NGM 2016 Reykjavik
Proceedings of the 17th Nordic Geotechnical Meeting
Challenges in Nordic Geotechnic 25th – 28th of May

A preliminary attempt towards soil classification chart from total sounding

E. Haugen
Norwegian Public Roads Administration, Norway, eigil.haugen@vegvesen.no

X. Yu, S. A. Degago, D. Nigussie, O. V. Kirkevollen
Norwegian Public Roads Administration, Norway

ABSTRACT

Total sounding is an in-situ soil investigation method that combines conventional rotary pressure sounding with rock control drilling. It is a quick method that can be used in most soil types. It is mainly used for preliminary characterization of soil layering and to identify location of bed rocks. In Norwegian geotechnical practice, total sounding is generally adopted as a standard method to start an in-situ soil investigation scheme. The main measurement in a total sounding is the penetration resistance force (in kN). The main shortcoming of this measurement is its susceptibility to the increasing rod friction by depth. As a result this measurement is only used subjectively but it still usually provides an important first time insight to the soil layering that is later verified with additional field and laboratory investigations. Thus, it would be an advantage to systematically study measurements of total sounding for a better soil characterization in a more objective way. In this work three parameters were derived from the penetration resistance force: the smoothed normalized penetration pressure, the standard deviation of penetration force, and the gradient of the smoothed normalized penetration pressure. Then the correlations among these parameters and grain size distributions are explored. Based on this an attempt is made to sketch a soil classification chart, in which four general soil types including quick clay are distinguished. Using data from selected sites the proposed chart is evaluated by comparing with two CPTU-based classification methods as well as laboratory-based classification. The paper also discusses additional potential improvements that can be incorporated to the chart and more broadly to this sounding method to asses its possible use for the current geotechnical practice.

Keywords: In-situ investigation, total sounding, soil classification chart

1 INTRODUCTION

Total sounding is a rotary pressure sounding technique which can be used in almost all soil types. The method was developed in Norway through cooperation between the Norwegian Geotechnical Institute and the Norwegian Road Research Laboratory back in 1980s, with the purpose of combining rotary pressure sounding and bedrock control sounding into one operation (NGF, 1994). It is now established as the most used sounding method in Norway. The Swedish *rock soil total sounding* (JB totalsondering) is based on the Norwegian counterpart and is increasingly used in Sweden (Wister, 2010).

In the Norwegian geotechnical practice, a total sounding is generally adopted as a standard method to start an in-situ soil investigation scheme. The main use of total sounding is for a preliminary characterization of soil layering and to identify location of bed rocks. It provides a basis for planning subsequent in-situ investigations such as CPTU (cone penetration test with pore pressure measurement), soil sampling and pore pressure measurements. The main measurement in a total sounding that is used in classifying soil layering is the penetration resistance force (in kN). This is used for a qualitative classification of soil. A main shortcoming in this measurement is its susceptibility to the influence of increasing rod friction by depth. The inaccuracy is especially remarkable in soft to medium firm soils as compared to CPTU (Sandven et al., 2012).

However, given the fact that it is used extensively as a standard method in the practice, it is appealing to attempt to get more out of its measurements in an objective way and explore further extensions. Thus, this work is a preliminary attempt in that direction. The aim of this work is to quantitatively explore the potential of total sounding in soil classification, and evaluate its soundness against two CPTU based classification methods and grain size analysis from laboratory investigation. Laboratory data on physical and mechanical properties are used as references.

On this instance, it is worthwhile to mention that Sofia (2010) has correlated the penetration force of total sounding with tip resistance from CPTU in a simple manner, and proposed formulas for evaluating friction angle and elastic modulus out of the penetration force of total sounding in accordance with the Swedish practice.

2 CURRENT PRACTICE

2.1 Equipment and procedure

The total sounding equipment consists of a 57 mm diameter rock-drilling bit, connected to hollow 45 mm "geo-rods". The drilling bit has a hole with a spring-loaded steel ball, for flushing. The penetration rate is kept at 3 m/min and rotation rate might vary from 25 rev./minute up to 70 rev./minute (NGF, 1994). An illustration of the equipment is given in Figure 1.

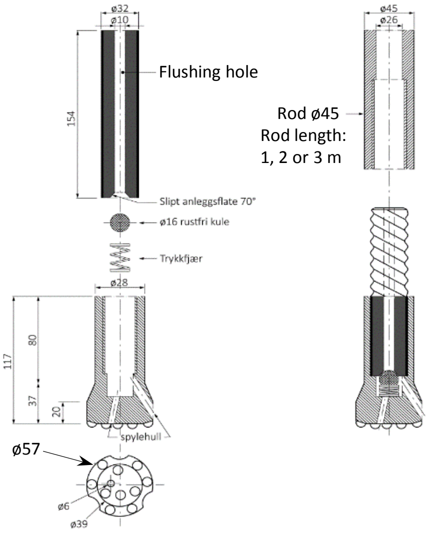

Figure 1 Total sounding drilling bit and rod (courtesy of NGF Pub. 9, 1994).

When encountering very firm layers and penetration cannot be maintained at a desired rate, the operator can increase rotation rate. If this does not penetrate further, flushing and hammering mode can be enabled in sequence to facilitate drilling through firm soil or rock (NGF, 2016).

The total sounding system records the following data: depth (m), penetration force (kN), penetration rate in rock (sec/m), rotation rate (rev./sec), hammering and flushing (binary) and flushing fluid pressure (kPa).

2.2 Interpretations of results

In Norway, the interpretations of total sounding results are done in accordance with Norwegian Geotechnical Society (Norsk Geoteknisk Forening (NGF)) guideline nr. 7 and nr. 9. However, considerable subjective judgement has to be involved. Generally, smooth curves and low resistance indicate soft clays. Increasing fluctuations of the penetration resistance indicates a larger fraction of coarse material. Also the overall trend of resistance force changing with depth gives an indication in relative stiffness. Sensitive soils have been observed to have a decreasing resistance with depth. Increased rotation rate indicates very firm soils or boulders. Enabled hammering together with recorded low resistance and constant low penetration rate imply the existence of bedrock, rather than boulders or very firm soils. Figure 2 shows a total sounding plot together with soil classifications. Information of the first four layers are obtained from laboratory tests, while glacial till is speculated considering the geological history of the site.

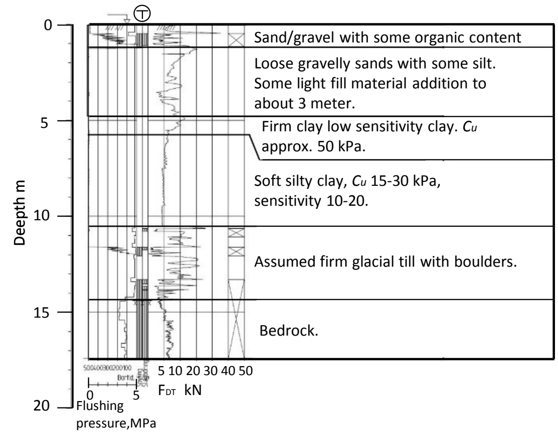

Figure 2 Example of a total sounding from a project in Drammen, Norway.

3 SOME LIMITATIONS OF TOTAL SOUNDING

In principle, the penetration force is a function of the soil firmness. This concept is adopted in total sounding for a rough interpretation of soil types and layering. The limitations in accuracy of such use arise due to certain inherent aspects of the method. The main one being the effect of friction along the rod and its significant influence on the measurement of penetration resistance. Another aspect is the lack of control on the inclination of the rod during drilling.

Resistance force is measured at the top (as opposed to CPTU's tip resistance measurement). This means that all resistance in the system is included in the measured values, such as friction along the rods and resistance in the drill tower itself.

Water flushing is used to push the rod further down in firm layers as it reduces friction along the rods and the drilling bit. It has also been observed that, when flushing is enabled to penetrate through firm layers, it disturbs relatively soft soil layers below, and gives recorded resistance much lower than in soils undisturbed by flushing. Thereafter, two similar soils may show different resistance depending on if flushing has been used or not in the above layer. It is also worthy to mention that under favourable soil condition the bore hole may not collapse and very limited friction could be expected (Fredriksen, 1997).

It is logical to assume that total sounding results could be sensitive to change in rod direction while drilling. The drill tower direction may not be identical to the rod direction. This adds a lateral force to both the rod and the drill tower; and is often seen as abruptly increased resistance near the end of each 2-meter rod. Considering the aforementioned aspects, one must take caution when interpreting results from total sounding.

It is well known by both geotechnical engineers and drilling operators that the fluctuations of the penetration force curve is descriptive of the coarseness of soil. The penetration force is indicative but could be deceiving when used alone as forces may come from other places in the system than the tip. Therefore a preliminary study is initiated by analysing some existing data aiming to (1) explore more indicative parameters from total sounding results; (2) investigate where total sounding results may be misleading or ambiguous; (3) investigate if a quantitative soil classification chart can be made, in a similar fashion as to those extensively used with CPTU (Robertson, 1998).

4 DATA SETS AND PROCESSING

4.1 Total sounding data

Total sounding data, together with laboratory investigation results, were compiled from road projects under the Norwegian Public Roads Administration (NPRA) Region South for the study in this paper. The data are gathered from 2011 to 2015 in the counties; Buskerud, Vestfold, Telemark and Aust-Agder. Figure 3 displays the geographic distribution of tests; the number in circle indicates the number of data sets obtained from that site.

Cases where there has been no use of hammering, flushing and increased rotation rate have been chosen. Besides this care was taken to include only data that are not close to rod changes, as abrupt resistance changes are often observed at those points.

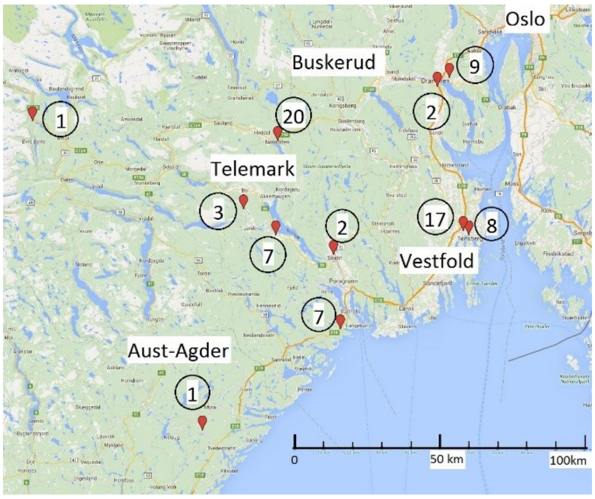

Figure 3 Geographic distribution of sites for data sets (background map courtesy of Google.com).

4.2 Total sounding data processing

Analogous to CPTU, penetration force (F_{dt}) tends to increase with depth in most layers. For CPTU various normalization methods have been proposed to account for this influence as can be seen in work by Wroth (1984, 1988), Olsen (1984), Senneset and Janbu (1982), Douglas et al. (1985), Olsen and Farr (1986), Robertson (1989). In most of these approaches, the normalized cone resistance (*Q*) is computed by first subtracting overburden stress (σ_{v0}) from corrected tip resistance (q_t) and then dividing the remainder by the effective overburden stress (σ'_{v0}). Sometimes different normalization methods and iterations are applied to account for different type of soil (e.g. Robertson, 2009). In that case *Q* is also dependent on rod friction f_s.

In this paper, taking into account the available reading, a straightforward normalization method has been adopted. Thus, F_{dt} is first divided by σ'_{v0} and then divided by crossectional area of the drilling bit A to give the normalized penetration pressure q_n as shown in Equation 1. Moreover, as soil unit weights are only made available when laboratory investigations are performed. Besides, generally the ground water level is unknown until piezometer is installed. Therefore, a uniform effective soil weight for all layers and ground water level at terrain surface are assumed to facilitate a fast interpretation right after total sounding is finished.

$$q_n = \frac{F_{dt}}{A\cdot\sigma'_{v0}} = \frac{F_{dt}}{A\cdot\gamma'\cdot z} \qquad (1)$$

where,

q_n is the normalized penetration pressure;

F_{dt} is the penetration force measured on the top of rod;

A is the cross-area of drilling bit (i.e. $A = 2.55 \times 10^{-3}\ m^2$);

σ'_{v0} is the effective overburden stress;

γ' is the average effective unit weight of penetrated soils (a value 8 kN/m^3 is taken for simplicity);

z is depth from terrain level.

The normalized penetration pressure q_n is further smoothened by a median filter and then referred to as smoothened normalized penetration pressure and denoted as q_{ns} Besides, the gradient dq_{ns}/dz and the standard deviation of penetration force $std(F_{dt})$ within the smoothing length are also adopted. The fluctuation of penetration force F_{dt} instead of q_n or q_{ns} was found to offer better indication of soil grains composition.

A suitable length needed for smoothening q_n and calculating dq_{ns}/dz and $std(F_{dt})$ was chosen with these criteria met: (1) being small to keep resolution with depth; (2) including a reasonable amount of data in order to deliver stable results; (3) being robust for small changes of the length. In current study, 0.3 m appears to be suitable.

An example of the processed data is shown in Figure 4.

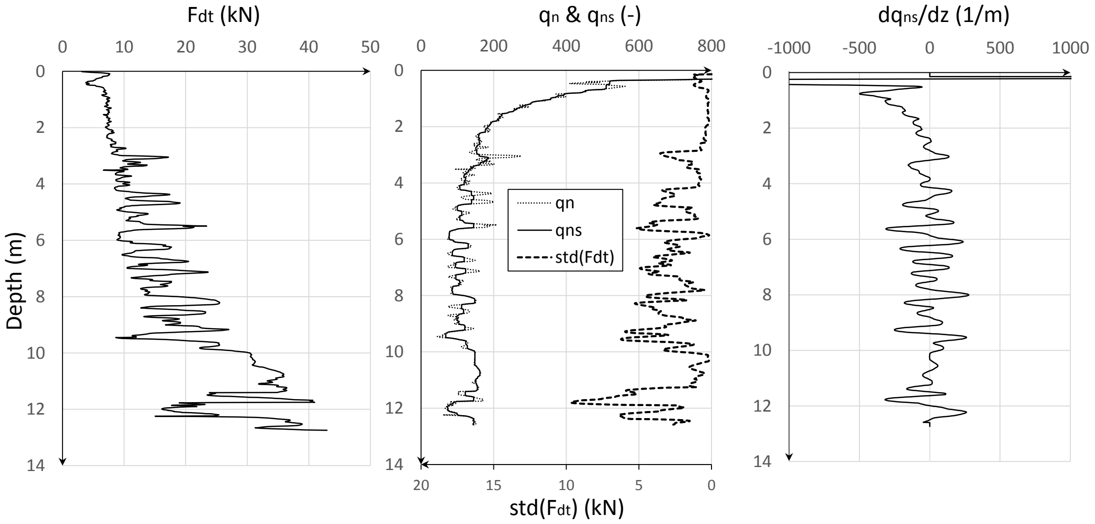

Figure 4 An example of processed sounding data (raw data taken from project Rv. 359 Kaste-Stoadalen).

4.3 Laboratory data

Grain size analysis has been performed on soil samples taken from the selected sites. This shall provide basis for soil classification. The undisturbed (c_u) and remoulded shear strengths (c_{ur}) are determined from fall cone tests. The sensitivity (S_t) is calculated as the ratio of c_u and c_{ur} (i.e. $S_t = c_u/c_{ur}$).

5 RESULTS

5.1 *Possible correlations among the parameters and soil fractions*

In an attempt to examine the dependence or independence of parameters q_{ns}, dq_{ns}/dz and $std(F_{dt})$ each two of them has been plotted below (Figure 5).

In all the three plots (Figure 5), most data points cluster near the origin and some others are randomly farther distributed. No simple or decisive relationships could be identified.

An attempt has also been made to correlate the parameters q_{ns}, dq_{ns}/dz and $std(F_{dt})$ to grain size distribution in terms of fractions of sand or gravel (f_s), silt (f_{si}) and clay (f_c) by weight (Figure 6). These three parameters are seen to have no role in classification of soil type in terms of fractions of specific soil grains. Nevertheless, comparatively q_{ns} and $std(F_{dt})$ tend to have better convergence of data than dq_{ns}/dz. Though considerable scattering exist, q_{ns} greater than 100 and $std(F_{dt})$ over 1.0 are likely to indicate sands or gravels.

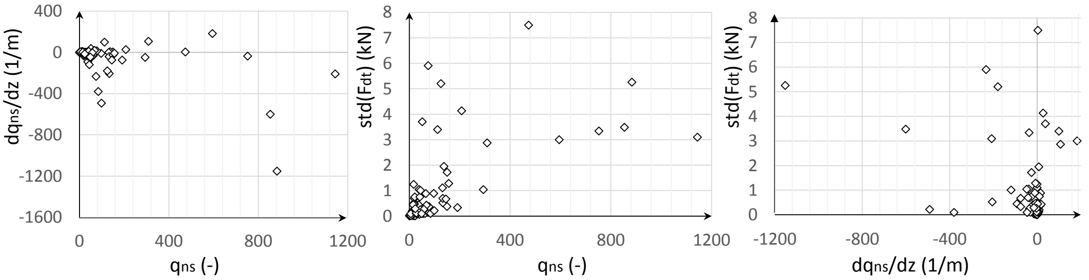

Figure 5 Correlations among *q_{ns}, dq_{ns}/dz and $std(F_{dt})$.*

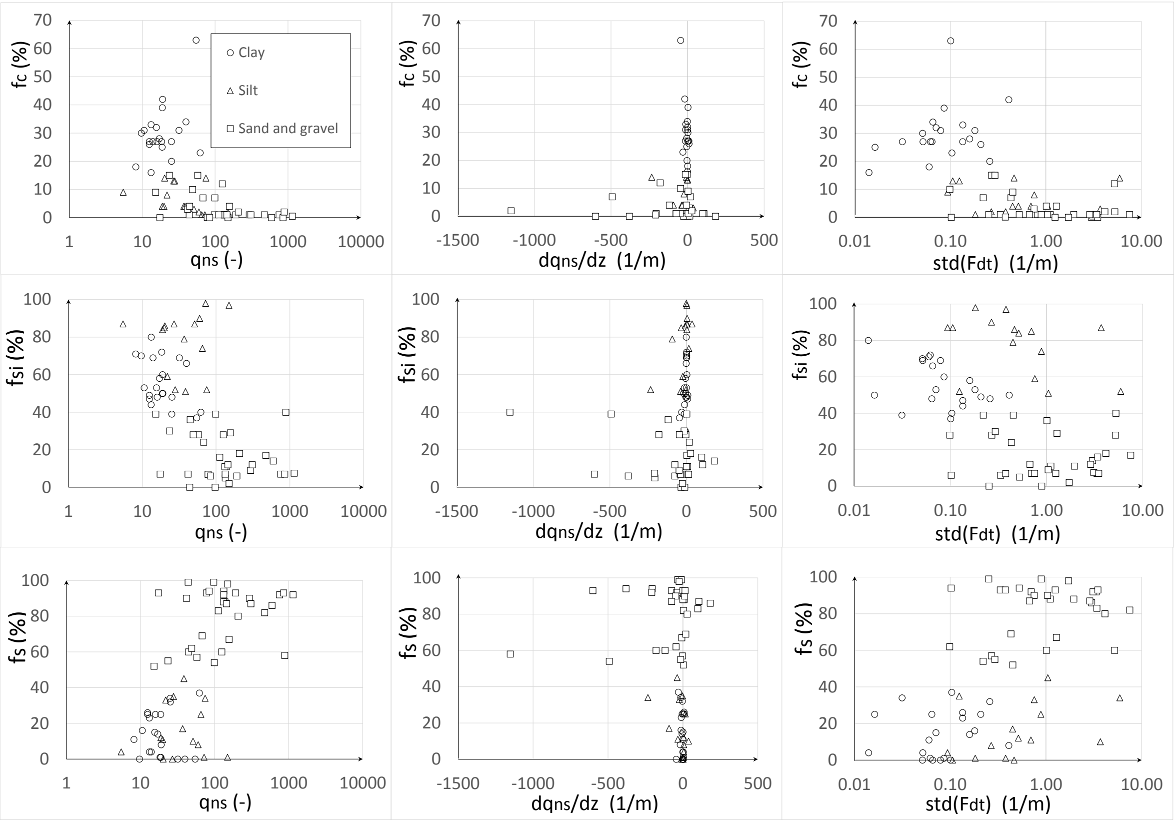

Figure 6 Correlations between parameters q_{ns}, dq_{ns}/dz and $std(F_{dt})$ and grain size distribution.

5.2 Soil classification chart

The proposed classification is based on the mechanical response of soils, in a similar fashion as CPTU soil behaviour type charts. The reference soils are classified by laboratory grain size analysis. Other mechanical properties such as friction angle, overconsolidation ratio (OCR) and physical properties like water content were disregarded. Despite this inconsistency, the current classification method, based on laboratory grain size analysis, is considered as identical to classification that incorporates comprehensive soil characteristics.

According to Figure 6, parameters q_{ns}, dq_{ns}/dz and $std(F_{dt})$ cannot be expected to deliver accurate classifications of soil based on grain size distributions but offer a guide of soil type. Besides q_{ns} and $std(F_{dt})$ have demonstrated more distinctive correlation to soil type than dq_{ns}/dz.

Having all data plotted against q_{ns} and $std(F_{dt})$ in Figure 7, the data points are found confined in a band in which $std(F_{dt})$ tends to increase with increasing q_{ns}. Within the band, three zones as separated by wide shaded transition areas could be distinguished.

In the lower-left zone, all clay-type soils are located though very few points of silt and sand can be seen near the boundary. In case of specific soil type, clays cluster closely, while silty sandy clays and silty clays distribute sparsely. In the transition area between clay and silt, a handful of all three general types of soil exist.

The zone to the upper-right is dominated by sand-type soils with one exception of silt. Manifested by gravely sand, data sets in this zone are highly scattered if plotted with linear x-axis. Another zone confined in the middle sees the majority of silts, but also has considerable number of sandy soils randomly mixed.

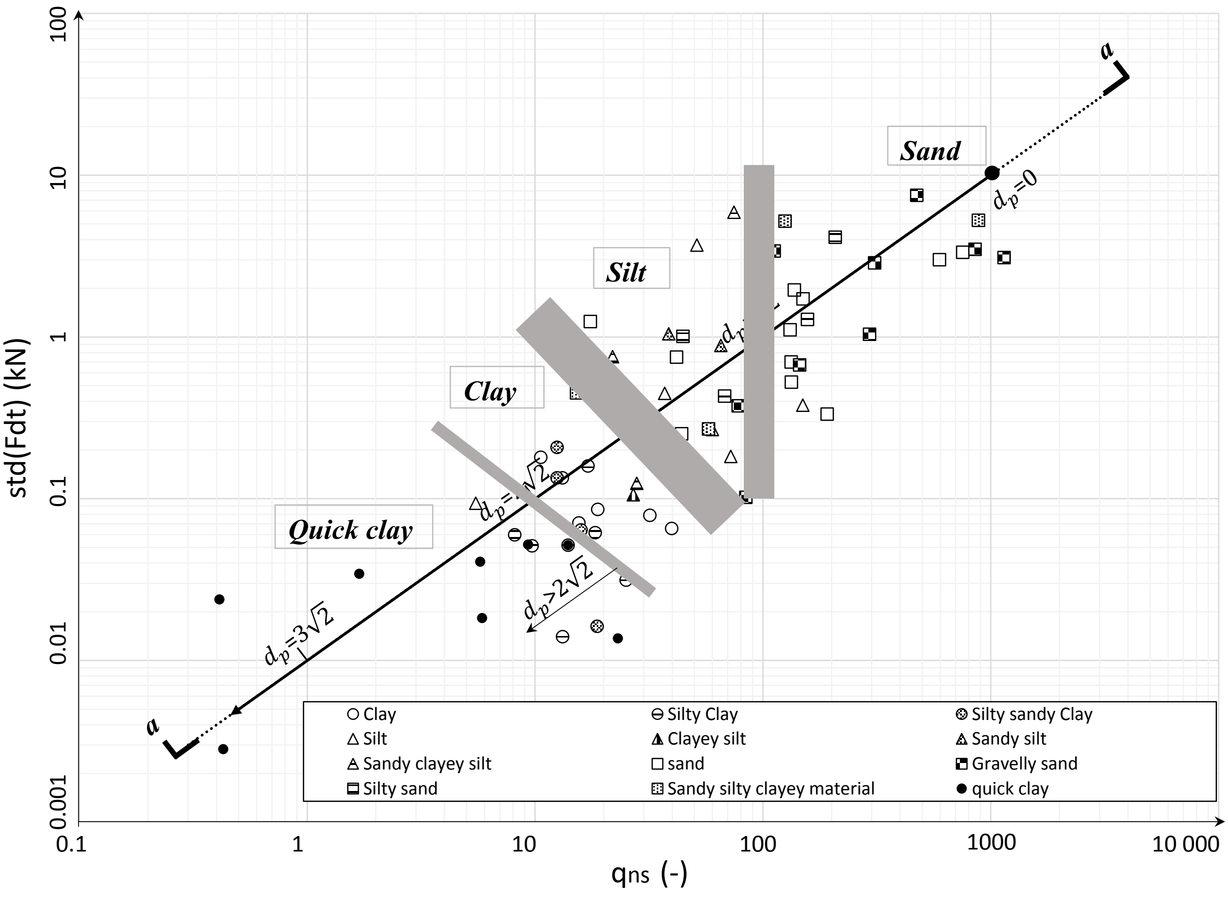

Figure 7 Soil classification chart.

One of the most important soil parameters that can be interpreted from CPTU tests is the undrained shear strength of soils (c_u) (Kjekstad et al., 1978; Lunne & Kleven, 1981; Aas et al., 1986; Senneset et al., 1982; Karlsrud et al., 2005). A common trend with these extensive studies is that there exists a correlation between c_u and excess pore pressure Δu or corrected cone resistance q_t. In the study presented in this paper, possible relations of remoulded undrained shear strength c_{ur} and sensitivity S_t to the parameters derived from total sounding (q_{ns} and $std(F_{dt})$) were also explored.

Inspired by the soil behaviour type index I_c introduced by Robertson (1998), which behaves as radius and delineates the boundaries of soil behaviour type zones, and the fact that all present data points congregate in a band, it becomes natural to study the trend of c_{ur} and S_t along the band. Therefore a line (*a-a*) going through the data points is chosen and defined in equation 2. Later these points are projected to line *a-a*, and distances are measured starting from a reference point (1000, 10) to the projected points. Then the S_t and c_{ur} information mainly of clay-type soils are plotted against their projection distance d_p (Equation 3) as shown in Figure 8.

$$\log\left(std(F_{dt})\right) = \log(q_{ns}) - 2 \qquad (2)$$

$$d_p = \sqrt{\left[\log\left(\frac{q_{ns}}{1000}\right)\right]^2 + \left[\log\left(\frac{std(F_{dt})}{10}\right)\right]^2 - 0.5\left[\log\left(\frac{q_{ns}}{100 std(F_{dt})}\right)\right]^2} \qquad (3)$$

It can be seen that S_t increases with increased d_p while c_{ur} decreases. In spite of considerable scattering, $d_p > 2\sqrt{2}$ potentially suggests the existence of quick clay, which requires $S_t > 30$ and $c_{ur} < 0.5\ kPa$ (NVE, 2011).

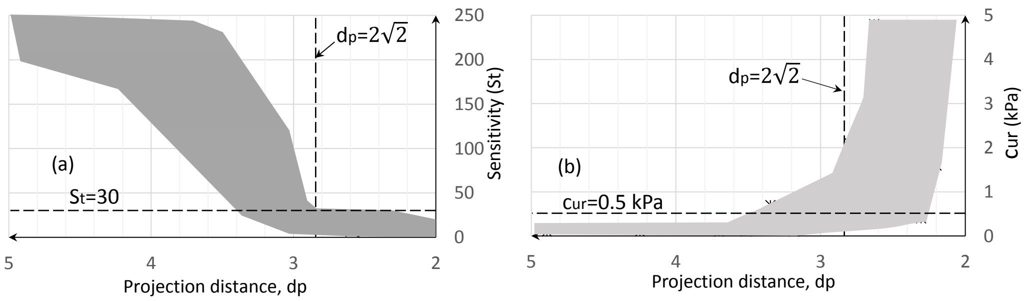

Figure 8 Sensitivity (a) and remoulded shear strength (b) on projection line a-a (in Figure 7).

6 EVALUATION AND COMPARISON

6.1 *Evaluation based on employed data*

Soil type zones in the proposed chart are evaluated against all data points that were employed in producing this chart in Figure 7. Results are shown in Table 1. Values in every row explain the fact that the number of data points of each soil type decided by grain size analysis is distributed over multiple zones of the chart. Underlined numbers in the table signify the dominance of good or acceptable correspondence, and thus sound predictions.

Compared with current practice of total sounding interpretation, this chart provides more objective interpretations into soil types. The major advantages are summarised as:

- Clay-type soils could be differentiated from silts, which is difficult before performing laboratory tests as only penetration force is interpreted in current practice.
- One could imply the existence of sand or gravel type soils with considerable confidence if data points lie in the upper-right zone.
- It turns out to be ambivalent when silt or mixture of silt and sand are encountered.
- When d_p exceeds $2\sqrt{2}$ the chart successfully classifies all quick clay data points correctly. However, it has been observed that some silty clays are also wrongly classified as quick clay.

Given that the analysed database is not sufficiently large, the boundaries of zones could be altered, and the specific areas for transitional soil types could be delineated after the inclusion of more data.

Table 1 Evaluation of the soundness of the proposed chart.

Results from laboratory	Predicted results by present study					
	Sand or gravelly sand	Transition sand-silt	Silt	Transition silt-clay	Clay	Quick clay
Gravelly sand	9	2				
Sand	8	1	3	1		
Silty sand	2	3	1			
Sandy silty clayey material	2	1	1	3		
Sandy silt	1	2				
Sandy clayey silt		1	1	3		
Silt	1	1	3	1	1	
Clayey silt				1	1	
Silty sandy clay				2	4	
Silty clay				1	2	5
Clay			1	1	10	
Quick clay*						8

*Silty clays that behave as quick clay are counted here.

6.2 *Comparison with other classification methods*

Site investigations performed in five sites, that involve both total sounding and CPTU, together with laboratory test results make it possible to evaluate the accuracy of the predictions of the present chart.

The soil behaviour type chart proposed by Robertson (1998, 2009) and the classification method developed in Swedish Geotechnical Institute (SGI) (Larsson, 2007) are adopted for comparison. In the chart by Robertson, the normalized tip resistance Q_m, the normalized friction F_r and the soil behaviour type index I_c altogether define 9 soil behaviour type zones. Using similar parameters $(q_t - \sigma_{v0})/\sigma'_{v0}$ and $f_t/(q_t - \sigma_{v0})$, SGI's chart characterizes three general soil types: clay/organic soil, silt and sand. As for silt and sand, plural subtypes are defined in light of varying firmness, which makes it distinct from Robertson's chart.

Through comparison (Table 2), some significance could be drawn as below.

- Compared with laboratory results, the proposed classification method exhibits promising consistency.
- The proposed soil classification method has another advantage over CPTU in case of firm materials, as the drilling bit is adaptive in penetrating through gravels and boulders.
- Deviation of prediction by present method is more noticeable when data points fall into the zone of silt.
- Predictions of present study seem to closely resemble the results by the soil behaviour type chart of Robertson (1998, 2009).

Table 2 Comparison with other classification methods

Site	Depth (m)	q_{ns} (-)	$std(F_{dt})$ (kN)	Soil type			
				Based on Lab. investigation	Based on total sounding	Based on CPTU	
					Present study	Robertson (1998, 2009)	SGI method
Fv32 Gimlevegen – Augestadvegen. Hovenga borehole 101	3.2-4.0	46.69	1.42	sand	silt	sand/silty sand	silt/sand
	5.2-6.0	19.73	0.31	sand	silty clay/clayey silt	silt/clayey silt	clay
	9.2-10 .0	13.18	0.41	clayey sandy silt	silty clay/clay	silt/clayey silt	silt
	16.2-17.0	6.67	1.10	clayey sandy silt (quick)	silty clay/clayey silt	sensitive soil	clay
	29.2-30.0	3.85	0.60	silty clay (quick)	clay	clay	clay
	38.2-39.0	8.73	5.08	silty clay	silt		
Fv415 Ubergsmoen borehole 1002	2.0-3.0	59.79	0.63	sand (humus)	silty sand/sandy silt	sand/silty sand	silt
	4.0-5.0	245.63	4.47	gravelly sand	sand		
	6.0-7.0	145.21	2.55	gravelly sand	sand		
Fv308 Kjelle-Barkåker borehole 1104	7.2-8.0	14.05	0.39	silty clay	clay/silty clay	clay/silty clay	clay
	8.2- 9.0	11.94	0.08	clay	clay	clay/silty clay	clay
	9.2- 10.0	12.74	0.37	clay	clay	clay/silty clay	clay
E18 Skjeggestad bru, borehole b2	5.0- 5.8	52.15	0.28	silty clay	silt	silt/clayey silt	silty clay
	7.0- 7.8	37.30	0.69	silty clay	silt	clay	clay
	10.0- 10.8	36.03	0.17	clay	silty clay/clayey silt	clay	clay
E18 Skjeggestad bru, borehole G5	2.2- 3.0	23.39	0.10	silty clay	clay	clay	clay
	5.2- 6.0	11.65	0.11	clay	clay	clay	clay
	9.2- 10.0	10.33	0.24	silty clay	clay	quick clay	clay
	11.2-12.0	9.77	0.37	quick clay	clay	quick clay	clay

7 CONCLUSIONS

In this study, a preliminary attempt towards soil classification chart from total sounding is made. In doing so, a simple normalization method to account for depth influence is introduced for measured penetration force of total sounding. Later the normalized penetration pressure (force measurement divided by the tip end area and effective overburden stress) and the standard deviation of penetration force were used to explore the possibility of classifying soils into four general soil types. This generally seems to be promising. However, noticeable ambiguity remains especially in classifying silty soils.

Sensitivity and remoulded shear strength of clays are found to demonstrate somehow a distinct trend along a projected data points band. A threshold is thus sketched to enable the detection of quick clay. Nevertheless, extensive data points are needed to improve the proposed classification chart. Through comparison with two CPTU and a laboratory based classification method, the proposed approach is seen to be in fairly consistent agreement.

In evaluation of total sounding results, factors like rod friction, inclination of rods have not been taken into considerations. And ground water level and soil unit weights have been assumed for the sake of simplicity. Additionally, the soil types referred merely express the grain size distributions; other essential information like the mechanical properties, void ratio or OCR were not incorporated.

It is vital to mention that the data adopted in this study is from selected road projects in southern part of Norway. The suitability of the proposed classification chart has to be evaluated cautiously as it is a preliminary work based on a few test sites. It will be interesting to look at extensive sounding data from different location and ground conditions to test the applicability of the proposed approach presented in this paper.

Regarding future work, extensive studies can be foreseen. For instance, the effects of recording penetration force and torque at the rod tip rather than at the top could be explored. This is believed to reduce the effect of rod friction that has a huge effect in the current measurements resistance force from total sounding. In addition to some possible modifications to the equipment, some aspects of the test procedure (e.g. penetration rate) could be made similar to that of CPTU to explore possibility of benefiting from the existing correlations for CPTU. Another important aspect that could be considered in further development of the equipment is to explore the possibility of incorporating seismic test with total sounding. Recent developments on the use of seismic measurements with CPTU have been very promising (Mayne, 2016). Given the fact that total sounding test can be performed in any geomaterials, unlike CPTU, measuring seismic waves with total sounding seems to be appealing and one that needs to be considered. Such measurements will definitely be valuable and help significantly in better characterization of geomaterials.

8 REFERENCE

Aas, G., Lacasse, S., Lunne, T., & Hoeg, K. (1986). Use of in situ tests for foundation design on clay. Publikasjon-Norges Geotekniske Institutt, (166), 1-15.

Douglas, B. J., Strutynsky, A. I., Mahar, L. J., & Weaver, J. (1985). Soil Strength Determinations from the Cone Penetrometer Test. Civil Engineering in the Arctic Offshore (pp. 153-161). ASCE.

Fredriksen, F. (1997). P-466 Totalsondering. Statens vegvesen Intern rapport 1984.

Karlsrud, K., Lunne, T., Kort, D. A., & Strandvik, S. (2005). CPTU correlations for clays. Proceedings of the international conference on soil mechanics and geotechnical engineering (Vol. 16, No. 2, p. 693). AA Balkema Publishers.

Kjekstad, O., Lunne, T., & Clausen, C. J. (1978). Comparison between in situ cone resistance and laboratory strength for overconsolidated North Sea clays.Marine Georesources & Geotechnology, 3(1), 23-36.

Larsson, R. (2007). CPT-sondering. Swedish Geotechnical Institute, Information, (15).

Lunne, T., & Kleven, A. (1981, October). Role of CPT in North Sea foundation engineering. In Cone penetration testing and experience (pp. 76-107). ASCE.

Lunne, T., P. K. Robertson, P. K., & Powell, J. J. M. (1997). Cone penetration testing in Geotechnical Practice.

Mayne (2016). In-Situ Geocharacterization of Soils in the Year 2016 and Beyond. 15th Pan-American Conference on Soil Mechanics and Geotechnical Engineering. Geotechnical Synergy in Buenos Aires 2015 - Invited lectures, Page.139-161.

Norsk Geoteknisk Forening (1989). Veiledning for utførelse av dreietrykksondering. Melding Nr. 7.

Norsk Geoteknisk Forening (1994). Veiledning for utførelse av totalsondering. Melding Nr. 9.

Norsk Geoteknisk Forening (2016). Veiledning for utførelse av totalsondering. Melding Nr. 9, Rev. Nr. 1, 2016. (unpublished manuscript).

NVE (2011). Plan for statlig skredfarekartlegging: Delrapport kvikkleireskred. Noregs vassdrags-og energidirektorat (NVE) rapport 18/2011. Written by Wiig T., Lyche E., Helle T.E, Hansen L., Solberg I. L, L'Heureux J. S, Eilertsen R..

Olsen, R. S. (1984). Liquefaction analysis using the cone penetrometer test. InProc., 8th World Conf. on Earthquake Engineering (pp. 247-254). San Francisco: EERI.

Olsen, R. S., & Farr, J. V. (1986). Site characterization using the cone penetrometer test, Proceedings of Insitu '86, ASCE specialty Conf., Blacksburg, Virginia.

Robertson, P. K., & Campanella, R. G. (1989). Design manual for use of CPT and CPTU. The University of British Columbia, Vancouver, BC.

Robertson, P. K., & Wride, C. E. (1998). Evaluating cyclic liquefaction potential using the cone penetration test. Canadian Geotechnical Journal, 35(3), 442-459.

Robertson, P. K. (2009). Interpretation of cone penetration tests - a unified approach. Canadian Geotechnical Journal, 46(11), 1337-1355.

Sandven, R. et al. (2012). Detektering av kvikkleire fra ulike sonderingsmetoder (Rapport nr. 46/2012). Norges vassdrags og energidirektorat i et samarbeid med Statens vegvesen og Jernbaneverket.

Senneset, K., Janbu, N., & Svano, G. (1982). Strength and deformation parameters from cone penetration tests. Proceeding of the Second Eouropean Symp. on Penetration Testing, Amsterdam (pp. 24-27).

Wister, S. (2010). JB-totalsondering: Jämförande sonderingar och utvärdering av egenskaper i isälvsavlagringar kring Igelstaviken

Wroth, C. P. (1984). The interpretation of in situ soil tests. Geotechnique, 34(4), 449-489

Wroth, C. P. (1988). Penetration testing-A more rigorous approach to interpretation, Penetration Testing. ISOPT-1, 1988, 1, 303-311.