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Sediment shear strength.
Using the laboratory T-bar and effect of the diameter

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Abstract:
Dehydration of the dredged sediments is necessary in different operations of sediment valorization: lagunage, handling and transport of sediments. The evaluation of hydric properties (*WC* water content, L_L liquidity limit, P_L plastic limit, S_L shrinkage limit) and of undrained shear strength *Su* must be made to ensure the follow-up of these operations (slopes stability, reversal of wind-rows in lagunage basins, bearing capacity of engines circulating on layers of sediments, consistency of the sediments, effect of remolding under cyclic request,…), rate of dehydration or drying. In first approach, the relation *Su*–*WC* could answer the problems posed. Measurement of the water content *WC* can be given by sampling; these samples obtained which also make it possible to follow the evolution of the components of the sediments (environmental properties, *OMC* organic matter content, pollutants level). For measurement of undrained shear strength, two laboratory tools are transposable on site: Vane Shear Test (VST) and the T-Bar Test (TBT). The first provides discrete measurements of *Su*, the second, continuous measurements. This last is sometimes used in laboratory. TBT Test can be used in vertical alternate cycles (penetration-extraction) and record the degradation of undrained strength. This tool allows the establishment of the relation *Su*–*WC*. Once presented the T-Bar Test geometry, kaolin clay properties and experimental set-up are given. Some geometry influences, (diameter, proximity, roughness) are commented.

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1. Introduction

The undrained shear *Su* of fine soils governs stability mechanisms and failure of many works in coastal geotechnical engineering (embankments, banks, foundations, earth dams, …). The identification of the *Su* parameter is partly made *in situ* to address the delicate sampling particularly in the case of fine soft soils. Two tests are used, recommended for large depth recognitions CPT (Cone Penetrometer Test) and VST (Vane Shear Test). Another test widely used in offshore engineering, TBT (T-Bar Test) has appeared, it combines the advantages of both. We find this last device in reduced size for soil characterization for geotechnical centrifuge modelling, (STEWART & RANDOLPH, 1994). In geotechnical laboratories at 1g tests, only the miniature VST is used. The interest of the miniaturization of TBT in laboratory is important. This allows *(i)* continuous *Su* identifying over large lengths (soil cores, cells and reconstituted soil testing tanks), *(ii)* to perform penetration-extraction cycles and *(iii)* to understand the sensitivity of fine soft soils. So, it is necessary to define the limits and the performance of this laboratory TBT, *i.e.* to define the testing operating procedures. This is the subject of this communication. Few studies have been conducted in the laboratory on the study of failure mechanisms and different influences for low depths of less than 0.50 m (OROZCO-CALDERON *et al*., 2010). The geometry of TBT effect was studied in cells of height limited to 200mm with a diameter of 300 mm.

2. Materials and methods

2.1 Fine soil tested

It is a common clay used in laboratory, a Speswhite™ kaolinite which is used for reconstituting thick clay layers with controlled physical and mechanical properties. That is the case of clay soils in centrifuge models. Table 1 reports the average characteristics reported from previous studies.

The test material is prepared by kneading with a quantity of water necessary to obtain a *WC* water content of $2W_L$, equal to 103% for these tests. The mixture is allowed to stand for 24h and then it is mixed again for one hour before filling the test cells.

Table 1. Kaolinite properties.

L_L (%)	P_L (%)	P_I (%)	Specific surface (m^2/g)	ρ_s (g/cm^3)	Particles <2 µm	Particles >10 µm	k (m/s)	C_v (m^2/s)	C_c	C_s
55*	30*	25*	30	2.65	79	0.5	0.15 to 10 10^{-9}	1.5 to 7 10^{-7}	0.5	0.1

*Note: * according BOUSSAID (2005)*

2.2 Testing equipment

The miniaturized TBT is made at the base of a horizontal cylinder forming a T with the vertical shaft which allows its installation on a test device dedicated to penetration tests.

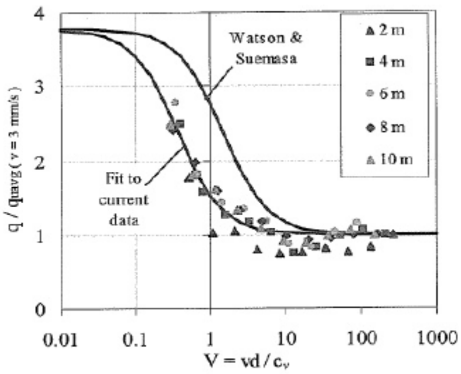
The latter comprises a servo cylinder controlled in displacement and/or in effort. The TBT has a body made of aluminum, equipped with strain gauges connected in a complete bridge; the assembly is coated with an epoxy resin to permit the insertion in water of the TBT. The model used for testing has undertaken a capacity of maximum load of 375 N possible in tension/compression for a depth of 0.60 m. The penetration test device features is equipped with step-by-step motors for a positioning in x and y (horizontal) and a vertical motion z (penetration and extraction). Data acquisition is done at a frequency of 5 Hz.

2.3 Calibrations miniature TBT

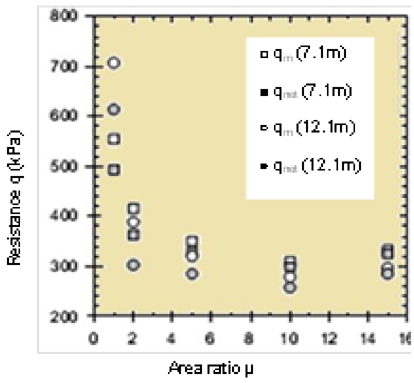
The calibration of the force sensor is made experimentally using a plate hanging by a thread to the test body on which masses are disposed. The loading and unloading of these masses is correlated with the sensitivity of TBT in mV/V (CHERIFI, 2013). The penetration rate *v* of TBT in the tested clay soils must be determined so as to comply with the conditions of tests in undrained behavior. This phenomenon has been studied by HOUSE *et al.* (2001) who provided a relation between a dimensionless rate of penetration *V* as a function of the penetration speed *v*, the diameter *d* of the rod (3 mm) and the consolidation coefficient C_v (1.5×10^{-7} m^2/s) from tests performed in 2 to 10 m deep kaolin clay layers.

$$V = \frac{v \times d}{C_v} \quad (1)$$

The undrained conditions are met when *V* has a value greater than 30. For our penetration tests speed was taken as 2 mm/s.



a) Test speed (HOUSE et al., 2001)



b) Effect of the rod (YAFRATE et al., 2007)

Figure 1. Relationships deduced from TBT tests.

2.4 Geometry of miniature TBT

2.4.1 Definition of the coefficients

The main geometric relationships that allow standardizing TBT field tests are:

- the horizontal bar slenderness $\lambda = L$ (length) / D (diameter),
- the rod diameter's ratio $\alpha = d$ (diameter of the vertical rod) / D (diameter of the bar),
- the ratio of sections μ= (footprint section of the bar) / (vertical shaft section).

We have the relation:

$$\mu = 4\,DL / (\pi d^2) \quad (2)$$

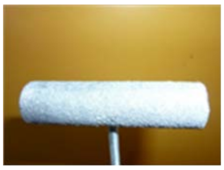
The coefficient $\lambda=4$ is sufficient to ensure the conditions of plane deformation around the horizontal cylinder. In this case, equation (2) with $D/d=1/\alpha=\beta$ becomes: $\mu=4\lambda D^2/\pi d^2$ hence $\mu=4\lambda\,\beta^2/\pi$ and finally, $\mu=5.09\,\beta^2$.

The coefficient $\mu\geq10$ is sufficient for that the vertical rod has no influence on the penetration resistance (see Figure 1b), (YAFRATE, 2007).

2.4.2 Proposed geometries

For the various tests, a series of 5 bars were offered respecting a λ coefficient of 4. They are made of manufactured steel *i.e.* the roughness state is considered smooth in this case. The 3 mm diameter vertical rod for mounting bars as tip to the test body, has provided for these 5 bars, a μ coefficient greater than 10, see Table 2. A series of bars was proposed with a different roughness state. They were roughened using a gluing of Fontainebleau sand with a 0.2 mm median diameter on the lateral surface of each bar (see Table 2).

Table 2. Geometric parameters of the bars used.

Geometric characteristics of TBT used						smooth T-bar	rough T-bar
D (mm)	L (mm)	λ	d (mm)	β	μ		
5	20	4	3	1.67	14.13		
7.5	30	4	3	2.50	31.81		
10	40	4	3	3.33	56.44		
12.5	50	4	3	4.17	88.08		
15	60	4	3	5.00	127.25		

2.5 <u>Determination of *Su*</u>

The *Fv* penetration or extraction force is recorded during each test. Determination of *Su* is done using a N_{TBT} bearing factor depending on the state of roughness, smooth or rough, according to equation (3). This force, to great depths, can be corrected for pore pressure and the vertical stress at the level of the measurement, it is the net resistance. The effort of penetration and/or extraction is reported per unit area (footprint of the bar) and divided by the N_{TBT} factor. Plane strain numerical simulations allowed to propose factors commonly used (see Table 3).

$$Su=Fv/(D\times L\times N_{TBT}) \quad (3)$$

Table 3. Recommended N_{TBT} Factors.

Surface condition	***N_{TBT} Factor***
Smooth S	*9.2*
Rough R	*12*
Intermediate or indeterminate state S <status < R	*10.5*

2.6 Test cell

Cylindrical test cells (diameter 300 mm, height 205 mm, 10 mm wall thickness) provided at the base of a drainage system with water recovery over time by watertight plastic bottles, served to all testing (see Figure 2).

a) Cells and bottles. *b) T-bar apparatus.* *c) T-bar before penetration.*

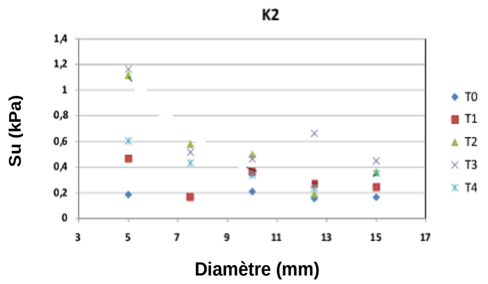
Figure 2. Experimental device for T-bar tests.

3. Effect of the diameter of the smooth and rough miniature T-bar

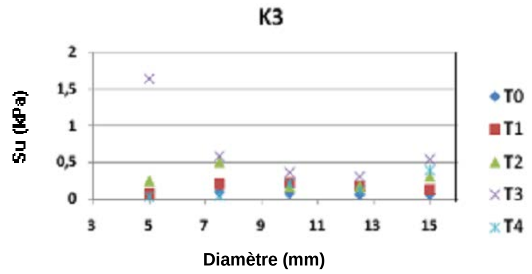
From penetration-extraction test performed over time (*T0* is the reference time at 24 hours after filling) and water content measurements, it was possible to follow the evolution of *Su* and *WC* according to the time and, depending on different diameters of the T-bar and condition of roughness. The undrained shear strength increases with time in relation to the water content and depth respecting the type of drainage applied to the sample surface and the bottom (LEVACHER *et al.*, 2014). There are differences between the values of *Su* for the 2 roughness conditions tested. *Su* variation depending on the diameter, whatever the state of roughness is shown in Figure 3. There is a similar trend to that observed by YAFRATE *et al*. (2007). *Su* values appear to be stabilizing from a diameter of 8 or 10 mm. They are also more dispersed for smooth diameters, (see Figure 3a).

4. Conclusions

The T-bar seems to be a relevant laboratory tool for determining *Su* but many questions about the procedure (conditions) remain unanswered. Considering these tests, we have characterized the effects of the size of the diameter *D*, the surface state of the T-bar, the proximity between the testing and the cell edge effect. It is noted that beyond a 10mm diameter, with λ=4 and β=3.33, the *Su* values are stabilized showing that the effect of diameter is negligible. This condition remains valid for well-established flow conditions of the soil around the T-bar; this depends on *Su* values. One can add that edge and proximity effects between tests become negligible from a distance of 2 to 3 D.



a) Smooth T-bar.



b) Rough T-bar.

Figure 3. Effect of the diameter D of the T-bar on the measurement of Su (CHERIFI, 2013).

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