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Autor: Bernatzik, W.

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Electro-Chemical Consolidation of the Ground.

Elektrochemische Bodenverfestigung.

La consolidation électro-chimique des argiles.

Dr. Ing. W. Bernatzik,

«Centre d'Etudes et de Recherches Géotechniques». Fondation M. G. Rodio, Paris.

When a direct current is passed through clay a number of phenomena occur simultaneously:

- 1) *Heating* of the clay on account of its electrical resistance.
- 2) Decomposition of the pore water (*Electrolysis*).
- 3) Polarisation of the electrodes in accordance with their nature. This gives rise to a back E.M.F. which weakens the current passing through, or in other words increases the resistance (*Polarisation*).
- 4) If there is an excess of water¹ so that the particles of clay are free to move about, the negatively charged particles (basic) travel to the positive electrode (anode), and the positively charged (acid) particles to the negative electrode (kathode) (*Electro-cataphoresis*).

Where, however, there is an excess of clay so that the particles have no freedom of movement, the pore water will itself move to the negative side if the clay particles are negatively charged, and vice-versa (*Electro-osmosis*).

(Conversely if water under a hydraulic head is caused to circulate through a system of capillaries, an electrical difference of potential will be set up between the point of entry and the point of exit.) (*Electro-capillarity*.)

- 5) *Exchange of the adsorbed bases* and removal of these by the current, leading directly to the formation of new ions; hence the nature of these can be influenced by the choice of electrode and by the addition of suitable chemicals. Present knowledge^{2, 3} of this last process may be stated as follows:

The particles of clay are micro-anions which present a stratified lattice structure. They have unsatisfied electrical valencies on their surfaces which tend to saturate themselves with bases from the pore water: or, in other words, the surface reacts chemically. The inside of the particles remains inert since here all valencies are satisfied or are in equilibrium. The bases absorbed in this way effect the pore water in their turn to a varying range and intensity, according

¹ *Freundlich*: Kapillarchemie. Leipzig 1930.

² *Endell und Vageler*: Der Kationen- und Wasserhaushalt keramischer Tone im rohen Zustand (Berichte der deutschen Keram. Gesellschaft E. V., Sept. 1932).

³ *Endell und Vageler*: Über die Natur der keramischen Tone (Berichte der deutschen Keram. Gesellschaft E. V., October 1933).

to the nature of the bases. It is only outside this region that the pore water is truly free. If, now, it is possible to replace the particles of clay adsorbed on the surface by others, then the strength and thickness of the adsorbed water sheath changes, and a physical alteration of the clay may be expected.

The idea of using an electric current for consolidating the ground was put forward by *Dr. Leo Casagrande*, and the experiments he described — which are still in their preliminary stages — are being carried out in the earth mechanics laboratory of the Centre d'Etudes et de Recherches Géotechniques started by *Mr. M. G. Rodio* in Paris. Their object is to clarify the phenomena and to arrive at a process which can be applied in practice.

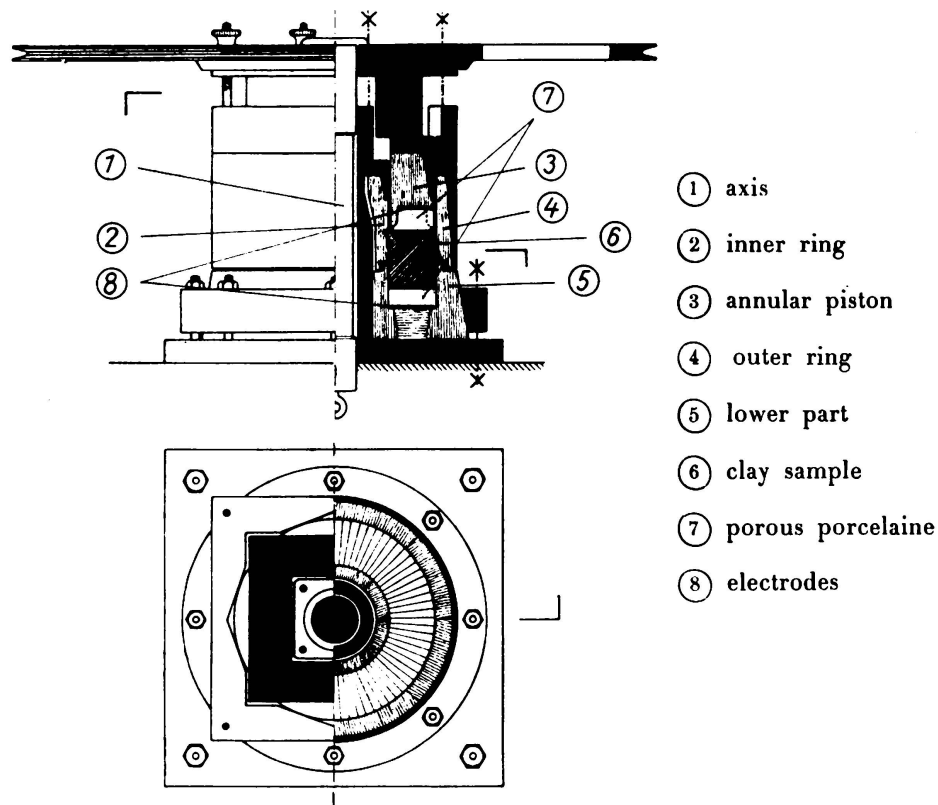


Fig. 1.

Fig. 1 shows the construction of a circular shear apparatus which, being lined with electrically inert material, renders it possible to observe the clay under the influence of a current passing through. The specimen of clay *F* is of annular shape and is held between two porous stones *G*, behind which are situated the electrodes *H*. The apparatus consists of a fixed lower half *E* and a moveable upper portion *C* made up of two moveable rings *B* and *D*. These moveable portions are centred by the axis *A* which serves to transfer the vertical load. The moveable rings *B* and *D* may be lifted away from the lower portion by means of screws before the shear test is carried out. All three portions *B*, *G* and *D* are made square at the top and in anticipation of the shear test they are fixed under one another by means of wedges.

Fig. 2 shows the general arrangement, Fig. 3 the details of the shear box ready for the experiment, and Fig. 4 the latter taken to pieces.

This apparatus enables a disturbed clay to be consolidated which a known initial water content under a given load and the shear value then to be determined. Next, the current is switched on and the change in volume of the clay is measured, after which another shear test is carried out. The results thus include

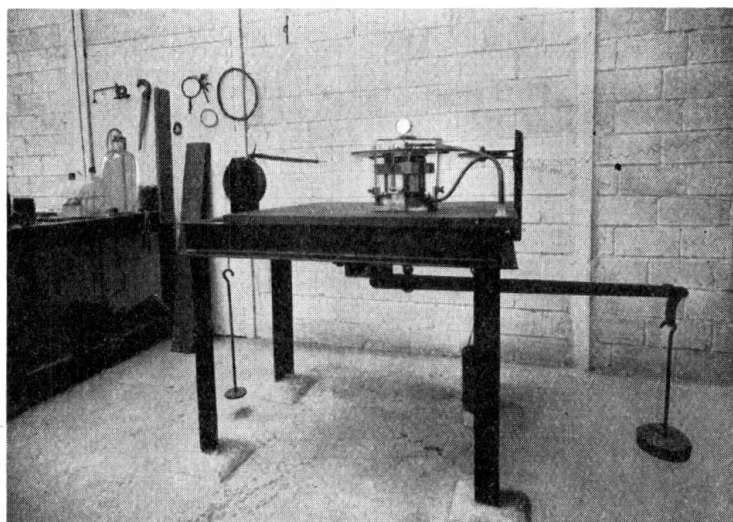


Fig. 2.

the shear values of the same specimen before and after treatment, the change in volume undergone during the passage of the current, its initial and final water content, and hence the corresponding theoretical values for the clay specimen. The constants measured before the passage of the current — that is,

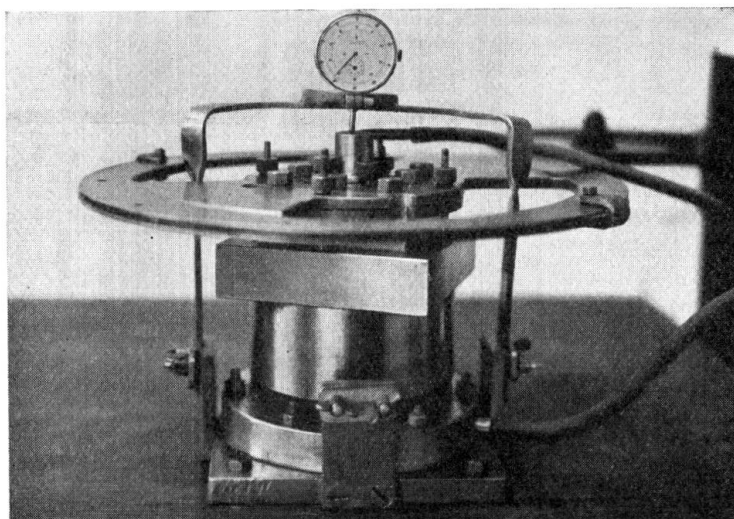


Fig. 3.

the effective voids ratio diagram and the shear value — are checked by reference to standard tests.

Fig. 5 represents the soil-mechanical properties of the clay examined, Part A being the void ratio diagram and the K-value (permeability) at the liquid limit which are taken to represent the initial conditions. Using the same system of

ordinates, the effective void ratio diagram for the clay in the condition it was used for the experiments is given below.

Part B shows the curve of particle sizes (peptised with lithium carbonate). Part C gives the angle of friction and the cohesion (the shear load being applied

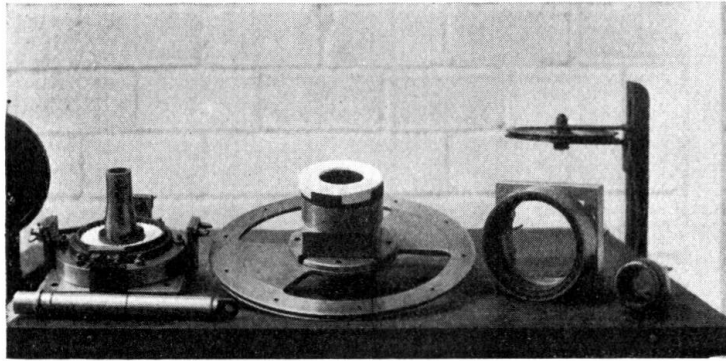


Fig. 4.

at the rate of $1/40^{\text{th}}$ of the vertical load per minute). Part D represents the S-value, that is the quantity of exchangeable bases per gramme of clay substance, and the elements present in solution are stated below.

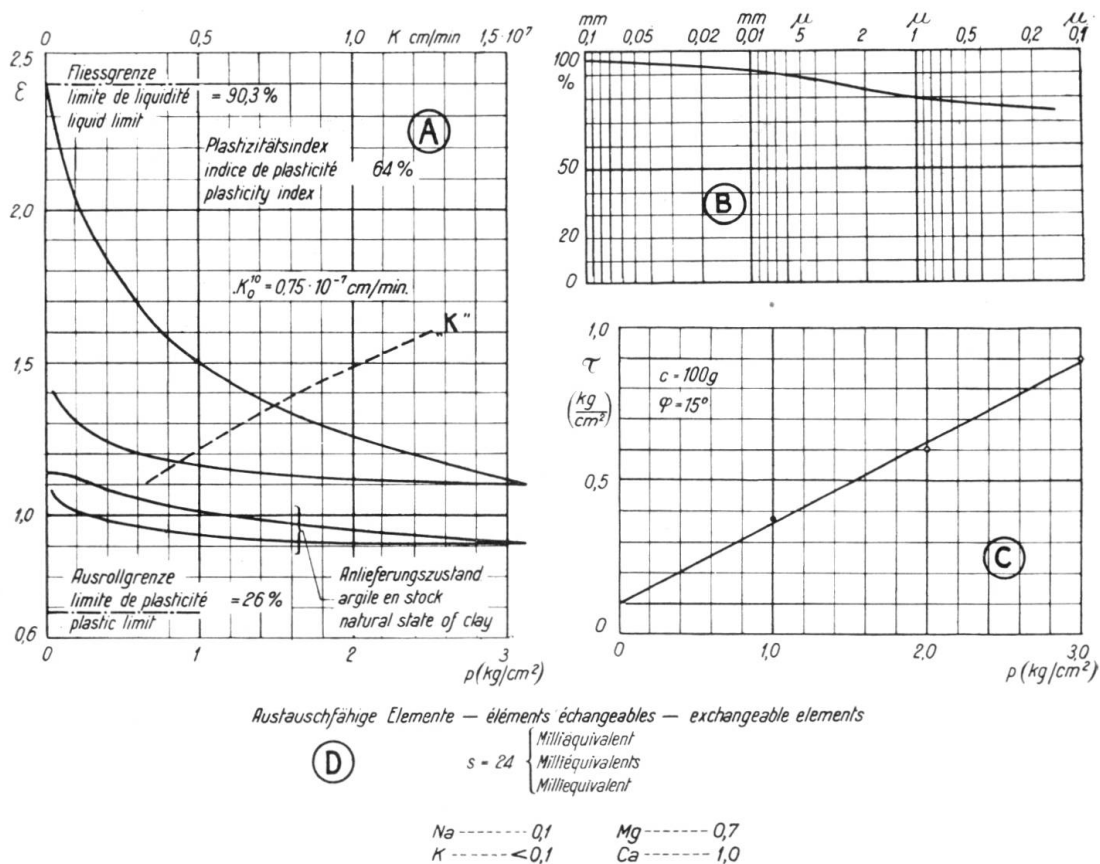


Fig. 5.

It will be clear that the clay used here is not very well adapted for consolidation as it contained only a very small amount of sodium, on the exchange

of which the process largely depends; it was chosen, however, because it was commercially available with a uniform consistency, under the German name of Töpfer-Ton (pottery-clay).

The first of the experimental results are shown in Fig. 6, and are now being checked.

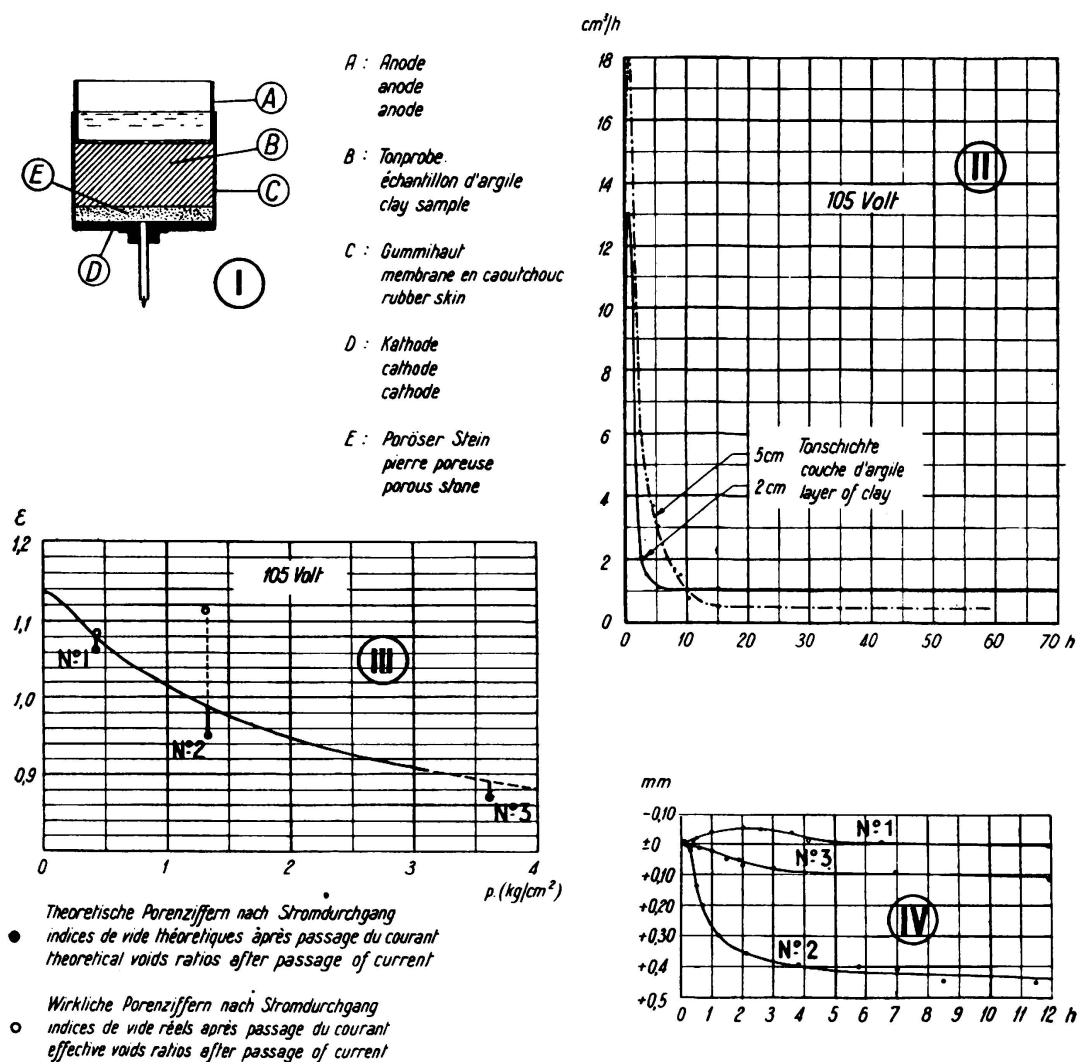


Fig. 6.

In Part III of this statement the shrinkage which occurred under differing amounts of loads during the passage of the current is indicated. Part IV gives the change in volume expressed as a function of the time. In Part III, therefore, the void ratios ought to fall away from the main axis of the void ratio diagram towards the points marked in full; if, however, the water content is determined after the completion of the experiment the void ratios work out very much higher. After the experiment the clay sediments were not left to continue shrinking, and it is certain that a small absorption of water must have taken place. Consequently the true water contents must be so high as to warrant the assumption that the shrinkage is attributable, in the first place, to the absorbed water: that is to say, the water not withdrawn from the clay when attempting to determine the water content by the customary method of drying at 105° C. These results are in process of being checked by an oedometer.

It is remarkable how rapidly the change in volume is completed (IV), and also that the clay in experiment N° 1 should have been swollen originally. This rapidity is explained by the second series of experiments (I), wherein the clay C was kneaded in a rubber skin C without the imposition of any load, a porcelain stone E placed underneath, the electrodes A and D arranged on either side, and the amount of water forced out by the passage of the current was measured. In Part II this quantity of water is represented as a function of the time, separately for each layer thickness of clay of 2 and 5 mm. After a heavy release of water, which came to a stop after a few hours, the flow of water assumed a stationary condition attributable to electro-osmosis. If the pressure necessary to bring about this constant flow of water through the clay is calculated, the result works out somewhere between 5 and 6 atmospheres. It is clear, then, tha:

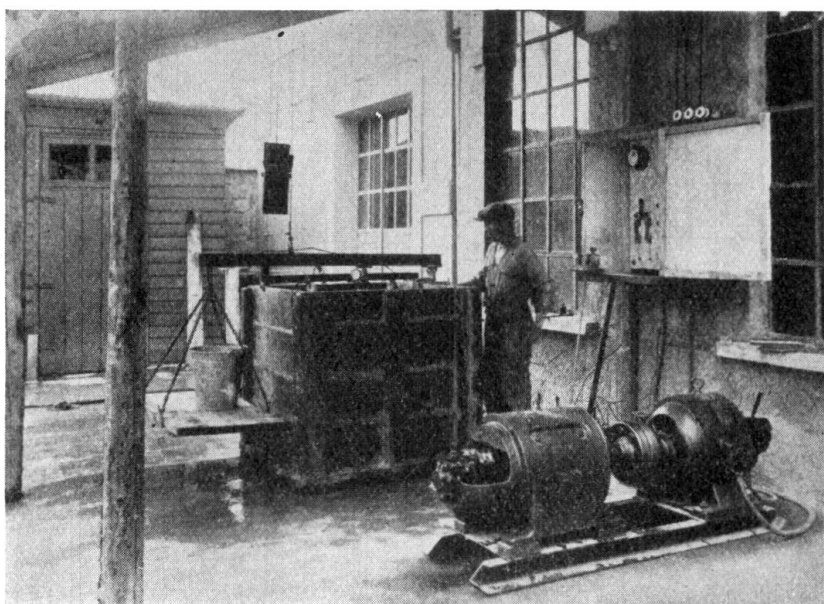


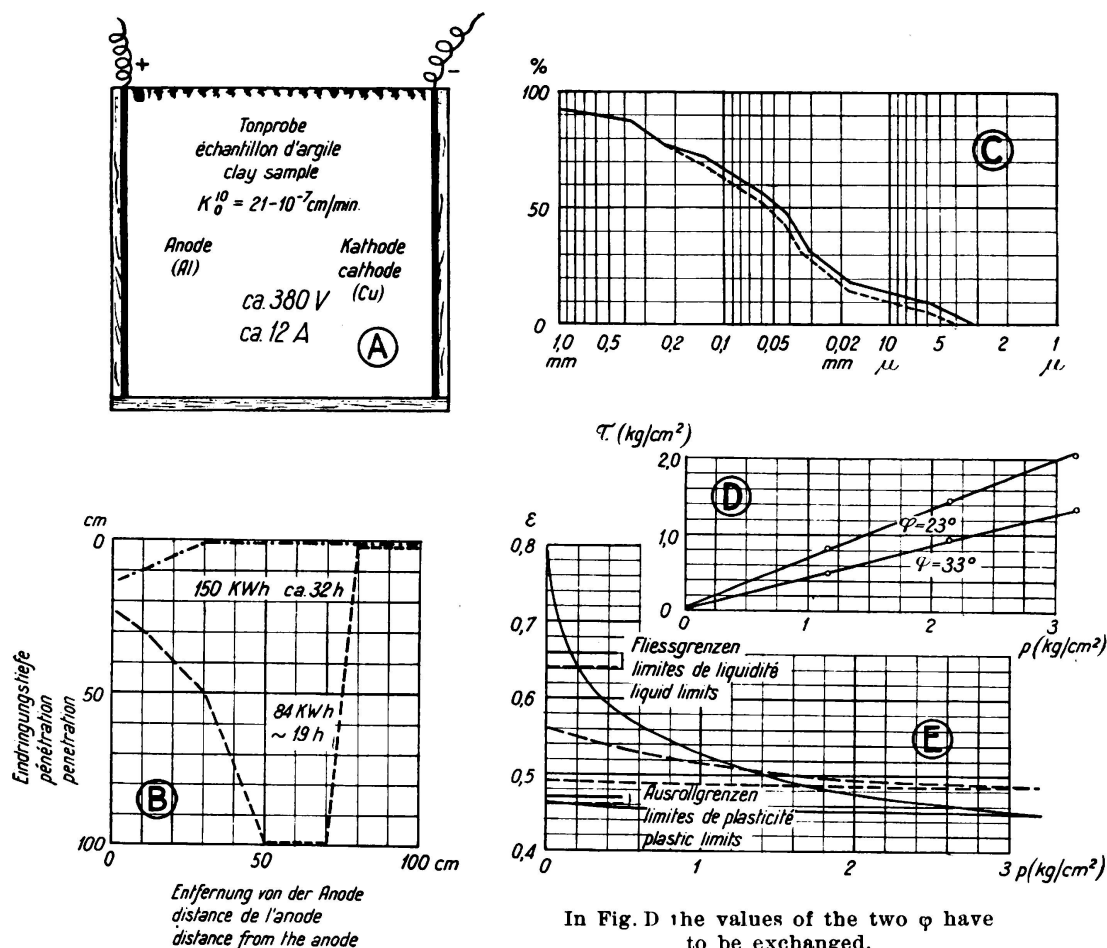
Fig. 7.

very considerable forces are in operation and these, of course, must exert an effect on the clay; that is to say, the clay becomes consolidated by the "electrical load" as represented at IV, and presumably this occurs when no exchange of bases or release of adsorbed water from the pores takes place.

Before the experiments were undertaken, a large-scale test on a cubic metre of clay was made in the Rodio Earth-Mechanics Laboratory at Milan, which is of interest in that a positively charged (acid) clay was used, so that the pore water therein flowed towards the positive pole.

Fig. 7 shows the arrangement of the experiment and Fig. 8 the result. At A is shown a cross section through the clay specimen. The clay when filled in was fairly fluid and well above the liquid limit. As a means of determining the changes undergone by the clay a kind of Vicat needle was applied from time to time to measure the penetration at different points; these penetrations are shown at B, as broken lines after 19 hours and as dotted lines after 32 hours operation. It will be seen that after 19 hours the clay has become firm on either side; on the negative side this has occurred in a zone which is quite narrowly bounded,

but on the positive side the degree of consolidation falls off gradually towards the middle. In the middle the clay has at first undergone no alteration, but at the end of 32 hours practically the whole of the clay specimen has become consolidated. Clearly the consolidation at the negative pole is attributable to electrocatophoresis; that is to say, the particles of clay are drawn towards the cathode and are consolidated there to a horizontal stratum. On the positive side, whence the migration of the ions originates, the consolidation appears to be attributable to base exchange.



In Fig. D the values of the two φ have to be exchanged.

Fig. 8.

After the completion of the experiment the determination of the earth-mechanical constants for the disturbed sediment was repeated.

According to the granulation curve C (broken line), the grains appear to have become somewhat larger (areometer method); that is to say, the grains sink more rapidly, and this may be explained by the reduction in the absorbed water skin.

The shear diagram at D shows the alteration in the angle of friction, which has increased from 23° to 33° .

The diagram of void ratios at E gives the compressibility before the passage of the current (shown by full line) and after (shown by broken line). It will be seen that the character of the clay has become more "sandy", that is, the angle of friction has increased, and the compressibility has become less.