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Determination of representative CPT-parameters

von

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A computerized 8-step procedure to determine representative CPT-parameters is presented, which has been developed within a comprehensive research program on the facilities of CPTs in geotechnical "every day engineering". The results of the procedure are the soil stratification and the input parameters for any soil classification and correlation chart. The quality of the results is at least the same as in case of borings with classification of disturbed samples by drillers, but it depends on the most accurate calibration of the whole system, as large capacity cones are used.

INTRODUCTION

Due to the high costs of conventional soil investigations constructions of less importance are often realized with poor information or even without any information about the subsoil. A comprehensive program has been started at the IGBE at Hannover University to scrutinize, if and how the facilities of CPTs can satisfy basic needs of geotechnical "every day engineering" without additional information. Due to this condition the use of high capacity cones is required. As smaller constructions usually need less sophisticated information about the subsoil, the idea of the intended method is to derive sufficient soil type information and "minimum values" of basic soil properties from CPT-results, which can be correlated to strength and deformation characteristics by general experience. With respect to this concept the research program is focussed on 5 subjects:

1. Reliability of CPT-measurements
2. Definition of CPT-parameters
3. Determination of representative CPT-parameters
4. Soil type identification
5. Basic soil property correlations

This paper deals with subjects 1 to 4, while subject 5 is still under research.

EQUIPMENT

The CPTs in the program are performed with a 100 kN standard setup with several electric GOUDA-cones [1] of different sensitivity, layed out for the measurement of 3 forces : cone resistance, local friction and pore water pressure (Fig. 1) and one more item like inclination or temperature. A computer-controlled data handling system was developed. The analogous signals of 4 channels provided by a signal conditioner are digitized simultaneously every 5 mm of depth. This data is saved on floppy disks during sounding interruptions due to pushing rod installation. Because of the high digitizing rate the plots of the data series are identical to any analogous writing. For further details see Harder and Blümel (1987).

[1] Goudsche Machinefabriek B.V., GOUDA, Netherlands

RELIABILITY OF MEASUREMENTS

From the technical point of view the reliability of CPTs is widely discussed in international publications (e.g. Schaap and Zuidberg 1982). Generally it is found to be excellent, proved by repeatability of test results. Problems arise here, as the subsoil in the north of FRG is usually found in layers of different soil types, and the thickness of the layers varies from a few centimeters to several meters. A rigidly constructed cone with at least 50 kN capacity should be used to avoid damages by overloads during sounding in dense sand layers. Data of weak layers then extends only over the very low part of the scale range and is extremely sensitive to zero-shifts and other deviations of the devices. The whole procedure therefore hinges on most accurate calibration of the system.

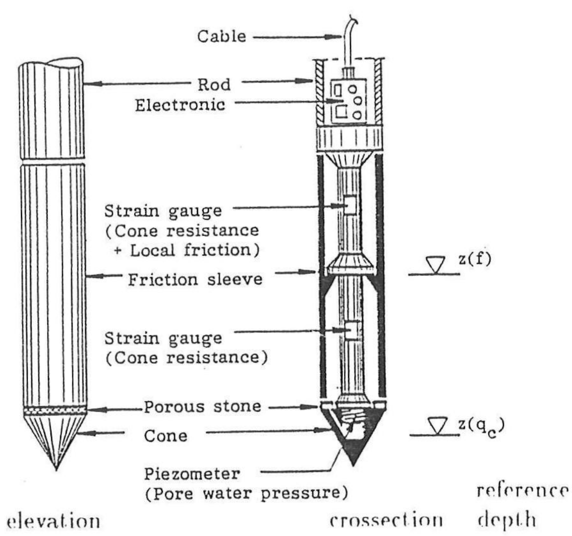
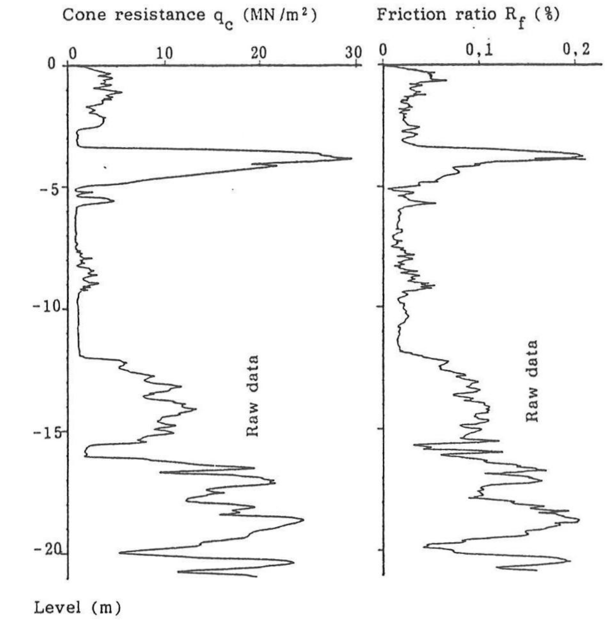


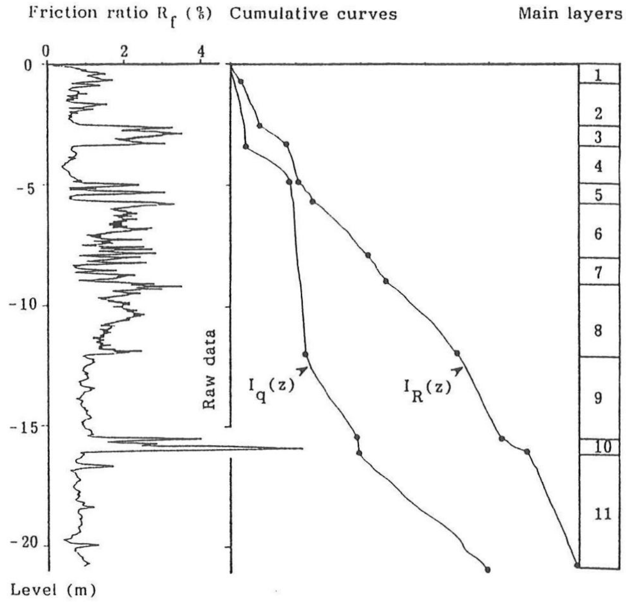
Fig. 1 Construction principle of GOUDA-cones

The GOUDA-cones used within the program are layed out rigidly and they have proved to be good for soundings in any



(a) (b)

Fig. 2 Raw data of CPT (Example)



(a) (b) (c)

Fig. 3 Friction ratio and cumulative curves

soil. The cone resistance force is measured separately, but the force of local friction is got by subtraction of cone resistance force from total tip force, which leads to significant interaction of the measured values. A series of calibration tests in the laboratory leads to individual correction functions of every cone, which include the load-level dependent deviations of the measurement devices caused by interactions and temperature dependent zero-shifts. But temperature measurement is not essential. The readings immediately after having pulled the cone back to the surface give the zero-level with good accuracy, as the underground temperature is approximately constant and the reaction of the cone to temperature changes is sufficiently slow.

The measurement of cone resistance q_c is most reliable, while local friction f sometimes tends to scatter. Reliable measurement of pore water pressure u hinges on the perfect saturation of the tip and of the soil. In case of non-perfect saturation the measured pore pressure profile indicates only the sand and gravel layers below groundwater tables. Tip saturation with silicon oil often can keep the tip saturated during sounding through non-saturated soils, but not always. In most sites the groundwater table is found several meters below ground level. As successful saturation cannot be checked until the end of the test, preboring would usually be necessary. In case of two or more water tables reliable u-measurements cannot be guaranteed.

DEFINITION OF CPT-PARAMETERS

CPT-parameters commonly proposed in publications are the directly measured *cone resistance* q_c and derived values like the *friction ratio* $R_f = f/q_c$ and the *pore pressure ratio* $R_u = u/q_c$, or more complex parameters like $\Delta u/(q_T - \sigma_{v0})$, where $\Delta u = u - u_0$ is the excess pore water pressure, q_T the cone resistance "corrected" by pore water pressure influences and σ_{v0} the initial overburden pressure.

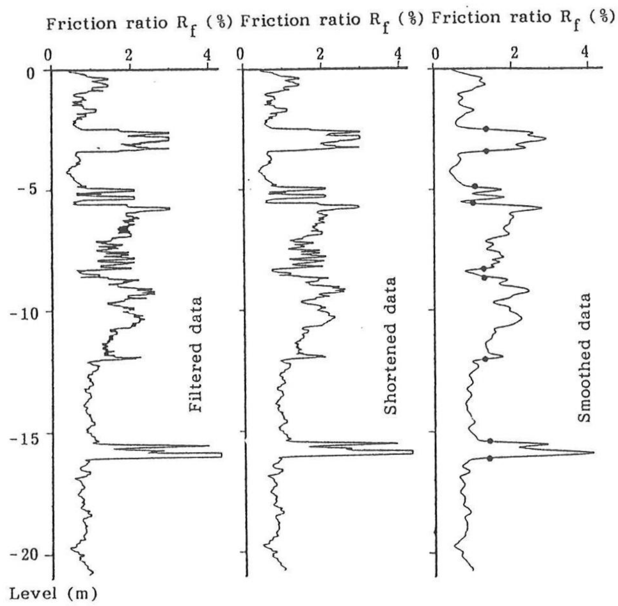
Tests in a calibration cell show that there is no need for a correction of q_c-values in case of GOUDA-cones, as the waterpressure is acting nearly all around the cone, except for the very small area of the thread at the screw joint. On the other hand excess pore pressure at cone tip can be quite different from the one measured at the cone shoulder during the sounding process (Levadoux 1980), so the "correction" of q_c by means of measured u or Δu does not always make sense. In geotechnical practice cones with u-measurement facilities are not widely in use. As reliable u-measurements are not easy to get, u is not considered in this concept. The parameters we deal with are the most reliable *cone resistance* q_c and the quite reliable *friction ratio* R_f. The friction ratio is computed with the values of q_c and f referring to the same depth z, which is related to half the height of the cone and of the sleeve, respectively (Fig. 1).

DETERMINATION OF REPRESENTATIVE PARAMETERS

The readings of CPTs usually show a fairly wide scatter within the same layer, not only from one test to another but during the same sounding, too. Not every peak indicates sublayers, but appears due to small inhomogeneities. The use of CPT-results beyond qualitative methods needs a standardized procedure to determine representative values of the CPT-parameters, because "engineering judgement" leads to significant different results and interpretation charts are quite sensitive to the input parameters. Continuous CPT-profiles provide a sufficient amount of data to apply semi-automatical procedures, so a computerized 8-step procedure of data processing was developed.

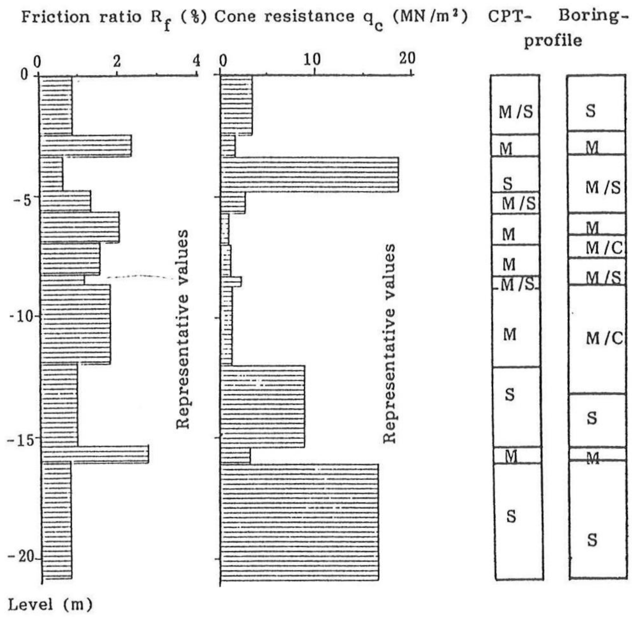
Following a remark of Albert Einstein [2] the procedure is a tool and does not decide everything by itself. Since there

[2] Make things as simple as possible, but not simpler!



(a) (b) (c)

Fig. 4 Filtering, shortening and smoothing



(a) (b) (c)

Fig. 5 Representative Parameters and Stratification

is no physical relation between the CPT-data of different layers the data series have to be divided into subseries before applying any numerical algorithm. Self-stratification by strictly defined classes of parameters is not helpful, when the parameters of a layer scatter around a classes boundary. The procedure better gets some help in defining stratification. This help is no engineering judgement, it is nothing but support by decisions.

The 8-step procedure is explained using the R_f-data of the example in Fig. 2. The original values have been measured with a 100 kN capacity cone (!). The subsoil of the test site consists of about 6 m of different hydraulic landfills over naturally stratified soils.

Step 1 : Raw Data Preparation. The raw data is the originally measured digital values of q_c and f, corrected by the individual function of the cone and combined for the friction ratio R_f (Fig. 2 and 3a).

Step 2 : Cumulative curves. The cumulative curves of the friction ratio and of the cone resistance over depth z

$$I_R(z) = \sum R_f \Delta z \qquad and \qquad I_q(z) = \sum q_c \Delta z$$

are taken as the base of the "main stratification determination". As R_f is assumed to be of constant value for a certain soil, the I_R-curve is approximately a series of straight lines with different inclinations (Fig. 3b). Compared to the raw data of R_f there is no confusing scatter. The I_q-curve does basically not consist of straight lines, but characteristical changes of the inclination are clearly detectable as well.

Step 3 : Main Stratification Determination. The bends of the I_R-curve give the depth of the main layer boundaries very clearly. Additional boundaries, for example caused by different states of the same soil type, can be derived from the I_q-curve (see for example main layers 9 and 11 in Fig. 3c : sand of different density). The following filtering and smoothing (steps 4 to 6) are done within these main layers separately!

Step 4 : Filtering. The non-characteristic elements of the raw data series, caused by small inhomogeneties, are eliminated by the filtering procedure proposed by Vivatrat (1978). This automatic filter needs two input parameters Δh and a to determine the degree of filtering and it works like this:

- Main layers are divided into substrata of thickness Δh.
- The standard deviations σ within each of three consecutive sublayers i,k,l are computed.
- The "representative" standard deviation S is selected: $S = 0.5 \cdot min\{(\sigma_i + \sigma_k); (\sigma_k + \sigma_l); (\sigma_l + \sigma_i)\}$
- The median M of the data of all of the three sublayers is computed.
- All data in layer k outside the range of $(M \pm aS)$ is replaced by the appropriate boundary values.

By this filtering procedure the insignificant information is cut. In our investigations the input parameters $a = 1$ and $\Delta h = 0.3$ m gave good results (Fig. 4a).

Step 5 : Shortening of data. For the acceleration of the following smoothing procedure the data series can be shortened by replacing every m elements by their mean:

$$\bar{V}_m = \frac{1}{m}\sum_{i=1}^{m} V_i$$

The example in Fig. 4b was produced with $m = 5$. Note that no information is cut.

Step 6 : Smoothing of data. The shortened data series are smoothed then by the application of a "moving average" procedure. A lot of sophisticated smoothing procedures for random data series are described by Davis (1973). Several of them were tried, but it proved to be the best, to apply several times the simplest version, which is a moving window of three. Every time the value $\bar{V}_m$ is replaced by:

$$\hat{V}_m = \frac{1}{3}(\bar{V}_{(m-1)} + \bar{V}_m + \bar{V}_{(m+1)})$$

The example in Fig. 4c has been smoothed 7 times. Note that no information is cut.

Step 7 : Final Stratification Determination. The smoothed curve of the friction ratio R_f is the base for the final stratification determination. The boundaries of the sublayers are detected by the turning points of significant changes of the curve, marked by • in Fig. 4c. Another set of cumulative curves may be helpful sometimes.

Step 8 : Representative Parameters. Within the intervals found by the final stratification decision the representative values of CPT-parameters for every layer are calculated as the mean values. The coefficient of variation can be used as a measure of uniformity. Fig. 5a and 5b give the results of the whole procedure for the friction ratio and for the cone resistance.

The quality of the stratification determination becomes clear by comparing the results to the stratification detected by a boring (Fig. 5c), which is located in a distance of about 10 m from the CPT.

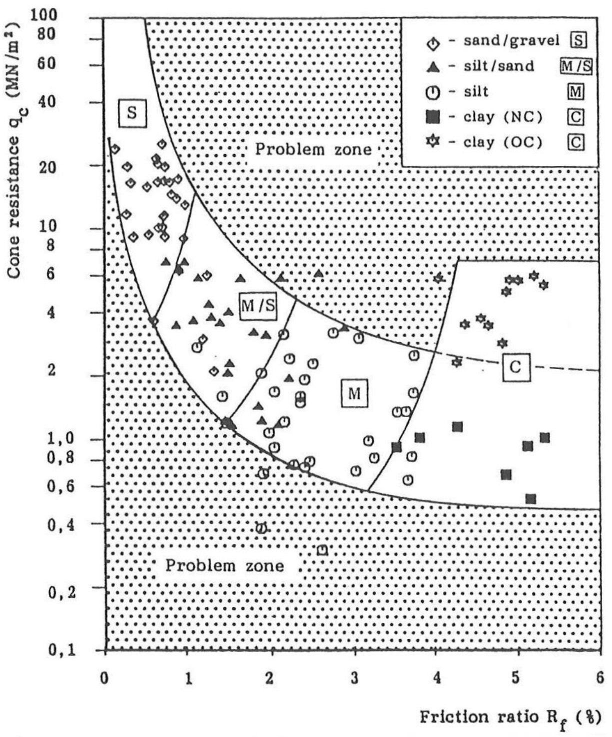


Fig. 6 Soil Identification Chart

SOIL TYPE IDENTIFICATION

The data of 21 CPTs performed with 50 kN and 100 kN cones at 3 different sites was treated by the above mentioned data processing procedure, and the results were used for soil identification, based on the classical scheme of q_c vs. R_f. The soil types are divided into five main groups (see legend in Fig. 6), as most of the soil is mixed and more sophisticated schemes could not be verified. Note that for example *silt* is rarely found in a pure state, but soil classified as *silt* is usually enriched with sand and/or clay up to 40%.

Soil classification charts have been proposed by various authors (see Douglas and Olsen 1981). They all have more or less similar tendencies, but they are quite different in important details. The results of our work fit best to the chart type proposed by Douglas and Olsen (1981). For design practice we will propose to use a slightly modified version like the one in Fig. 6, where less detailed information is layed out, but *"problem"*-zones are marked. Data points in those zones indicate either special soil conditions or non-reliable CPT-data, and additional soil investigation should be done. In Fig. 5c the soil type identification by the chart is compared to the results of the conventional soil classification by visual and manual means.

CONCLUSIONS

The determination of representative CPT-parameters can easily be performed by applying the proposed numerical filtering and smoothing procedure to digitized data. Uncertainties of engineering judgement are omitted this way. These representative parameters give sufficient information about soil stratification and soil type. This information satisfies basic needs of geotechnical "every day engineering" in many cases. The quality of the results is at least the same as in case of low quality borings with disturbed sampling. Note that laboratory tests on those samples give random data, while CPTs are continuous information profiles. However, since rigid application of a simple scheme can obscure the view of reality, representative value profiles should not be considered as substitutes for the raw data, but as one of their results.

ACKNOWLEDGEMENTS

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