Proceedings of the XVIII ECSMGE 2024
GEOTECHNICAL ENGINEERING CHALLENGES
TO MEET CURRENT AND EMERGING NEEDS OF SOCIETY

ISBN 978-1-032-54816-6
DOI 10.1201/9781003431749-123

Soil plugging in small diameter tube samplers in silty soils

Le bouchage du sol dans les échantillonneurs de tubes de petit diamètre dans les sols limoneux

E. Pöyry*, M.S. Farhadi, M. Haikola, T.T. Länsivaara
TERRA Research Center, Department of Civil Engineering, Faculty of Built Environment, Tampere University, Tampere, Finland

eetu.poyry@tuni.fi

ABSTRACT: One of the challenges in a geotechnical ground investigation is to obtain high quality samples, especially from coarser soils like sands and silts. Piston samplers are commonly used in the Nordic countries to take undisturbed soils samples. For coarser soils, one commonly reported issue is that the sample is disturbed particularly during withdrawal, causing even loss of sample. To avoid this, different types of catchers can be used. The paper presents some preliminary results of a study aimed to improve sampling quality for silty soils. ST1 and ST2 piston samplers with different setups are compared in a test site near Pori, Finland. One important observation of the study was that in some conditions the sampler was plugged, causing densification, disturbance and partly empty sample tubes. To avoid plugging, lubricant was used both inside the tube as well as on the outside surface. In this paper results from four different type of sampling setups will be presented, namely 1) ST1 with lubricant 2) ST2 with lubricant 3) ST1 with catcher, and 4) ST1 without lubricant. Type 4 presents the standard method used in Finland. The amount of soil plugging was measured after sampling. The sample quality is assessed by comparing unit weight and water content. The results show that plugging appears the most for ST1 sampler with the catcher, but to some extent plugging was an issue even without the catcher. The applied lubricant reduced the plugging effect quite effectively. Another important conclusion from the study is that plugging, due to its densification effect, may lead to results on the unsafe side. This has traditionally not necessarily been noted, as the lack of sample has been interpreted as loss of sample rather than plugging.

RÉSUMÉ: L'un des défis d'étude géotechnique est de prélever des échantillons de bonne qualité, en particulier aux sols plus grossiers, comme les sables et les limons. Les échantillonneurs à piston sont couramment utilisés dans les pays nordiques pour prélever des échantillons de sols non perturbés. Pour les sols plus grossiers, un problème fréquemment signalé est que l'échantillon est perturbé, en particulier lors du retrait. Pour éviter cela, différents types de récupérateurs peuvent être utilisés. Le présent document présente les résultats préliminaires d'améliorer la qualité de l'échantillonnage pour les sols limoneux. Les échantillonneurs ST1 et ST2 avec différentes configurations sont comparés sur un site d'essai près de Pori, en Finlande. Une observation importante de l'étude était que dans certaines conditions, l'échantillonneur était bouché, provoquant de densification, perturbation et des tubes d'échantillons partiellement vides. Pour éviter le bouchage, un lubrifiant a été utilisé à l'intérieur du tube et sur la surface extérieure. Dans ce document, les résultats de quatre types différents de configurations d'échantillonnage seront présentés, 1) ST1 avec lubrifiant 2) ST2 avec lubrifiant 3) ST1 avec récupérateur, et 4) ST1 sans lubrifiant. Le type 4 représente la méthode standard utilisée en Finlande. La quantité de bouchage du sol a été mesurée après l'échantillonnage. La qualité de l'échantillon est évaluée en comparant le poids unitaire et la teneur en eau. Les résultats montrent que le bouchage apparaît le plus pour l'échantillonneur ST1 avec le récupérateur. Le lubrifiant appliqué a réduit l'effet de bouchage. Une autre conclusion importante de l'étude est que le bouchage, en raison de son effet de densification, peut conduire à des résultats du côté dangereux. Cela n'a pas nécessairement été noté traditionnellement, car le manque d'échantillon a été interprété comme une perte d'échantillon plutôt que comme un bouchage.

Keywords: Soil sampling; sample quality; piston samplers; soil plug; silts.

1 INTRODUCTION

One of the main objectives of geotechnical investigation is to obtain representative samples of the subsurface soil. However, sampling is not a trivial task, especially for coarser soils like sands and silts, which are prone to disturbance and loss during the sampling process. Disturbed samples may not reflect the real in-situ conditions of the soil and may lead to erroneous or unreliable results in the laboratory tests. Disturbance can affect the soil structure, density, water content, and strength, leading to inaccurate or misleading results (Clayton, Matthews, & Simons, 1982). Therefore, it is important to minimize the disturbance and maximize the recovery of undisturbed samples.

As a popular sampler in Nordic countries, piston sampler can take high quality samples in soft clays, but it may encounter difficulties in silty and sandy soils, especially during the withdrawal stage, when the sample may drop. One of the problems is also the soil plugging effect, which occurs when the soil inside the tube is compressed, as a result of sampler diameter, wall friction, length of the sampler tube, soil cohesion, etc. (Baligh, Azzouz, & Chin, 1987; Carroll & Long, 2017). To prevent or reduce the soil dropping or plugging, different techniques can be used, such as applying lubricant to the inner surface, or using a catcher at the tip of the tube to retain the sample.

This study aims to compare the most common soil sampling methods used in Finland. The preliminary results are presented herein to improve the sampling quality for silty soils. The performance of two types of piston samplers, ST1 and ST2, are compared with different setups and modifications.

2 TESTING SITE

The testing site is located in the southwest of Finland, at Haistila, which is located in Pori (according to: https://www.google.com/maps/). The location of the testing site is shown in Figure 1.

The Haistila testing site is close to the Gulf of Bothnia, and it has been covered by sea in the past. The sulphide soil is verified there, approximately deeper than 2 m.

The information on the sampling boreholes IDs and the sampler types are presented in Table 1. The boreholes are located at least 2 m far from each other, and the farthest distance between them is about 6 m.

Table 1. The sampler types for each borehole at Haistila; mentioned by S2~S7, in the Borehole IDs.

Borehole ID	Sampler type
HAI22-S2-S050	ST2
HAI22-S5-S060	ST1-FIN with friction tapes
HAI22-S4-S070	ST1-FIN with catcher
HAI22-S3-S090	ST1-normal
HAI22-S7-S100	ST1-FIN without lubricant

2.1 Soil type

The CPTu-based soil stratification profiles, using the RIGTOSS$_{Fr\text{-}Qt}$ and RIGTOSS$_{Bq\text{-}Qt}$ models (Farhadi et al., 2022; Farhadi, Länsivaara, & Tonni, 2022; Farhadi & Länsivaara, 2022), are presented in Figure 2. The identified soil behavior type (SBT) in Figures 2-(a,b) show mainly three or four layers, with SBT values as 6, 5, 4 and 3, respectively at the depth ranges of 1-1.7, 1.7-2.8, 2.8-4.1, and 4.1-10 m; including some minor variations. Distribution of data points on the two related charts of F_r-Q_t and B_q-Q_t in Figures 2-(c,d) confirm the identified layers.

Figure 1. Location of the testing site at Haistila, located in Pori (https://asiointi.maanmittauslaitos.fi/karttapaikka/).

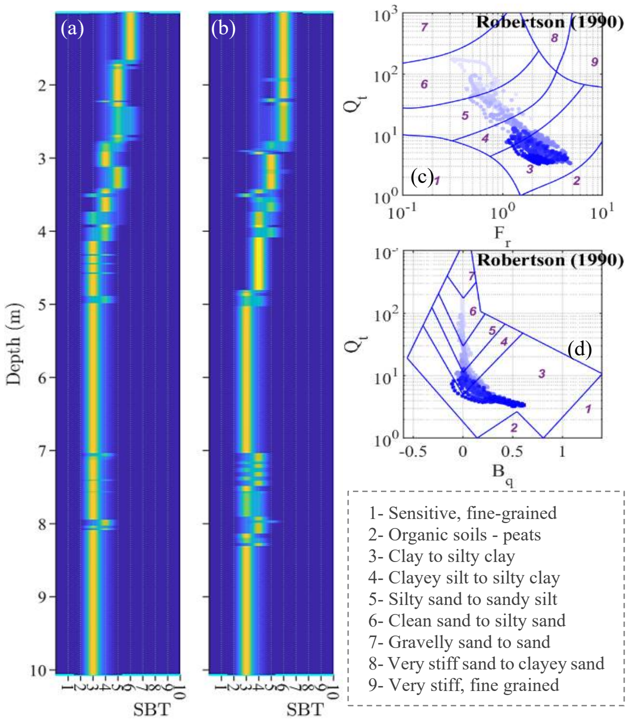

Figure 2. (a) RIGTOSS$_{Fr\text{-}Qt}$, and (b) RIGTOSS$_{Fr\text{-}Bq}$ stratification-characterization profiles of the Haistila testing site, and (c,d) distribution of data points on the characterization charts, by Robertson (1990). The legend introduces different soil behavior types (SBTs) numbers.

The grains size distributions at different depths, for the Haistila testing site are shown in Figure 3. The chart shows that the soil type at the site is silty, and the size of the particles reduces with depth; which is in agreement with the SBT profiles in Figure 2.

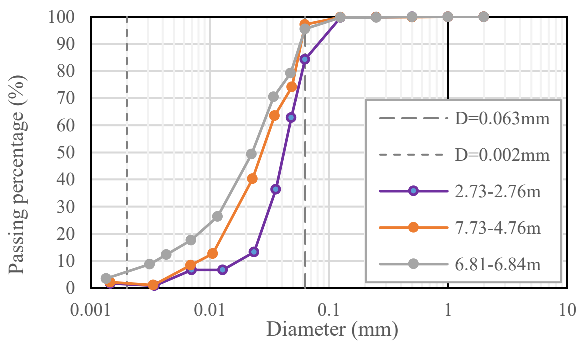

Figure 3. Grains size distribution of the soil at different depths, at the testing site, Haistila. The diameter of the silt particles range from 0.002 to 0.063 mm are marked on the chart by the dotted grey gridlines.

3 METHODOLOGY

The study focuses on identifying plugging and how it affects the soil properties, such as the bulk unit weight, *γ*, and natural water content, w_n. Herein, plugging is simply defined by the 'core recovery' parameter, defined as the height of the soil taken inside the sampling tubes, H_F, to the theoretical sample height, H_T; i.e. $H_P=H_F/H_T$. Additionally, we estimated plugging by measuring the weights of the three 170 mm inner tubes (higher, middle, and lower sampling tubes) at each sampling depth: 2.5, 4.5, and 6.5 m. The masses of the sample tubes were used to estimate the intensity of the potential plugging and its effect on the unit weight of the soil.

The sampler penetration rate into ground varied for different techniques and depths between 0.8 and 2.2 cm/s, and was kept as constant as possible because it was found that the penetration rate influences the soil plugging, i.e., the intrusion of the soil into the sampler tubes.

The two 50 mm piston samplers used here are ST1 and ST2. The details can be sought in the guidelines of Finnish Geotechnical Society (Suomen Geoteknillinen Yhdistys, 2023). As mentioned in Table 1, sampler with catcher is used at borehole HAI22-S4-S070. Its photo is shown in Figure 4-(a). As a novel method, the ST1 sampler is modified in this study, and used at HAI22-S5-S060. Several friction tapes are mounted at six slots, in a 4 cm high inner tube, added behind the cutting shoe of the sampler. It can be seen in Figure 4-(b). Lubricant was used at every borehole except HAI22-S7-S100.

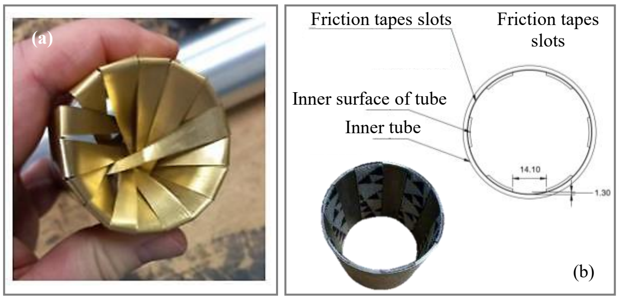

Figure 4. a) photo of the sampler catcher, and, b) the friction tape inner tube of the ST1 sampler.

4 RESULTS

The results indicate that there are correlations between plugging and the soil properties w_n and *γ*; which are explained in the following section.

4.1 Field observations

Plugging is compared for five different sampling techniques at the boreholes S050, S060, S070, S090 and S100 (the full ID of the boreholes are mentioned in Table 1). For each borehole, the weight of the inner tubes is measured, and the measurement results are shown in Figure 5.

Based on the results, it is found that at the boreholes S070 and S100, the sample tubes differ mostly from the average of the results, and the difference is the greatest at the reference depths of 2.5 and 4.5 m.

In addition, at the depth of 4.5 m, it is observed that the lowest sample tubes are partly empty at the boreholes S090 and S100, resulting in much lower sample tube masses. Most likely, part of the samples is dropped when the withdrawal of the sampler started. This phenomenon occurred with ST1 samplers with polymer and without polymer gel. Thus, it is concluded that the polymer gel could not significantly contribute to the retention of the samples within the sampling tube, during the sample lifting phase in the field.

In addition to the dropping of the samples, the other observed problem was the soil plugging into the sampler tubes. As presented in Table 2, plugging is observed especially at the sampling points S070 and S100. The lowest core recovery is found at the sampling depths 2.5 and 4.5 m, which equals 57 and 89%, respectively. The soil at these depths have been coarser; in contrast to the soil at 6.5 m. The higher masses of the lowest tubes at the depths 2.5 and 4.5 m confirm the densification of soil, at boreholes S070 and S100. Table 2 also indicates that the lubricant has a positive impact to reduce the soil plugging, comparing the sampling points S090 and S100 (ST1 sampler with and without the polymer gel at the inner sampling tubes). Using lubricant at S090 has led to 100% core recovery.

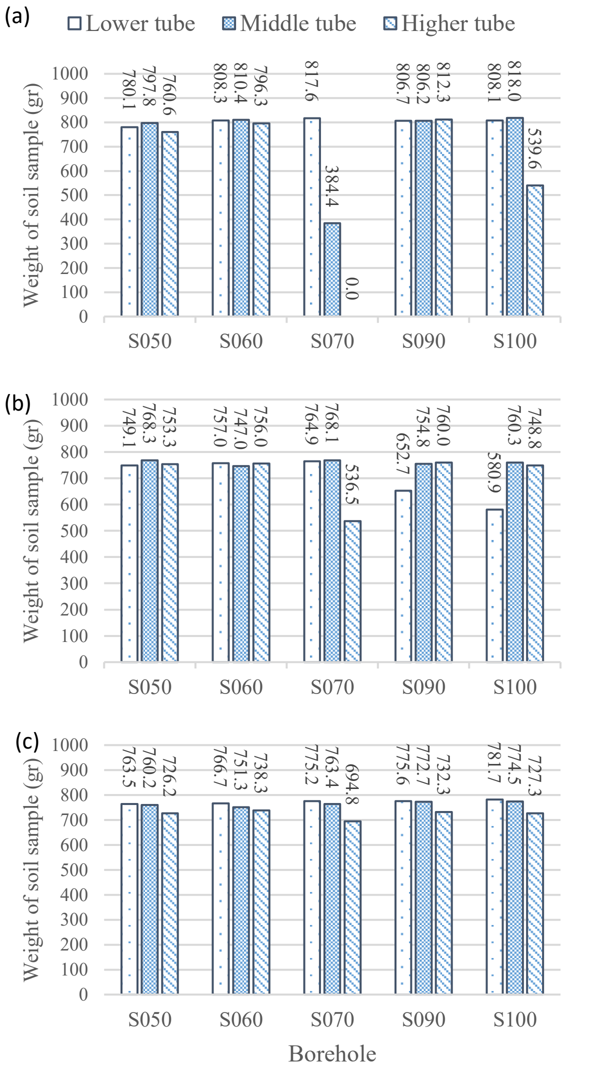

Figure 5. Weight of soil samples at approximate depths of: a) 2.5, b) 4.5, and c) 6.5 m. The boreholes full IDs are mentioned in Table 1, which are shortened herein as the x-axis labels; for example, S050 stands for HAI22-S2-S050.

Table 2. Core recovery for the three reference depths.

	Core recovery (%)		
Borehole ID	**2.5**	**4.5**	**6.5**
HAI22-S2-S050	100	100	100
HAI22-S5-S060	100	100	100
HAI22-S4-S070	57	89	98
HAI22-S3-S090	100	100	100
HAI22-S7-S100	86	100	99

4.2 Unit weight

The water content, w_n, and bulk unit weight, γ, results are shown in Figure 6. It shows significant variations in both w_n and γ, for different samplers, at the same depth. The variation is greatest at the reference depths of 4.5 and 6.5 m, while at the reference depths of 2.5 m, the results are closer together.

Figure 6-a shows that there is a natural variation in γ in depth, due to different soil types; which is approved by the CPTu results shown in Figure 5-b. The maximum γ is measured at the depth of 2.5 m, where the soil contains more sand, in contrast to 4.5 m and 6.5 m. However, it is also found that there are differences between different sampling methods, as there is considerable variation in the γ of samples taken from the same depth. Based on the results, it can be concluded that the γ of the sample is increased by the plugging, mainly due to the large friction of the sampler's wall. Plugging has occurred mostly at the boreholes S070 and S100, where γ has been also the highest, especially at the depth of 2.5 m. But some impacts on γ can also be seen in 4.5 and 6.5 m depth, in Figure 6-(a). At the depth of 4.5m, it seems that catcher has a negative impact on γ. At this depth, the γ values for the low and middle tubes are highest among all tested samplers, which means densification of soil; and at the top tube (which has been left partly empty) γ is the lowest. At the depth of 6.5 m, the highest γ is measured when the lubricant is not used. Definitely, the whole sampling process (transportation and lab test preparation) may affect the results which can magnify the variation.

4.3 Water content

Based on the results in Figure 6, it is found that the higher bulk unit weight, γ, is correlated with the lower water content, w_n, especially at 2.5 m, where the soil is coarser. However, for silts at 4.5 and 6.5 m, the measured parameters are more variable, for different samplers. At the depth of 2.5 m the lowest value of w_n has been measured when using catcher, at the borehole S070. At the depth of 4.5 m, the lowest values of w_n is measured at the boreholes S060 and S070, and at the depth of 6.5 m, the lowest values are measured at the borehole S100. At the same points, γ has been the highest value. It seems that soil densification resulting from the shear and vertical strains during penetration of the sampler causes higher pore pressure in the samples and the escape of water, which could also have led to lower w_n – discussed also by (Baligh, Azzouz, & Chin, 1987; Bjerrum, 1973).

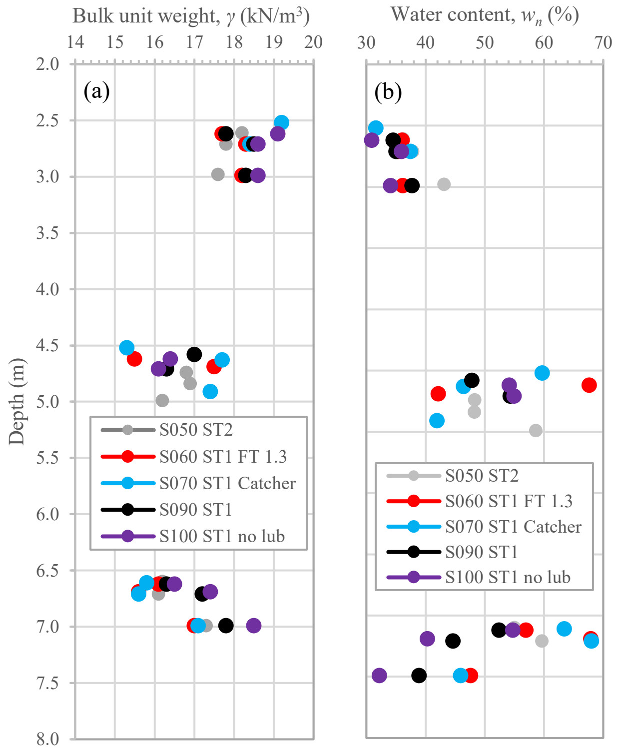

Figure 6. Bulk unit weight, γ, and water content, w_n, measurements for different samplers. (FT stands for friction tapes, used at S060; and 'no lub' shows not using lubricant.).

5 CONCLUSIONS

In this study, several small diameter samplers are employed in silty and sandy soils. They are used mainly in a testing site, Haistila, Ulvila, in Finland. The problem of soil plug in sampling is addressed by the assessment of some sampling and soil properties, such as core recovery, bulk unit weight, γ, and natural water content, w_n. The study led to several concluding marks, for instance:

- Using catcher led to the highest soil densification, and the smallest core recovery.
- Using lubricant lead to less plugging. Plugging was also observed when the lubricant was not applied to the samplers.
- Plugging affected the measurements of γ and w_n, more in silty soils rather than sandy soils. The higher the densification, the higher the γ, and the lower the w_n.
- The novel idea to modify the samplers with friction tapes prevented the soil drop during the withdrawal of the sampler, not leading to plugging and soil densification.

ACKNOWLEDGEMENTS

The authors are grateful for the financial support provided by Tampere University.

REFERENCES

Baligh, M. M., Azzouz, A. S., & Chin, C.-T. (1987). Disturbances due to "ideal" tube sampling. *Journal of geotechnical engineering*, *113*(7), 739-757. https://doi.org/10.1061/(ASCE)0733-9410(1987)113:7(739).

Bjerrum, L. (1973). Problems of soil mechanics and construction on soft clays and structurally unstable soils. *State-of-the-art report, Session IV, Proc. 8th Int. Conf. Soil. Mech. and Found. Eng., Moscow., Volume 3, pp. 111—159.*

Carroll, R., & Long, M. (2017). Sample disturbance effects in silt. *Journal of Geotechnical and Geoenvironmental Engineering*, *143*(9), 04017061. https://doi.org/10.1061/(ASCE)GT.1943-5606.0001749.

Clayton, C. R., Matthews, M. C., & Simons, N. E. (1982). *Site investigation*. Granada London.

Farhadi, M., Länsivaara, T., L'Heureux, J.-S., & Lunne, T. (2022). Application of two novel CPTu-based stratification models. In *Cone Penetration Testing 2022* (pp. 400-406). CRC Press. https://doi.org/10.1201/9781003308829-55.

Farhadi, M., Länsivaara, T., & Tonni, L. (2022). Application of integrated Game Theory-optimization subground stratification (-IGTOSS) model to Venetian Lagoon deposits. In *Cone Penetration Testing 2022* (pp. 394-399). CRC Press. https://doi.org/10.1201/9781003308829-54.

Farhadi, M. S., & Länsivaara, T. (2022). Development of an integrated game theory-optimization subground stratification model using cone penetration test (CPT) measurements. *Engineering with Computers*, *38*(Suppl 2), 1227-1242. https://doi.org/10.1007/s00366-020-01243-0

Suomen Geoteknillinen Yhdistys. (2023). *Kairausopas III: Näytteenotto geoteknisiä tutkimuksia varten*.