The Static-Dynamic Penetrometer

Le Pénétromètre Statique-Dynamique

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SYNOPSIS Static and dynamic penetrometers are being used increasingly for evaluation of the density of cohesionless soils in Sweden. As the penetrating power of the static cone penetrometer is ofte insufficient, a static-dynamic penetrometer has been developed in Sweden. With this equipment it is possible to perform a continuous dynamic probing test and intermittent static cone tests. A dynamic penetrometer with a slip coupling close to the point has also been developed so that the skin frictior resistance along the rod can be measured directly in hammer blows per 0.2 m of penetration. This paper reviews the results of some investigations from different test sites and different soil conditions in which the investigations with the new equipment have been compared with the results of static cone pen tration tests and pressuremeter tests.

INTRODUCTION

Static and dynamic penetration tests are frequently used in many countries for site investigations and foundation design. At the IXth ISSMFE conference in Tokyo in 1977 proposed standards for both static and dynamic penetrometers were adopted. However, in Sweden the penetrating power of the cone penetrometer is often insufficient and the sensitivity of the dynamic probing test is sometimes too low. The main disadvantage of the dynamic penetrometer is the difficulty of separating the point and skin friction resistances. These are the reasons for the development of a static-dynamic penetrometer fitted with a movable cone tip, and a dynamic penetrometer with a slip coupling close to the point. This equipment was presented briefly at the VIIth ESSMFE conference in Brighton in 1979 (Bergdahl, 1979).

The Swedish standard dynamic penetrometer consists of 32 mm dia. steel rods and a 90 mm long, 45 mm dia. point (Bergdahl, Dahlberg, 1973). The penetrometer is driven using a 63.5 kg hammer which falls freely 0.5 m. This is the reason for the special shape of the penetrometer tip, with the slip coupling and the movable cone (Fig.1). However, the principle of the penetrometer can of course be used for other types of standard dynamic penetrometers.

This paper reviews the results from some field investigations in which the new technique has been used and compared with electrical cone penetration tests and pressometer tests, for example. The test results from one site, Kolari, are shown in Fig.2.

Fig. 1 Shape of the dynamic probing points with a slip coupling to the left and a movable cone to the right.

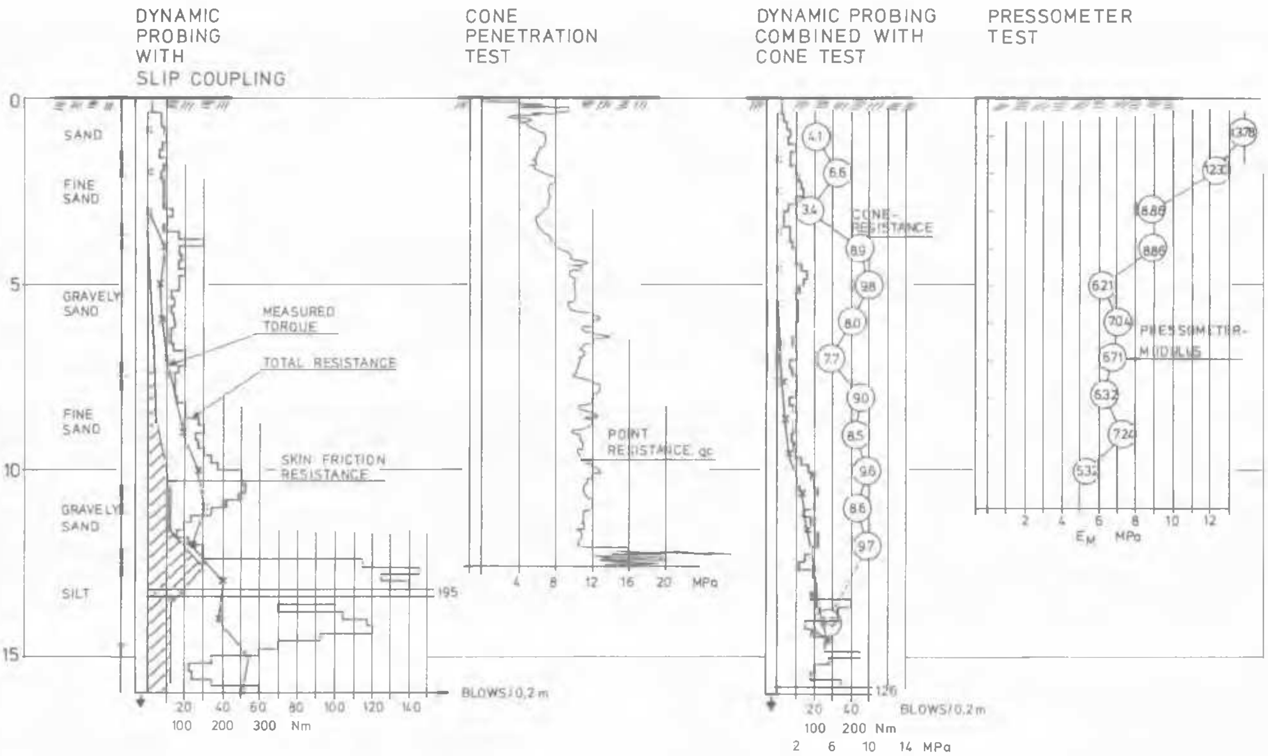

Fig. 2 Results from the different investi- gations at Kolari.

TESTS WITH A SLIP COUPLING AT THE POINT

The slip coupling has been used on six different test sites with different soil conditions, from sand and gravel to clay. At these test sites, the total penetration resistance in blows/ 0.2 m of penetration was measured. Every metre, the penetrometer rod was withdrawn 0.2 m from the point and redriven, while the skin friction resistance along the rod in blows/0.2 m of penetration was measured.

For comparison, the torque required to turn the rods was also measured every metre. According to Bergdahl & Dahlberg (1974), the skin friction along the rods, expressed in the number of blows/ 0.2 m of penetration, can be calculated from the torque required to turn the rods by using the following formula:

$$N_{skin} = \frac{2 M_v \cdot e}{D\, m_o g\, \alpha h} \qquad (1)$$

where N_{skin} = skin friction resistance along the rods in blows/0.2 m penetration
M_v = measured torque
e = penetration of the rods
D = diameter of the penetrometer rods
m_o = weight of the hammer
g = acceleration due to gravity
α = efficiency factor
h = height of fall

For the Swedish standard dynamic penetrometer, the formula (1) may be reduced to the following expression:

$$N_{skin} = 0.04\, M_v \qquad (2)$$

where M_v is the measured torque in Nm.

This formula is based on the assumption that the skin friction along the rods is the same during turning as during driving of the penetrometer.

The test results indicate (Fig.2) that the skin friction resistance at dynamic probing may also form a considerable part of the total driving resistance at quite limited depths, such as 10-15 m below ground level. In another test site (Åstorp) where the soil consists of silt and stiff clay, the skin friction along the rods was about 90% of the total driving resistance.

In Fig.3, the relationship between the measured torque and the measured skin friction resistance in blows/0.2 m of penetratiom from six test sites are summarized. The theoretical relationship from equation (2) is also included. These relationships show that there is a good correlation (correlation coefficient = 0.8-0.9) between the skin friction resistance in blows/0.2 m of penetration as measured with a slip coupling and the torque required to turn the rods.

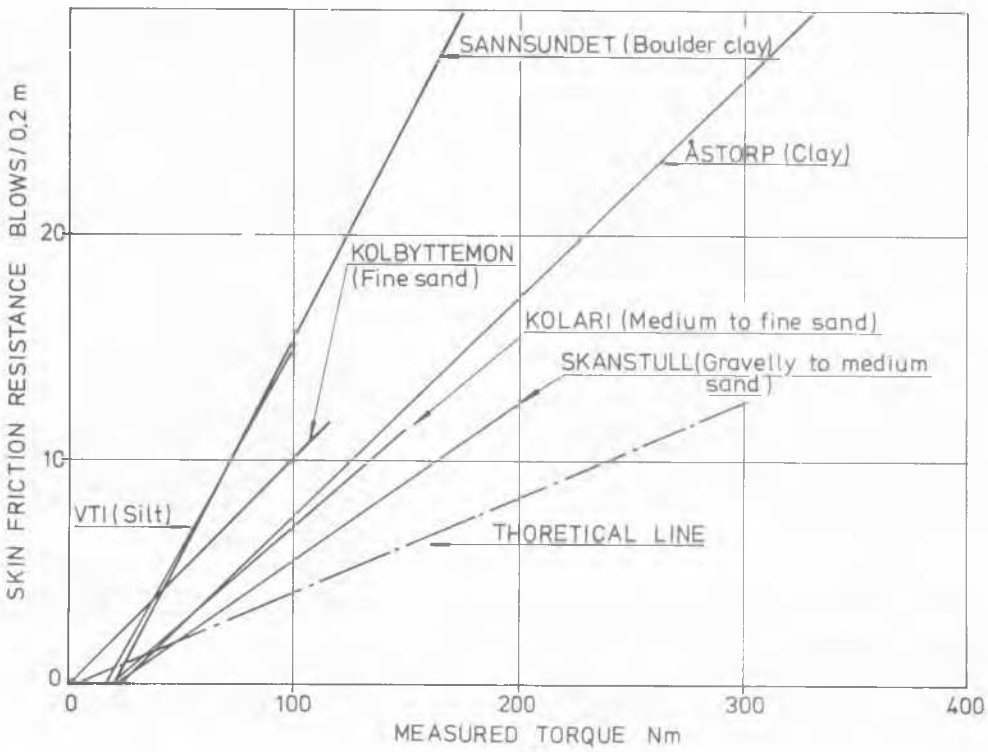

Fig. 3 Relationships between the skin friction resistance in blows/0.2 m of penetration as measured with the slip coupling and the torque applied to turn the rods.

However, these relationships differ from the theoretical values. In sand, for instance, the skin friction along the rod in blows/0.2 m of penetration is about twice the value calculated from the measured torque. In clay the skin friction resistance in blows/0.2 m of penetration is about four times the theoretical value calculated from the measured torque. These differences indicate that there are big differences between the skin friction along the rod in the static case during turning and in the dynamic case during driving. In spite of these differences, the use of torque measurements can be recommended because they indicate very well when the penetrometer starts to bend.

Results from dynamic penetrometer tests, e.g. SPT tests are often used to evaluate the density of cohesionless soils. However, from pile driving it is known that high driving resistance can occur in sandy and silty soils below the ground water table. It is therefore interesting to compare the net point resistance, total resistance minus skin friction, from the dynamic probing tests with the static point resistance from cone penetration tests, CPT. Such a comparison is shown in Fig.4 for three test sites. This figure also includes lines for accepted relationships between the values of q_c from cone penetration tests and SPT tests in different soils. These conversions have also been found to be valid for the Swedish dynamic penetrometer (Dahlberg, 1975).

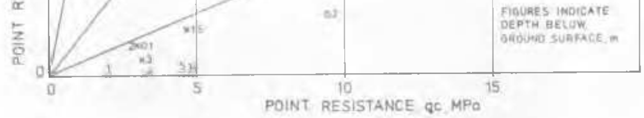

Fig. 4 Relationships between the point resistance in dynamic probing tests and in electrical cone penetration tests.

It can be seen directly from Fig.2 that the dynamic point resistance in fine sand and silt is higher than in gravelly sand. From Fig.4 it can be seen that the correlations between the point resistances during static and dynamic penetration tests are fairly good but that there are differences between the investigated test sites. However, there are also large deviations within one site, because of the soil conditions. The dynamic resistance is much higher than the static resistance especially in silty soils. It is also evident that the relationships do not coincide at the origin but cut the q_c axis at a point resistance of about 3 MPa.

These test results also indicate that during penetration testing the resistance under dynamic tests can be too high in silty and sandy soils which may be the result of dynamic pore pressure changes in the soil during driving. In foundation design, such test results must therefore be handled with care. In these types of soils it is better to use a cone penetration test to evaluate the design parameters.

TESTS WITH A STATIC-DYNAMIC PENETROMETER

The static-dynamic penetrometer point is shown to the right in Fig.1. The conical tip of the penetrometer point can be moved 40 mm by means of a system of inner rods and a hydraulic jack. The arrangement of the Borros automatic ram sounding machine, fitted with a hydraulic jack and anchor augers is shown in Fig.5-6. The hydraulic jack is connected to a special oil pump which gives a predetermined amount of oil per minute.

Fig. 5 Arrangement of the Borros AB static-dynamic penetrometer rig.

Fig. 6 The movable point is pushed down by a system of inner rods and the settlement of the point is measured on a dial gauge.

In field tests, normal dynamic probing tests were performed while the penetration resistance as the number of blows/0.2 m of penetration was recorded. A cone test was performed at every metre. In this test, the cone was pushed down at a constant rate of penetration (3 mm/min) while the corresponding point resistance and settlement of the point were recorded as shown in Fig.7. The plotted curves have been adjusted for the weight and the compression of the inner rods.

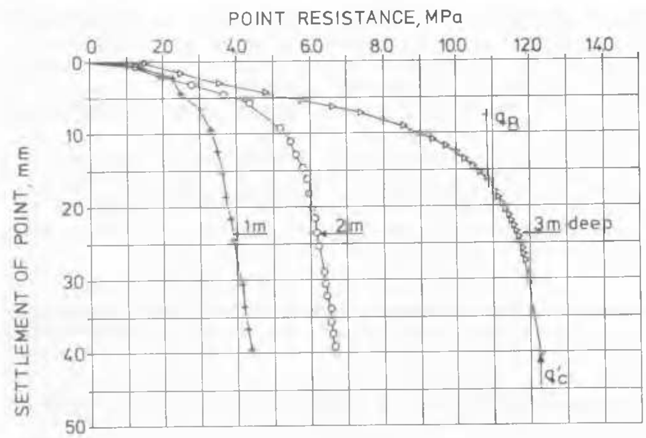

Fig. 7 Curves of point resistance versus settlement from some cone tests performed using the static-dynamic penetrometer.

Two characteristic values have been taken from these curves - one is the point resistance, q_c', for 40 mm of penetration, which might be regarded as corresponding to the case of continuous failure with the electrical cone penetrometer. The other value, q_B, is taken where the radius of curvature of the curve is a minimum. This value might be regarded as corresponding to a failure load evaluated from a plate load test, for instance. Obviously there can be large differences between these two characteristics. The slope of the resistance - settlement curve might indicate the settlement characteristics of the soil. This method of interpretation would make the static-dynamic penetrometer more useful than the normal mechanical cone penetrometer.

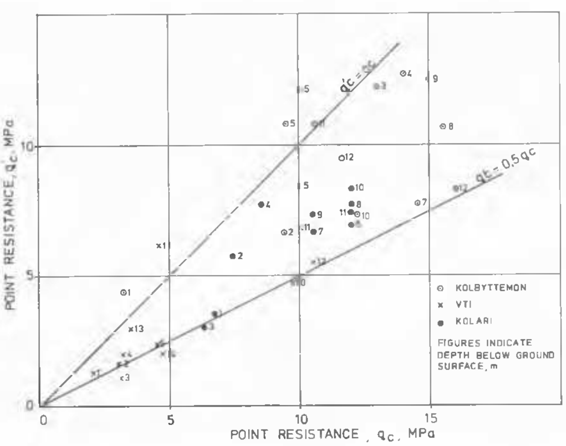

Fig. 8 Relationships between the point resistance measured using the movable cone tip and using the electrical cone penetrometer.

Fig.8 shows the relationship between the point resistance, q_c, evaluated from the electrical cone penetration tests, using Borros type equipment and the point resistance, q_c', evaluated from the settlement-resistance curves from three test sites. This plot indicates that most q_c' values are between 0.5 and 1.0 times the q_c values. This difference between the point resistances is probably due to

(i) different rates of penetration

(ii) different cone shapes

(iii) different stress levels at the beginning of the tests

(iv) the scale effect.

The greatest differences occurred in silty soils below the ground water table. This might indicate that the penetration rate for the standard cone penetrometer is too high in these types of soils. So the results cannot be used directly for foundation design. Further investigations are needed in this field, in which the point resistance is compared at different rates of penetration.

The evaluation of the point resistance-settlement curves from the static cone test indicates that this test could be used as a method of in-situ testing. Attempts have therefore been made to correlate the characteristic values from the cone tests with the results of pressuremeter tests. Such a correlation from two test sites is presented in Fig.9, in which the correlation coefficient has been obtained to 0.63. However, more investigations are necessary in order to generalise the relationships between the point resistance, q_c', from the cone tests with the movable cone tip and the plastic limit pressure obtained from pressuremeter tests. Corresponding correlations with the pressuremeter modulus, E_m, have not been obtained so far.

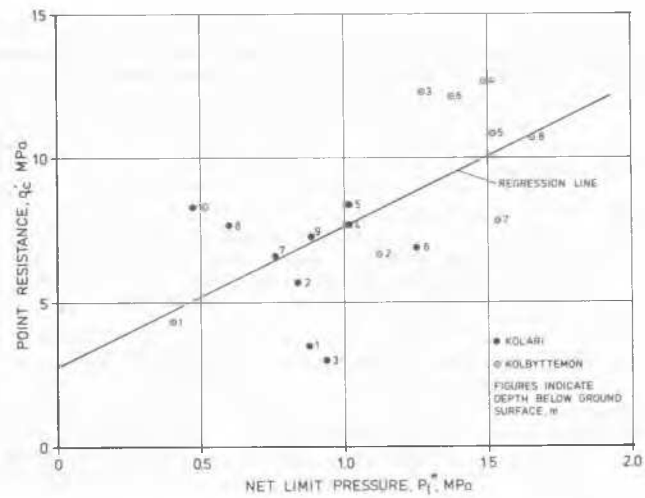

Fig. 9 Relationship between the point resistance, q_c', from tests carried out with a movable cone tip and the plastic limit, p_l^*, obtained from pressuremeter tests.

CONCLUSIONS

The test results obtained with a dynamic penetrometer fitted with a slip coupling indicate the importance of measuring the skin friction resistance along the rod directly and not only indirectly by turning the rods and measuring the torque applied. The use of torque measurements is still recommended because a sudden increase in the measured torque often indicates a bending of the penetrometer rods.

The comparison between static and dynamic penetration tests indicates that the dynamic penetration point resistance in silty and fine sandy soils can be higher than that corresponding to the density of the soil. This must be considered in foundation design. To avoid this problem, the use of a static cone penetrometer is recommended in these types of soils.

The results from tests using a movable cone tip showed that the point resistance obtained using the new equipment is lower than that obtained from standard electrical cone penetration tests. This is especially true in the case of silty and fine sandy soils where pore pressure changes may cause excessive penetration point resistances in the standard test.

The point resistance-settlement curves from the movable cone tests can be used to determine the design parameters of a soil.

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