CPT-Investigations in Young Sediments in the Northern Part of Jutland

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Published in:
CPT'95 : Proceedings of the International Symposium on Cone Penetration Testing, Linköping

Publication date:
1995

Document Version
Publisher's PDF, also known as Version of record

Presented at CPT-95-International Symposium on Cone Penetration Testing, Linköping, Sweden, Oct. 1995.

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CPT-investigations in young sediments in the northern part of Jutland.

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SYNOPSIS: This paper presents results of analyses of CPTs carried out at the sea shore on the west coast of Northern Jutland, Nørre Lyngby, and in the town of Skagen. The results of the CPTs are analysed on the basis of values for the cone factors for Danish soils as recommanded by Kirsten Luke 1994. At Nørre Lyngby the results of the CPTs are correlated with the results of vane tests. The results from Nørre Lyngby together with the results from vane tests in a boring at the very top of Denmark are used to estimate the kind of sediments from 40 to 80 m below the surface in the town of Skagen.

The CPTs have been carried out in connection with investigations in progress to explain some geophysical problems at Nørre Lyngby, and to explain the geological structure and the land movements in the area around Skagen.

1. INTRODUCTION

The use of CPT to classify Danish soils has been investigated with special emphasis on measuring the undrained shear strength (Luke, 1994). This investigation has been concentrated on examination of soil at shallow depths e. g. less than 20 m below surface.

In 1993 Kampsax Geodan carried out a series of CPTs in Late Glacial clay at the sea shore on the west coast of Northern Jutland, Nørre Lyngby (fig. 1). Vane tests were carried out in borings at a depth of 2 m below surface, and the variation of the cone factors with the friction ratio was determined. (Luke, 1994).

Close to two existing borings taken to a depth of 40 m and 70 m respectively, CPTs were taken to 11 m and 24 m respectively.

In January 1995 Kampsax Geodan carried out a CPT from 40 m to 80 m below surface in the town of Skagen (fig. 1). A boring was taken to a depth of 40 m, and the CPT was carried out from the bottom of the boring. The purpose was to investigate if the sediments below the town of Skagen were similar to the sediments found in a boring at the very top of Denmark, the Grenen Point.

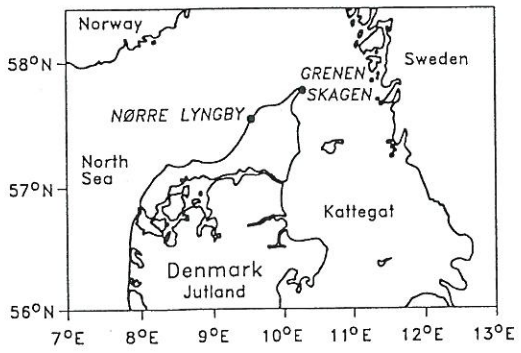

Fig. 1. The position of Nørre Lyngby and Skagen.

2. CPT-EQUIPMENT

The CPT-equipment used in the actual investigations is the van den Berg system developed in Holland. The cone used is a piezo-cone. The penetration resistance on the tip (cone resistance), the side friction resistance on a friction sleeve (sleeve friction) and in addition also the pore water pressure, present

just above the cone shoulder are measured during the penetration. The friction ratio, e. g. the ratio of sleeve friction to cone resistance is calculated.

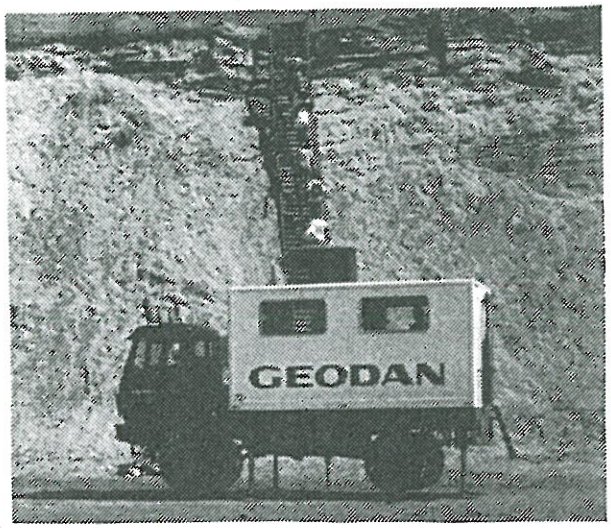

Fig. 2. The CPT-rig at the sea shore on the west coast of Northern Jutland, Nørre Lyngby.

3. SYMBOLS

List of symbols used in this paper.

c_u = undrained shear strength
c_v = vane shear strength
c_{vr} = remoulded vane shear strength
C_c = index of compressibility
e_0 = initial void ratio
f_R = friction ratio f_s/q_c
f_s = measured sleeve friction
I_P = plasticity index
n_k = cone factor = q_c/c_u
n_{kt} = cone factor = q_t/c_u
N_k = cone factor = $(q_c - \sigma_{v0})/c_u$
N_{kt} = cone factor = $(q_t - \sigma_{v0})/c_u$
N_{kt}-f_R = $15(f_R^{-0.4})$
q_c = measured cone resistance
q_t = cone resistance, corrected for pore pressure effects. For the actual piezo-cone $q_t = q_c + 0.3\ u_T$
Q = $C_c/(1+e_0)$
S_t = sensitivity = (c_v/c_{vr})
u = hydrostatic pore water pressure
u_T = measured total pore water pressure
w = water content
γ = total unit weight
σ_{v0} = total initial vertical stress
σ'_0 = effective initial vertical stress

4. NØRRE LYNGBY

The area has been the subject of several geological and geophysical investigations through the years (Jessen, 1931, Knudsen, 1978, Lykke-Andersen, 1992). Seismic investigations have shown some remarkable spatial variations in the frequency spectra of reflected signals.

The actual investigation is a part of an EU geological research project supported by the research program MAST 2. The purpose is to find a correlation between parameters for soil determined in the geotechnical laboratory, results from geotechnical field investigations and seismic results from the field.

The work are carried out as a collaboration between Aarhus University and Aalborg University.

4.1 Existing results from CPTs

Along a seismic investigation line 10 CPTs were carried out, and the results were correlated to results from vane tests from 2 m's depth along the same line (Luke, 1994). The results of this correlation are shown in fig. 3.

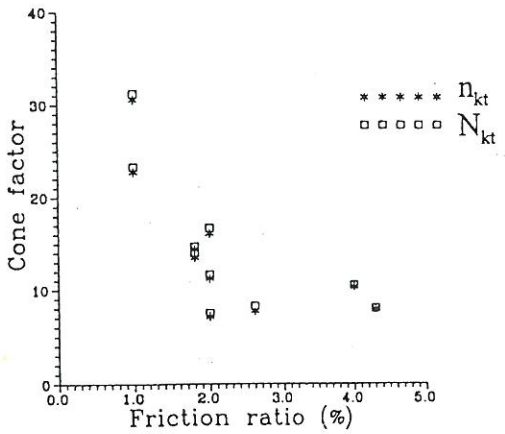

Fig. 3. N_{kt} and n_{kt} plotted as a function of f_R for the clay in Nørre Lyngby (Luke, 1994).

The results from Nørre Lyngby shows, that the cone factor decreases with increasing friction ratio. This is supported of results from other Danish areas.

Average values of n_k and N_k for the investigated Danish soils to depth's of about 20 m are listed in fig. 4 (Luke, 1994).

Clay type	N_k	n_k	w(%)	I_p (%)	S_t	f_R(%)
Yoldia clay	8.7	10.0	30-40	30-40	2.0-8.5	1.8-3.7
Clay till	10.3	10.9	10-16	4-10	1.4-2.7	0.8-2.6
Plastic clay	7.8	8.4	35-40	67-	2.5-	5.5-8.0
Meltwa-ter clay	7.6	7.9	19-26	10-15	-	-
Holoce-ne orga-nic clay	15.1	17.2	40-180	-	3.8-	1.0-3.3
Peat	9.0	12.9	66-540	-	-	2.4-5.5

Fig. 4. Average of the cone factor n_k and N_k in different soils in Denmark (Luke, 1994).

4.2 Correlation between CPTs and results from the deep borings.

In connection with the geological research project two borings were carried out in areas with very different acoustic properties. Boring A was taken to 70 m and boring B to 40 m below the surface.

The borings were carried out as rotary borings with continuous coring. Undisturbed 70 mm diameter samples were extracted and vane tests carried out at 6 meters interval in clay deposits.

The samples from the borings were used for geotechnical laboratory testing and in fig. 5 some of the results from the upper 25 m of the borings are shown.

CPTs were carried out to 24 m's depth close to boring A and to 11 m's depth close to boring B. Boring A has shown Late Glacial silty clay to more than 24 m's depth. In boring B silty clay was found to a depth of 9,5 m, underlain by sandy and stony deposits, all supposed to be of Middle Weichselian age.

The results of the vane tests together with the results of the CPT tests, f_s, u_T, and $0.1q_c$ (corresponding to n_k=10), are shown in fig. 6 and fig. 7.

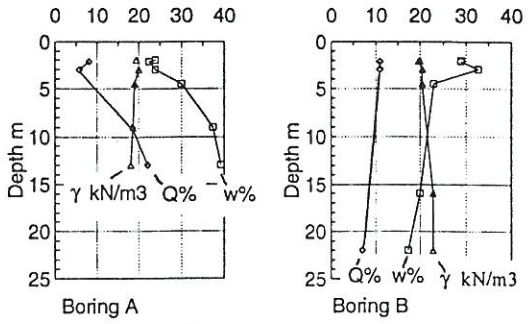

Fig. 5. Results from classification tests.

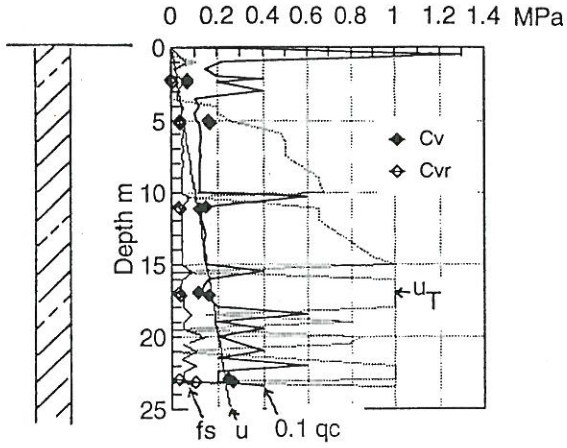

Fig. 6. Boring A. CPT and vane tests.

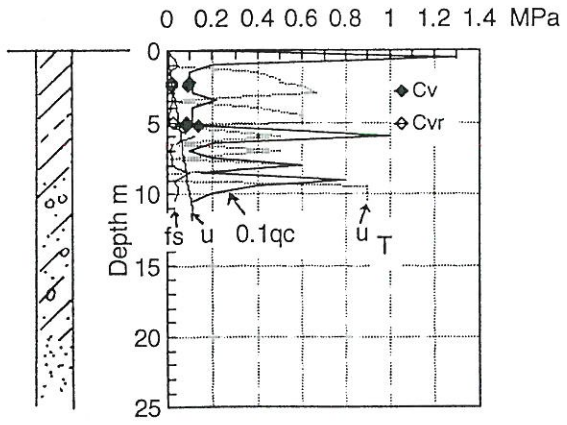

Fig. 7. Boring B. CPT and vane tests.

Luke (1994) has recommended a value of the cone factor N_{kt} = 10 to be used to estimate the undrained shear strength corresponding to that measured in triaxial tests.

To estimate minimum values for the field vane strength Luke has recommended to use a cone factor based on the measured values of the friction ratio f_R,

$$N_{kt} = 15(f_R^{-0.4})$$

On the basis of the results from the CPTs the cone factors have been calculated. The results are shown in fig. 8. The two values above 20 for some of the cone factors are from the very silty top soil in boring A.

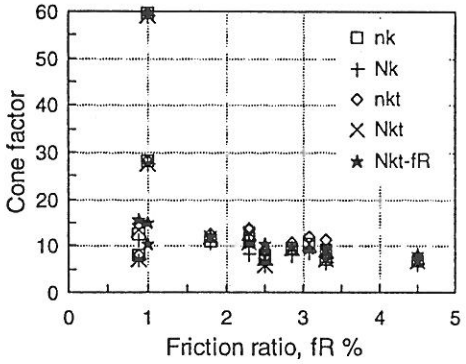

Fig. 8. Cone factors calculated from the test results in boring A and B.

In fig. 9 the estimated values for

$$c_u = (q_t - \sigma_{v0})/10, \qquad (1)$$

and the estimated values for

$$c_v = (q_t - \sigma_{v0})/15(f_R^{-0.4}), \qquad (2)$$

are shown together with the results of the vane tests in boring A. Except for the silty top soil, the estimated values for the undrained shear strength and the vane strength are very close to or below the measured values.

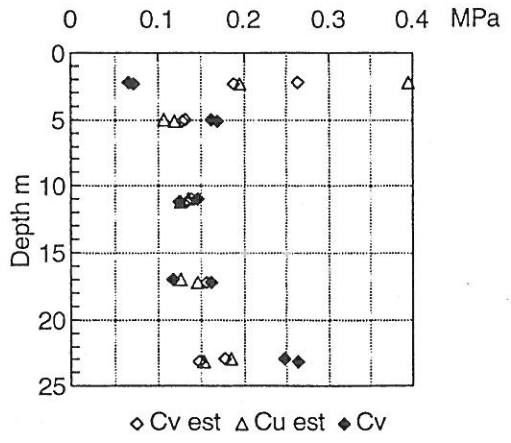

Fig. 9. Boring A. Results of vane tests and estimated values for the undrained shear strength.

5. SKAGEN

At the very top of Denmark, the Skaw Spit, detailed levellings during the period from 1942 to 1991 have shown, that the most northern part of the Skaw Spit has not followed the general isostatic uplift in the northern part of Denmark (Hauerbach, 1992).

The area has been the subject of several geological investigations through the years.

A study of the foraminiferal faunas in samples from an older boring in the area (Knudsen, 1985) has indicated an unusual thickness of very young sediments at the Skaw Spit.

Seismic investigations have been carried out around the Skaw Spit in an integrated geological research project, the GeoKat project, run at the Department of Earth Sciences, University of Aarhus. The results of these investigations confirmed the thickness of very young sediments (Lykke-Andersen & Knudsen, 1992, Lykke-Andersen et. al. 1993a & b).

5.1 Boring Skagen 3

In connection with the GeoKat project a boring at the outermost part of the Skaw Spit, the Grenen Point, was taken to a depth of 220 m below sea level.

The Boring showed at the top 30 m sand, which has been deposited within the latest 1000 years. (Conradsen & Nielsen, 1994). Below the sand was found about 85 m of Holocene clayey silt and clay underlain by clay and sand deposits from Weichselian, Eemian, Saalian and Lower Cretaceous (Knudsen, 1994).

The Skagen 3 boring was carried out as a rotary boring with continuous coring from the depth of 30 m. In the Holocene silt and clay layers, undisturbed 70 mm diameter samples were extracted and vane tests carried out at 3 to 6 meters interval. In the clay deposits below level -80 the undrained shear strength measured by the vane represents values of about 0.2 - 0.25 σ'_0. The results of the vane tests are shown in fig. 10.

The samples from the borings have been used for laboratory testing (Thorsen, 1995a & b). Some of the results are shown in fig. 11.

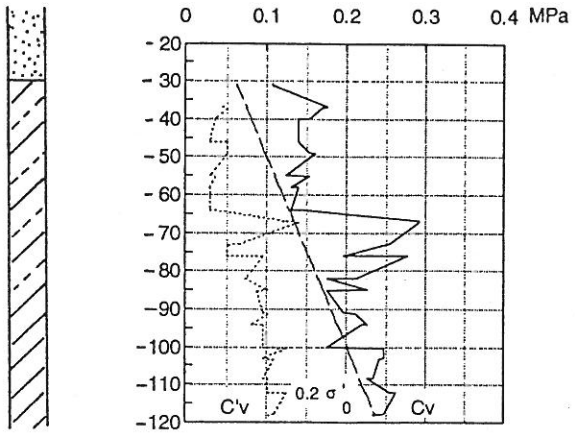

Fig. 10. Boring Skagen 3. Vane tests.

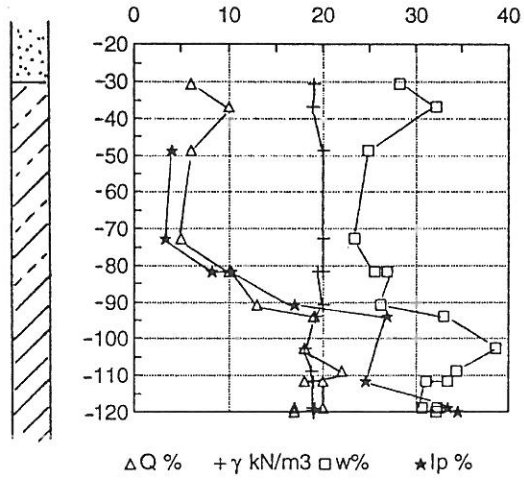

Fig. 11. Boring Skagen 3. Results from classification tests.

5.2 Boring Skagen 5

To investigate if the sediments below the town of Skagen are similar to the sediments at the Grenen Point as indicated by Fredericia, (1988), a boring, the Skagen 5 boring, was taken to a depth of 40 m, and a CPT was carried out from the bottom of the boring and to 80 m below surface.

The boring showed at the top 25 m sand underlain by Holocene silty clay. A few 70 mm diameter samples were extracted from the silty clay and vane tests were carried out in the clay sediments. Some of the results from the laboratory testing are shown in fig. 13. The results of the vane tests together with estimated values for the undrained shear strength from (1) and (2), based on results from the CPT are shown in fig. 12. The results of f_s, u_T and $0.1q_c$ are shown in fig. 14.

The measured pore water pressure in the CPT shows an excess pore water pressure of about 0.8 MPa, corresponding to the excess pore water pressure measured in the CPTs in the clay sediments in Nørre Lyngby.

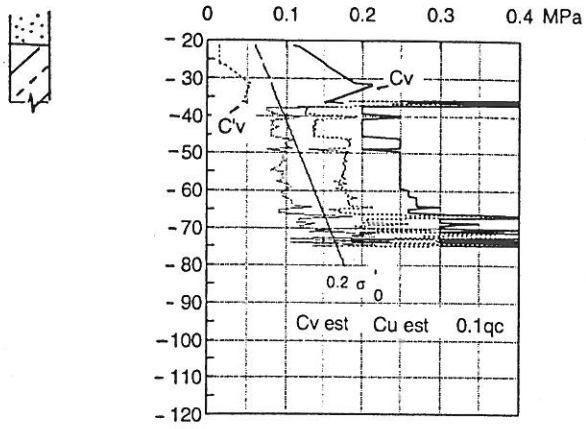

Fig. 12. Boring Skagen 5. Vane tests and estimated values for c_u and c_v, based on CPT.

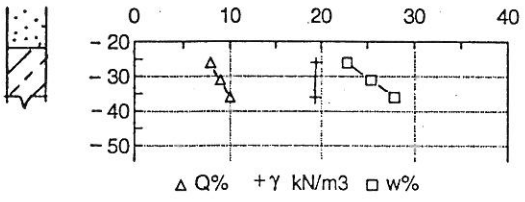

Fig. 13. Boring Skagen 5. Results from Classification tests.

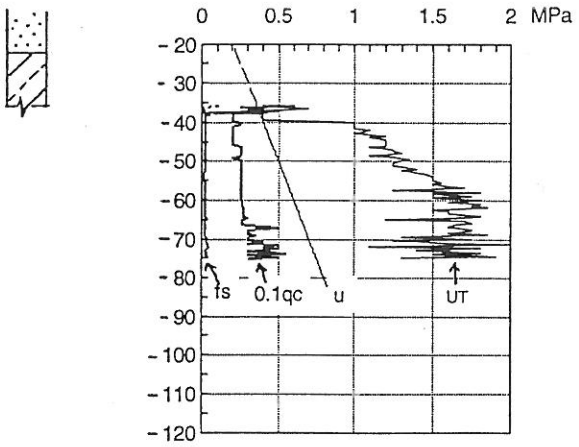

Fig. 14. Boring Skagen 5. Results from CPT.

The age of a sample from level -35 m in boring Skagen 5 is radiocarbon dated by the Accelerator Mass Spectrometry (AMS) to about 400 BP, an age corresponding to about level -60 m in boring Skagen 3 (Conradsen & Nielsen, 1994).

Comparing the results from the Skagen 5 boring, soil description, the vane strength above level -35 and results of the CPT, f_s , u_T, q_c, with the results from the Skagen 3 boring, it seems reasonable to assume, that the sediments below the town of Skagen are similar to the sediments found at the Grenen Point, and that estimations on the basis of (1) and (2) give a good estimation for the values of the shear strength and a minimum value for the vane strength, respectively.

6. CONCLUSION

The results found by Luke (1994) for estimation of the undrained shear strength from CPT for Danish soils have been used to estimate the kind of sediments from 40 - 80 m's depth in the town of Skagen.

Results from two CPTs to 10 m and 24 m below surface respectively, carried out close to two borings in Nørre Lyngby, have been analysed. The estimated values for the undrained shear strength on the basis of $N_{kt} = 10$, and $N_{kt} = 15(f_R^{-0.4})$ as suggested by Luke (1994) are very close to the measured vane strength.

Comparing the results from the boring and CPT, Skagen 5, with the results from the CPTs at Nørre Lyngby and the results from the boring, Skagen 3, at the Grenen Point, it seems reasonable to assume, that the sediments below the town of Skagen are similar to the sediments at the Grenen Point, but also that the estimations on the basis of $N_{kt}=10$, and $N_{kt}= 15(f_R^{-0.4})$ may give good estimations for the values of the shear strength in the actual case.

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