"Origin Cohesion" of Clay

Cohésion d'origine de l'argile

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Summary

The prevalent opinion is that the shear strength curve of normally consolidated clays, as a function of the normal pressure, is a straight line passing through the origin. Thus, a clay that has not been consolidated under any external pressure should have no shear strength. A clay layer that has always been under water (and has not been exposed to erosion or to suction due to plant roots) cannot be preconsolidated, and the shear strength at the surface of such a layer should therefore be zero. However, the author has investigated such a layer, and has found a shear strength of 0.06 to 0.08 kg/cm² at the surface. The author has proposed the term "origin cohesion" for this shear strength.

Sommaire

On est généralement d'avis que la courbe de résistance au cisaillement de l'argile normalement consolidée en fonction de la pression normale est une ligne droite qui passe par l'origine. Il s'ensuit qu'une argile qui n'est pas consolidée par une pression extérieure ne doit pas avoir de résistance au cisaillement. Une couche d'argile qui a toujours été immergée (et qui n'a pas été exposée à l'érosion ou à la succion due aux racines des plantes) ne peut pas être préconsolidée. Par conséquent, la résistance au cisaillement près de la surface d'une telle couche doit être nulle. Cependant, l'auteur a examiné un type de ces couches et constaté une résistance au cisaillement de 0,06 à 0,08 kg/cm² près de la surface. L'auteur propose l'expression «cohésion d'origine» pour cette résistance au cisaillement.

The resolution of the shear strength of clays into a cohesional part and a frictional part has been carried out most consistently by *Hvorslev* (1937) in his theory which has been generally adopted. According to this theory, the frictional part is directly proportional to the effective normal pressure, and the cohesional part is directly proportional to the so-called equivalent pressure. As is generally known, the equivalent pressure is that pressure on the virgin compression curve which corresponds to the actual void ratio. (*Hvorslev* made his tests in a consolidometer, i.e. with prevented lateral expansion, and this is often at variance with field conditions. Therefore, it would have been more logical to assign the cohesional part of the shear strength and the equivalent pressure to the sum of the principal pressures or to the mean principal pressure.)

For normally consolidated clays, the equivalent pressure is equal to the normal effective pressure. Therefore, the shear strength of such clays increases from zero rectilinearly with the normal pressure. All books on soil mechanics and foundation engineering also show that the curve of the shear strength as a function of the normal pressure passes through the origin (for normally consolidated clays).

However, the author has long been of the opinion that a normally consolidated clay has a certain shear strength also when the external effective pressure is zero, i.e. when the clay has not been consolidated under an external pressure. (The definition of "the external effective pressure" is given below.) This opinion could not be verified by testing samples from ordinary clay soils, as we usually do not know the value of the equivalent pressure in the ground (it is influenced in an unknown way by repeated freezing and thawing, by evaporation at the ground surface, and by suction due to plant roots).

However, a clay layer that has always been under water cannot be preconsolidated (provided that no erosion has occurred and that no vegetation has existed). A determination of the shear strength of such a layer should therefore show whether there exists any origin cohesion. The author proposes the term "origin cohesion" for the cohesion (= the shear strength) of normally consolidated clay at the normal pressure equal to zero.

Accordingly, the shear strength was determined by means of vane borings in three boreholes. Two of them (boreholes I and II) were sunk in the same lake (Lake Vallentuna, 20 km north of Stockholm) at a distance of about 100 m from each other, and the third (borehole III) was sunk in a gulf in Stockholm (at Blockhusudden). At least the clay layer in Lake Vallentuna seems to comply with the above conditions; the

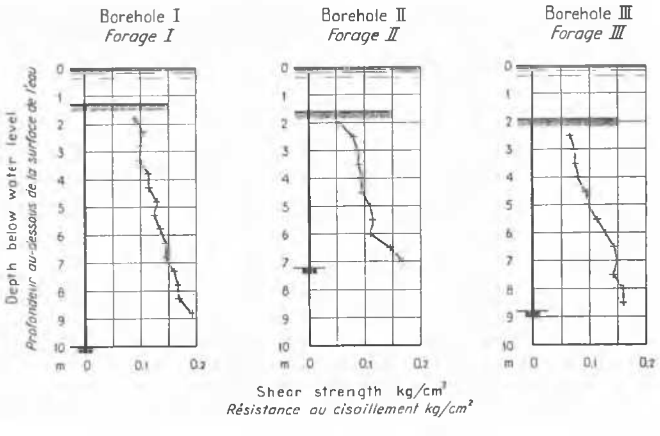

Fig. 1 Results of Shear Strength Measurements with the Vane Apparatus
Mesures de la résistance au cisaillement effectuées au moyen de l'appareil à palettes

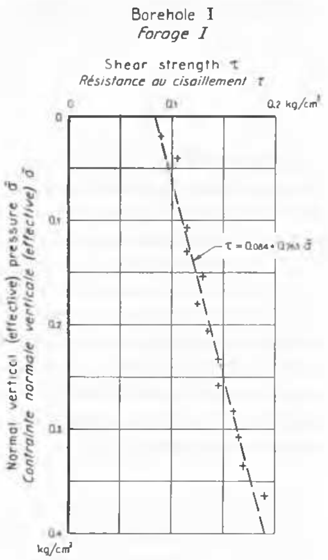

Fig. 2 Shear Strength in Borehole I as a Function of Vertical Pressure
Résistance au cisaillement au forage I en fonction de la contrainte verticale

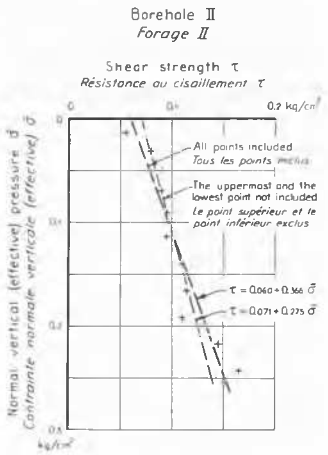

Fig. 3 Shear Strength in Borehole II as a Function of Vertical Pressure
Résistance au cisaillement au forage II en fonction de la contrainte verticale

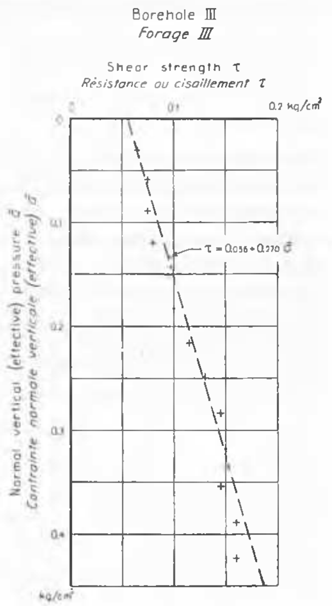

Fig. 4 Shear Strength in Borehole III as a Function of Vertical Pressure
Résistance au cisaillement au forage III en fonction de la contrainte verticale

ground down to the depth where the boreholes ended consists of post-glacial clay. In borehole III the clay is glacial; the uppermost sample in this borehole showed disturbed varves; erosion or disloading might have happened here, but this is not probable.

The results of the vane borings are represented in Fig. 1. Figs. 2 to 4 show the shear strength (determined by vane tests) as a function of the vertical effective pressure (computed as the depth multiplied by the submerged unit weight of the clay). Straight lines have been drawn in these diagrams according to the method of least squares.

The three boreholes show an origin cohesion of 0.06 to 0.08 kg/cm². These values are not inconsiderable, in any case for Swedish clays, which often have a shear strength of only 0.1 to 0.2 kg/cm² or even less.

The purpose of this report is only to demonstrate the existence of origin cohesion. However, in this connection, some investigations were made on samples taken by a piston sampler with stationary piston. They included the determination of unit weight, natural water content, plastic limit, and liquid limit for all samples, and specific gravity, percentage of organic matter, and particle size distribution for some of the samples. The results of these investigations are shown in Figs. 5 and 6. The decrease in the value of the liquid limit with the depth is obviously due to the decrease in the percentage of organic matter (Fig. 5), and not to any decrease in the percentage of

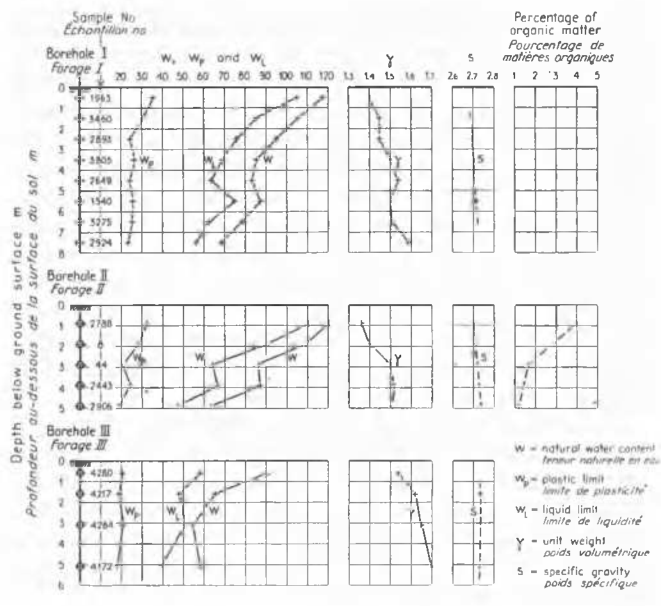

Fig. 5 Soil Characteristics of Boreholes I–III
Caractéristiques des sols des forages I–III

the colloidal fraction of the mineral matter (< 0.0002 mm) (Fig. 6). The author hopes to be able to repeat the experiments with a more homogeneous clay layer of a greater thickness. Then the pore water pressure will also be measured. However, there is no reason why an overpressure (artesian pressure) should exist in the present case. An overpressure would not have any influence on the origin cohesion, but would increase the slope of the straight line in the Figs. 2 to 4.

Furthermore, quick direct shear tests were made on normally consolidated slices of the samples and on preconsolidated slices. The tests on the normally consolidated slices were made partly at a normal pressure equal to the computed effective pressure in the ground, and partly at a considerably higher pressure. The purpose of these tests was to determine the true cohesion and the true internal friction of the clay according to a method previously developed by the author (*Jakobson*, 1952). The result is shown in Table 1.

Table 1

Borehole (Forage)	*Sample No. (Echantillon)*	*Effective pressure (Contrainte efficace) kg/cm²*	*Void ratio (Indice des vides)*	*Shear strength (Résistance au cisaillement) kg/cm²*	*N or P (N ou P)*	*Void ratio in the soil (Indice des vides dans le sol)*
I	2893	0.118	2.60	0.085	N	2.56
I	2893	0.118	1.89	0.067	P	
I	2893	0.980	1.80	0.262	N	
I	1540	0.266	2.43	0.134	N	2.38
I	1540	0.266	1.62	0.198	P	
I	1540	0.980	1.79	0.274	N	
II	8	0.077	2.89	0.065	N	2.96
II	8	0.077	1.83	0.076	P	
II	8	0.980	1.70	0.312	N	
II	2443	0.177	2.20	0.092	N	2.38
II	2443	0.177	1.52	0.115	P	
II	2443	0.980	1.56	0.265	N	
III	4217	0.086	1.92	0.057	N	1.79
III	4217	0.086	1.25	0.059	P	
III	4217	0.980	1.25	0.236	N	
III	4172	0.320	1.57	0.141	N	1.58
III	4172	0.320	1.15	0.167	P	
III	4172	0.980	1.26	0.232	N	

N = normally consolidated – normalement consolidé
P = preconsolidated – préconsolidé

The direct shear tests do not quite agree with the vane borings, and have given smaller values of shear strength, especially at the greatest value of normal pressure. We have also obtained different values of the coefficient of true friction for different samples (the greatest values for the most superficial samples).

When the clay layer was formed by clay particles being deposited on the top, the superficial sheet of the clay must have had a very great value of void ratio [According to tests by

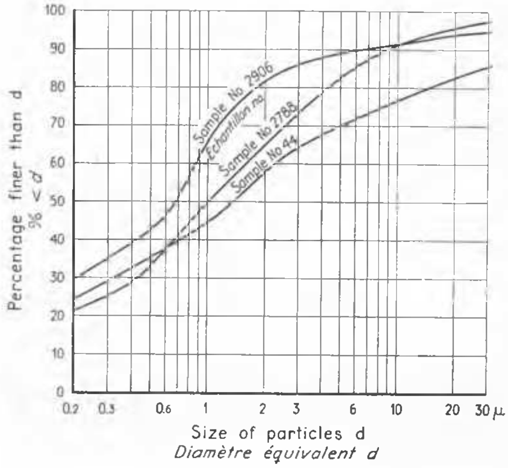

Fig. 6 Particle Size Distribution of Some Samples
Distribution granulométrique de quelques échantillons

Th. Brenner (1946) with sedimentation of clay suspension, a new clay (after some months) has a void ratio of about 9], and the shear strength must have been very low. However, now the superficial clay layer has about the same void ratio as the clay below (about 2.5), and the shear strength has a not negligible value. Thus, the clay must have been consolidated under a certain pressure. As there exists no external pressure near the surface of the clay, the superficial clay must have been consolidated under an internal pressure. In the vicinity of borehole I, where according to Fig. 2 the shear strength at the surface is 0.084 kg/cm² and the shear strength increases with depth by 0.263 times the normal vertical pressure, this internal pressure should be $\frac{0.084}{0.263} = 0.32$ kg/cm². (The conditions are certainly more complicated as, by using vane borings, we determine the shear strength in vertical planes and the shear strength may vary in different directions, as the effective pressure certainly varies.) It thus seems that the external effective pressure (= the depth below the ground surface multiplied by the submerged unit weight) should be increased by a certain amount in order to obtain the real effective pressure.

It may be asked why *Hvorslev* did not obtain any origin cohesion in his investigations. This may be due to the fact that *Hvorslev* worked with remoulded samples, which may behave in this respect otherwise than undisturbed samples. Furthermore, *Hvorslev* assumed that there is no origin cohesion. The author has examined the curves published by *Hvorslev*, introduced an origin cohesion of 0.05 kg/cm², and found that *Hvorslev*'s test values agree on the whole under this assumption as well.

References

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Hvorslev, M. J. (1937): Über die Festigkeitseigenschaften gestörter bindiger Böden. København, Ing.-vid. Skr. A Nr. 45.

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