Pressure-Settlement-Time Relationship by Screw Plate Tests In Situ

Relation de Pression-Tassement-Temps par Plaque Hélicoïdale

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SYNOPSIS The screw plate equipment, described by Janbu and Senneset (1973), has been used to determine the settlement-time relationship of soft soils in situ at different stress levels. Tests have been carried out in soft clay and silt at three different sites in Sweden. A general mathematical relationship between pressure, settlement and time has been developed based on the results from the field tests by using a procedure similar to that proposed by Singh and Mitchell (1968, 1969). Comparison between the mathematical solution and field results shows that the suggested relationship adequately describes the pressure-settlement-time behaviour of the investigated soils. The method was found to be valid for instanteneous loading as well as for incremental loading. The time to failure at a certain specified settlement could be calculated for different stress levels by the suggested method.

INTRODUCTION

Considerable attention has been directed in the last few years to the stress-settlement-time relationship of soft soils. Emphasis has been placed on the effect of time on the undrained shear strength of soft soils. This effect has been investigated either by laboratory tests on undisturbed samples (Berre, 1972; Bjerrum, 1972, 1973; Berre and Bjerrum, 1973; Schwab and Broms, 1975b) or by vane tests in the field (Torstensson, 1973; Wiesel, 1973).

The laboratory tests were generally carried out on undisturbed soil samples under controlled environmental and drainage conditions. The laboratory tests give qualitative results which are uneffected of e.g. inhomogeneity of the soil, drainage conditions, failure mode, anisotropy and zones of weakness generally present in situ.

The field vane test has the disadvantage that the measured shear strength is mainly governed by the shear strength along a vertical plane in the soil and the failure mechanism is different from that when e.g. the bearing capacity of the soil is exceeded. Vane tests are generally carried out on a routine basis at a constant rotation rate. Sophisticated research equipment is generally necessary when the loading rate is varied (c.f. Wiesel, 1973).

A screw plate test is stressed controlled and the time to failure can easily be varied by changing the magnitude of the applied load or the time interval between the load increments. An other advantage is that the loading condition corresponds closely to that for a footing. The scale is, however, different. In both cases the shear strength of the soil is mobilized progressively.

TEST PROCEDURE AND TEST SITES

The screw plate device is provided with a plate which is formed like a screw. The plate is screwed down to the required depth. The load on the screw plate is applied in increments. Each load increment corresponds to 10 to 15% of the estimated failure load. The relationship between pressure, settlement and time is recorded. For a standard screw-plate test the time interval between the load increments is 5 min.

The effect of time on the undrained shear strength has been investigated by varying the time between the increments. The following time intervals have been used: 1, 5, 10 and 30 min.

Tests were also carried out at constant pressure to investigate the time to failure, i.e. the time which is required to reach a certain specified settlement. The load was applied rapidly and then kept constant. The resulting settlement-time relationship was recorded.

Screw plates with 16.0 cm and 30.0 cm diameter were used with a cross sectional area of 201 cm^2 and 707 cm^2, respectively.

Three locations in Sweden have been investigated, Skå-Edeby, Umeå, Kalix. A detailed geological and geotechnical description of the test sites is given by Schwab (1976).

At Skå-Edeby a soft, normally consolidated medium sensitive clay was investigated. The natural water content is about 120% just below an approximately 0.5 m thick dry crust. At a depth of 6.0 m it is approximately 90%. The clay content is about 60%. The undrained shear strength, as determined by field vane and fall-cone tests, is about 15 kPa below the dry crust and decreases to about 9 kPa at 6.0 m depth.

At Umeå a slightly overconsolidated black organic clayey silt of medium sensitivity was investigated. The soil contains large amounts of amorphous iron sulphide which gives the soil a black colour. The natural water content varies between 45 and 60%. The organic content as determined from the ignition loss is about 3 to 4%. The clay content is low, about 2 to 5%, while the silt content is high, 80 to 90%. The undrained shear strength is about 24 kPa for the whole profile. Investigations by Schwab and Broms (1975a, 1975b) have shown that the undrained shear strength is overestimated by field vane and fall-cone tests. The undrained shear strength as evaluated from large-scale plate-load tests (ϕ1.6 m) was 15 to 17 kPa (Schwab, 1976).

At Kalix the soil consists of slightly overconsolidated black organic silty clay. The natural water content is about 140% down to a depth of 5.0 m below ground surface. Below 5.0 m it decreases slightly with depth. The organic content of the soil is high, about 10%,and the content of clay size particles is about 20%. The average undrained shear strength as determined from field vane and cone tests is 18 kPa for the whole profile. Also at this site the vane and fall-cone tests overestimated the shear strength which can be mobilized in the field. The field strength was about 8 kPa.

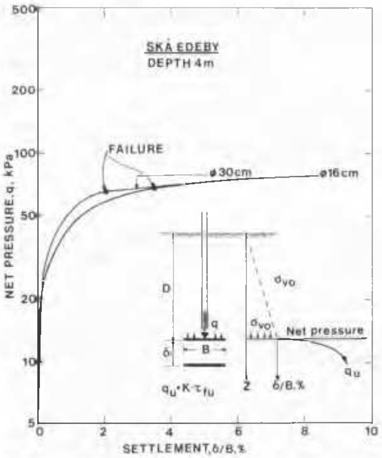

Fig. 1 Pressure-settlement relationship from standard screw-plate test

EVALUATION OF SCREW-PLATE TESTS AND TEST RESULTS

Typical pressure-settlement relationships from the standard screw-plate tests at Skå-Edeby are shown in Fig. 1. The pressure has been plotted in a logarithmic scale. The settlement is expressed in percent of the plate diameter. Plates with 16.0 cm or 30.0 cm diameter were used. Failure has been defined as either the peak value of the pressure-settlement curve or the pressure when the pressure-settlement curve reaches a relatively low and steady value.

The undrained shear strength was evaluated from the following general bearing capacity formula

$$s_u = q_u/K \tag{1}$$

where s_u is the undrained shear strength, q_u is the net ultimate pressure and K is a bearing capacity factor, which from calibration tests was found to be 9.0.

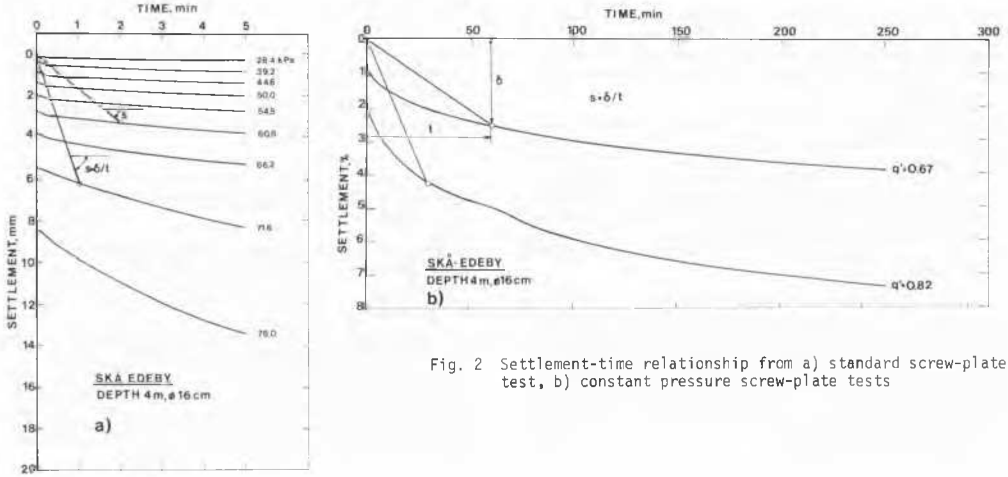

Fig. 2 Settlement-time relationship from a) standard screw-plate test, b) constant pressure screw-plate tests

The settlement-time relationships from a standard screw-plate test and a constant pressure test are shown in Fig. 2. The pressure increments at the standard test were 5.4 kPa and the pressure at the constant pressure tests corresponded to 67 and 82% of the failure pressure obtained at a standard test. It can be seen that the settlement at constant stress level decreased at a decreasing rate and that the settlement and the rate of settlement increased with increasing applied load.

The settlement-time curve is defined by the secant from the origo to any point, as indicated in Figs 2a and b. The slope s of the secant is given by

$$s = \delta/t \qquad (2)$$

in which t is the time after application of load and δ is the settlement at the time t. Thus,s corresponds to an average settlement rate.

It was found that log s decreased linearly with log t and that it increased with log q', i.e. the logarithm of the stress level. Fig. 3 shows the log s - log t and log s - log q' relationship for the tests in Fig.2.

The relationship between log s and log t are generally parallel lines at different stress levels. However, in some cases it was found that the slope of the log s - log t relationship decreased with increasing stress levels. This fact can be considered by a simple modification of the equations presented below.

The test data in Fig. 3a indicated that the log s - log t relationships curve slightly upwards at the stress level of 0.98. Creep tests carried out in the laboratory at high stress levels close to failure showed that there exists a definite transient minimum strain rate after which the strain rate increases. The test results indicated that the strain rate continued to increase and that the sample eventually would fail (Singh and Mitchell, 1968, 1969; Liam, Finn and Shead, 1973). In the field, this minimum strain rate has only occasionly been observed. The log s- log t relationship is curved slightly concave upwards at high stress levels, indicating a slight increase of the average settlement rate with time.

At low stress levels the average settlement rate is low. A straight line relationship seems then to exist between log s and log q'. At high stress levels, i.e. close to failure, the average settlement rate increases with q', as might be expected. In a range of about 0.2 to 0.8, log s increases linearly with log q'. Parallel lines are obtained for the log s - log q' relationship at different times after the load application.

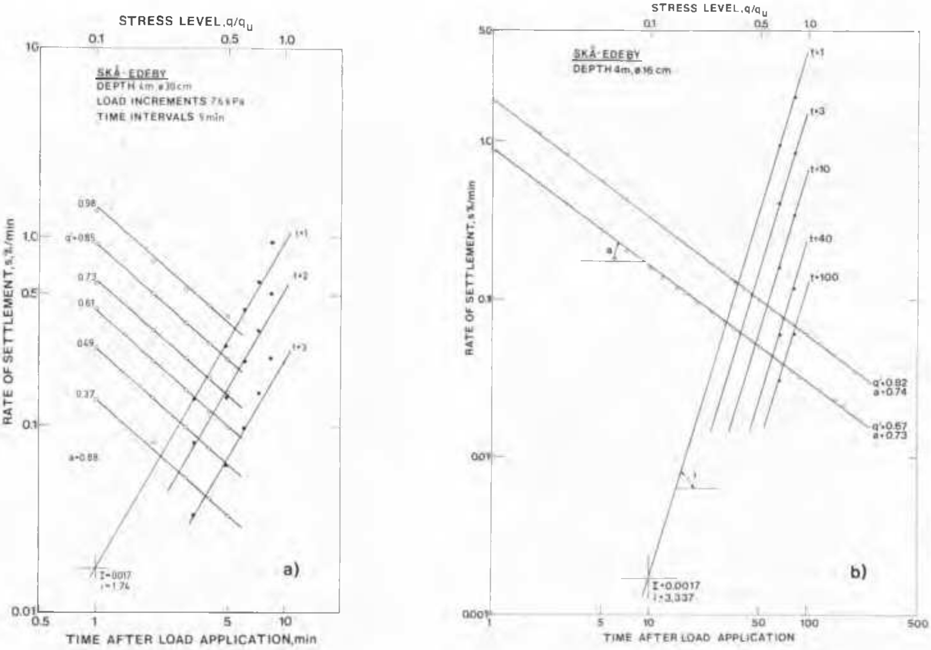

Fig. 3 Relationship between log s - log t and log s - log q' for a) standard screw-plate test, b) constant pressure screw-plate tests

The relationship for the screw-plate tests between average rate of settlement, pressure and time at a constant pressure test is given by the following equation

$$s(t,q') = I(q'/q'_1)^i (t_1/t)^a \qquad (3)$$

where $s(t,q')$ = average rate of settlement (a function of time and stress level)

t = time after load application

t_1 = unit time (e.g. 1 min)

q = stress level

q'_1 = unit stress level (e.g. 0.1)

I = intercept of straight line relationship between log s - log q'_1 for unit time, t , at unit stress level, q', i.e. the average rate of settlement at unit stress level after unit time after load application, Fig. 3.

i = slope of the linear portion of the log s - log q' relationship, Fig. 3.

a = absolute value of the slope of the straight line relationship between log s and log t.

If Eqs (2) and (3) are combined the settlement at different time and stress levels can be calculated

$$\delta = I\,(q'/q'_1)^i\,(t_1/t)^a . t \qquad (4)$$

Eq. (4) is valid for a constant pressure test.

When the effect of time on the pressure-settlement relationship is investigated with screw plate tests where the load is applied in increments, the influence of the time intervals between the load increments on I and i must be considered. It was found that i and I varied linearly with logarithm of the time interval between the load increments. These linear relationships can be expressed by the following equations

$$i_T = i_1 - h \log (T_T/T_1) \qquad (5)$$

and

$$I_T = I_1 + g \log (T_T/T_1) \qquad (6)$$

where

i_T = slope of the log s - log q' relationship for the time T_T between the load increments

i_1 = slope of the log s - log q' relationship at 1 min. intervals between the load increments (The intercept of the i-log t relationship at T_1 = 1 min.)

h = slope of the i - log t relationship

I_T = intercept of the log s - log q' relationship at unit pressure q_1 and unit time

I_1 = intercept of the I - log t relationship at time T_1 = 1 min.

g = absolute value of the slope of the I - log t relationship

T_t = time interval between the load increments

T_1 = reference time interval between load increments (1 min).

If Eqs (5) and (6) are substituted into Eq. (4) then

$$\delta = \left[I_1 + g \log(T_t/T_1)\right] (q'/q'_1)^{\left[i_1 - h \log(T_t/T_1)\right]} (t_1/t)^a . t \qquad (7)$$

This equation gives for screw-plate tests the general relationship between pressure, settlement and time at constant a when the load is applied incrementally.

It is often of interest to calculate the time t which is required to reach a specified settlement.

By rearranging Eq.(4) the following expression is obtained

$$t_f = \frac{\delta_f}{I(q'/q'_1)^i t_1^{\,a}} \exp \frac{1}{1-a} \qquad (8)$$

where δ_f is the specified settlement.

The results from the standard test (Fig. 3a) and from the test with 10 min. time intervals between the load increments, Fig. 4, were used to evaluate the parameters in Eq.(7). In Fig. 5 the i - log T_t and I - log T_t relationships are shown. The parameters are summarized in Table 1.

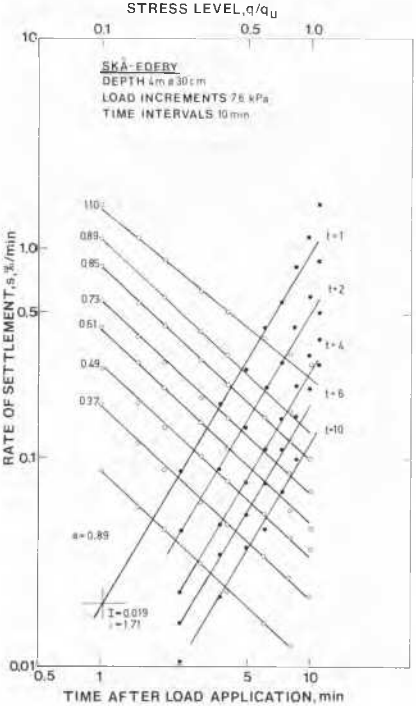

Fig. 4 Relationship between log s - log t and log s - log q' for screw-plate test at incremental loading with T_t = 10 min.

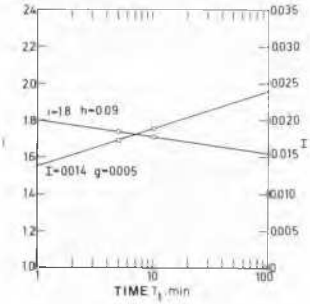

Fig. 5 Relationship between i - log T_t and I - log T from screw-plate tests at incremental loading

Table 1. Parameters obtained from two screw-plate tests at Skå-Edeby with T_t equal to 5 and 10 min.

Test	a	I	i	q_l	g	h	t_1
T_5	0.88	0.017	1.74	0.1	-	-	1
T_{10}	0.89	0.019	1.71	0.1	-	-	1
T_1	-	0,014	1.80	-	0.005	0.09	-
(from Fig. 5)							

Eq.(7) has been used to calculate the settlements at different stress levels for T_t equal to 1, 5, 10, 30 and 100 min. The calculated and measured relationships between pressure and settlement are shown in Fig. 6. Good agreement was obtained between the measured and calculated values when the stress level was less than about 0.8.

At higher stress levels, i.e. close to failure, the calculated settlements were smaller than those measured since the increase of the rate of settlement at failure is not considered. The effect of time on the pressure-settlement relationship can clearly be seen in Fig. 6. As the time interval between the load increments increases, the settlement also increases, as can be expected. The difference in settlement at a certain stress level is about 10% for a tenfold increase of the time to reach this settlement. Vane tests carried out at different rotation rates indicate about the same effect (Wiesel, 1973).

The calculated and measured pressure-settlement relationships for the test site at Umeå is shown in Fig. 7. Also here plate-load tests were used. The interval between each load increment was 5 to 10 minutes. It can be seen that the agreement between calculated and measured values is very good. The effect of time on the pressure-settlement relationship is relatively large for the organic sulphide soil from Umeå, as might be expected.

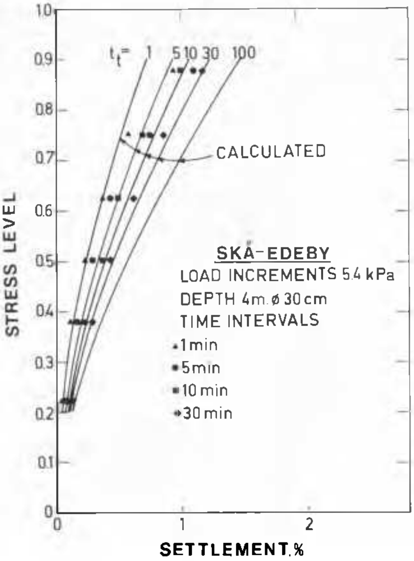

Fig. 6 Comparison between calculated and measured pressure-settlement relationships

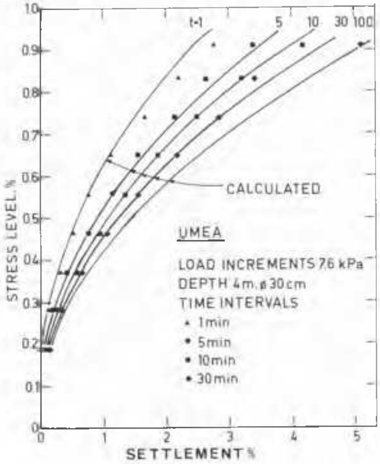

Fig. 7 Comparison between calculated and measured pressure-settlement relationships

The following values were obtained from two constant pressure tests at Skå-Edeby (Fig. 3): a = 0.73, I = 0.0017, i = 3.337. The settlement-time relationship at different stress levels has been calculated from Eq.(3). The calculated settlements at different stress levels are compared in Fig. 8 with measured values from the field tests. The same procedure was used for the constant pressure tests with the screw-plate at Umeå and Kalix. The results are shown in Figs 9 and 10. The agreement between calculated and measured values is good.

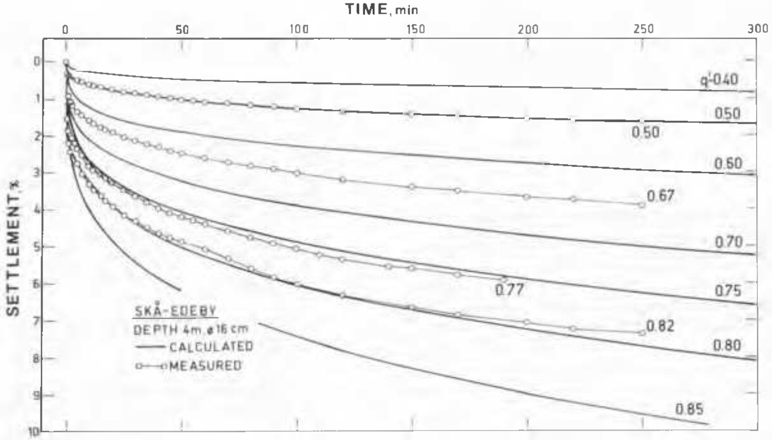

Fig. 8 Comparison between calculated and measured settlement-time relationship from constant pressure screw-plate tests

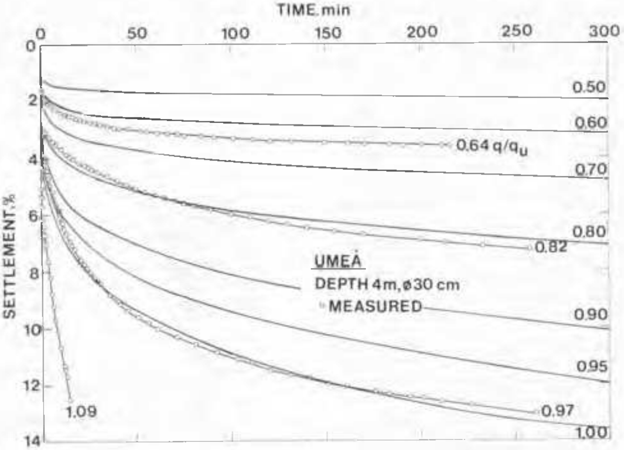

Fig. 9 Comparison between calculated and measured settlement-time relationship from constant pressure screw-plate tests

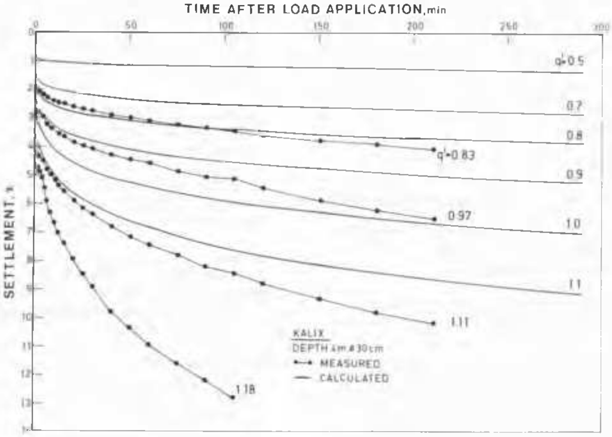

Fig. 10 Comparison between calculated and measured settlement-time relationship from constant pressure screw-plate tests

The time to failure, obtained at the standard tests, was calculated from Eq.(8) using the parameters determined from constant pressure tests. The results are summarized in Fig. 11. It can be seen that the stress level to reach failure decreased approximately exponentially with time. The results from Kalix and Umeå agreed well with the K_0-consolidated triaxial tests when the loading rate was varied (Schwab, 1976).

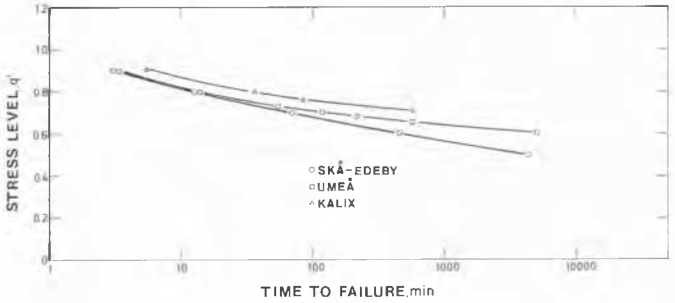

Fig. 11 Calculated relationship between stress level and time to failure

SUMMARY AND CONCLUSIONS

Screw-plate tests were carried out at three different locations in Sweden in order to investigate the in-situ strength and deformation behaviour of soft organic soils. The effect of time on the pressure-settlement relationship was investigated with screw-plate tests, where the time between the load increments was varied or the load was applied instananeously and kept constant during the test.

The test results indicate that the in-situ pressure-settlement-time relationship of soft soils can be expressed by simple equations. The proposed equations are valid for a pressure range from about 20% to 80 or 90% of the failure load determined by a standard screw-plate test. The method is applicable for both incremental and instantaneous loading.

The time to reach a certain specified settlement can be calculated for different stress levels at the constant-pressure tests.

The parameters in the proposed equations can be evaluated from two screw-plate tests with different time intervals between the load increments or from two constant pressure tests at different stress levels.

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