Statistical analysis of soundings and test results from a silty clay

Analyse statistique des sondages et résultats d'essai d'une argile limoneuse

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SYNOPSIS This paper describes studies of the ability of the most common sounding methods in Sweden, cone penetration test (CPT), dynamic probing (DPA) and weight sounding (WST), to indicate variations in the undrained shear strength of a silty clay. The coefficients of variation of the soundings have also been studied. The purpose of the investigation is to study the uncertainties in a site investigation and find out how to estimate their magnitude and how to take them into consideration. Statistical methods have been used in the analysis of the results from the site investigation. The results from the analysis show that the CPT soundings best described the variation in undrained shear strength in the investigated area. No great difference in the coefficient of variation of the soundings could be found.

INTRODUCTION

Up to now soundings have mostly been used to locate different layers in a soil profile. Today, more geotechnical parameters, such as the coefficient of compressibility and shear strength, are analysed from soundings. If greater accuracy is to be achieved more knowledge is required on the degree to which different soundings describe a specific geotechnical parameter.

Vanmarcke (1977) pointed out that there are three kinds of source of uncertainty in a soil profile modelled from a site investigation

* A natural heterogeneity of the soil properties along the profile.
* Statistical uncertainties, from the fact that an assessment of the variation along the profile must be made from a limited number of samples.
* Measurement errors.

A fourth group of uncertainties comes from the difficulty of correlating soundings or other indirect measurements to geotechnical parameters. All these uncertainties must be taken into account in a geotechnical investigation. The inhomogeneity of the soil, the sounding method selected and the number of samples and soundings are important for the quality of the investigation. This paper deals with the two last types of uncertainty in a site investigation.

FIELD INVESTIGATIONS

In an area 20 km east of the city of Lund in the southernmost part of Sweden a site investigation, including sounding and disturbed and undisturbed sampling was carried out. The soil profile in the area consisted of half metre of topsoil. Underneath the topsoil there is a layer of silty clay with lenses of silt which varies in thickness between 2 and 10 metres. Underneath the silt there is layer of sand of unknown thichness.

In this investigation the most interesting part of the profile is the layer of silty clay. Laboratory tests show that the natural water content of this layer varies between 25 and 35 per cent. The plastic limit varies between 16 and 24 percent and the liquid limit between 31 and 55 per cent along the profile. The clay content is between 25 and 55 per cent.

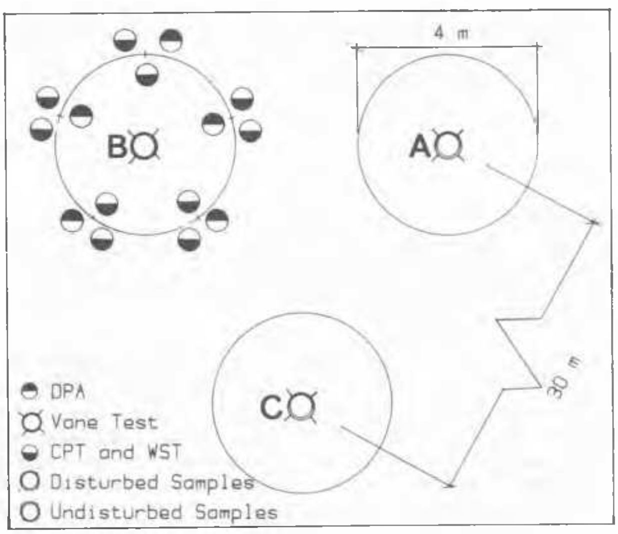


Fig. 1 Sketch showing the location of sampling and sounding points in relation of one another.

The soundings were carried out around three sample points called A, B and C. At these points, disturbed sampling and vane tests were carried out (see Fig. 1). Five groups of soundings were performed around each of the three sample points. Each group include one weight sounding, one dynamic probing and one CPT-sounding.

ANALYSIS METHODS

Different statistical methods were used in the analysis of the site investigation. First at every 0.2 m in the vertical direction the mean and standard deviation were calculated for every sounding method around the sampling points. The coefficient of variation was calculated using Eq. 1. The coefficients of variation were used for estimating the measurement errors from the three types of sounding. As the soundings around each sample point are very close to one another most of the variation is due to the sounding methods and are independent of the natural heterogeneity in the soil.

$$V = 100\% \cdot s/x_m \qquad (1)$$

V = coefficient of variation
s = standard deviation
x_m = mean value

In the analysis of ability of soundings to describe geotechnical parameters (undrained shear strength) the theory of serial analysis was used. A computer program based on this theory was employed. The geotechnical parameters were collected at intervals of 0.20 m in the vertical direction and a mean of the soundings at every 0.20 m unit were calculated, and these figures are the input for the program. The output from the program consists of correlation factors (r^2) that show how well the soundings describe the geotechnical parameter and a linear equation that converts the soundings into geotechnical parameters.

RESULTS

Soundings

The vane test results from the three sample points A, B and C are shown in Fig. 2. The undrained shear strength varies between 30 and 70 kPa in the profiles.

For the CPT-test an electric tip type BORROS was used. The cone resistance (q_c) was measured every 0.02 m and registered in digital form using a HP-85 computer. A mean of ten values in a vertical direction was calculated to get values for every 0.2 m. The q_c-value varies in the profiles between 0.5 MPa and 3 MPa.

The weight sounding and dynamic probing were carried out according to Swedish standards. For every 0.2 m penetration the number of half turns and blows were recorded. The weight sounding values in the profiles varied between 0 and 7 half turns/0.2 m penetration and the dynamic probing values varied between 1 and 7 blows/0.2 m penetration.

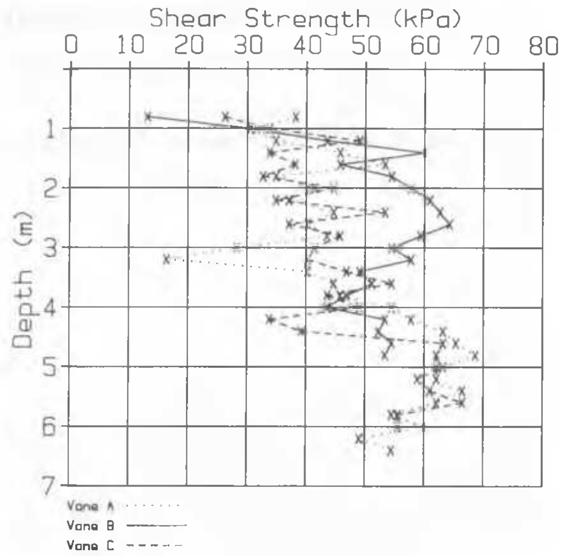


Fig. 2 Undrained shear strength determined by vane testing plotted against the depth in holes A, B and C.

Measurement errors

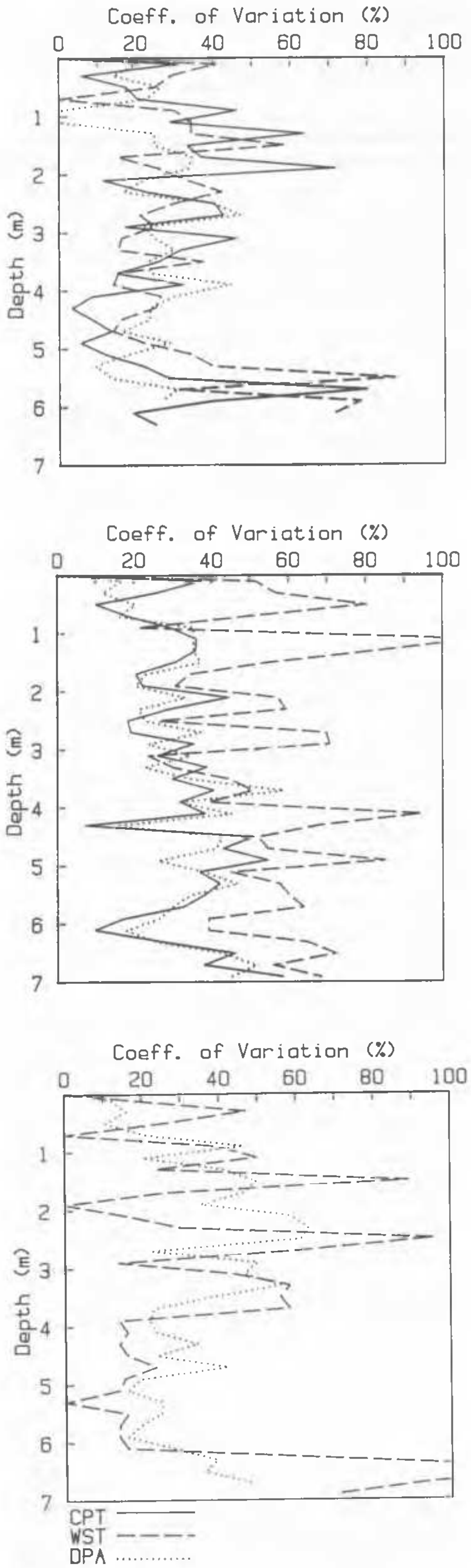
Fig. 3 shows the coefficient of variation for the three types of soundings that were used in the investigation (at point C just weight sounding and dynamic probing) as a function of the penetration depth. At point A the coefficient of variation for the three types of soundings are rather similar and at point B the weight soundings have the highest coefficient of variation.

The soundings' ability to describe the undrained shear strength

In order to compare the soundings' ability to describe the variation in undrained shear strength in the profiles the serial analysis computer program was used. The vane test results from points A, B and C were compared with the soundings around the points. The results from these comparisons show that the dynamic probing and CPT-sounding were equally able to describe the shear strength (mean of the correlation factors for the two types of sounding is r^2=0.36) while the weight sounding describes the shear strength less well (mean correlation factor r^2=0.26).

The output from the program is also a linear equation that converts the soundings into shear strengths. The principle for this linear equation is shown in Eq. 2 and numerical values for the parameters from one comparison each of the three different soundings are shown in Table I.

$$\begin{aligned} Y(z) = &(X(z-0.6)-M1)\cdot a_{-3} + (X(z-0.4)-M1)\cdot a_{-2} + \\ &+ (X(z-0.2)-M1)\cdot a_{-1} + (X(z)-M1)\cdot a_0 + \\ &+ (X(z+0.2)-M1)\cdot a_{+1} + (X(z+0.4)-M1)\cdot a_{+2} + \\ &+ (X(z+0.6)-M1)\cdot a_{+3} + (X(z+0.8)-M1)\cdot a_{+4} + M2 \qquad (2) \end{aligned}$$



Coefficients of variation for the three methods of sounding as a function of depth in the three holes A, B and C (no CPT sounding in C).

TABLE I

Numerical values for the parameters for the various sounding types in Equation 2.

Probing	M1	M2	a_{-3}	a_{-2}	a_{-1}	a_0	a_{+1}	a_{+2}	a_{+3}	a_{+4}
VaneB-CPTB5	1.01	46.6	0.00	0.11	2.91	-0.38	7.94	4.21	4.92	0.00
VaneB-WSTB5	3.57	46.6	-3.01	0.25	-4.15	2.95	1.92	3.76	2.95	2.00
VaneB-DPAB4	3.27	46.6	0.00	-0.97	0.35	3.12	2.88	2.77	0.73	0.00

M1 = mean value of the sounding
M2 = mean value of vane test (kPa)
z = depth below ground level (metre)
X(z) = sounding value at the depth z
Y(z) = strength at the depth z, as converted from soundings.

The equations described by Eq. 2 and Table I for the different sounding methods were used to convert all the soundings at point B to shear strengths. These are plotted in Fig. 4 along with the vane tests. The figures show that, using the equation, nearly all the CPT-soundings describe the shear strength very well along the profile. This is not the case for the weight soundings. This is also confirmed by the low r^2-value for the weight soundings. The reason for this difference could be that with the CPT-sounding the friction along the sounding rod does not influence the sounding value while it does in the case of the two other sounding methods.

CONCLUSIONS

This investigation indicated the necessity of investigating the measurement errors of a sounding method as well as the ability of the sounding methods to describe geotechnical parameter. In the investigation the measurement errors are of the same order of magnitude for the three types of sounding while the CPT-sounding best described the undrained shear strength. This result is probably not valid for all kinds of soil, and all geotechnical parameters.

The investigation also shows a method of comparing sounding methods and geotechnical parameters. The results from the analysis show that the undrained shear strength at depth z is best imitated by a linear combination of sounding values above and below this level.

The investigation also shows the advantage of a geotechnical investigation at one point, with many and qualitativly good measurements of a geotechnical parameter, and at this point calibrate one sounding method to the parameter. The chosen sounding method can then be used over a greater area to obtain a picture of the variation of the geotechnical parameter.

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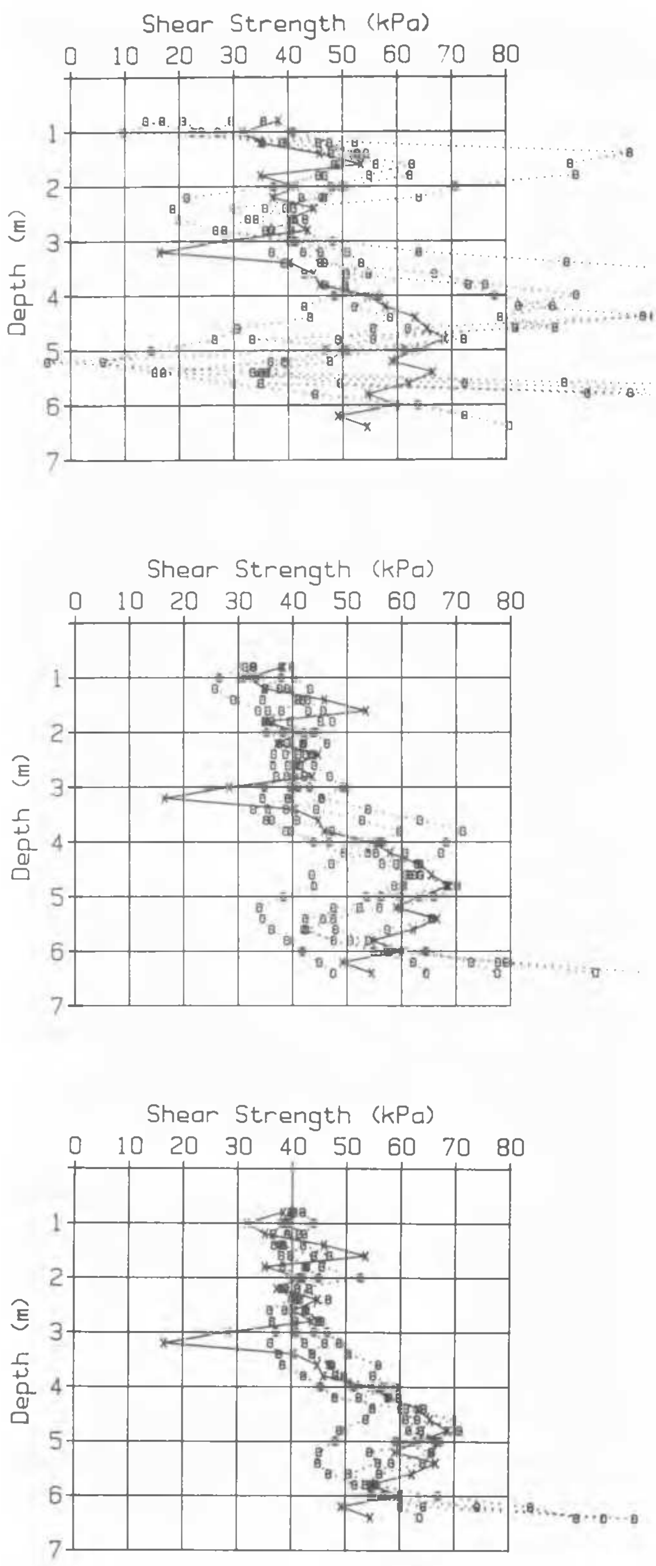

Fig. 4 The a) weight b) dynamic and c) CPT test results converted, using a linear equation, to undrained shear strength, and the vane strengths measured at point B.

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