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STUDENT REPORT

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Title: Seismic Cone Penetration Test - Annex
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Synopsis:

For onshore construction there is a growing need for analysing and determination of the elastic soil parameters. Accurate assessment of soil parameters is an important fact for foundation design. One of the most important parameters is the soil shear modulus, G. In order to obtain the density of the soil together with the G_{max}, soil classification test are to be performed. With a seismic geophone mounted on the CPTu probe it is possible to carry out CPTu and seismic test during the same penetration. This SCPTu will allow obtaining the direct determination of the value of G, function of shear wave velocity and soil density.
In order to find the shear wave velocity: two types of seismic waves that propagate through soil media are used: Compressional (P) and Shear (S) and different methods in acquiring it are used (reverse polarity and cross-correlation).
It is expected that both basic penetration test and seismic testing will be successful and the results are reliable.

Preface

This thesis is a product of group B122's project work at the 4th semester of the master degree of Structural and Civil Engineering at Aalborg University. The project is completed within the period from 20th of February 2012 to the 8th of June 2012.

The thesis consists of two parts; two articles, a annex report, which represent additional information to the articles and results which can be found in the back of the report. This paper represent the Master Thesis Project regarding Seismic Cone Penetration Test.

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Chapter 1

Introduction

The cone penetration test (CPTu) is frequently used in both onshore and offshore construction as geotechnical investigation. The seismic cone penetrometer can dramatically reduce the cost in time efficiency associated with seismic testing, especially if CPTu is used as part of the regular site investigation program. Comparisons of onshore seismic cone shear wave velocities with those measured by both down-hole and cross-hole techniques at sites in Canada, [Rice, 1984], United States, [J.A. Jendrezejczuk] and Belgium, [Bouhon, 2010] have already validated the seismic cone technique.

The articles present and discuss results from SCPTu performed in sand and clay in Aalborg area. The cone bearing, friction sleeve stress, cone pore pressure and shear velocity data can be used to provide a fast and reliable determination of soil type and shear strength, according to [P. K. Robertson]. Several seismic sources were tested to evaluate their effectiveness in the generation of compressional and shear waves.

1.0.1 Shear modulus

A polarized shear wave is generated in one SCPTu hole and the time it takes for the shear wave to travel a known distance to the geophone in the hole is measured. Elastic theory relates the shear modulus, G, soil density, ρ, and shear wave velocity, V_s as follows:

$$G = \rho V_s^2 \tag{1.1}$$

The shear modulus can be determined using in situ seismic methods for determination of the shear wave velocity. It is largest at low strains and decreases with increasing shear strain, thus the very low strain level dynamic shear modulus, G_{max} is usually obtained.
The introduction of seismic measurements into the cone penetration test procedures enables the specific determination of the dynamic shear modulus. The shear waves travel through the soil skeleton and are thus related to the soil shear modulus.

Chapter **2**

Cone Description

In the given research, onshore investigation are done. The cone used for the tests has a base area of 10 cm^2 with an apex angle of 60°, these being standard values specified in the E.U and American standards as seen in Figure 2.1. The friction sleeve, f_s, which is placed above the conical tip, also has a standard dimension of 150 cm^2.

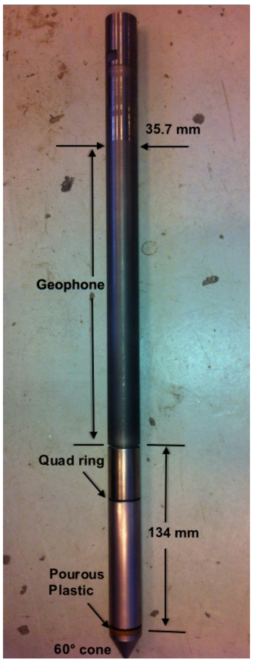

Figure 2.1: *The standard type of cone.*

A pore pressure transducer is installed to measure the dynamic pore pressure during the penetration.The cone penetrometer is pushed into the soil at a standard speed of 2,0 cm/s. In this case, for some of the soundings, a one meter hole was predrilled due to change in the soil conditions, then a "cone penetration vehicle" pushes the cone into the soil, at the wanted speed. Through out the center of the hollow rod there is a cable that connects the cone to a computer. The setup used to measure the velocity of penetration of the cone is presented as a wire system that is hocked to the top of the "cone penetration vehicle" and a speedometer measures the speed of the wire rolling up.

The data given by the cone can be interpreted to get a good continuous prediction of the soil type and shear strength parameters. When a seismometer is integrated into the cone penetration test procedure, the CPTu becomes SCPTu (Seismic Cone Penetration Test). The use of S-Wave velocity data in foundation investigations has become increasingly popular in recent years, but use of this valuable and diagnostic study has been delayed because of the difficulty of obtaining reliable data, particularly under varying geologic conditions, [Beckstead].

To obtain the measurements a rugged velocity seismometer has been incorporated into the cone penetrometer. Downhole seismic shear wave velocity measurements can be made during brief pauses in the CPTu.
The method of advancing the cone penetrometer provides continuous, firm. mechanical contact between the seismometer carrier and the surrounding soil. This allows excellent coupling and therefore exceptionally good sig-

nal response. In addition, seismometer orientation can be controlled and accurate depth measurements obtained. R. G. Campanella [1986] It is placed in the horizontal direction and oriented transverse to the signal source to detect the horizontal component of the shear wave arrivals. A steel hammer hitting a steel plate is used as the most suitable tool to obtain the most convenient signal.

Soil Classification Tests for Sand

With the data obtained both from the borings and the CPTs results, profiles with soil type stratigraphy, description and corresponding depths were plotted using as in Figure 3.1. It can be observed that the first layer is a fill layer for the first approx. 2 meters, being followed by a a layer of clay and gyttia and after approx 3 meters fine sand is reached.

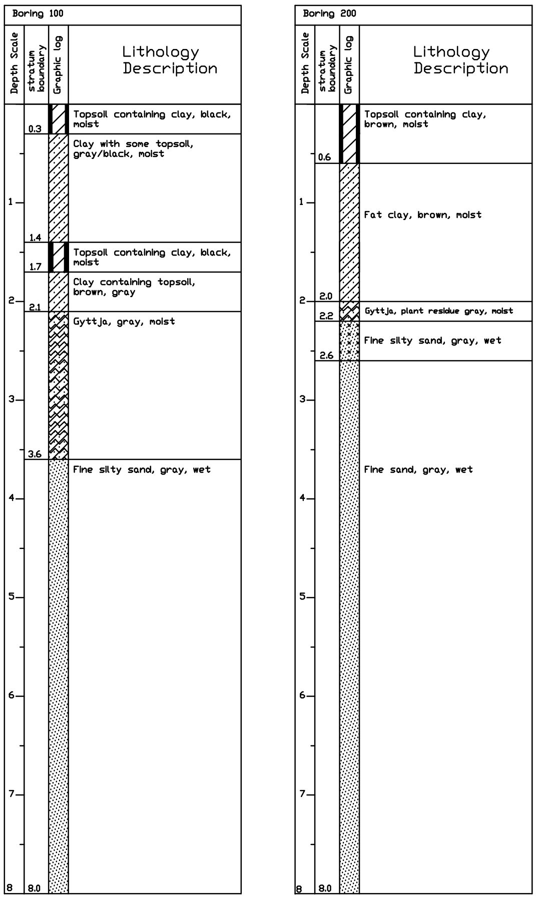

Figure 3.1: *Bore hole 100 and 200 profile with soil type and depth*

3.1 Determination of Water Content

From two of the borings seen in Figure **??**, soil samples were taken in order to perform several soil classification tests. According to the geotechnical survey from the boreholes, The first test performed was the water content one. This test is performed to determine the water (moisture) content of soils. The water content is required as a guide to classification of natural soils and as a control criterion in re-compacted soils and is measured on samples used for most field and laboratory tests according to [DS/S-19000, 2004a].

Figure 3.2: *Water content test instruments*

The water content is the ratio, expressed as a percentage, of the mass of "free" water in a given mass of soil to the mass of the dry soil solids. The procedure used in the laboratory was a standard one known as drying-weighting method. DS/S-19000 [2004a] states that the practical procedure for determining the water content of a soil is to determine the mass of water removed by drying the moist soil (test specimen) to a constant mass in a drying oven controlled at a given temperature, and to use this value as the mass of water in the test specimen. The mass of soil remaining after oven-drying is used as the mass of the solid particles.
The water content, w is defined as the weight loss of the soil in % of the dry weight by drying in an incubator (oven) at a temperature of 105 degrees Celsius to a constant weight.

$$w = \frac{W_w}{W_s} 100\% \tag{3.1}$$

$$= \frac{(W + Bowl) - (W_s + Bowl)}{W_s + Bowl} 100\% \tag{3.2}$$

where,

$Bowl$:	weight of the bowl	[g]
W :	weight of sample before drying	[g]
W_s :	weight of the dried sample	[g]
W_w :	weight of the water sample	[g]

The samples that were tested were taken from half of meter to half of meter until 8 meters were reached. The first two meters of the both borings were covered with topsoil clay. Furthermore, gyttia is found for the first boring until 3.6 meters, whereas for the second one until 2.8 meters. Until 8 meters the presence of fine silty sand was observed.

For all the samples taken from both boreholes Table 3.1 presents the ranges on which the water content varies in the samples. It can be observed that the range is wide due to the variation of types of soil. For Borehole 100, the maximum value represents a gyttia sample situated at 3.5 m depth, whereas the minimum value is fine sand found at 8m. For Borehole 200, the maximum value represents a clay sample situated at aprox. 2.0 m depth, whereas the minimum value is fine sand found at 4 m.

Table 3.1: *Water content results*

	Layer	Water content , %
Borehole 100	Topsoil - clay	23 - 38
	Gyttia	46 - 62
	Fine sand	17 - 27
Borehole 200	Topsoil - clay	26 - 55
	Gyttia	54 - 56
	Fine sand	20 - 24

For many soils, the water content may be an extremely important index used for establishing the relationship between the way a soil behaves and its properties. The consistency of a fine-grained soil largely depends on its water content.

3.2 Determination of Particle Size Distribution

Grain size analysis is required in classifying the soil. This test is performed to determine the percentage of different grain sizes contained within a soil. It is often important the way that the material performs in use.

A sieve analysis can be performed on any type of non-organic or organic granular materials including sands, crushed rock, clays, soil, grain and organic soil, down to a minimum size depending on the exact method. The sieve analysis is performed to determine the distribution of the coarser, larger-sized particles, and the hydrometer method is used to determine the distribution of the finer particles.

After performing the water content test on every sample, 8 samples were chosen for a sieving analysis, 4 out of each boring from different depths as seen in the Table 3.2.

Table 3.2: *Grain size analysis. Borehole sample details*

Borehole no.	Sample no.	Depth m	Type of soil -
100	9	3.6-4	fine silty sand
	11	4.6-5	fine sand
	14	6.-6.4	fine sand
	17	7.6-8	fine sand
200	25	3-3.4	fine sand
	28	5-5.4	fine sand
	31	6.-6.4	fine sand
	34	7.6-8	fine sand

According to DS/S-19000 [2004d], the grain size is defined as the mesh width of the finest square sieve through which the particle can pass. Therefore, the grain size analysis is done by determining the weight related distribution of the soil grains according to size.

If more than 90% of the particles are larger than 0.063mm, a screening is performed. If more than 10% of the

Figure 3.3: *Example of sieveing setup*

particles are smaller than 0.063, a hydrometer analysis is advised to be done. The grain size used depends on the estimaded D_{90}, which represents the sieve mesh width through which 90% of the material can pass and for the samples chosen the data refered to Table 3.3 is used.

Table 3.3: *Sample sizes depending on D_{90}, DS/S-19000 [2004b]*

D90 mm	Sample size g
0.5	50
1	100
4	150

After establishing that a screening must be performed, a fitting sample size was weighted, W and dried at 105 degrees Celcius. The next step was a wash out of the sample on the 0.063 *mm* sieve. The washed out sample is dried at 50 degrees Celsius and used further for the hydrometer test. The remnants of the sample are dried again and the sieving process can start.

A fine screening was done using the 0.5, 0.250, 0.212, 0.180, 0.150, 0.125, 0.090 and 0.063 sieves. The parts of the sample are placed on the sieve tower according to Table 3.4, they must not exceed the values given.

The screenings on each sieve in % of the dry weight of the total of each sample are plotted into a coordinate system which is function of the sieve dimension, as seen in Figure 3.4. The screening percentanges are plotted in the vertical axis in an arithmetic scale and the sieve dimensions on the horizontal one in a logarithm scale.

Table 3.4: *Maximum amount on the sieves used, DS/S-19000 [2004d]*

Mesh width mm	Maximum amount on sieve g
0.063	25
0.125	35
0.25	50
0.5	70
1	100
2	200
4	300

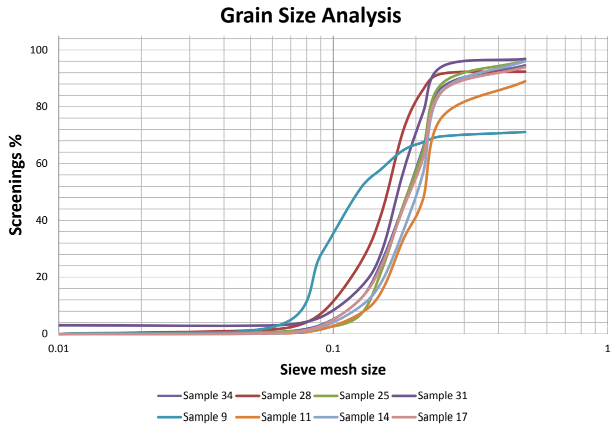

Figure 3.4: *Grain size analysis on sand samples*

3.3 Determination of Particle Density - Pycnometer method

From the results observed from the sieving curves four different soil samples were taken in order to perform the pycnometer test in order to obtain the "relative density" found using Equation (3.3), . which is a test to determine the relative density. It is part of a series, which is carried out at the geotechnical engineering laboratory, [DS/S-19000, 2004c].

The density is needed for the next test which is the hydrometer test. The particle density is the grain material relative density,*d*, is the ratio of the density expressed in g/cm^3 of a our soil to the density of a given reference fluid in our case is ionised water at 4°C. Specific gravity usually means relative density with respect to water. The term "relative density" is often preferred in modern scientific usage.

$$G_s = \frac{W_v}{W_i} \tag{3.3}$$

where,

W_s :	Weight of a given volume soil grain	[g]
W_i :	Weight of the same volume de-ionised water at 4°C	[g]

The weight of the soil grains is completed as in Equation (3.4) where it was made sure that no air bubbles were founded in the soil sample.

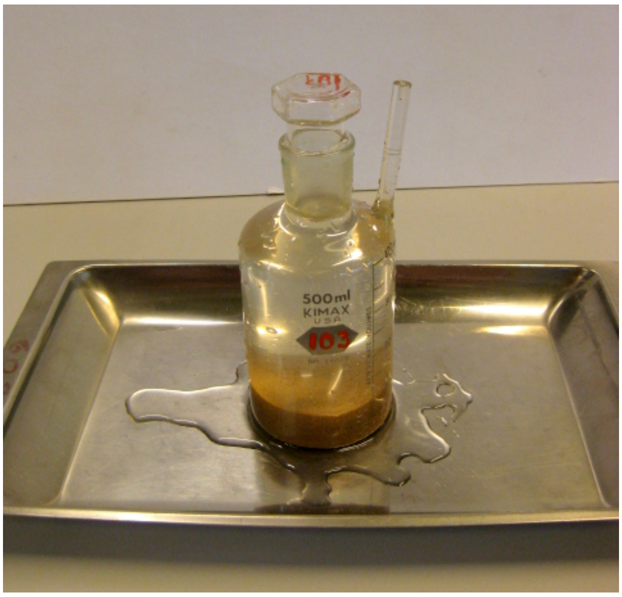

Figure 3.5: *Pycnometer Display*

$$w = \frac{\rho_s}{\rho_w^{4^0}} = \frac{W_s}{V_s * \rho_w^{4^0}} \tag{3.4}$$

where,

V_s :	Volume of dry grain material	$[cm^3]$
W_s :	Weight of sample before drying	[g]
ρ_s :	Weight of the dried sample	$[g/cm^3]$
$\rho_w^{4^0}$:	Density of de-ionised water at 4°C, $\rho_w^{4C} = 1$	$[g/cm^3]$

Generally the values obtained for G_s^2 are expected for none organic content, to vary from 2.65 for clean quartz sand to 2.85 for certain clay minerals. For soils containing especially heavy or light minerals, d_s, can have values outside of these values.

3.3.1 Calculations

The volume of dry matter is obtained using the following formulas :

$$\frac{W_s + W_2 - W_1}{\rho_w^t} \tag{3.5}$$

$$G_s = \frac{W_s * \rho_w^t}{W_s + W_2 - W_1} \tag{3.6}$$

where,

W_1 :	Weight of pycnometer filled with sample and de-ionised water	[g]
W_2 :	Weight of pycnometer filled with de-ionised water	[g]
ρ_w^t :	Density of de-ionised water at temperature t	$[\frac{g}{cm^3}]$

The results obtained can be observed in Table 3.5.

Table 3.5: *Relative density results*

Sample no	Relative density, G_s
9	2.66
14	2.65
25	2.65
34	2.66

3.4 Determination of Particle Size Distribution - Hydrometer test

The hydrometer analysis is the process by which the weight-related distribution of soil grains after size in the silt fraction ($2\mu m$-$60\mu m$). The hydrometer also determines the specific gravity (or density) of the suspension, and this enables the percentage of particles of a certain equivalent particle diameter to be calculated.

Figure 3.6: *Hydrometer Test Instruments*

According to Section 3.3 the relative density obtained for Sample 9 is 2.66 as seen in Table 3.5. From previous test, the water content, the weight of the dry matter in the slurry with a diameter less than $0,063mm$ can be calculated.

The grain diameter,d, is found by writing the Stoke's law, [DS/S-19000, 2004d] where the relative density is entered instead of the actual density so it becomes:

$$d = \sqrt{\frac{18\eta * 100}{(G_s - d_0)g * 60}} * \sqrt{\frac{h}{t}} \tag{3.7}$$

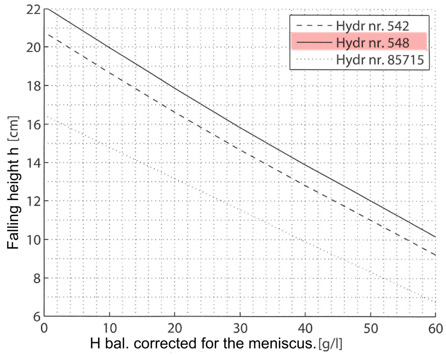

Figure 3.7: *Falling height h depending on corrected meniscus ans the hydrometer beaker used DS/S-19000 [2004c]*

The corresponding values of weight percentages and grain size are put in the same coordinate system as the sieve curve of Sample 9 as seen in Figure 3.8. The recorded curve part (the beginning one) is considered as the slurry curve.

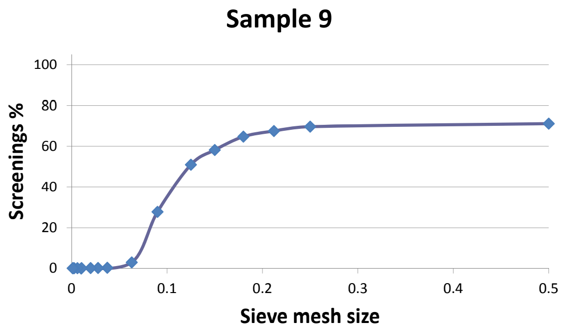

Figure 3.8: *Sample 9 Sieveing curve after Hydrometer Test*

Chapter **4**

Shear Velocities

Surface wave inversion is a technique for determining shear wave velocities as a function of depth. It is based on the analysis of surface wave dispersion and it has been discussed by [Borm, 1977] and [Jongmans]. In [J.A. Jendrezejczuk] the shear wave speed is computed by dividing the distance between two pairs of receivers by the time for the signal to travel from one receiver to the next. There are four types of seismic waves who propagates through the soil. These can be divided into two categories. The first category are the body waves also named flat/volume waves, their displacement is Longitudinal for the P wave and transversal for the S wave, as seen in Figure 4.1.

The Compression (P) wave are also referred as irrotational waves which propagate through solid and fluids. They propagate at a higher velocity than shear waves.

The Shear (S) as said before their direction is transversal but the S waves are also referred as the rotational waves and are unable to propagate through fluids.

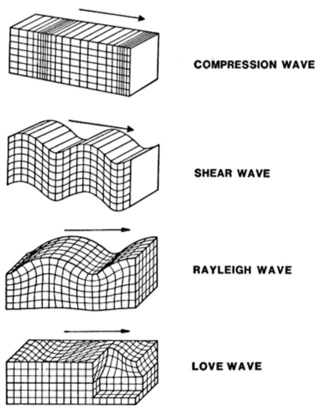

Figure 4.1: *Different types waves. [Rice, 1984]*

According to P. K. Robertson, a 10% erroe in V_s represents an error of about 20% in G_{max}. The shear wave velocity data can be used to determine the maximum dynamic shear modulus. Accurate depth determination is made by measuring the rod length (of 10 meters), and seismometer orientation is easily maintained throughout the SCPTu.

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