A Capacitive Cell Apparatus
L’Appareil à Cellule Capacitive

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Summary
The article describes a test device which permits the determination of the horizontal strain of cylindrical samples under loading conditions without touching the sample by means of an electrical capacitive method. Tests on samples to study soil pressure, compression and shear separately are outlined.

The capacity of shear resistance, according to the sample behaviour as determined by this test device, is discussed.

Introduction
The study of cylindrical soil samples under the influence of stresses as effected in test devices such as the Dutch cell or British triaxial apparatus becomes more interesting if the strains may be determined separately and without disturbing the applied stresses.

The capacitive cell apparatus described here permits the measurement of lateral deformation of the sample without touching it, so the horizontal stress applied by air pressure on the rubber envelope of the sample is not disturbed by the displacement determination. After a description of the test device and interpretation of the results, a discussion of typical test results in connection with the conception of shear resistance will be given.

Description of the Lateral Strain Determination
In Fig. 1 the apparatus is schematically represented. The cylindrical sample is loaded vertically by weights and horizontally by air pressure on the rubber envelope and the vertical movement is read on the dial gauge, these contrivances being of the conventional type.

The measurement of the horizontal strain is effected by using the sample surface as one of the two electrodes of a condenser, the metal housing being the other electrode.

If the sample dilates the distance between sample and outer wall is increased, thus increasing the electrical capacity of this condenser because the capacity is inversely proportional to the distance between the electrodes. By determination of this electrical capacity the horizontal strain may be deduced.

In order to measure this capacity a reference condenser is installed in the base of the apparatus which can be made electrically equivalent to the sample-wall combination. In Fig. 1 this reference condenser is shown in a substitute circuit consisting of a fixed condenser C0, which represents the main part of the capacity from the sample and connecting metallic parts, a resistance R0 as a substitute for the sample resistance and an adjustable condenser C which accounts for the remaining variable part of the sample-wall capacity.

To equalise this electrical substitute to the sample-wall capacity these two circuits are alternately connected to a zero indicator.

For this purpose use is made of an electronic device (type Boersma C.V.M. III, frequency over 1 Mc) which is sensitive to very small capacity variations: 0.002 pF gives a visible deflection on the Amp. scale. This sensitivity determines the possible accuracy for horizontal strain measurements. With a sample height (h) = 18 cm, diameter = 2r0 = 6.35 cm and the dis-

Essai et détermination de la déformation transversale d'éprouvettes cylindriques comparées à l'essai de triaxe et transformées, sans moyens mécaniques, mais en évaluant la variation de capacité électrique du système.

Au cours d'une série d'essais avec l'appareil, on étudie séparément la pression au mètre, la compression et le cisaillement.

La signification de la résistance au cisaillement est discutée en fonction du comportement de l'éprouvette, pendant les essais.

Fig. 1 Schematic representation of test device Schéma de l'appareil

The capacity of the sample-wall combination is determined by the zero indication of the device. The capacity of the coaxial condenser amounts to

\[ C = \frac{h}{18 \log (0.91)} \text{ in } 20 \text{ pF} \]

An increase of this capacity by 0.002 pF corresponds to a horizontal strain of \( e_{h} = \frac{0.03}{h} \) per cent, being the accuracy of the measurement.


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The apparatus was calibrated by the introduction of metal cylinders of different diameter and height. The experimental values for the capacity agreed with the values computed using formula 1; also, as a control, samples deformed in different stages were measured by an optical device of great accuracy again giving agreement with the capacitive measuring method.

Because of the rigid end plates the deformation of the sample in the horizontal direction will be larger in the middle if the friction between sample and end plates is large enough to prevent horizontal movement. By wetting the surface this friction is reduced and the barrel form is less pronounced, the disturbance being limited to small zones of the height of the sample, the rest deforming homogeneously and remaining cylindrical.

The capacity measuring system determines the summation of all horizontal displacements over the whole of the sample height and would therefore give the mean value if the capacity was proportional to the distance of the sample to the wall. However being inversely proportional to this distance, the parts that approach the wall must closely dominate. The deformations studied did not give a strain greater than 5 per cent and if the sample had become a barrel with a wall in the form of a sinusoid, which is very exaggerated, the error in the mean value would amount to 0.05 per cent strain, which is negligible part of the mean strain. So we can assume that the capacitive measuring system gives the mean horizontal strain. This may be compared with the vertical displacement obtained from the dial gauge readings which is proportional to the mean vertical strain over the sample height.

When a sample loses water during the test this water is captured in the hollow end plates (see Fig. 1). By surrounding these water storage rooms with metal connected to the sample this water is enclosed by a Faraday cage and so does not influence the capacity of the condenser.

Representation of Test Results

The test results consist of the variations of four variables, namely the principal stresses \( \sigma_1 \) and \( \sigma_2 \) and the principal strains \( \varepsilon_1 \) and \( \varepsilon_2 \) (the subscripts correspond to vertical and horizontal).

For the interpretation of the data however it is easier to consider compression and shear distinct from one another. We will therefore present the results in terms of the hydrostatic and deviatoric increments of stress and strain, \( \Delta \sigma \) and \( \Delta \varepsilon \), \( \gamma_0 \) which are related to the principal stresses and strains by:

\[
\begin{align*}
\sigma_0 &= \frac{1}{2} (\sigma_1 + \sigma_2) \\
\varepsilon_0 &= \frac{1}{2} (\varepsilon_1 + \varepsilon_2) \\
\gamma_0 &= (- \sigma_1 + \sigma_2) \\
\end{align*}
\]

Thus the quantities \( \sigma_0 \) and \( \varepsilon_0 \) relate to compression only and \( \gamma_0 \) and \( \varepsilon_0 \) to shear, the last two being the radii of respectively stress and strain circles in Mohr's diagram (see Fig. 2b).

In Fig. 2b, a typical test result is shown in these coordinates. The strain diagram (Fig. 2b) is plotted from dial readings and capacity determinations. In the same diagram the coordinates for \( \sigma_0 \) and \( \varepsilon_0 \) are also given. Comparing the result in these \( \varepsilon_0 \) and \( \gamma_0 \) coordinates with the applied stresses in the \( \sigma_0/\gamma_0 \) diagram we observe a remarkable resemblance. (The negative sign indicates pressure in accordance with the notations in elasticity.)

This sample showed resiliency for the compression strain which could be accounted for by the presence of air in the clay. The air content amounted to about 4 per cent of the volume. The test duration was not long and the sample being of impervious clay, by movement, practically no consolidation was obtained during the test.

Some Tests Executed with the Capacitive Cell

To show the use of the apparatus we describe some typical tests on Gouda clay. The grain size distribution of this illite clay is given in Fig. 3. Liquid limit 45 per cent, plastic limit 18 per cent. The samples were moulded and cast with a water content of 34 per cent of dry weight and left for four days to regain their strength.

At-rest pressure test—The study of horizontal stress caused by horizontal confinement is facilitated by the apparatus as it permits horizontal strain measurement. During the test the stresses are adjusted in such a way that \( \sigma_1 \) remains zero. In Fig. 4 two tests are shown: one in which...