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SOME FACTORS INFLUENCING IN-SITU VANE TEST RESULTS

QUELQUES FACTEURS QUI INFLUENCENT IN-SITU LES RESULTATS DES ESSAIS AU SCISSOMETRE
 НЕКОТОРЫЕ ФАКТОРЫ, ВЛИЯЮЩИЕ НА РЕЗУЛЬТАТЫ ПОЛЕВЫХ ИСПЫТАНИИ КРЫЛЬЧАТКОЙ

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SYNOPSIS. A new field vane borer which measures the torque and the angle of rotation in-situ down at the vane has been developed. Vane tests have been carried out in a soft normally consolidated clay in order to study the effects of vane shape and rotation rate on the measured shear strength. Also the anisotropy has been studied. The results indicate that the undrained shear strength is lower along a horizontal plane than along a vertical plane. The relation between shear strength and rate of rotation was found to follow a power function. There seems to be a better correlation between the exponent of the power function and the modulus of shear deformation, as determined in-situ with the new vane borer, than with the liquid limit.

INTRODUCTION

Vanes of different shapes can be used to determine the anisotropy of soft clays with respect to the undrained shear strength. Since friction in the ordinary vane borer and the degree of strength mobilization at the peak torque may influence the results (Wiesel, 1968 and 1971), a new vane borer which measures the torque and the angle of rotation in-situ at the vane has been developed.

Practical experience has shown that the methods which are usually used to determine the undrained shear strength of organic and other soils with a high liquid limit may give too high values. At the Swedish Geotechnical Institute (SGI) the undrained shear strength is generally reduced when the liquid limit of the clay is higher than 80%. The deformation rate is of importance for these soils. Vane tests have therefore been performed at different deformation rates in order to determine its effect on the shear strength. This effect has been correlated with the liquid limit and also with the modulus of shear deformation of the soft clay as determined with the new vane borer. It is believed that this modulus is a better indication of the stress-strain-time properties of a soil than the liquid limit.

TEST SITE

The tests reported in this article were performed at the SGI test field at Skå Edeby, located about 25 km west of Stockholm. The sediments at the test site were deposited during the Quaternary glacial and post-glacial time periods. The total thickness of the sediments is about 13 to 14 m. The post-glacial clay located at the ground surface is about 5 m thick. The glacial varved clay contains thin silt seams and near the bedrock layers of sand. The clay contains also some iron sulphide throughout the whole profile. The ground water surface is located at a depth of about 0.5 m.

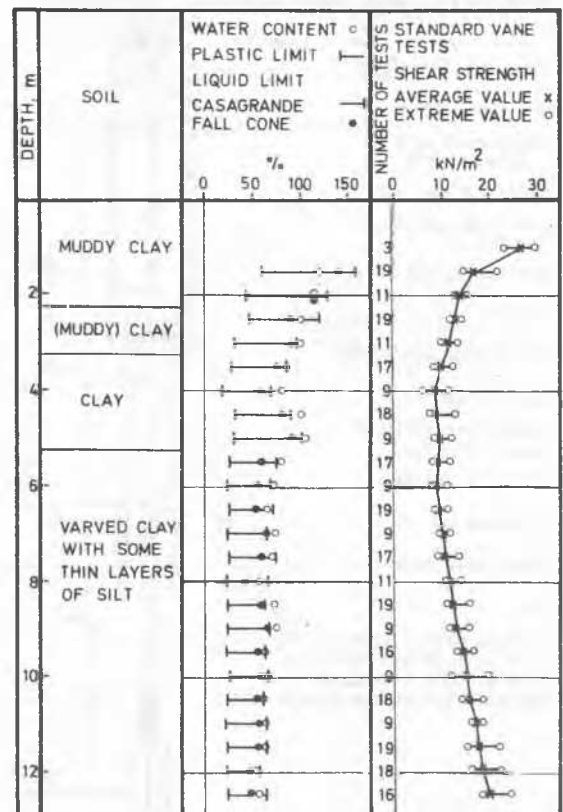


Fig. 1 Properties of the soil

The clay is soft and normally consolidated below an approximately 1.0 m thick dry crust. The unit weight of the clay increases from about 1.39 t/m^3 at 2 m depth to about 1.68 t/m^3 at 12.5 m depth. The corresponding increase of the sensitivity according to fall-cone tests is from about 11 to about 27.

Fig. 1 shows the variation with depth of natural water content, plastic limit, liquid limit and undrained shear strength as determined by conventional field vane tests. The liquid limit was determined by the Casagrande method and by the fall-cone method (Karlsson, 1961).

DESCRIPTION OF THE EQUIPMENT

The vane tests were performed with a standard vane borer (Andresen & Bjerrum, 1957; Kallstenius, 1957) and with a newly developed vane borer, which is shown in Fig. 2.

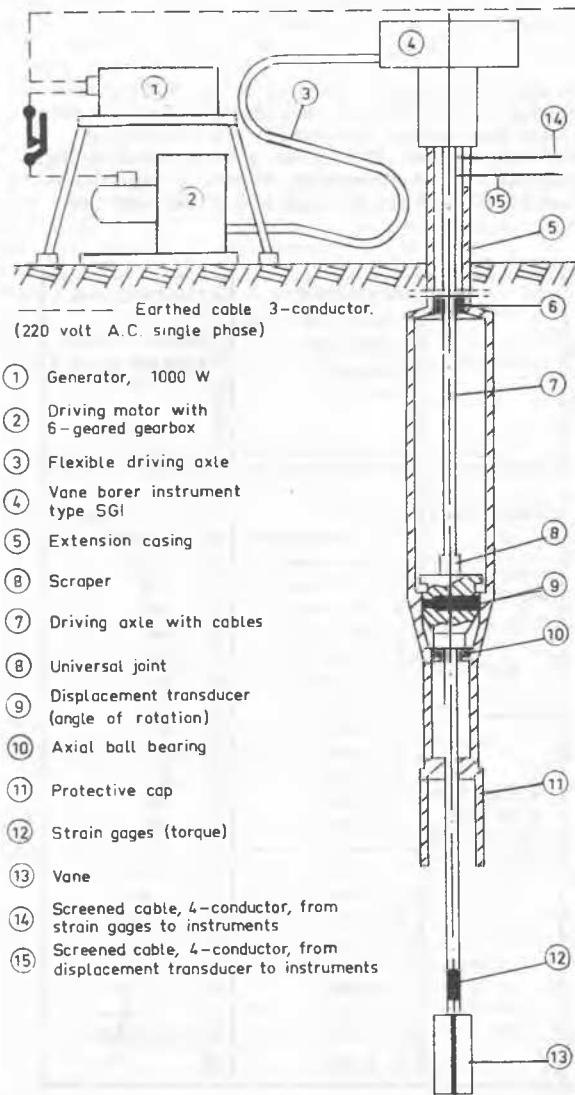


Fig. 2 Diagram of the new vane borer

The torque is measured by strain gages fastened on the shaft just above the vane. The angle of rotation is recorded by a displacement transducer located about 1.2 m above the vane. The relation between torque and angle of rotation is traced by an x-y recorder. The vane is rotated by an electrical motor attached to the vane borer instrument by a flexible driving axle. The rotation rate can be varied with a gear box.

The new vane borer was calibrated in a vertical position in a special calibration apparatus. The relation between torque and torsion (twist) of the part of the rod located between the vane and the transducer was also determined. The results from the field tests were corrected with respect to this torsion (twist).

Five vanes, all with 65 mm diameter, were used. The heights of the vanes were 130, 65, 32.5, or 16.25 mm. Two vanes with a height of 130 mm were used. One of these was a standard vane while the second vane was a new stiffer model. All vanes had 4 blades except the lowest vane, which had 8 blades.

TESTING PROCEDURE

The distance between the boreholes was at least 2.0 m. The vane tests were performed for each borehole every 0.5 m.

The standard vane tests as well as the tests with the new vane borer with vanes of different heights were performed at the standard rotation rate of $6^\circ/\text{min}$. Each test was started as soon as possible (within a few minutes) after the vane had been pushed out of the protective cap down to the test level.

Four different rotation rates were used with the standard vane borer and with the standard vane, namely $60^\circ/\text{min}$, $6^\circ/\text{min}$, $0.6^\circ/\text{min}$ and $0.06^\circ/\text{min}$. The rotation did not start until at least 15 hours had elapsed after the vane had been forced out of the protective cap down to the test level. This procedure was followed since earlier tests by the author at the standard rotation rate and at the same test field have shown that the strength of the clay is changed during this period and that this change probably will influence the results at the different rotation rates.

EVALUATION PROCEDURE

The vane test was evaluated from the assumption that the failure surface is a cylinder with a diameter and height equal to those of the vane and that the shear stresses are uniformly distributed along this surface during all stages of the test. It was also assumed that the shear strength is fully mobilized at the peak torque along vertical and horizontal surfaces of the failure cylinder. A rectangular stress distribution was assumed for the two horizontal end surfaces of the failure cylinder.

Tests with vanes of different heights were performed in order to evaluate the anisotropy of the clay with respect to the undrained shear strength along vertical and horizontal shear planes. Denoting the total torque by M , the torque from the vertical surface by M_v and the torque from each of the two horizontal surfaces by M_h , the following relation is valid

$$M = M_v + 2 M_h \quad (1)$$

If the height of the vane is denoted by H and the torque from the shear stresses along a unit height of the vertical surface of the cylinder by m_v , Eq. (1) can be rewritten as

$$M = Hm_v + 2 M_h \tag{2}$$

Since the tests were performed with vanes with the same diameter, the values of m_v and M_h will depend only on the angle of rotation and not on the dimensions of the vane. In a graphical plot with the vertical and horizontal axis representing M and H , respectively, Eq. (2) will be a straight line which intersects the vertical axis at $2 M_h$ and has an inclination equal to m_v . The values on m_v and M_h can be used to determine the shear stresses τ_v and τ_h acting along the vertical and horizontal surfaces of the failure cylinder. The procedure was repeated for different angles of rotation until a peak value of τ_{vf} and τ_{hf} was obtained. Results from tests with at least two vanes with different heights are however required. This method, unlike that proposed by Aas (1965), can be used even if the peak values are not reached at the same angle of rotation.

The values on m_v and M_h were in this investigation determined with the least square method. In order to check the consistency of the results, m_v and M_h were evaluated from three different combinations of vanes. Combination 1 consisted of the vanes with 16.25, 32.5 and 65 mm height, Combination 2 of the vanes with 32.5 and 65 mm height and Combination 3 of the vanes with 32.5, 65 and 130 (new vane) mm height.

The modulus of shear deformation of the soil was obtained with the new vane borer using the new 130 mm vane from the relationship between average shear stress and angle of rotation. The modulus was defined as the secant modulus at a shear stress equal to 4 kN/m² and was calculated from the following equation (Cadling & Odenstad, 1950)

$$G = \frac{\tau}{2.25 \omega} \tag{3}$$

where G = modulus of shear deformation, kN/m²
 τ = shear stress, kN/m²
 ω = angle of rotation, radians.

TEST RESULTS

The undrained shear strength and the angle of rotation at failure decreased with decreasing vane height. The strength obtained with the 65 mm vane was roughly 95 % and with the 16.25 mm vane 80 % of the strength obtained with the new 130 mm vane. While the angle of rotation at failure below 4.5 m depth was about 2.5 degrees for the new 130 mm vane, it was only 1.3 degrees for the 16.25 mm vane. Above the 4.5 m level the angle was much larger. It exceeded 5 degrees for all vanes at a depth of 2.0 m. The angle at the peak strength was much larger for the standard vane than for the new 130 mm vane because of the relatively low stiffness of the standard vane. The angle increased from about 2.8 degrees at 4.5 m depth to about 4.5 degrees at 12.5 m depth. These results were therefore not used for the study of the anisotropy.

The values of the ratio τ_{hf} / τ_{vf} shown in Fig. 3 correspond to the depths where at least two tests were performed with each of the four vanes. Combinations 1 and 2 gave similar results except for a few levels, while the results from Combination 3 differed from the other two combinations probably because of the relatively high flexibility of the vane with 130 mm height. It can be seen that the average value of the ratio τ_{hf} / τ_{vf} obtained with Combinations 1 and 2 is about 0.6. If a triangular stress distribution is

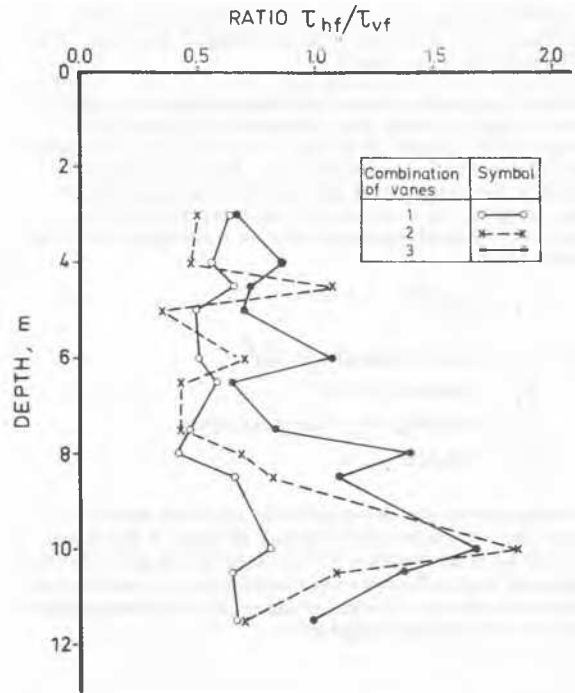


Fig. 3 Variation with depth of the ratio τ_{hf} / τ_{vf} at three different combinations of vanes

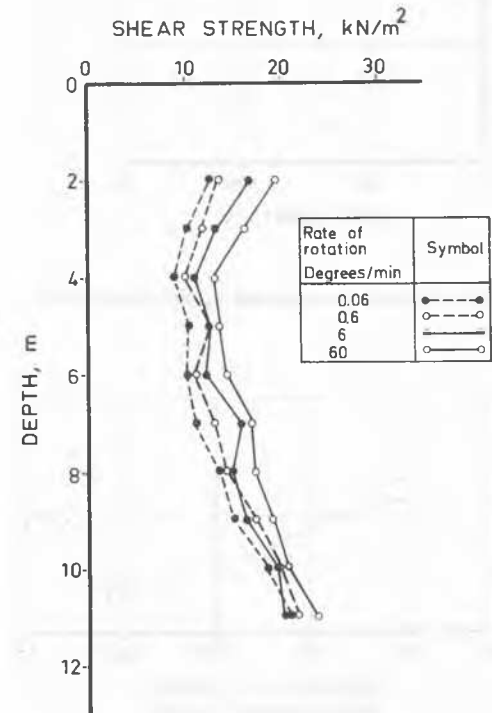


Fig. 4 Variation with depth of shear strength at different rates of rotation

assumed along the two horizontal end surfaces at the maximum value of M_h the average value of τ_{hf}/τ_{vf} will increase by 33 % to about 0.8.

The shear strength obtained at different rotation rates is shown in Fig. 4. Each point represents in general the average of two values. It is clear that the lowest strengths were obtained at low rotation rates. When the shear strengths from each level are plotted in a double-logarithmic diagram as a function of the rotation rate, the results are located approximately on a straight line of the following form

$$\tau_f = k_1 \dot{\omega}^{k_2} \quad (4)$$

where τ_f = shear strength, kN/m²
 k_1 = constant, kN/m²
 $\dot{\omega}$ = rotation rate, degrees/minute
 k_2 = exponent.

The exponent k_2 was determined by the least square method for the investigated depths. In Figs. 5 and 6 the exponent k_2 is compared with the liquid limit and with the modulus of shear deformation, respectively. It can be seen that the correlation with the modulus of shear deformation is better than with the liquid limit.

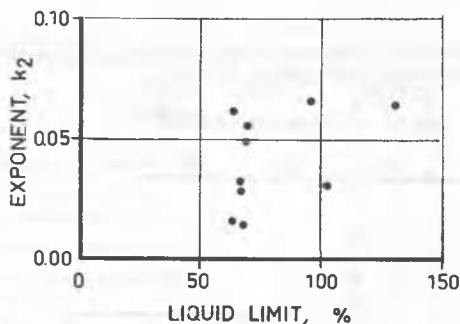


Fig. 5 Relation between the exponent k_2 and liquid limit

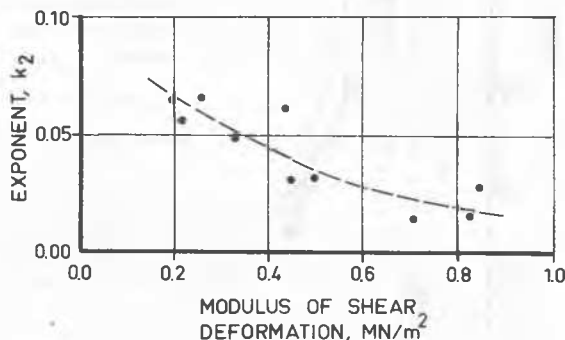


Fig. 6 Relation between the exponent k_2 and modulus of shear deformation

DISCUSSION OF THE TEST RESULTS

The test results indicate that the ratio τ_{hf}/τ_{vf} is about 0.6 to 0.8 for the Skå Edeby clay while the tests in Norway by Aas (1965) gave values of 1.5 to 2.0 for normally consolidated clays. The low ratio obtained for the Skå Edeby clay may at least partly be caused by micro-structural anisotropy. Pusch (1970) has observed a preferred particle orientation parallel with the horizontal plane for the relatively large particles in the glacial Skå Edeby clay. These particles may contribute to a larger dilatancy when the clay is sheared along a vertical than along a horizontal plane. The glacial varved clay contains some silt layers. These layers may contribute to the discrepancy at a depth of 10 and 10.5 m between Combinations 1 and 2 in Fig. 3 and to lower coefficients of correlation for the exponent k_2 in Eq. 4 at some levels in the glacial clay. The shear strength decreases with decreasing rotation rate in spite of the drainage which takes place during a vane test.

CONCLUSIONS

The following conclusions have been drawn for the Skå Edeby clay:

1. The shear strength and the angle of rotation at failure were both found to depend on the vane shape.
2. The ratio τ_{hf}/τ_{vf} was found to be lower than one when the degree of strength mobilization at the peak torque was considered.
3. The strength value was found to depend on the rotation rate according to a power function. A better correlation was found between the exponent k_2 and the modulus of shear deformation than with the liquid limit.

ACKNOWLEDGEMENT

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