SHEARING TESTS ON COHESIVE SOILS

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The following tests were made in 1944 at Magdeburg and Munich with kind permission of Prof.Leo Casagrande and Prof.Huber in order to obtain soil characteristics, especially of sand-loam mixtures (soil-mortars). The apparatus and the test procedure itself must be simple in regards to their application in the field. Besides the manner of loading the sample must be plain, thus the created stresses easily computable and still the results accurate. The soil characteristics stated in the present report are closely related to cohesion and fulfill the above requirements. It is emphasized, however, that the figures are depending on the apparatus and the test procedure and therefore are not yet soil constants.

APPARATUS

The apparatus consists of 3 vertical staves, i.e. the middle stave "M" and the two side staves "S" (Fig. 1). The latter are placed on wheels "R" rolling on a rail "T". Both parts of the soil sample being enclosed by the staves have free surfaces in front and back. They have a length of ℓ=25 cm, a breadth b = 2 cm, and a thickness t=1,5 cm. The shearing force is transmitted to the sample by means of small horizontal plates "B" being attached to the staves

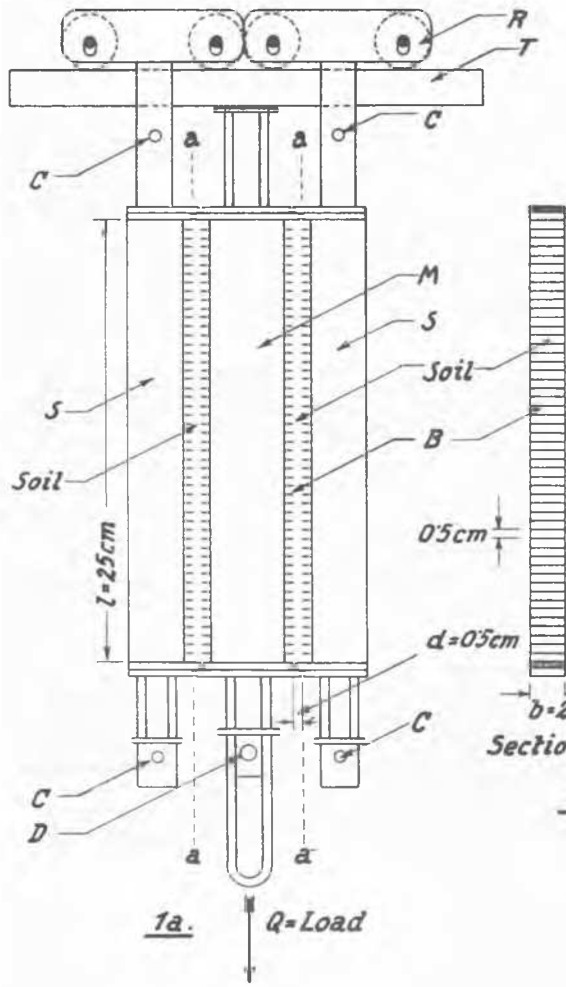

FIG 1a.1b

like the teeth of a comb, standing in distances of 5 mm apart from each other and penetrating into the sample for a depth of 5 mm. The side staves move only in horizontal direction, the middle stave on the contrary being loose is pulled downwards by the shearing force. In this manner 2 symmetrical shearing planes are created (Fig. 1 b, section a-a) measuring in area $F = 2\,\ell.b = 100\ cm^2$ altogether. The shearing strength s is determined by the load Q when breaking ..$s=Q/F$...with respective destinction $s=s_I$ and $s=s_{II}$ according to both types of test procedure described in the following.

By means of the small plates "B" the shearing plane is created in the middle and the "effective"thickness of the sample reduced to the distance d= 5 mm between the opposite rows of shearing plates "B". Attention is called that the ratio between the effective thickness d and the length ℓ of the sample ..$d/\ell = 1/50$.... is a very small figure this being favourable with regard to a plain manner of loading (plain loading conditions). The accurate distribution of stress, however, remains unknown, considering the single plates. It must be mentioned finally that the capillarity, caused by the free surfaces and the influence of rapid load application have not been investigated in particular.

PREPARATION OF SOILS AND TEST PROCEDURE.

The soils described in Table 1 were mixed in a consistency near the liquid limit, dried slowly, mixed again at a certain moisture content, and after this preparation filled into the apparatus.

Special attention was paid to avoid any air bubbles in order to obtain a dense structure. Describing the test procedure it must be said that no external load was acting normally to the shearing plane neither before nor while the shearing force was raised up to breaking point. As stated above the tests were performed in two different types of procedure:

1) According to test procedure I both side staves were fixed firmly by means of the screws "C". Hence the lateral expansion of the sample caused by the change of soil structure was possible only at the free surfaces. On the other sides, however, the resistance of the s staves created a stress p, acting normally to the shearing plane.

2) According to test procedure II the screws "C" were removed and thus both side staves being placed on wheels could yield laterally. In this manner a stress p acting normally to the shearing plane was avoided p = 0.

The shearing force was applied by attaching a scale with weights directly to the middle stave. After removing the holding screw "D" the shearing force was raised up rapidly to the breaking point. The deformations of the samples were not measured being small only. There-upon a quantity of 200 grams of soil was taken from the shearing planes in order to determine the moisture content. At last the apparatus was cleaned by means of a steel brush and prepared for the next test.

DETERMINATION OF MOISTURE CONTENT.

Determining the moisture content special attention was paid to the weight of thoroughly dried samples. It must be realised that the determined figures, especially those in field laboratories have a relative significance only. Therefore it was necessary to treat a series of samples simultaneously in order to create and obtain exactly equal conditions and well comparable figures.

Besides the moisture content w also the voids ratio e of several soils (Nr. 5, 11 and 12) had to be determined.

RESULTS.

The tests showed a strict logarithmic relation between the moisture content w (in per cent) and the shearing strength s (in t/m^2) given by the formula

$$w = a - b \log {}^{s}/{}_{s_0}$$

The term s_0 is defined as the "unit shearing strength" (1 metric ton per square meter). By substitution of s_0 respectively 0,1 s_0 for s we get

$s = s_0 = 1\ t/m^2$ ....w = a

$s = 0{,}1\ s_0 = 0{,}1\ t/m^2$ ....w - a = b

Thus the characteristic "a" represents the moisture content at a shearing strength s_0 = 1 t/m^2.

The characteristic "b" is given as the difference between the values of moisture content at 0,1 s_0 and 1,0 t/m^2.

Hence if the moisture content of a soil is enlarged from w = a to w = a+b the shearing strength drops to 0,1 (1/10) of its original value, that is a decline of 90% (per cent). Considering a value b = 8% (per cent) shown by Table 1 the importance of an exact determination of the moisture content can easily be perceived. Fig. 2 and Fig. 3 show the relation between w and s being a straight line in the semi logarithmic diagram. The lines are shown fully as far as shearing tests were actually performed and dotted where tests are considered as possible. The results of tests for the sand-loam mixtures Nr. 8,9 and 10 do not differ very much from each other and it was therefore necessary to express the moisture content in 1/10 per cent an accuracy valid only fore figures determined at exactly equal conditions. Testing pure sands (soils Nr. 5, 11 and 12) it was impossible to determine any relation between s and w.

But there exists a logarithmic relation between the voids ratio e and the shearing strength s. Hence the values of $w = 100e/\gamma$ were computed. As testing of such soils is difficult and the results therefore are not accurate the values w_d, s_d and w_l, s_l for dense and loose structure are given only. The shearing strength of sands is due primarily to capillarity and

TABLE 1.

Results of shearing tests given by soil characteristics.
Moisture content w, especially a,b,w_d,w_l in per cent.
Shearing strength s, especially s_d, s_l in t/m^2.

SOIL No.	Soil type	Test Procedure I	Test procedure II
1	Clay liqu.lim = 65 plast.lim = 21	a = 47 b = 24	a = 44 b =(24)
2	Loam liqu.lim = 27 plast.lim = 10	a = 23 b = 12	
3	Silt-loam liqu.lim = 28 plast.lim = 19	a = 23 b = 8	
4	Loamy-sand liqu.lim = 11 plast.lim = ?	a = 12 b = 8,6	
5	Fine-sand uniform	w_d = 25 s_d = 1,26 w_l = 33 s_l = 0,45	w_d = 25 s_d = 0,49 w_l = 33 s_l = 0,19
6	Loam "L"	a = 28 b = 12	a = 26 b =13
7	Loam-sand mixture 50 L/50 S	a = 19 b = 7,5	a = 17,7 b = 7,5
8	Loam-sand mixture 30 L/70 S		a = 12,9 b = 8,0
9	Loam-sand mixture 20 L/80 S	a = 16 b = 7,5	a = 11,8 b = (8,3)
10	Loam-sand mixture 10 L/90 S		a = 10,6 b = 8,6
11	Loam-sand mixture 5 L/95 S		w_d= 14,5 s_d= 0,43
12	Coarse-sand "S" nonuniform		w_d= 16,2 s_d= 0,36

Notes:
a) liqu.lim = liquid limit, plast.lim = plastic limit.
b) As mechanical analysis was not performed the constituents were roughly estimated by comparing the soils with similar ones.
Soil No.5 rather uniform, grain size likely to be about 0,1 mm.
Soil No.6 likely to contain about 25 percent of particles smaller than 0,002 mm.
Soil No.12 likely to contain about 97 per cent of sand (2 mm - 0,1 mm) and about 3 per cent of particles smaller than 0,1 mm.

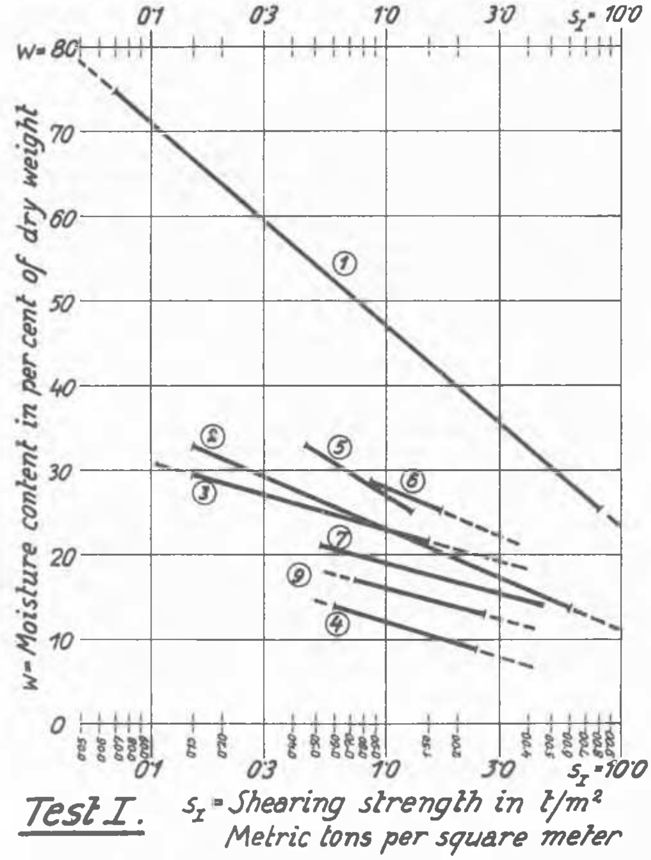

FIG.2

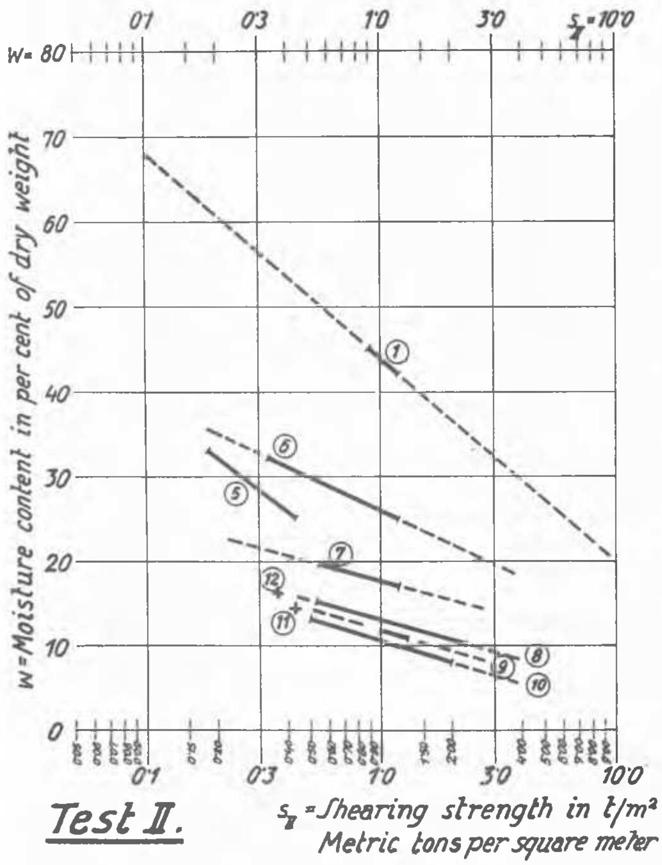

FIG.3

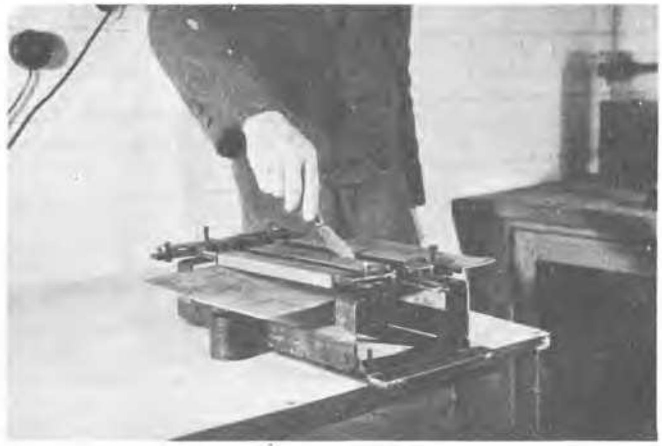

FIG.4

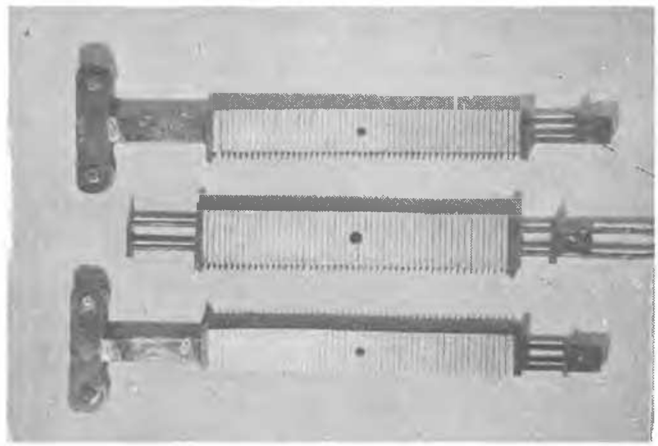

FIG.5

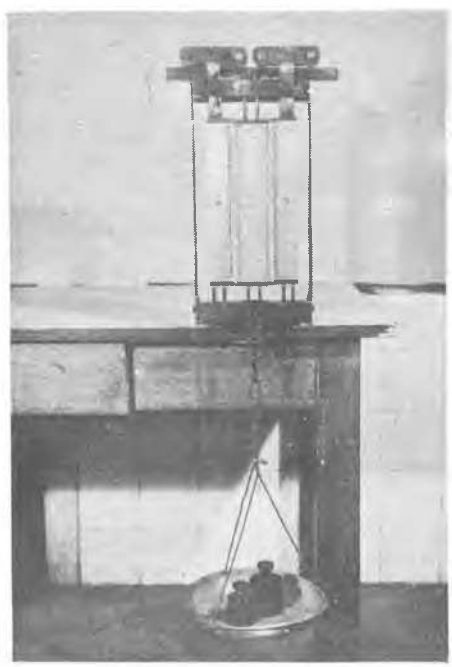

FIG.6

of interest mainly in order to show the difference in comparison with cohesive soils.

Considering the lines for the sand-loam mixtures (Fig. 3) it is noticed that the good soil mortars showing but small differences from each other differ noticeably from the bad ones respectively from the sands. Mixture Nr 7 for instance being bad on account of a too large percentage of clay has far higher values of moisture content. On the other side there is a striking difference between the mixtures Nr. 10 and 11 with regard to the maximum of their shearing strength which for mixture 11 amounts to about 1/5 only of that for Nr. 10. Therefore Nr. 11 can easily be classified as sand, mixture 10 on the other hand must be marked as soil mortar. It is possible, however, that the maximum of shearing strength being dependent not only on the percentage of clay but also on other matters would show different results if samples would be tested taken directly from the surface of a road instead of soil mixtures made in the laboratory.

CONCLUSIONS.

By determination of the shearing strength as well as the moisture content it is possible to distinguish the soils numerically. The accuracy depends mainly on the moisture content. As an example two semi logarithmic diagrams are given showing both soil characteristics and explaining the behaviour of certain sand-loam mixtures.

If only the shearing strength is given, it describes the consistency of a certain soil better than the moisture content would do this.

The apparatus in its present form is not perfect but will be improved.

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SUB-SECTION II f

ELECTRO-OSMOSIS

II f 2 RESULTS OF LABORATORY INVESTIGATIONS ON THE ELECTRICAL TREATMENT OF SOILS

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INTRODUCTION.

The electrical treatment of soils has created the interest of the soil mechanics experts, especially in the years after the war. Since the first experiments by L. Casagrande a number of technical applications have been made, which proved the necessity of a closer study of this method of treatment, its possibilities and its limitations.

The opening phase of this study, as made by the authors in the Delft Laboratory, has resulted in some preliminary investigations, which will be described in the following pages.

Two phenomena resulting from the electrical treatment of soils were taken as a starting point for the authors' investigations.

a) the improvement of the mechanical properties of soils, resulting from an accelerated process of consolidation, including the so-called "electro-chemical hardening".

b) the possibility of influencing pore-water flow, and of establishing favourable hydraulic gradients in soil masses, which do not permit the application of the usual drainage methods (well pumping a.o.) because of their low permeability. This explains the use of the term "electrical drainage".

In order to investigate the effects of electrical treatment, with respect to the abovementioned points, it was necessary to develop a suitable technique for laboratory experiments and to test a range of soils from coarse sand to fat clay.

FUNDAMENTAL THEORIES.

The changes in the soil brought about by an electrical treatment are the result of combined electrolytic and electrokinetic phenomena, varying strongly with the composition and the properties of both the soil (including the soil solution) and the electrodes used.

The effect of an electrical current primarily causes a transport of pore-water in the soil. This flow of porewater may be accompanied by a decrease of the water content (consolidation effect).

Secondly a hardening may occur as a consequence of electrochemical changes, like a precipitation of aluminum-hydroxyde (when a aluminum is used for the electrodes) and eventually a flocculation of colloidal clay substance (electro-chemical hardening of clays).

Both last-mentioned phenomena are usually not or partly reversible, causing an important decrease of compressibility and a subsequent increase of internal frictional resistance.

The transport of pore-water is usually referred to as an electrokinetic effect (electro-osmosis), which is made possible by an electrical charge of the soil particles due to the