A laboratory investigation for assessment of rod friction in dynamic probing

Une étude de laboratoire pour la determination du frottement de tige dans la sonde dynamique

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ABSTRACT: A laboratory test model has been prepared for determining skin frictions of a rod in driving and rotation. It is composed of a mold, a probing rod, a surcharge kit, a driving kit and a rotation kit. This equipment simulates the performance of dynamic probing test without tip resistance. Unit skin frictions developed during driving and rotation can also be determined with this equipment. Probing tests without tip resistance have been performed on several cohesionless and cohesive soil samples. During the performance of the laboratory tests; void ratio for cohesionless samples, liquidity index for cohesive samples and surcharge for both have been varied. Equipment used, method of testing, characteristics of the soil samples, test results and their evaluation have been presented. Driving and rotational unit skin friction values for all sample groups tested have been found to be linearly dependent.

RÉSUMÉ: Un équipement d'essai laboratoire a été préparé pour la détermination du frottement de surface d'une tige en battage et en rotation. L'équipement se compose d'une tige de sonde, une série de surcharge, des appareils de battage et de rotation. Cet équipement simule la sonde dynamique sans résistance dé pointe. Le frottement de surface unitaire qui se développe au cours de battage et de rotation peut également se mesurer par cet équipement. Des essais de sonde sans résistance de point ont été effectués sur plusieurs sols cohésifs et sans cohésion. Au cours des essais de laboratoire, le pourcentage de vide des échantillons des sols sans cohésion, l'index de liquidité des sols cohésifs et les surcharges pour dans les deux cas ont été variés. On présente l'équipement utilisé, la procédure d'essai, les caractéristiques des échantillons des sols, les résultats de essais et leur évaluation. On a trouvé qu'il avait une relation linéaire entre les valeurs de frottement de surface unitaire en battage et en rotation pour tout les groupes d'échantillons.

1 INTRODUCTION

Dynamic probing is a continuous soil investigation technique. A conical probe attached to the base of an extension rod is driven into the ground by means of a constant energy hammer system. The number of hammer blows required to drive each increment of depth is counted. Testing is carried out continuously from ground level to the final penetration depth. Additions of the extension rods are the only interruptions.

Dynamic probing measures only a single parameter (blow count) during driving. The blow count measured is not always entirely due to the soil resistance at the probe point. Depending on the soil conditions, driving skin friction on the surface of the probing rods inside the ground may occur at a certain depth.

Certain number of blow counts N_S is required to overcome the total driving skin friction, which is additive on the number of blow counts to overcome the driving resistance of the probe. Skin friction development on the surface of the extension rods has been the major difficulty in the quantitative evaluation of the dynamic penetration test data.

Certain methods have been proposed by the investigators to eliminate the skin friction. These methods require new additions to the standard probing equipment and result in increased testing time. Yet, use of these methods may not eliminate skin friction totally.

The torque T measured to turn the group of extension rods in the soil has also been used for determining the number of blows N_s required to overcome the rod skin friction. A theoretical expression for N_s has been presented in an earlier study (Dahlberg & Bergdahl 1974)

Theoretical expression for N_s depend on the value of α, which is the ratio of the rod unit skin frictions in driving $f_{s,v}$ and rotation $f_{s,h}$. The authors have met no specific value for α in the literature, except the ones given in Ünal (1999). Depending on the field measurements of some investigators, it can implicitly be concluded that α can take values in the 1 – 4 range (Bergdahl 1979, Scarf 1988 and Kayalar et al. 1996).

A test model has been designed and realised for determining α in the laboratory (Ünal 1999). Test equipment simulates the performance of dynamic probing test without tip resistance. This equipment provides the measurement of unit skin frictions developing during driving and rotating a rod inside a soil sample.

This paper presents an evaluation of rod friction in dynamic probing, description of the above mentioned equipment, method of testing, the results of the tests performed on several soil samples and their evaluation to obtain α values.

2. ROD FRICTION EVALUATION

Neglecting the energy losses, total driving energy E is expressed as follows:

$$E = mghN \tag{1}$$

where, m = mass of the hammer, g = gravitational acceleration, h = height of fall of the hammer, and N = blow count for depth increment Δ of the probe.

Energy to overcome the skin friction resistance E_s is,

$$E_s = mghN_s \tag{2}$$

where, N_s = blow count to overcome skin friction resistance. This energy can also be expressed in terms of average unit driving skin friction $f_{s,v}$:

$$E_s = f_{s,v}\,\pi DL\Delta \tag{3}$$

where, D = diameter of the rod (= 2r), L = rod length producing friction, and Δ = penetration depth for N blows. Torque T required to turn the string of rods in the ground is expressed as follows:

$$T = f_{s,h}\,\pi DLr \tag{4}$$

where, $f_{s,h}$ = average unit rotational skin friction. Let,

$$\frac{f_{s,v}}{f_{s,h}} = \alpha \tag{5}$$

Combining Equations (1), (3), (4) and (5):

$$N_s = \frac{T\alpha\Delta}{mghr} \tag{6}$$

Considering Heavy Dynamic Penetration Test (DPH / DIN4094 SRS 15) Equipment properties D/2 = r = 0.016 m, mg=500 N, h = 0.5 m and Δ = 0.2 m, and inserting in the above Equation (6),

$$N_s = \frac{\alpha T}{20} \tag{7}$$

If α = 1, then from Equation (7), N_s = T / 20. That is, a reductive correction of N_s = 1 blow count per 20 cm depth increment is needed for every measured T = 20 Nm torque value. However, recent studies indicate that measured field values of N_s are 1 ~ 4 times the values obtained from Equation (7) for α = 1 (Bergdahl 1979, Scarf 1988, and Kayalar et al. 1996).

3. LABORATORY INVESTIGATION ON ROD FRICTION

3.1. Equipment Used

Test equipment is composed of five parts. These are cell, probing rod, surcharge kit, driving kit and rotation kit.

The cell is a cylindrical mould open at the top. Its diameter and height are 101 mm and 92 mm respectively. At the bottom of the mould, there is a 17 mm thick base plate. At the center of the base plate a sharp edged, conical hole (bottom hole) is opened. A 10 mm diameter high-density plastic gasket having a spring inside is placed to this bottom hole for the slippery extrusion of the tip of the probing rod.

The probing rod is made of brass with 10 mm diameter and 400 mm length. There is an internal thread at the top of the rod for connection of driving and rotation kits. The tip of the rod is conical.

The surcharge kit is composed of a rigid cylindrical plate (diameter = 100 mm, thickness = 2 cm) with a hole at the centre, a hanger and weights. With this system it has been possible to apply a maximum weight of 150 kg (surcharge q = 1.87 kg/cm^2).

A cylindrical guide rod with an anvil and external thread at the bottom, and a sliding weight of 1043 gr comprise the driving kit. Free fall height of the sliding weight is 100 mm. Guide rod, anvil and probing rod totally weigh 398 gr.

Laboratory vane shear apparatus and an adaptor are the main parts of the rotation kit. The adaptor provides a firm link between the spring of the vane shear apparatus and the probing rod.

General view of the test equipment is shown in Figure 1.

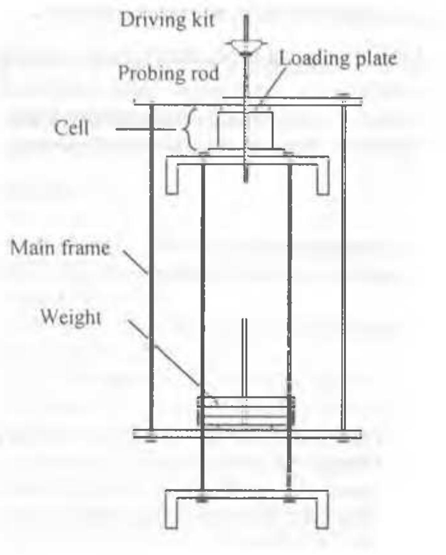

Figure 1. General view of the test equipment.

3.2. Method of Testing

Preparation of the soil samples in dynamic probing without tip resistance has been somewhat different for cohesive and non-cohesive soil samples.

Cohesive soil sample at a certain consistency is placed in the mould with kneading action until the mould is filled. The upper surface of the full mould is smoothened by a trimming saw. The mould and soil is weighed together and bulk density of the soil is determined. The mould is placed on the test table. The loading plate and the hanger are put concentrically on the soil sample. The probing rod is inserted, by vertical centering, into the soil until its tip is extruded from the bottom hole. Required surcharge is applied by placing weights on the hanger plate. Cohesive soil sample is now ready for the measurements of driving and rotational resistances of the probing rod.

In the case of non-cohesive soil sample, first the probing rod is put vertically and concentrically in the empty mould, and the tip of the rod is extruded from the bottom hole. Pouring while holding the rod places non-cohesive soil sample. After filling the mould, the surface of the soil sample is smoothened. The mould with the soil inside is weighed to determine the unit weight of the soil. The mould is placed on the test table. Required surcharge is applied by the loading plate- hanger-weight system.

After the application of the surcharge, the probing rod is first rotated to measure the rotational skin friction resistance, then driven to measure the driving skin friction resistance, and then rotated again to obtain an average value for rotational skin friction.

The laboratory vane shear test equipment is used for the measurement of the torque (T) required to turn the probing rod inside the soil mass under a certain surcharge (Figure 2b). Rotational unit skin friction ($f_{s,h}$) on the rod is found by the following expression:

$$f_{s,h} = \frac{2T}{\pi D2L} \tag{8}$$

Driving kit (sliding weight, guide rod and anvil) is attached on the probing rod to measure the vertical displacement (depth increment, Δ) of the probing rod under one blow of the hammer (Figure 2a). Using the handles, the hammer is raised manually exactly 100mm high above the anvil and let fall free on the guide rod. Vertical displacement of the rod is measured by means of a compass. If the vertical displacement under one blow is observed to be too small to measure, then average displacement under several blows is determined. Unit driving skin friction on the probing rod is determined by the following expression:

$$f_{s,v} = \frac{mgh}{\pi DL\Delta} \tag{9}$$

Spring reinforced plastic gasket placed to the bottom hole helps to avoid the plugging of probing rod due to simultaneous outward movement of the sticking soil particles on the rod. But, this gasket also introduces a slight frictional resistance on the rod in both rotating and driving. This resistance is measured as the required torque to turn the probing rod with empty mould after the execution of each test on a soil sample under a certain condition and reduced from the corresponding values obtained with full mould

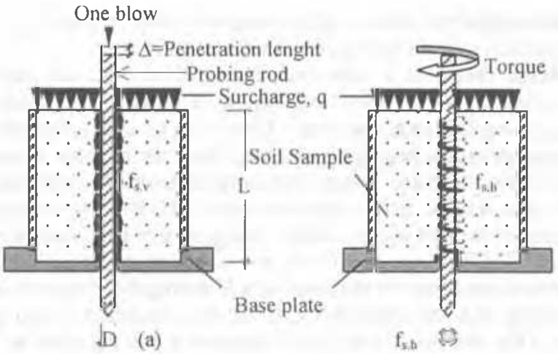

Figure 2. Unit skin friction resistance (a) driving unit skin friction resistance $f_{s,v}$ (b) rotation unit skin friction resistance $f_{s,h}$

3.3 *Soil samples*

Laboratory tests have been executed on 15 different soil samples. Samples 1 to 4 are clean sands, sample 5 is sand with silt fines (silty sand), sample 6 is plastic silt, samples 7 to 13 are clay, and samples 14 and 15 are bentonite. Considering their common behavior in laboratory probing tests, Sample 6 is included in the clay samples; and although being clay, bentonite samples are presented apart from clay samples. Classification test results and group symbols according to the Unified Soil Classification System (USCS) are presented in Table 1.

Table 1. Results of classification tests.

Sample	Percent passing		Atterberg Limits		Coefficients		USCS
No	No.4 (%)	No.200 (%)	W_L (%)	W_P (%)	C_u (-)	C_c (-)	Group Symbol
1	85	2	-	-	11	1,4	SW
2	93	1	-	-	6	1,5	SW
3	100	-	-	-	4	0,9	SP
4	100	3	-	-	2	8,5	SP
5	98	38	34	30	-	-	SM
6	100	56	41	33	-	-	ML
7	100	90	47	24	-	-	CL
8	100	60	52	28	-	-	CH
9	100	75	56	32	-	-	CH
10	100	98	68	36	-	-	CH
11	100	95	77	39	-	-	CH
12	100	98	79	43	-	-	CH
13	100	100	117	59	-	-	CH
14	100	100	195	35	-	-	CH
15	100	100	467	57	-	-	CH

3.4 *Test Results*

In order to obtain a wide range of driving and rotation skin friction pairs of values, dynamic probing tests without tip resistances have been carried out under different surcharge values for all soil samples. Void ratio for non-plastic soil samples and consistency of plastic soil samples have also been changed. Totally 393 tests have been performed. Results of 370 tests have been qualified as significant and presented here.

In each test, measured values are the torque T required to turn the probing rod, and the average penetration length Δ under one blow of the hammer. Results of total 370 significant tests have been plotted as a scatter diagram of T versus Δ and presented in Figure 3.

As expected, Δ decrease with an increase in T. This variation is non-linear. T-Δ scatters exhibit groupings related with soil types. Clouds of points corresponding to clean sand samples, silty - sand sample, clay samples and bentonite samples are separated clearly. Very interestingly, cloud of points for bentonite samples are located as a harmonious continuation of

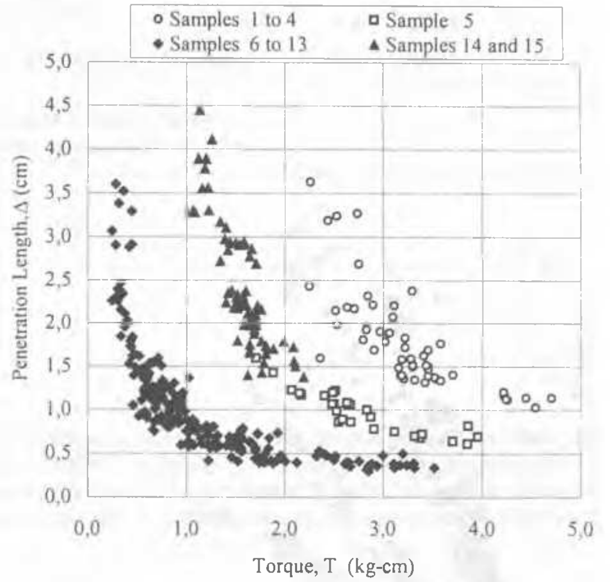

Figure 3. Laboratory penetration test results for all soil samples

cloud of points corresponding to silty sand samples. This behavior of bentonite samples could not be easily interpreted. For the same torque value, penetration depth increases in the order of clay, silty sand, bentonite and clean sand.

Unit driving skin friction $f_{s,v}$ and unit rotational skin friction $f_{s,h}$ values have been calculated including gasket resistance reductions using Δ and T values, respectively (Equations 8 and 9).

Scatter diagrams of unit driving skin friction ($f_{s,v}$) versus unit rotational skin friction ($f_{s,h}$) are shown in Figure 4. Grouping of points as separate clouds for different soil types is also present in this figure. Scatters of $f_{s,v}$ versus $f_{s,h}$ seem linear. For the same $f_{s,v}$ value, $f_{s,h}$ values increase in the order of clay, silty sand, and clean sand. Cloud of points corresponding to bentonite samples are located harmoniously with the cloud of points of silty-sand.

It can easily be concluded from Figure 4 that, α (= $f_{s,v}$ / $f_{s,h}$) value of clean sand is the smallest. It increases in the order of silty sand and clay. α Value for bentonite is very close to the α value of silty-sand.

Totally 58 laboratory probing tests have been performed on the clean sand samples (Sample 1 to Sample 4). Results of 46 tests have been accepted for use in the evaluations. Ranges of surcharge (q, kg/cm^2) and void ratio (e) have been arranged as q= 1.24 – 1.87 and e = 0.61 – 0.71. Torque (T, kg-cm) and penetration length (Δ, cm) values have been measured in T = 2.25–4.70 and Δ = 1.05 – 2.70 ranges. Δ decrease somewhat non-linearly as T increase, which is harmonious with the general results. Range of $f_{s,v}$ and $f_{s,h}$ values are 0.10 kg/cm^2–0.31 kg/cm^2 and 0.15 kg/cm^2 – 0.30 kg/cm^2 respectively. There is a strong linear variation of $f_{s,v}$ with $f_{s,h}$. α values are in 0.68 – 1.10 range, which is very narrow. The expected value of α is 0.92. Although there is some dependence of α on $f_{s,v}$, dependence of α on $f_{s,h}$. is not significant at all. Since the range of α values is very small, its expected value can be used to represent $f_{s,v}$ / $f_{s,h}$ ratio for clean sand samples.

Number of probing tests performed on the silty sand sample (Sample 5) is 29. All of these tests have been qualified as acceptable for use in the evaluations. These tests have been carried out under q (kg/cm^2) = 0.36, 0.87 and 1.24 surcharges. Void ratio of the samples are e = 0.85 in the first 20 tests, and e = 0.88 in the rest. Ranges of T, Δ, $f_{s,v}$ and $f_{s,h}$ are 1.70 kg-cm – 3.95 kg-cm, 0.60 cm – 1.60 cm, 0.18 kg/cm^2 – 0.54 kg/cm^2 and 0.11 kg/cm^2 – 0.25 kg/cm^2 respectively. Δ decrease somewhat non-linearly as T increase, which is harmonious with the general

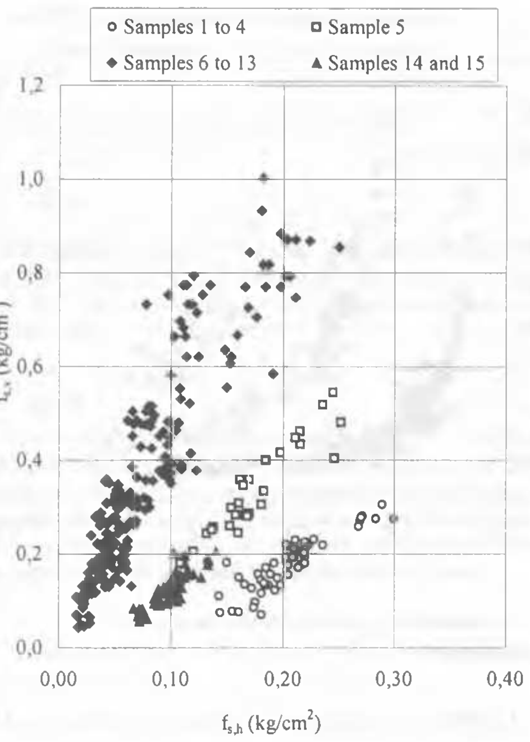

Figure 4. Driving skin friction $f_{s,v}$ versus rotational skin $f_{s,h}$ for all soil samples

results. There is a strong linear relation between $f_{s,v}$ with $f_{s,h}$. α values have been calculated in the range of 1.6 – 2.2, which is very narrow. The expected value of α has been calculated to be 1.92. As in the case of clean sand samples, there is some dependence of α on $f_{s,v}$, but dependence of α on $f_{s,h}$. is not significant. Since the range of α values is very small, its expected value can be used to represent $f_{s,v}$ / $f_{s,h}$ ratio for silty sand sample.

Totally 229 laboratory probing tests have been performed on the clay samples (Sample 6 to Sample 13). Results of only two tests have been rejected for use in the evaluations. Range of Δ, T, $f_{s,v}$ and $f_{s,h}$ values are 0.30 cm – 3.60 cm, 0.25 kg-cm – 3.5 kg-cm, 0.05 kg/cm² – 1.0 kg/cm² and 0.01 kg/cm² – 0.25 kg/cm² respectively. For clay samples, Δ value decrease non-linearly as T value increase, which is also harmonious with the general results. There is quite a strong linear variation of $f_{s,v}$ with $f_{s,h}$.. α values are in the 1.9 – 9.4 range, which is relatively large. The expected value of α is 4.34. There is no dependence of α on $f_{s,v}$ and $f_{s,h}$.

Totally 68 significant tests on two bentonite samples (Sample 14 and Sample 15) have been evaluated. In these tests, Ranges of surcharge, liquidity index, measured and calculated parameters have been q (kg/cm²) = 0.36 – 1.74, I_L = 0.28 - 0.49, T (kg-cm) = 1.1 – 2.2, Δ (cm) = 1.4 – 4.5, $f_{s,h}$ (kg/cm²)= 0.07 - 0.14, and $f_{s,v}$(kg/cm²) = 0.05 - 0.20. Shapes of T – Δ, and $f_{s,h}$ – $f_{s,v}$ relations are quite in accordance with corresponding relations for the other soil samples. Range of α values has been 0.8 – 2.0. Expected value of α for bentonite samples is found to be 1.23.

4 RESULTS AND CONCLUSIONS

Laboratory dynamic probing tests without tip resistance have been carried out on samples of clean sand, silty sand, clay and bentonite using a model test equipment.. Torque T required to turn the probing rod, which passes through the soil sample and penetration length Δ of the rod under one blow of the hammer, has been measured. Ratio α of driving unit skin friction $f_{s,v}$ to rotational unit skin friction $f_{s,h}$ have been calculated.

Average values of α have been found to be 0.92 for clean sand samples, 1.92 for silty sand sample, 4.34 for clay samples and 1.23 for bentonite samples. These values are within the range of the values implicitly obtained from the existing a few studies in the literature. Taking into consideration the scattering of the test results, and natural variation of the engineering properties of the soil in-situ, authors suggests α = 1 for sand, α = 2 for silty sand and non-plastic silt, and α = 4 for clay.

Physical conditions at the bottom hole during the extrusion of the probing rod has somewhat effected the measured T and Δ values. This has been tried to be controlled and reduced to a certain degree by making use of a special spring reinforced plastic gasket.

The authors believes that, number of soil samples used and number of tests performed within the content of this study have been satisfactory for understanding the variation of α over the soil types investigated. But, the authors also feels that, more data are needed for the generalization of suggested α values and their practical use.

Quantitative evaluation of dynamic penetration test results largely depends on the determination of number of blows required to overcome the skin friction on the probing rods. More investigations, which will be performed in the laboratory together with the ones performed in-situ, will help solution of this problem.

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