Extended interpretation basis for the vane shear test

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ABSTRACT
The vane shear test has been widely used as an in-situ test device in Norway from the sixties to the eighties. However, the last decades, its popularity has decreased, partly because of the increasing popularity of the CPTU-test, but also because of uncertainties related to interpretation of the vane shear test. With the aim of an improved and extended interpretation basis for the vane shear test, a database consisting of parallel vane shear tests and laboratory tests performed on high quality block samples has been compiled. The work focus on correlations between the vane shear test and active undrained shear strength and stiffness as well as factors that could improve the vane test as a "quick-clay-detector", e.g. sensitivity and remoulding energy. The latter factors are important in areas where mapping of sensitive clays is necessary and an efficient tool is needed. The work show that it is possible to establish a strong relation between the active undrained shear strength and the undrained shear strength as interpreted from the vane shear test as a function of the plasticity index. If is further seen that there is a potential for deducing OCR from the vane test. There is not a one-to-one relation between sensitivity as measured from the vane test and by the falling cone test in the laboratory. The vane appears to measure too high values for the remoulded undrained shear strength. On the other hand, work on deducing disintegration energy from the shear vane tests show promising results. In total, the shear vane holds several advantages and further research on the device is recommended to strengthen its position in the geotechnical tool case.

Keywords: In-situ testing, clays, undrained shear strength, interpretation

1 THE VANE SHEAR DEVICE

The vane shear test (VST) is mostly used in clays and clayey silts for determination of undrained intact and remoulded shear strength. The vane shear device consists of two rectangular plates forming a perpendicular cross (Figure 1). The cross is penetrated into the ground to a given depth before rotation is applied. Torque and rotation is measured.
Despite its simplicity, the VST suffers from several uncertainties related to installation-effects, equipment and interpretation. In order to shed new light on the VST, a database of test results is here presented where the potential of deducing active undrained shear strength, soil stiffness, remoulded shear strength, disintegration energy and OCR from the test is investigated.

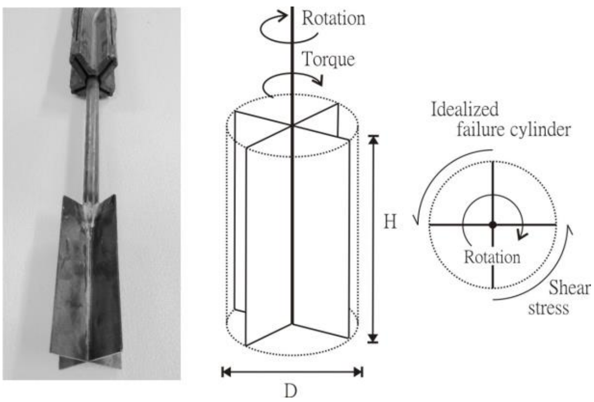

Figure 1 Vane shear blade cross

2 EQUIPMENT AND TEST SITES

2.1 The NTNU vane shear device

For the execution of the VST-experiments, a rotation device was developed at NTNU (Figure 2). It utilizes the hammer on the drill rig to apply rotation and incorporates an encoder, 1:100 gear and torque cell before connection to the rod system. Torque and rotation is continuously logged. The vane itself is produced by Geotech and based on the protection shoe principle. A system for measuring the internal friction in the system is incorporated. The tests were performed at a rotation rate of 0,2 ˚/s using a D = 65 mm, H = 130 mm vane.

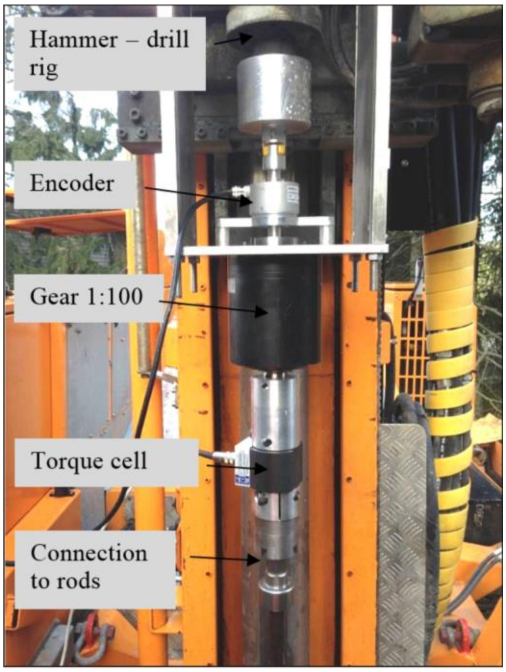

Figure 2 NTNU vane shear device

2.2 Characterization of test sites

The main data source in the work is based on data from three clay sites in Mid-Norway: Esp, Glava and Tiller. At these sites there exists high quality lab data from block samples (NTNU-Miniblock and Sherbrooke sampler). Vane tests are performed at depths equal to the block samples to allow one-to-one comparison. The database is also supplemented by two other sites: Klett and Fallan (only VST). All sites, except Glava, consists of sensitive and quick clays. Glava is a more plastic and less sensitive clay. A set of characteristic parameters is summarized in Table 1. All sites have a clay content in the range of 30-40% and an undrained shear in the range of 20-80 kPa, increasing with depth. Block sample data from Tiller is gathered from Ørbech (1999), Gylland et al. (2013) and new sampling at NTNU. Data from Glava is gathered from Sjursen (1996). Data from the other sites is gathered in relation to this study.

Table 1 Characteristic parameters of test sites

	Esp	Glava	Tiller	Klett	Fallan
w [%]	38	38	40	34	33
I_p [%]	5	18	5	7	9
S_t [-]	100	8	200	150	120
OCR [-]	1,7	4	1,7	1,5	1,6

2.3 Typical response curves and definition of parameters

A typical test result from the VST is shown in Figure 3, including definitions of peak and remoulded torque as well as peak undrained shear strength.

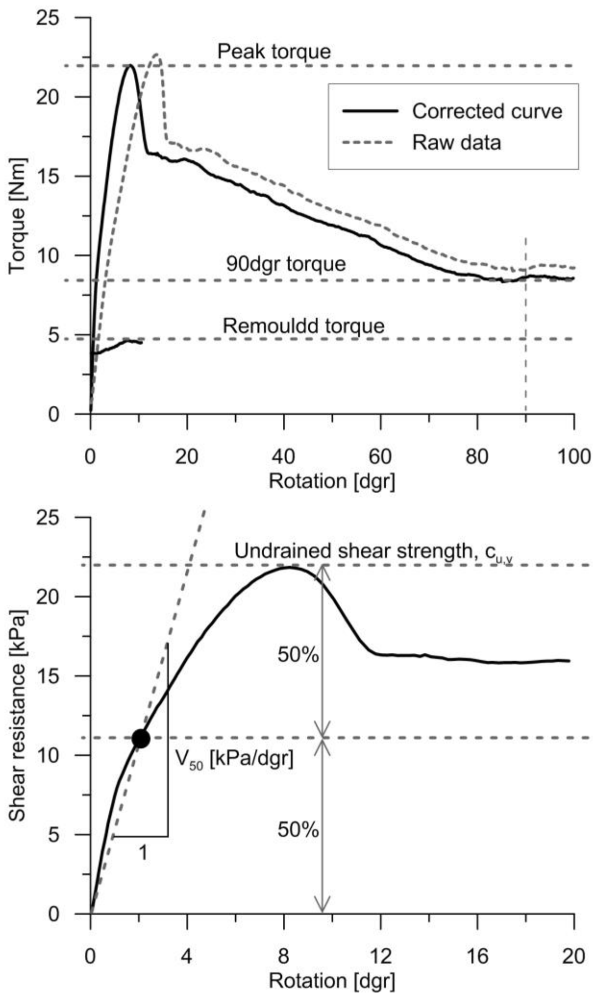

Figure 3 Definition of parameters

The corrected curve is obtained by subtracting the measured friction in the system and adjusting for rotation in the rods. A full circle is sheared in the soil at 90˚ rotation and the torque stabilizes at a constant level. The remoulded reading is done after rotating the vane 25 manual turns. The mobilized shear resistance is interpreted using $c_{u,v}$=6T/(7πD^3) where T is the torque.

The parameter V_{50} [kPa/°] is defined as shown in Figure 3. This parameter gives a representative inclination of the mobilization curve and is thus a measure of stiffness.

3 CORRELATIONS

This section presents correlation between parameters deduced from the VST and relevant engineering parameters. The plasticity index (I_p) and stress state are used as the main correlation parameters as these are important factors when strength, stiffness and anisotropy are concerned.

3.1 Active undrained shear strength

Figure 4 shows a compilation of data points found in the literature where active undrained shear strength ($c_{u,a}$) from triaxial tests are reported at sites and depths parallel to vane tests. The gathered data points incorporates uncertainty regarding execution and interpretation of both vane and triaxial tests and should thus be viewed as a background for evaluating the new tests.
There is a clear trend in increasing $c_{u,a}/c_{u,v}$ ratio for reducing I_p. For low I_p, the ratio approaches 3,5. This range is mostly governed by three sites: Ellingsrud, Rissa and Esp, all being fairly silty and highly sensitive clays. The high $c_{u,a}/c_{u,v}$ ratio is mainly caused by low $c_{u,v}$ readings. For high I_p, the $c_{u,a}/c_{u,v}$ ratio approach 1,0.

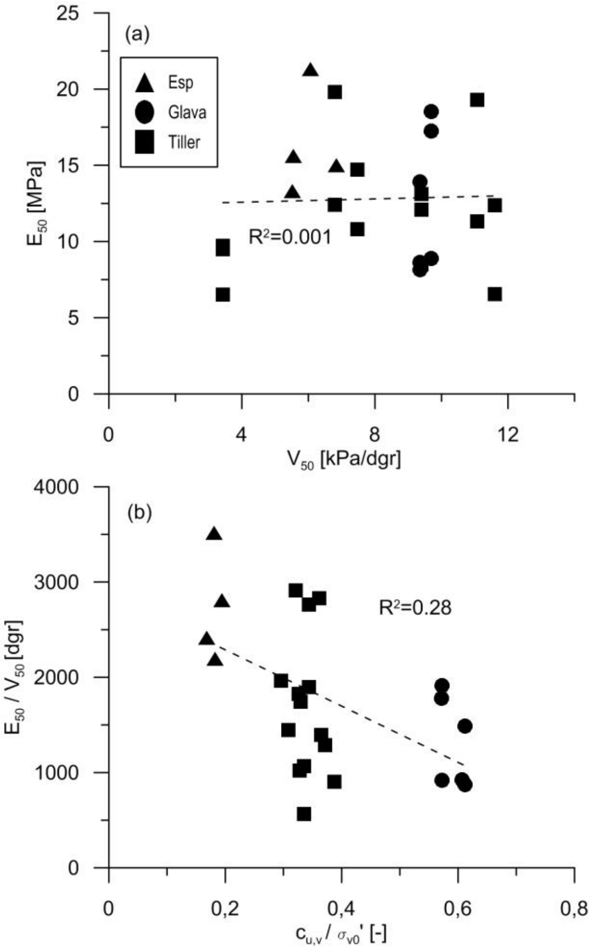

Figure 5 Stiffness

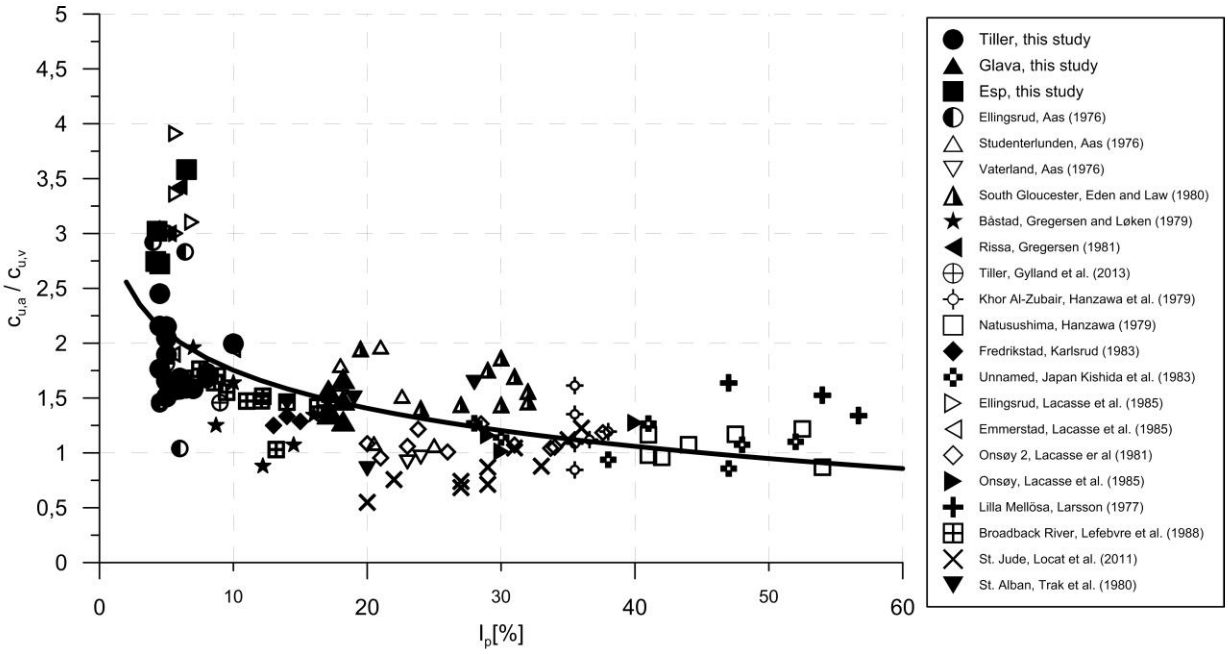

Figure 4 Active undrained shear strength

3.2 Stiffness

Two plots showing relations related to the stiffness parameters V_{50} from vane tests and E_{50} from triaxial tests are shown in Figure 5. In (a) it is clear that there is no direct relation between V_{50} and E_{50} for the sites investigated here. In (b) there is a possible trend of reducing E_{50} / V_{50} relation for increasing $c_{u,v}/\sigma_{v0}'$ (vertical effective overburden stress). This suggests that the V_{50} increases for increasing strength ratio. No relation between V_{50} and σ_{v0}', OCR, I_p nor sensitivity is found.

3.3 Remoulded shear strength and sensitivity

One of the strengths of the VST is its ability to measure the soil sensitivity in situ. Often one finds a deviation when comparing values as obtained from the vane and obtained with the falling cone in the laboratory. This is investigated in Figure 6. From Figure 6a it is quite clear that the remoulded shear strength from the vane in general is higher than what is measured in the lab. Figure 6a and c suggests that the deviation between remoulded shear strength and sensitivity between vane tests and laboratory tests does not show any trend with increasing vertical effective overburden (depth). The main reason for this deviation is that for low values of the remoulded shear strength it appears that the device used is not able to measure reliably the low torques involved. Figure 6d indicates that the different in vane and laboratory measurements of the remoulded shear strength increases with increasing water content.

3.4 Overconsolidation

Work on the relation between OCR and the VST exists in the literature. One of these, Mayne and Mitchell (1988), use the SHANSEP framework (Ladd and Foott 1974)

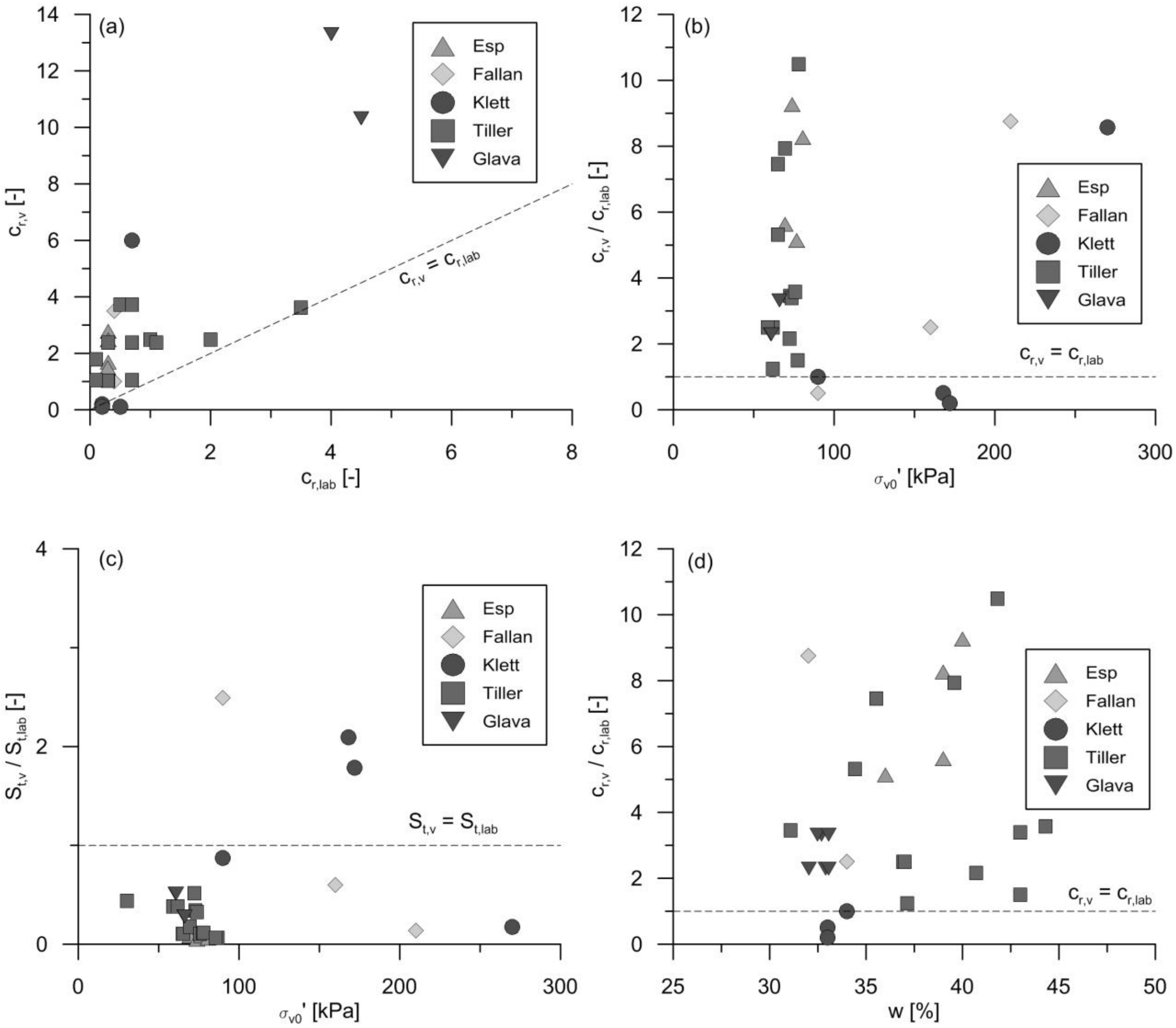

Figure 6 Sensitivity and remoulded shear strengt

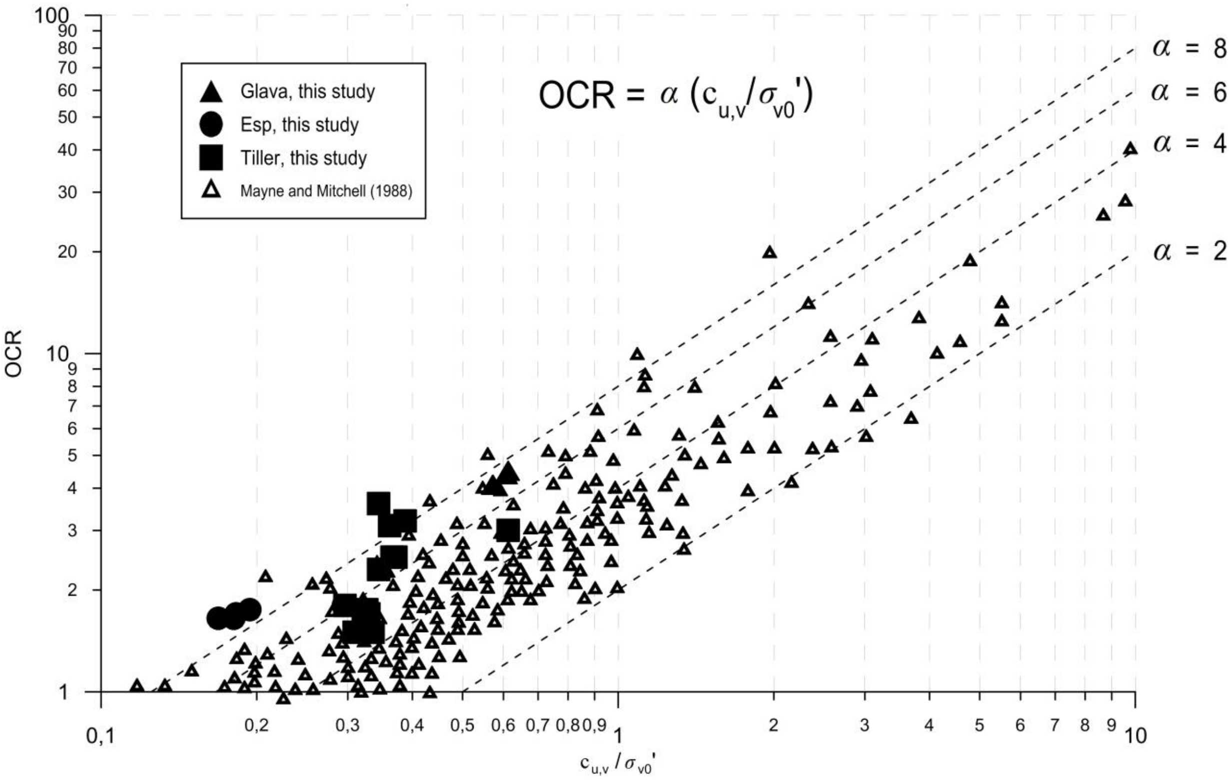

Figure 7 OCR and $c_{u,v}$ / σ_{v0}‘ (adapted from Mayne and Mitchell 1988)

which is based on the relation between undrained shear strength and OCR: (c_u/ σ_{v0}') = a OCR^m. By knowing the undrained shear strength from the VST together with appropriate factors (a og m), it is possible to determine OCR. A considerable dataset is gathered in Mayne and Mitchell (1988) to investigate the validity of this approach. The dataset is reproduced here in Figure 7 together with data from Glava, Esp and Tiller. The dataset of Mayne & Mitchell (1988) show a clear trend of increasing c_u/ σ_{v0}' for increasing OCR. Lines for four α-values (1/a) are included in the figure. The three Norwegian clays tested here lies within the data trend. α-values in the range of 6-8 are indicated. m = 1 is assumed in this interpretation.

3.5 Disintegration energy

The disintegration energy is a measure on how easy it is to remould a material. Some clays needs extensive remoulding to reach the fully remoulded state whereas some others can barely be touched before they collapse. This property of a clay is a useful supplement to the remoulded shear strength when the potential for retrogressive landslides is assessed. A clay that remoulds easily has a higher likelihood of fully reaching the fully remoulded shear strength during the failure process and hence flow out of the slide pit so that further retrogression can take place. Tavenas et al. (1983) investigated different approaches for determining the energy needed to remould a material; disintegration energy. The VST holds a potential to determine the disintegration energy in situ as the area under the torque rotation curve from peak to the residual state as shown in Figure 8. The normalized disintegration, W_N, is the disintegration energy divided by the area under the curve in the intact state, W_{LS}, as defined in Figure 8. Due to effects related to local drainage in the failure zone around the vane, the residual torque at 90˚ rotation does not correspond to the remoulded level after several manual turns. To overcome this issue it is possible to either draw a pragmatic curve extension of the torque reading to zero torque or to use the levels of disintegration that can be read from the graph. The latter can be handled through the remoulding index as defined by Tavenas et al. (1983). I_r (x) = (c_{ui}-c_{ux})/(c_{ui}-c_{ur}) where x is the degree of remoulding, c_{ui} is the intact strength and c_{ur} is the remoulded strength.

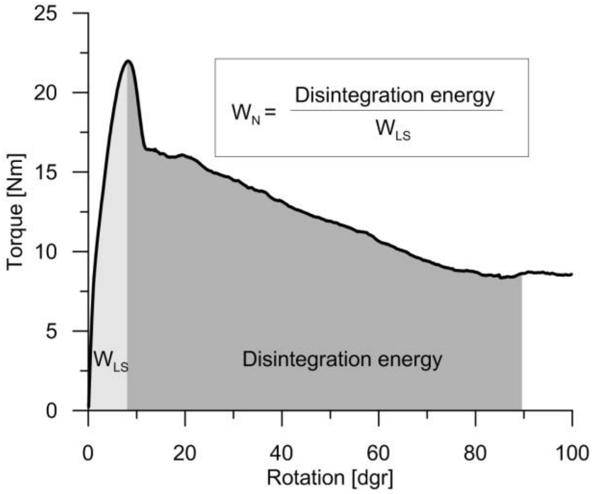

Figure 8 Definition of disintegration energy

Thakur et al. (2015) has interpreted disintegration energy from the same vane tests as included in this study (Tiller, Fallan, Klett). The results are summarized in Figure 9 and Figure 10 where a good match between disintegration energy from vane interpretations and previously reported values is seen. The reader is referred to Thakur et al. (2015) for further details.

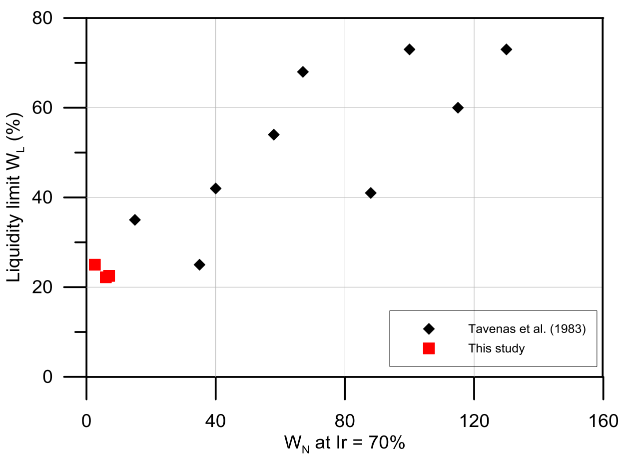

Figure 9 Disintegration energy at I_r = 70% as a function of liquid limit (from Thakur et al. 2015)

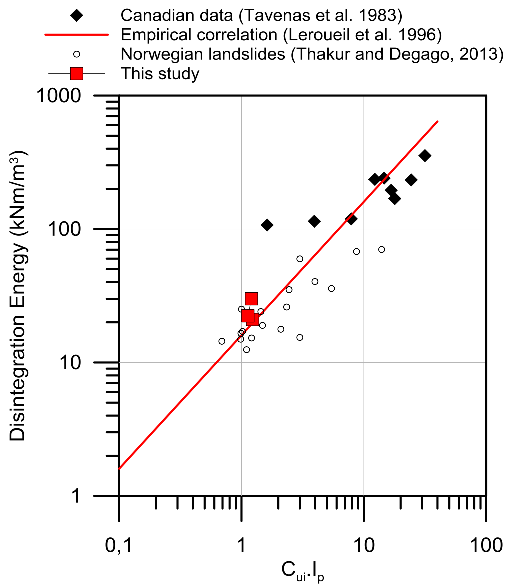

Figure 10 Disintegration energy of Norwegian and Canadian clays (from Thakur et al. 2015)

4 DISCUSSION OF RESULTS

The main strengths of the VST is its ability to give the intact and remoulded shear strength in situ and thus reduced the need for sampling in a project. The main drawbacks of the VST includes disturbance of the soil during installation, accounting for friction in the system and interpretation of a design shear strength through a correction factor. However, these factors does not all act equally strong under all circumstances.

4.1 Undrained shear strength

Disturbance effects appears to be highly relevant for low plastic and highly sensitive clays. Such clays show very low $c_{u,v}$-values compared to active triaxial tests. This introduces significant uncertainty related to the use of $c_{u,v}$-values in such clays and it is suggested that the VST is not used for this purpose in clays with I_p under 10%. For clays with higher plasticity the correspondence between $c_{u,v}$ and $c_{u,a}$ is better and use can be recommended provided that a proper correction factor is applied.

4.2 Stiffness

It is suggested by the results presented here that the interpretation of soil stiffness from the VST torque-rotation curve is not feasible.

4.3 Remoulded shear strength

With a VST device that measures torque at the top of the rod system, the influence of friction in the system appears to reduce the validity of measurements of the remoulded undrained shear strength. The friction in the system is often measured in the range of 2-5 Nm. A remoulded shear strength of 0,5 kPa corresponds to about 0,5 Nm. To separate the actual contribution from the soil resistance under such circumstances is not reliable. For measurements of remoulded shear strength in sensitive soils it is recommended that equipment where torque is measured close to the vane cross is used. For clays with higher remoulded shear strength (over 5 kPa), equipment with the torque cell at the top can be considered.

4.4 OCR

It is indicated that the approach for determination of OCR from the vane as proposed by Mayne & Mitchell (1988) is valid for the clays tested here. However, as the interpretation relates to $c_{u,v}$, care should be taken if operating in low plastic clays.

4.5 Disintegration

The disintegration energy as interpreted from the vane shear test fits well with other data reported in the literature. The disintegration energy is to a less extent influenced by friction in the system and installation effects and can thus be used also in low plastic clays. The initial investigations by Thakur et al. (2015) fit well with previous published data and further research on this particular application of the shear vane device can be recommended.

5 CONCULSIONS

The main conclusions are as follows:

- Interpretation of undrained shear strength from the VST should only be done for clays with I_p>10%. A proper correction factor must be applied
- Stiffness parameters can not be interpreted from the VST
- For measurement of remoulded shear strength (and sensitivity) it is recommended to use a VST-device with torque registration close to the vane cross
- OCR can be interpreted from the VST
- Disintegration energy can be interpreted from the VST, but more research is needed on this particular topic.
- With proper use and setup, the vane shear device has a strong potential as a reliable “quick clay detector”.

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