diameter, d_{eq}.
2. The initial slope parallels the unload-reload slope on the volume - pressure curve.
3. The volume - pressure curve is described by the equation (Arnold 1981):

$$p=\sigma_{ho}+\frac{\epsilon_c}{a+b\epsilon_c} \tag{7}$$

where p = the radial pressure, ϵ_c = the strain at the soil-probe interface; a, b are constants and σ_{ho} = the initial horizontal stress.

In the above equation, ϵ_c is a function of the equivalent diameter d_{eq}, while a, b are functions of the shear modulus G_{ur} and the shear strength S_u.

A second computer program has been developed using the simplex algorithm (Caceci et al. 1984) to obtain the values of a, b, d_{eq}, and σ_{ho}. The simplex algorithm is a numerical curve fitting method. A set of a,b,d_{eq} and σ_{ho} is treated as a vector, which can be varied following certain rules. The solution for a, b, d_{eq} and σ_{ho} is obtained when the vector is so chosen that it gives the best curve fitting for the observed volume pressure data. After analyzing many cases with this program, it is found that the constants a and b are not very sensitive to small variation of σ_{ho}. Therefore, a reasonable K_o value is assumed for the analysis. The unknowns are then reduced to a, b, and d_{eq}.

The formulation of disturbance index was incorporated in the program in the following way. From Equations 4 and 5:

$$G_{ur}=G_0(1-I_r)=\frac{P2-P1}{2(\epsilon_{\theta,1}(2)-\epsilon_{\theta,1}(1))} \tag{8}$$

Then:

$$G_0=\frac{P2-P1}{2(\epsilon_{\theta,1}(2)(1-I_r)-\epsilon_{\theta,1}(1)(1-I_r))} \tag{9}$$

Defining:

$$\epsilon'=\epsilon_{\theta,1}(1-I_r) \tag{10}$$

One obtains:

$$G_0=\frac{P2-P1}{2(\epsilon'(2)-\epsilon'(1))} \tag{11}$$

This program was developed in C language. The program can produce graphics output during the time of analysis, which helps the user to examine the intermediate and final results on the screen.

APPLICATION AND TEST RESULTS

As part of a research project in Sackville, New Brunswick (N.B.), a series of in-situ tests were performed, which includes piezocone penetration test, self-boring pressuremeter test and FDP test. The layout of these tests is shown in Figure 3.

One of the purposes of these tests is to investigate the repeatability of FDP test results. As described earlier, the soil is disturbed during the initial installation. Now the question is: is this kind of disturbance repeatable? Repeatability of the test results depends on the repeatability of the disturbance. If the disturbance is repeatable, certain correlation with other in-situ tests becomes possible.

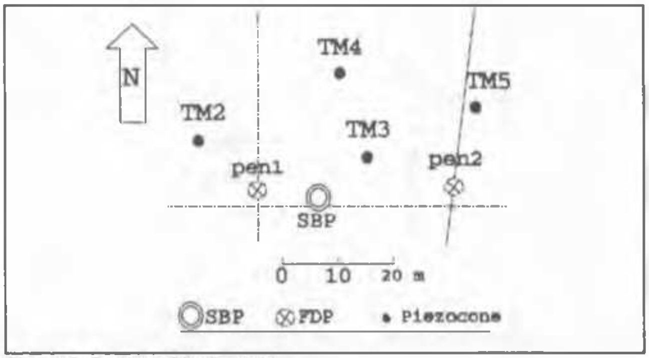

Figure 3. Layout of in-situ tests

Repeatability of test results also depends on the uniformity of soil at the site. Two cone tests were performed at a distance of about 25 m from each other (see Figure 3). The results show that the soil layers are reasonably uniform. Two series of FDP tests were performed at locations shown in Figure 3. The tests data were analyzed using the proposed method in this paper. The results are shown in Figure 4. The good agreement between the two series indicates good test repeatability.

In order to compare the FDP tests with other pressuremeter tests, several self-boring pressuremeter tests were performed at the same site. The locations are again shown in Figure 3. The unload-reload shear modulus from self-boring pressuremeter tests are shown in Figure 4, together with the shear modulus from FDP tests interpreted by the proposed method. The agreement between the results of these two tests are good.

At the site of National Research Council, two series of FDP tests and a

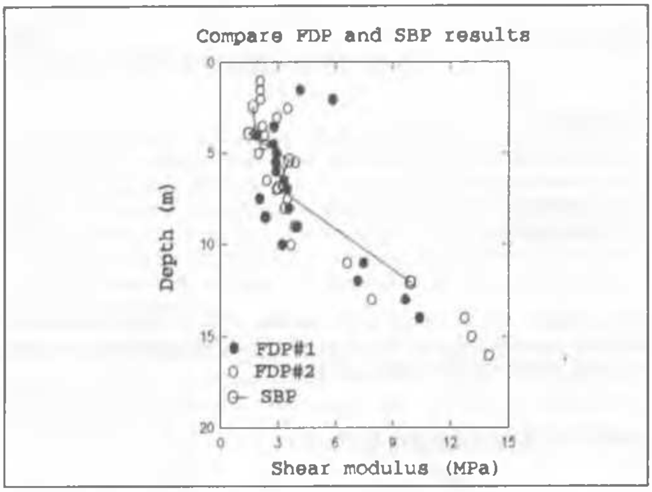

Figure 4. Shear modulus from FDP and SBP tests

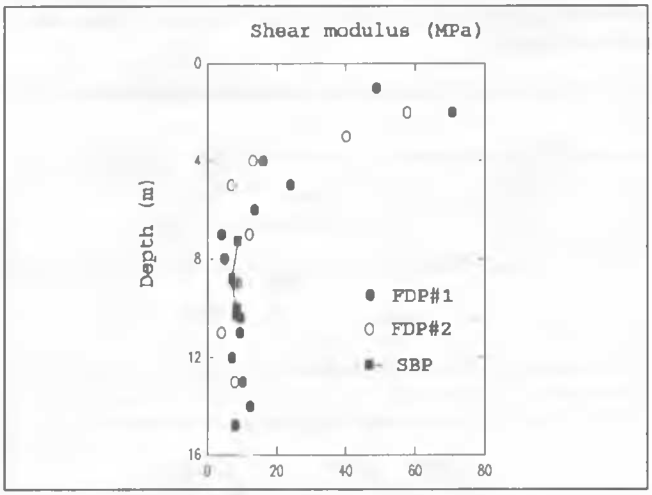

Figure 5. Shear modulus from FDP and SBP tests at NRC site

series of self-boring pressuremeter tests were conducted. The FDP results of shear modulus were again analyzed using the proposed method. The repeatability between the two series of FDP tests is good. Also, the results from the FDP tests agree with those from the self-boring pressuremeter tests, as shown in Figure 5.

CONCLUSIONS

A new method is proposed in this paper for analyzing the full displacement pressuremeter test. The method takes into account the disturbance effects due to the installation of the pressuremeter. Full displacement pressuremeter tests and self-boring pressuremeter tests were conducted at two sites and the following conclusions can be drawn:

1. The full displacement pressuremeter significantly disturbed the soil during installation.
2. The extent of disturbance is repeatable for a given site of reasonably uniform soil.
3. The disturbance can be accounted for by the method proposed in this paper.
4. The proposed method gives shear modulus from the full displacement pressuremeter test almost identical to that from the self-boring pressuremeter test.

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