

Use of Fall Cone Test for the determination of undrained shear strength of cohesive soils

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Abstract. CT156, *Geotechnics and civil engineering*, has been developing efforts to create standards with the generic designation EN ISO 17892, *Geotechnical investigation and testing - Laboratory testing of soil*. The recent publication of EN ISO 17892-part 6, *Fall Cone Test* which describes in detail the use of this test method to estimate the undrained shear strength of cohesive soils leads to the necessity for the laboratories to get familiar with this test method and to acquire the required sensibility to analyse the results obtained. Originally designed to determine the liquid limit of fine soils, for which purpose it is considered as an accurate substitute of the Casagrande method, the method may constitute an alternative to the direct shear test, which takes certainly longer time to be carried out and is more complex. The present work aims to compare the values for liquid limit obtained with the Casagrande's method and the cone method and as well as the use of this test to estimate undrained shear strength, correlating with results from other laboratory tests such as the Direct Shear Test and the Laboratory Vane Test on remoulded samples. The results obtained show that there is a good correlation between the applied test methods for determination of the liquid limit and that, for some water contents, the results obtained by the three test methods are comparable.

1 Introduction

The Fall Cone Test was originally developed in Scandinavia as a method to estimate shear strength in remoulded cohesive soils and has since then become a staple method to determine the Liquid Limit. In 1957 Hansbo [1] developed a study establishing a correlation between the penetration of the cone and the shear strength of the soil for cones with different configuration and mass, and published the equation to determine the shear strength values in cohesive soils.

The recently published standard EN ISO 17892-part 6 [2] refers to this method as an estimate of shear strength values but with the same relevance as others test methods recommended in Eurocode 7. Like the Laboratory Vane Test (LVT) this test method has an

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exclusive use for cohesive soils and holds a considerable advantage against other methods for being a very fast test method, using smaller test specimen and having a wide range of workability when the water contents are close to the liquid limit, something hard to achieve when using other test methods such as the Direct Shear test (DST), triaxial test and unconfined compression test. In theory, it is possible to use Hansbo's equation for any water content although in practice the test is hard to perform for very low water contents.

In the 1960's [3] and [4] observed that the relationship between water content and shear strength is not linear and a bilogarithmic correlation was proposed [5, 6, 7].

Tanaka et al. [8] studied shear strength in clayey soils using the Fall Cone Test method and comparing it to Vane Shear Test, both in situ and in laboratory, and with the unconfined compression test, which is the standard test to determine shear strength in Japan. It was concluded that the Fall Cone Test and the Unconfined Compression Test did not present a good correlation, however the test results showed a good correlation between the Fall Cone Tests and the Vane Test for water contents close to the liquid limit of the soil.

The present study was conducted to compare results between the Fall Cone Test and other test methods commonly applied to obtain the shear strength of soils. All tests were conducted on remoulded test samples and this remoulding process was done manually in plastic bags and individual recipients with a spatula. This was a lengthy process since it was necessary to guarantee that the test conditions were in fact remoulded for all samples, ensuring that the original structure of the sample was completely destroyed in the process and also to guarantee homogeneity in the water content of the test specimen. In an initial phase Fall Cone Tests were conducted, and consistency limits determined. Direct Shear Tests and Laboratory Vane Tests were prepared and conducted considering the water contents determined in the Fall Cone Tests, allowing for a more direct comparison between the test results.

2 Materials and methods

2.1 Materials

Four different cohesive soil samples were studied. The samples were collected in the centre-west region of Portugal, both from drilling cores, which were cased in PVC containers (A and C) and from superficial outcrops (B and D). All samples were carefully remoulded in order to obtain similar conditions for all tests and test specimen.

In order to characterize the samples, the size distribution of the particles and the consistency limits were determined. The samples were classified according to AASHTO classification (American Association of State Highways and Transportation Officials, AASHTO M 145 [9]) and USCS (Unified Soil Classification System, ASTM D2487 [10]) as presented in Table 1.

2.2 Consistency limits

The plasticity limit (PL) and liquid limit (LL) were determined according to the pre-standard ISO 17892-12 [11]. As stated in the standard, both the Casagrande method and the cone method were used to determine LL.

The plastic limit (PL) was determined with the traditional method by rolling out a portion of the soil on a flat, non-porous surface.

Table 1. Classification of the soil samples according to AASHTO and USCS.

Sample	Place of collection	Depth	Classification	
			AASHTO	USCS
A	Vila Franca de Xira	12 m	A 7-5	CH
B	Santa Cruz	Outcrop	A 6	CL
C	Carregado	3 m	A 7-6	CH
D	Lisboa	Outcrop	A 7-6	CL-CH

2.3 Estimation of the undrained shear strength

Three different methods were used to determine the undrained shear strength: Fall Cone Test (FCT), Direct Shear Test (DST) and the Laboratory Vane Test (LVT). According to the standards, the specimen needed for the LVT are considerably larger than the specimens used for both the DST and FCT which imposed limitations in the total amount of tests performed by LVT. For each soil sample, multiple tests were carried out in specimens with increasing water contents. However, efforts were developed to perform all three tests at similar water contents, in order to be able to correlate them. Figure 1 shows the equipment used for the three types of tests.



Fig. 1. Equipment used to perform the tests for s_u determination: a) Fall Cone Test; b) Direct Shear Test; c) Laboratory Vane Test

The FCT was used in accordance with ISO 17892–6 with a cone of 30° of aperture and 80 grams of mass with a coefficient (K) of 0.8.

Shear strength was obtained by using Hansbo's [1] equation (1), where s_u is the undrained shear strength (kPa), k the cone coefficient (characteristic values for each cone configuration), m the mass of the cone (g), g the acceleration of gravity (m/s^2) and d the depth of penetration of the cone (mm).

$$S_u = k (m \cdot g / d^2) \quad (1)$$

The Laboratory Vane Tests were performed according to ASTM D4648/4648M-10 [12]. The several sample specimens tested were previously prepared in an appropriate

container with the necessary dimensions to uphold the standard's indications: inner diameter of 75mm and 200mm in height. A vane blade with a squared section of 12,7mm was used and the shearing speed was of 12° per minute.

The Direct Shear Tests were performed according to ISO 17892–10 [13], for specimens of square section of 60x60 mm² and 20 mm in height. In order to reproduce undrained conditions, similar to the ones found in FCT and LVT, the shear load started immediately after applying the vertical load to avoid any significant consolidation.

3 Results and analysis

2.1 Consistency limits

The test results for the liquid limit are displayed in Figure 2 where a good correlation between both methods can be observed, even though the results obtained with the cone method were always higher than with de Casagrande cup, in terms of water content. The correlation coefficient is close to 1, suggesting that the cone method is a valid alternative to the more traditional Casagrande method. Identical correlation was found by [8] and [14] which work was included in the Japanese standard on the Fall Cone Test.

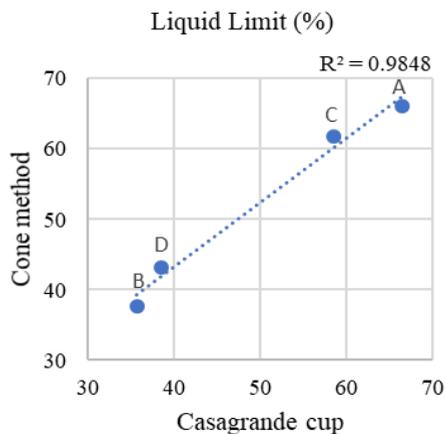


Fig. 2. Correlation of the values of LL obtained by the fall cone test and the Casagrande cup.

1.2 Undrained shear strength

The results obtained by using the three methods were plotted in charts against the water content, as shown in Figure 3 for the comparison of FCT and DST, and Figure 4, for FCT and LVT. It is confirmed that the shear strength decreases for increasing water content. The values obtained for s_u by the DST are higher than those of the FCT, in special for sample D. The results obtained by the two tests show higher dispersion for higher water content. Samples A and C exhibit higher values of water content (from 40 to 80%) that samples B and D ($w < 40\%$) for similar values of s_u .

On the other hand, the values of s_u are comparable and more similar for low contents of water.

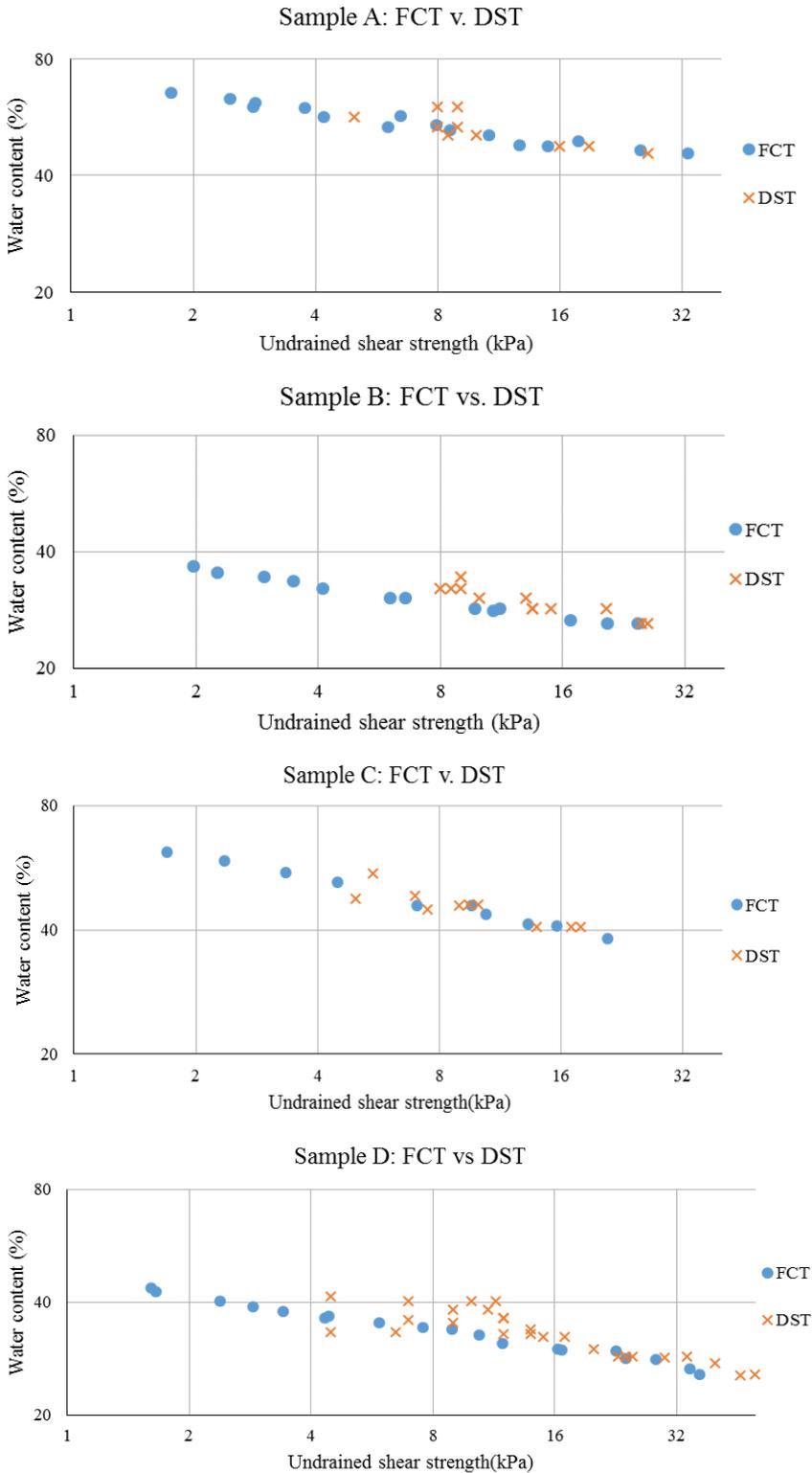


Fig. 3. Results of the undrained shear strength obtained by Fall Cone Test and Direct Shear Test plotted against the water content of the specimens.

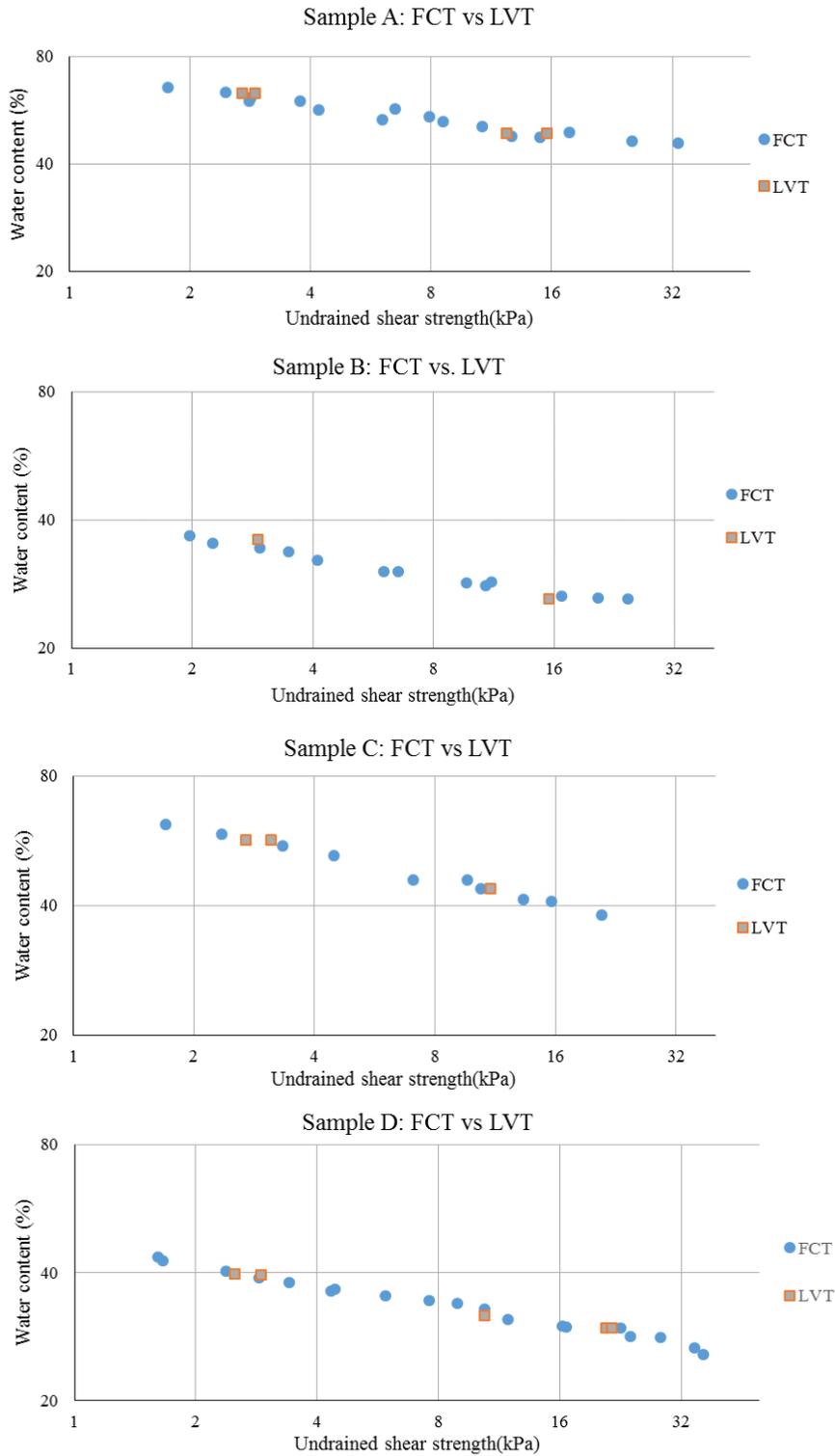


Fig. 4. Results of the undrained shear strength obtained by Fall Cone Test and Laboratory Vane Test plotted against the water content of the specimens.

The comparison between the results of the FCT and LVT has the drawback of the limited number of tests performed with the LVT. This is due to the larger size of the specimens needed for this test, considering that two tests were carried out at two different depths on each specimen. Nevertheless, it can be concluded that there is a correlation between the two test methods, for a given water content, which is quite encouraging for the acceptance of the FCT to estimate undrained shear strength.

It should be highlighted that the execution of the DST is much more complex than the other tests as it takes into account the vertical load and the rate of shear. In the procedure adopted, it is assumed that the test occurs under undrained and unconsolidated conditions, which is not exactly the case whilst for the FCT the only variable is the water content of the specimen.

Similar conclusions were published in [14] where the authors state that there is a reasonable correlation for the test results when the water content of the specimen is close to the liquid limit.

4 Conclusions

In the present study the applicability of the fall cone test was evaluated for the determination of the liquid limit and the undrained shear strength by comparing the results with those obtained by other well know methods. This is a simple, mechanical test reasonably independent of the operator experience with the exception of care needed in the preparation of the specimen and the determination of water content. The results obtained lead to the following conclusions:

- 1) The results for the liquid limit obtained by the traditional Casagrande cup are comparable to those of the Fall Cone Test with a correlation coefficient close to 1.
- 2) For the estimation of s_u , compatible results were obtained for the Fall Cone Test and the Direct Shear Test. However, due to the complexity of performing the DST for high water content, the correlation is better for low water content.
- 3) The results for s_u obtained with the Laboratory Vane Test are identical to the ones of the Fall Cone Test, even for variable water contents.

The correlations presented need to be confirmed with a much larger number of samples and specimen and, in special, using undisturbed samples.

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