A comparison of grain size distribution methods applied to Halden silt

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ABSTRACT: As part of the Norwegian GeoTest Sites (NGTS) project, the grain size distribution of the silt deposit at Halden has been studied from 5 to 14 m depth. Hydrometer and Falling Drop analyses have been run on these material and differences up to 10% in the clay content have been measured between methods for samples collected at the same depth. This paper presents the collected data at Halden and supplements the data with additional tests run on Ø54 mm samples collected from Halden silt site. Samples of coarse, medium and fine silt were carefully mixed prior testing to guarantee sample uniformity. Four different grain size distribution methods were applied: Hydrometer analysis, Falling Drop analysis, Coulter analysis and SediGraph analysis. Variations in clay content up to 10% between the methods were encountered. The grain size distribution agrees well between most of the methods for the coarser silt sample. However, for the medium and fine silt sample, the grain size distribution from SediGraph seems to overestimate the results.

Keywords: silt; grain size distribution; laboratory testing; ngts

1. Introduction

The grain size distribution (GSD) is commonly used for soil classification and can be used for e.g. estimating the hydraulic properties of a soil, its unsaturated behavior, frost or erosion susceptibility. The amount of clay and silt is also important when considering geotechnical solutions in e.g. design of foundations. Typically, a GSD curve presents the percentage of the total dry weight of soil occupied by a given grain size fraction.

When measuring GSDs for coarse soils like gravels and sands with grains larger than 0.075 mm, sieving is used. For finer soils like silts and clays (grains smaller than 0.075 mm), alternative analysis like Hydrometer, Falling Drop, SediGraph and Coulter LS method are applied.

Silts are granular materials of a size somewhere between clay (0.002 mm) and sand (0.063 mm) where more than 45% of the mass of the material is in that range and less than 15% of the material is clay [1]. In the Unified Soil Classification System [2], silt is defined as soil passing the 0.075 mm sieve (more than 85% passing) and that shows a plasticity index lower than 4%. ISO 14688-1[3] defines silt as soil with a particle size between 0.063 mm and 0.002 mm; while the AASHTO system states that silt range from 0.075 mm to 0.005 mm. The British Standard 1377 [4] defines silt as a fine soil with particle sizes ranging between 0.002 mm and 0.060 mm. In this paper, the clay content (CC) will follow the Norwegian Geotechnical Society (NGF) definition [1] (i.e. particles < 0,002 mm) and the fines content (FC) will refer to the amount of material with particles < 0.063 mm as recommended by NGF [1].

This paper presents a comparative study of grain size analysis methods conducted on the Halden silt, which is part of the Norwegian GeoTest Sites (NGTS) project, see [5] and [6]. Experience with Hydrometer and Falling Drop analyses at Halden have shown large discrepancies between GSDs results at given depths (Fig. 1). The differences range from 10% in the clay content to 15% in the fine contents. To assess whether the differences in grain size can be attributed to natural soil variability, or simply to the methods themselves, a study of GSDs methods was initiated and presented herein.

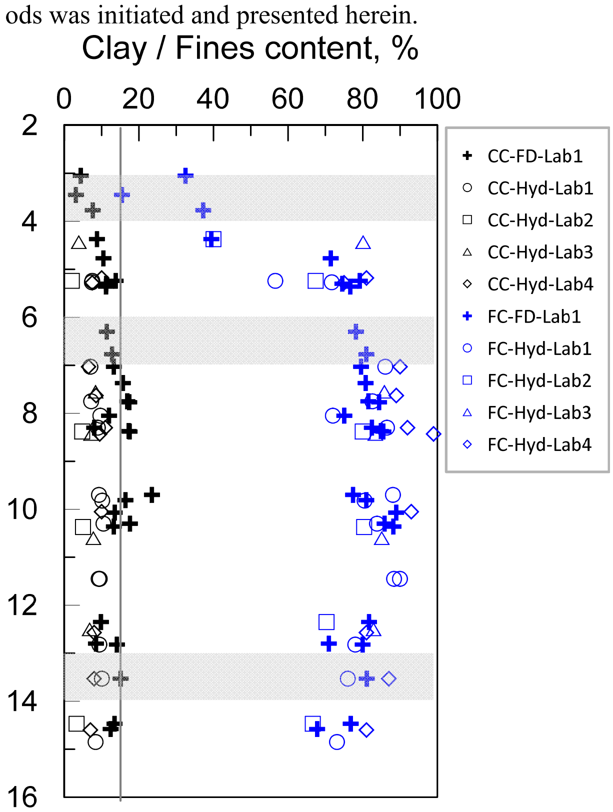

Figure 1. Variation of clay content (CC) and fines content (FC) with depth for Halden silt. The particle size was determined by Hydrometer (Hyd) and Falling Drop (FD) methods carried out at four different laboratories. The shaded areas correspond to the sample depths of the material analyzed in the present paper.

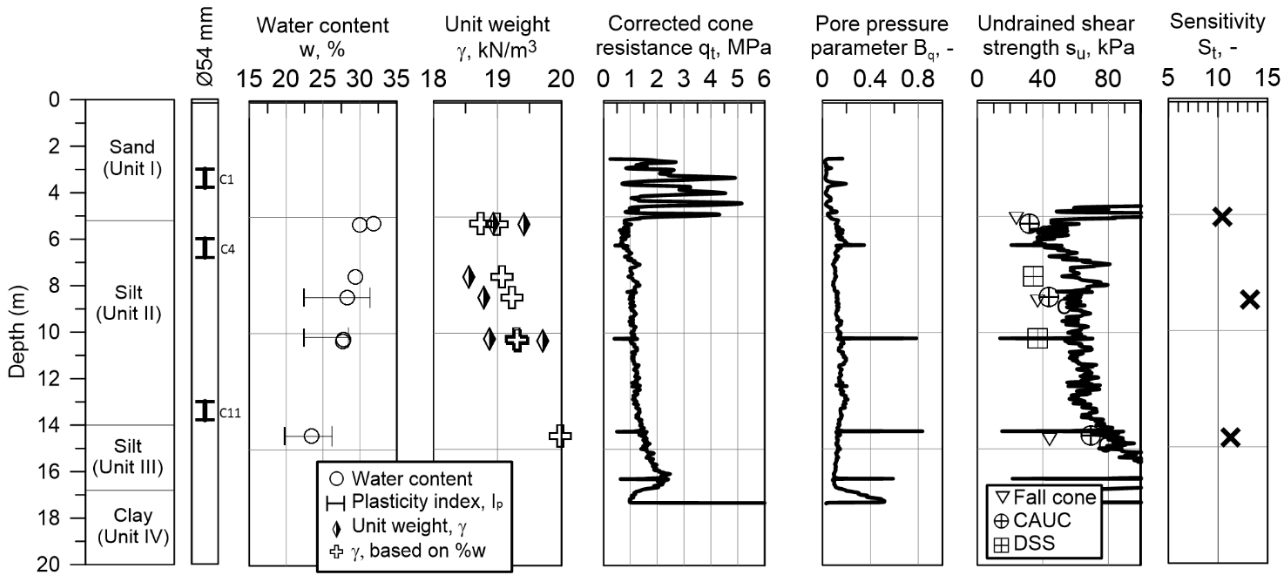

Figure 2. Typical soil parameters and stratigraphy for Halden silt based on borehole HALB03 (after [6])

In this paper, four different GSD methods are evaluated and compared; i.e. Hydrometer, Falling Drop, SediGraph and Coulter method. The scope is to quantify the differences that these methods can give when evaluating the GSD of silts. Additional data must be collected to conclude on which method may be more suitable for determining GSDs in silty soils.

2. Methods for determining GSDs

Most of the methods for grain-size analysis, like Hydrometer [7] and Falling Drop [8], assume that the sedimentation process follows the sedimentation theory or Stokes' law: *if all other variables are held constant, settling velocity is proportional to particle size*. Other methods, like SediGraph [9] combine this theory with the absorption of x-radiation or Beer-Lambert law: *if all other variables are held constant; x-ray attenuation is proportional to mass concentration*. Some others make use of image analysis and laser diffraction measuring a plan-view of particle diameters, like the LS 13320 Coulter Particle Size Analyzer [10].

Previous studies conclude that SediGraph gives a clay content that is a bit higher or relatively equal to the one obtained with the Hydrometer method [11]. Rise & Brendyen [11] mention that laser analysis (i.e. Coulter) gives a much lower clay content and a higher fine content compared to the other methods.

The existance of different methods, in addition to other methods not mentioned in this paper, raises the question of how similar the results are between the different techniques. Beuselinck et al. [12] summarized different works that have been carried out in this topic and remark that the Coulter method underestimated the clay content of lacustrine sediments respect to classical sedimentation analysis. For silty soils, the same authors found out that the clay content was underestimated with the Coulter method with respect to classical sedimentation methods (i.e. Hydrometer and Falling drop). Rise & Brendyen [11] present some observations of the grain-size analysis with Sedigraph and Coulter methods for marine and glaciomarine Norwegian sediments. They found out that that SediGraph overestimated the clay content compared to classical sedimention analysis.

The mayority of the soils do not follow Stokes law regarding the grain shapes. This is valid in particular with sediments that have a large amount of clay minerals. This might cause difference between the methods used for GSD determination. Flaky clay grains will be longer in suspension than rounded grains of the same weight.

3. Experimental investigation

3.1. Soil description

The natural fjord marine deposit at Halden consists mostly of low plasticity silt. The water table is approximately 2.5 m below ground level. The silt deposit is relatively uniform between 4.5 m and 15 m, with small variations in grain size. Fig. 2 presents some typical soil parameters and stratigraphy for Halden silt based on borehole HALB03. Blaker et al. [6] have recently published a complete overview and geotechnical characterization of the site.

For this study, samples were collected with a Ø54 mm piston sampler at borehole HALB03. Cylinders were collected at three different depths (see Table 1 for details and Fig. 1 and 2 for the locations in depth).

Table 1. Ø54 mm cylinders from HALB03 used in this study

Parameter	C1	C4	C11
Depth	3-3,8 m	6-6,8 m	13-13,8 m
Water content	15%	29%	25%
Density of soil grains	27 kN/m³	26 kN/m³	27 kN/m³
Soil classification [1]	silty clayey sand (coarse silt)	clayey silt (medium silt)	clayey silt (fine silt)

3.2. Sample preparation and testing

The samples were prepared by first mixing the soil of each cylinder carefully to make them as homogenous as possible. Each cylinder sample was put in a steel mixing bowl and mixed manually for 2 min. Then, a laboratory mixer was used for 2 min at low speed. If the sample didn't look homogenous after the second mixing step, additional mixing was performed manually and gently with a spatula for additional 2 min. Finally, the samples were separated in equal portions and grain size analyses were performed. Only one test per method was performed at each depth. The hydrometer analyses were performed at the Norwegian University of Science and Technology (NTNU), the falling drop analyses were carried out at the Norwegian Geotechnical Institute (NGI), the coulter analyses were completed at the Geological Survey of Norway (NGU) with a Coulter LS 13320 instrument and the sedigraph analyses at Wiertsema & Partners. The hydrometer analyses were performed only on the soil fraction with particles smaller than 0,075 mm.

4. Analysis of experimental results

Fig. 3 shows the GSDs for the coarse silt / fine sand from 3-3,8 m depth (sample C1). Assessment of clay content (CC) varies between 2-7% between the methods, being the lowest value the obtained with the hydrometer. The fines content (FC) vary between 45-70% between the methods, where hydrometer is the one in the upper range.

Fig. 4 presents the GSDs for the medium silt (i.e. sample C4) from 6-6,8 m depth. The clay content (CC) varies between 1-10% between the methods, being the lowest value the obtained with falling drop, followed by hydrometer, coulter and sedigraph. The fines content (FC) vary between 86-91% between the methods, where the coulter data is in the lower range.

Fig. 5 shows the GSDs for the fine silt from 13-13,8 m depth. The clay content (CC) varies between 6-12% between the methods, being the lowest value the obtained with hydrometer, followed by falling drop and coulter, and sedigraph in the upper range. The fines content (FC) vary between 88-89% between the methods, where data from the hydrometer is in the upper range.

When looking at the shape of the GSDs, it is noticeable that the curves for the different methods tend to be more similar for the coarse silt than for the finer silt. The GSD from hydrometer defines a lower limit in the variation and GSD from SediGraph an upper limit. The distance between both limits increases with silt fineness.

Table 2 presents the variation on the coefficient of uniformity c_u for the different methods and silt types tested in the present study. In general, all the curves fall in the classification "well graded soil". For the coarse silt, the hydrometer and the coulter results give the lowest c_u value. This tendency seems to be repeated with the hydrometer results for the medium and fine silt.

Fig. 6 reproduces the data presented in Fig. 1 and includes the range of variation of CC (in purple color) and FC (in green color) obtained with the different methods from this study. The data presented in black and blue is collected from different boreholes at Halden.

Eventhough Halden silt is an uniform silt deposit, some variations are observed between the previous data and the results from the present study:

- By making the sample more homogenous, the FC is increases and the CC decreases.
- The range of variation of FC between the different methods seems to increase with an increase in silt coarseness. However, for the coarse and medium silt, this variation is very similar.
- The variation range of CC between the methods is largest for the medium and fine silt (up to 9%).

The data presented in this study gives a short insight on the implications of using different GSD methods for for soil classification. In geotechnical practice the the amount of clay is an important parameter as the clay controls the physical properties of the soil. According to NGF [1] if the CC is larger than 30%, the material is clssified as clay, if the CC is between 15-30% the material is classified as clay with an adjective (for example, silty clay); if the CC is between 5-15% the material gets an adjective of "clayey" (for example, clayey silt) and if the CC is lower than 5% the material is classified as clay poor or it does not get a clay adjective.

Results presented here show that, for a given sample, different GSD methods lead to a different soil description: e.g. clayey silt after sedigraph results and silt after hydrometer analysis. Hence, care should be taken when selecting the the appropriate GSD method and this should be linked to the geotechnical problem at hand. If the purpose is to focus on the geotechnical evaluation that moves towards a clay behaviour, then sedigraph might be suitable for GSD determination. On the other hand, if one is interested on the silt behaviour, then the hydrometer analysis is the most recommended method for GSD method.

The observations presented in this paper for the medium and fine silt agree well with those made by Rise & Brendyen [11] when more than 1200 samples of marine and glaciomarine sediments were tested i.e. the coulter method tends to underestimate and the sedigraph tends to overestimate the clay content compared to classical sedimention analysis.

Table 2. Coefficient of uniformity, c_u, for this study's GSDs

Method	Coarse silt	Medium silt	Fine silt
Hydrometer	5	6	9
Falling Drop	10.5	8	11
SediGraph	10	12.5	12*
Coulter	7	10	14

*this was determined by the ratio d_{75}/d_{25}

5. Conclusions

The GSD of a natural silt deposit has been determined by four different methods. The silt deposit has particle fractions from coarse, medium to fine silt. No particular differences between the shape of the curves determined by the different methods were observed for the coarse silt. These differences were more notorious for the medium and fine silt. In these cases, the exact same material led to differences in the clay content due to the GSD method used. This will imply a different classification according to NGF [1] soil classification system.

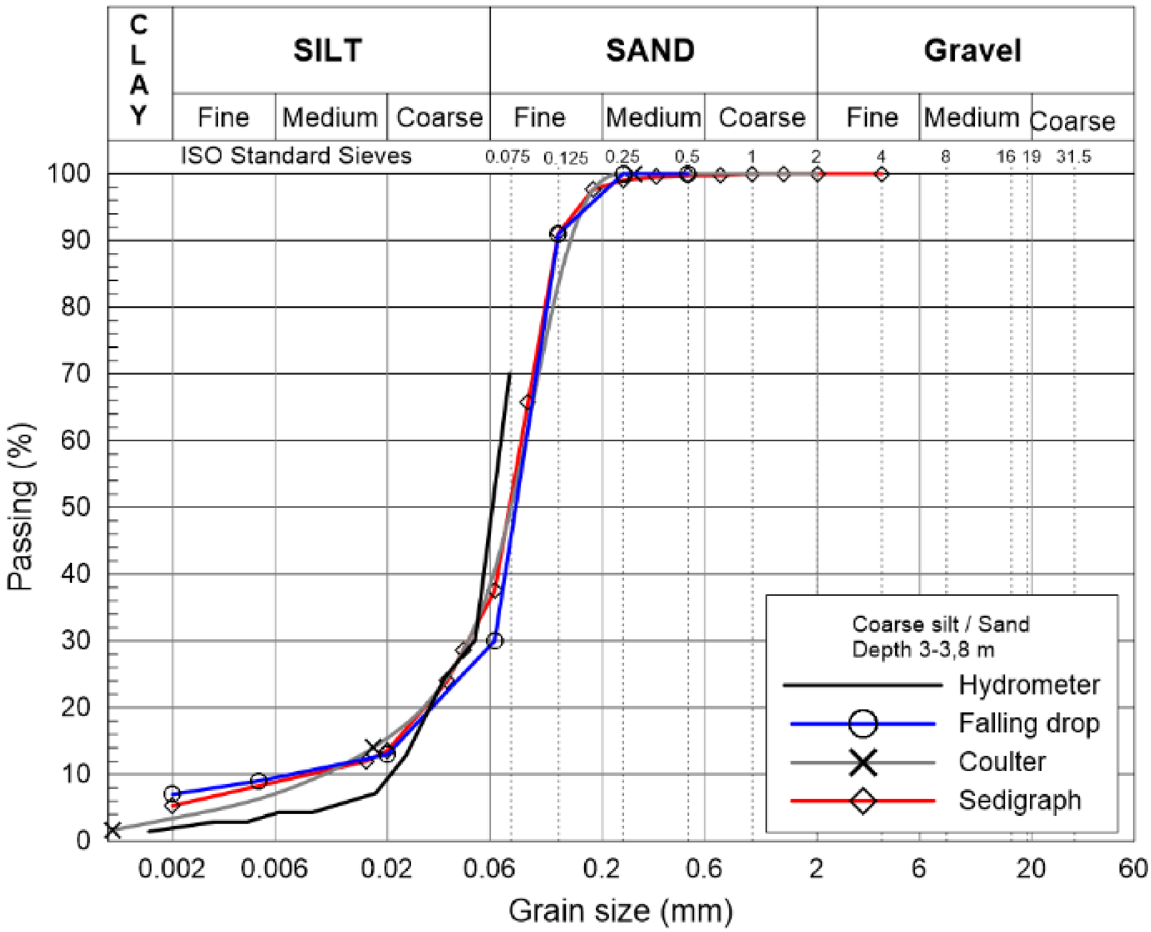

Figure 3. GSDs for the coarse silt / fine sand from 3-3,8 m depth

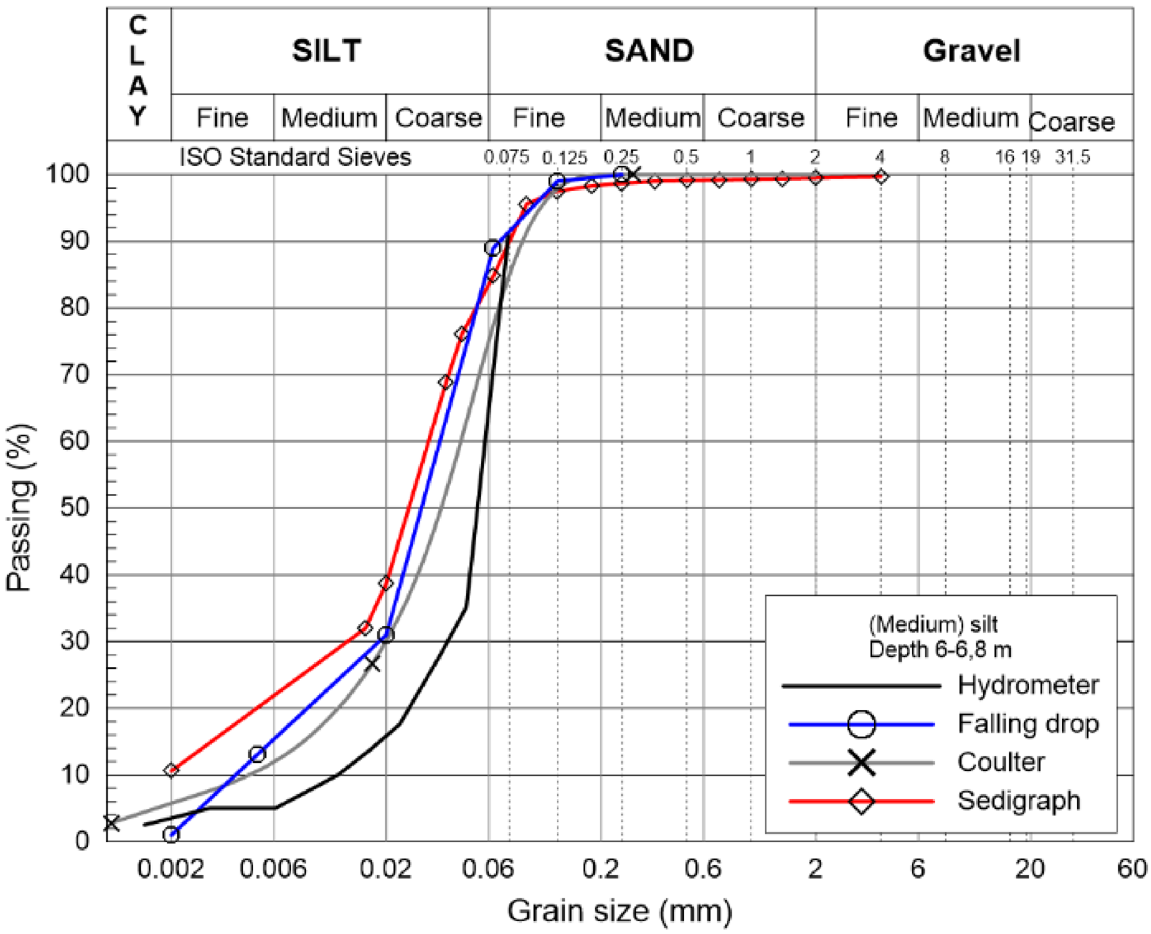

Figure 4. GSDs for the medium silt from 6-6,8 m depth.

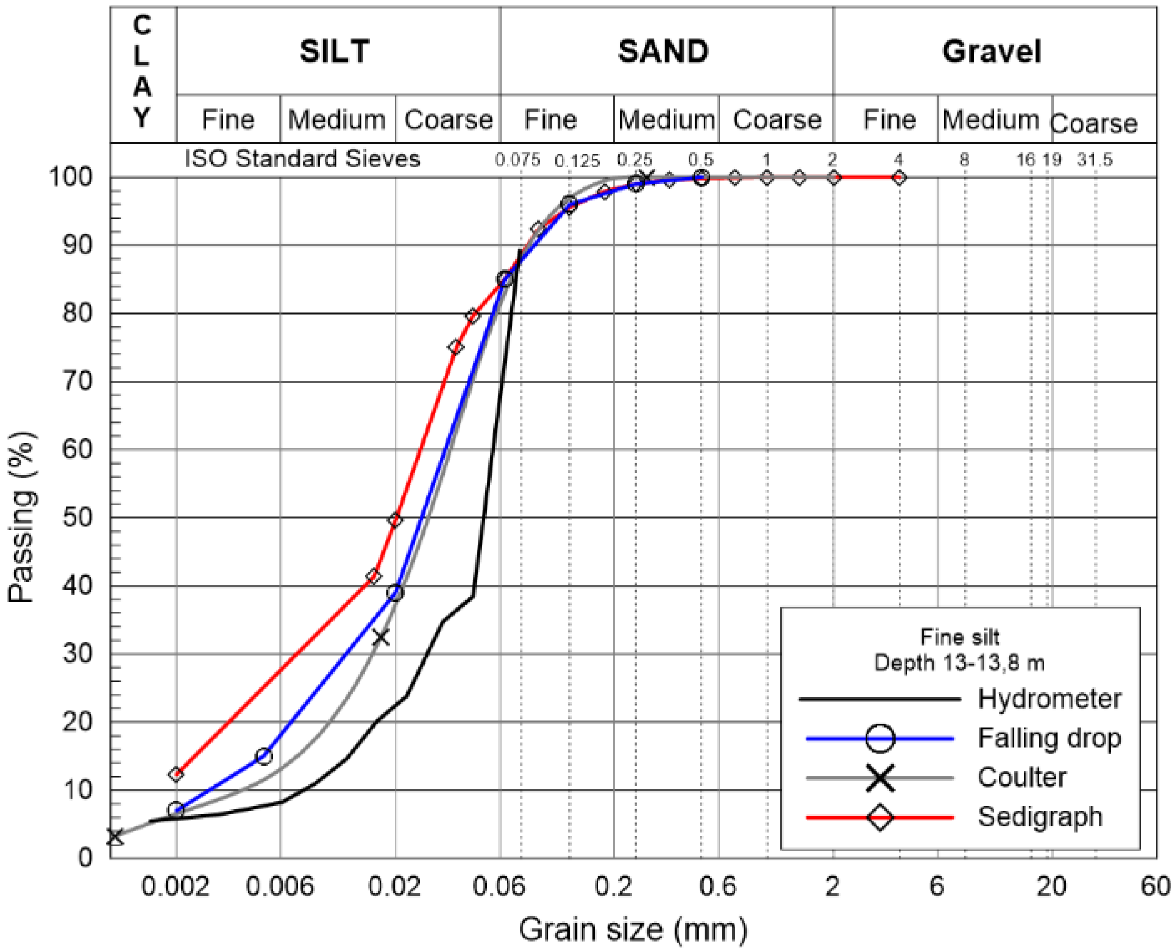

Figure 5. GSDs for the fine silt from 13-13,8 m depth.

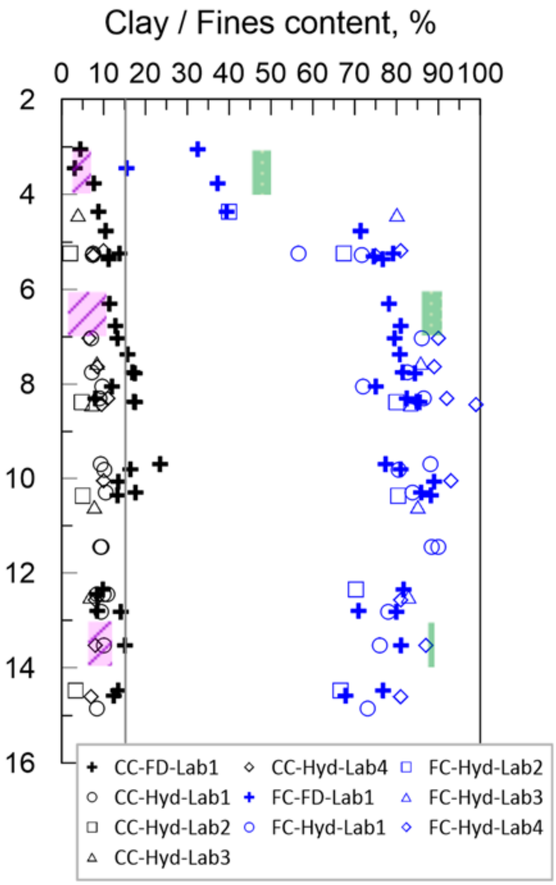

Figure 6. Data presented in Fig. 1 and range of variation of CC (in purple color) and FC (in green color) obtained with the different methods from this study.

The observations presented in this paper are very specific for the silt material analyzed. Additional data must be collected to conclude on which method may be more suitable for determining GSDs in silty soils.

Acknowledgement

The authors would like to thank The Research Council of Norway for their generous infrastructure grant to establish the five Norwegian GeoTest Sites for research (Grant No. 245650/F50).

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