DEVICE OF CONDENSER-TYPE SOIL STRAIN METER

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1. INTRODUCTION

It is of great importance in the field of soil mechanics to measure exactly local strains as well as local stresses in soil without any disturbance. Since soil stress gauge instrumentations have been developed so much, it is fairly easy to measure stresses in natural state of the ground. On the other hand, an appropriate instrumentation to measure local strains in soil has not been established in this country. Especially, it has been impossible to measure local dynamic strains in soil.

The authors devised the condenser-type soil strain meter in order to measure the one-dimensional soil deformations during stress wave propagation.[1] This type of strain meter has been used in the air but has not been used in soil as a dielectric substance. The advantages of this type of strain meter are as follows;[2]

(1) able to measure such a large strain that cannot be measured by strain gages,

(2) able to measure strains as well as displacement and vibrating amplitudes as it is operated without physical connection between two electrode plates, and

(3) the construction is very simple and inexpensive.

However, this meter has also disadvantages as follows;

(1) since radio frequency is used in this meter, it is influenced by a man approaching or things without shielding,

(2) it is very difficult to calibrate the relationship between the spacing of two electrode plates in soil and change in capacity, and

(3) we have a chance to disturb soil condition in burying two electrode plates in a sample.

The authors remove the above disadvantages

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by using the needles instead of the plates as the condenser constructed in the soil. One-dimensional microscopic strains of soil can be measured simply and exactly by means of this type of soil strain meter.

2. PREVIOUS DEVICES OF SOIL STRAIN MEASUREMENT

In U.S.A., soil strain gage instrumentation has been developed by IITRI to measure transient soil deformations in both laboratory and field applications. This strain sensor consists of two flat-coil disks which are embedded in soil in near parallel and concentric orientation without physical connection between them. The remainder of the gage hardware consists of a second set of coil disks, identical to those used as the strain sensor, and specially designed electronic driving, amplifying, balancing, and recording circuitly. Soil deformations are measured by the resulting changes in the spacing of embedded coils which are sensed as changes in the mutual inductance of the coils.[3] This strain sensor is used so many kinds of soil testing, for example, tri-axial compression test,[3] wave propagation studies in soil[4],[5] and so on. However, this strain sensor have disadvantages as follows;

(1) since the size of the coil disk is relatively large (laboratory gage: 3/4 inch in diameter and 1/16 inch in thickness, field gage: 4 inches in diameter and 1/4 inch in thickness), soil sample seems to be considerably disturbed in embedding the coil disks, and

(2) the equipment is expensive.

Nishigaki[6] emphasizes that the measurements of microscopic strain are very important to obtain the elastic constants of soils and tries to paste a strain gage on the side of soil sample of unconfined compression test. By this procedure, he obtains Young's modulus of clay in microscopic strain level. This procedure is very available with relatively stiff clay such as diluvial clay but unavailable with sandy soils or relatively soft clay

such as alluvial one.

3. PRINCIPLE OF OPERATION IN CON-DENSER-TYPE SOIL STRAIN METER

3.1 Apparatus

In the device of this condenser-type soil strain meter, 'Infinitesimal Displacement Meter MD-31' (Iwasaki Communication Apparatus Co., Ltd.), is used. This meter, as shown in Photo. 1, consists of a meter MD-31, a probe MDG-643 and a condenser embedded in soil. A main variable condenser (100 pF), a fine variable condenser (20 pF) which is installed by the authors are contained in the probe MDG-643. The size, shape and material of the electrode plates as a condenser embedded in soil are optional. In the previous paper,[1] the authors used the rectangular thin copper plates (2.5 cm × 1.5 cm) with coated by enamel (see Photo. 2) so as to use even in wet soils. In this paper, however, two needles (6 cm in length and 0.5 mm in diameter) with emveloped by a vinyl tube, as shown in Photo. 3, are used as two electrodes in order to decrease
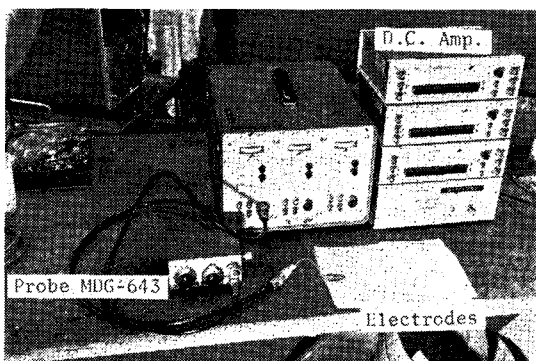

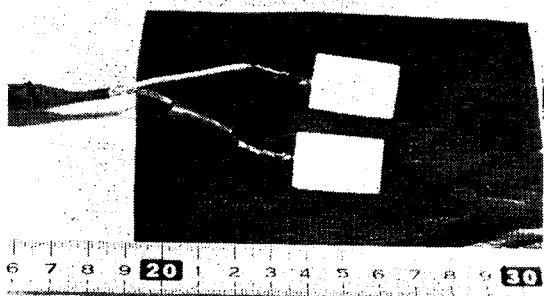Photo. 1 Apparatus of the condenser-type soil strain meter.

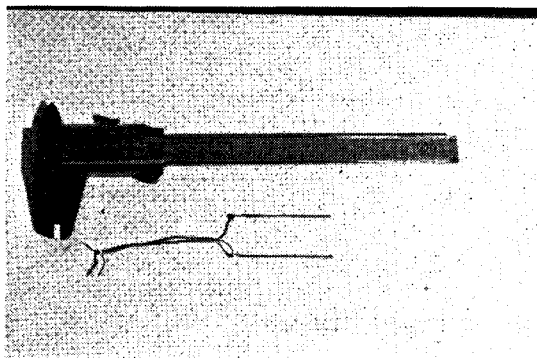Photo. 2 The rectangular thin electrode plates with coated by enamel.

Photo. 3 The electrode needles with emveloped by a vinyl tube.
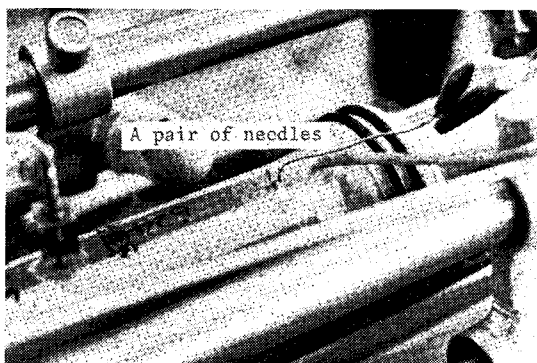

Photo. 4 The electrode needles embedded in soil sample.

disturbance of soil sample in embedding into soil. In experiments, as shown in Photo. 4, these two needles are embedded in parallel in soil. Soil deformations are measured by the resulting changes in the spacing of embedded two needles which are sensed as changes in the electrostatic capacity of them.

3.2 Principle of Operation

For simplicity, consider two flat rectangular electrode plates but not two needles to explain the principle of operation in this type of soil strain meter. When two conductors are placed in parallel as shown in Fig. 1, the resulting
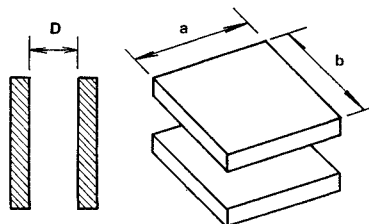

Fig. 1 Two conductors in parallel.

electrostatic capacity is given by

$$C = \frac{A\varepsilon_0\varepsilon_s}{D} = 8.885 \times 10^{-12} \times \frac{A\varepsilon_s}{D} \quad [F]$$

$$= 8.885 \times \frac{A\varepsilon_s}{D} \quad [pF] \qquad \cdots(1)$$

where, A denotes the cross sectional area ($a \times b$ [m²]) of the conductors, D the spacing of two conductors [m], ε_0 the dielectric constant and ε_s the specific dielectric constant. Eq. (1) implies that if ε_s is assumed to be constant through testing, the variation in the spacing ΔD of two conductors results in the change in capacity ΔC:

$$\Delta C = \frac{\partial C}{\partial D} = -8.885 \times \frac{A\varepsilon_s}{D^2}\Delta D \quad \cdots\cdots\cdots(2)$$

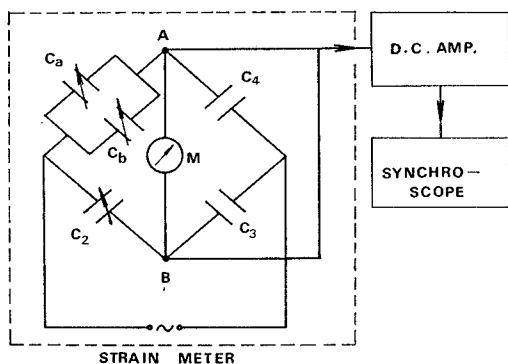The strain meter consists of the bridge circuit indicated in Fig. 2, where C_3 and C_4 denote the

Fig. 2 Bridge circuit in the strain meter.

fixed condensers and has also equal capacity, C_2 the variable condenser for balance, C_a the measuring condenser embedded in soil and C_b the variable subcondenser which is used when C_a is less than 20 pF. If $C_a + C_b$ is replaced by C_1, a balance condition for this bridge circuit due to these four condensers (C_1, C_2, C_3 and C_4) is given by

$$\frac{C_1}{C_2} = \frac{C_3}{C_4} = 1 \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots(3)$$

i.e., if C_2 is so controlled that it is equal to C_1 for measurement, no electric current occurs in the meter M. When C_1 changes, however, a potential difference occurs between the point A and B shown in Fig. 2, and an electric current flows in meter M.

4. CALIBRATION

A relationship between a change in spacing of two electrode plates and a resulting potential difference should be obtained by a calibration test.

The previous manner of calibration[1] was that the soil sample was packed in a ring made of vinylchloride of which inside diameter and height were 5.2 cm and 2.0 cm, respectively. Two electrode plates were put on the upper and the lower surface of the packed soil sample in concentric orientation so that the initial spacing between two plates was about 2.0 cm. The initial spacing of them was accurately measured by the travelling microscope. After setting up the apparatus and balancing the bridge circuit in the prove MDG-643, soil sample was compressed by means of unconfined compression apparatus and, at the same time, the resulting potential difference was measured by means of a synchroscope. This manner of calibration test, however, was rather primitive so that the measurements of soil strain was relatively inaccurately. The authors found that such a calibration test was needless.

When a pair of electrode needles is embedded in the soil sample in parallel the electrostatic capacity stored in this condenser can be expressed by the expression same as Eq. (1) to the rectangular electrode plates,

$$C_0 = \frac{a}{D_0} \quad [pF] \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots(4)$$

where, C_0 denotes the initial capacity stored in the condenser [pF], D_0 the initial spacing of the two needles [m] and a the constant which is determined by the size and shape of the electrode needles. When the soil sample deforms and ΔD changes in the spacing of the two needles, the corresponding change of the capacity ΔC is expressed by the following equation if ΔD is very small,

$$\Delta C = -\frac{a}{D_0{}^2}\Delta D = -\frac{a}{D_0}\frac{\Delta D}{D_0}$$

$$= -C_0\frac{\Delta D}{D_0} \quad \cdots\cdots\cdots\cdots\cdots\cdots(5)$$

Since $\dfrac{\Delta D}{D_0}$ is a quantity of soil strain, Eq. (5) means that the corresponding change in capacity ΔC with the change in spacing ΔD is proportional to the soil strain. Namely, if the initial capacity C_0 is known, the soil strain is calculated from Eq. (5). The initial capacity C_0 is easily obtained by the following equation;

$$C_0 = C_A - C_B \quad [pF] \quad \cdots\cdots\cdots\cdots(6)$$

where, C_A denotes the capacity with the condenser embedded in the soil and C_B the capacity without it.

When we observed the strain record by means of a synchroscope or an electromagnetic oscillo-
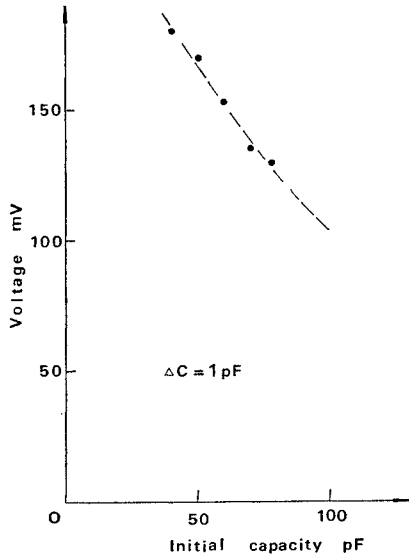
Fig. 3 Typical results of the relationship
        between the initial capacity and the
        corresponding voltage.

graph, we must obtain the relationship between
the change in capacity ΔC and the corresponding
voltage ΔV from calibration test. This relation-
ship depends on the initial capacity. Typical test
results are shown in Fig. 3 as $\Delta C=1$ pF. If the
relationship between ΔC and ΔV at a certain initial
capacity C_0 is expressed by the following equa-
tion;

$$\Delta V=\frac{1}{k}\Delta C \quad [\text{mV}] \quad\cdots\cdots\cdots\cdots\cdots\cdots(7)$$

where, k denotes a constant, then the strain ε
can be calculated from,

$$\varepsilon=\frac{\Delta D}{D_0}=-\frac{\Delta C}{C_0}=-\frac{k}{C_0}\Delta V \quad\cdots\cdots\cdots\cdots(8)$$

The authors have confirmed that the linearity
between strain ε and voltage ΔC exists in the
range of strain less than 2%.[7]

5. APPLICATIONS

5.1 One-Dimensional Stress Wave Propagation
Test

The soil strain meter is used in the one-dimen-
sional stress wave propagation test in clay in
order to obtain the stress-strain relationships
during rod wave propagation.[8] The rod of clay
is 135 cm in length and 7.5 cm in diameter which
is consolidated at confining pressure $p=1.06$ and
0.54 kg/cm² in the special acryl cell designed by
the authors.[8] Then the cell is relieved and a

pair of needles as a strain meter is embedded in
parallel with the initial spacing of about 1 cm.
At the one end of the rod, the pulsative stress
is applied by means of the shock tube. When
the applied dynamic stress is propagating in the
rod as a wave, the stress and the strain are at
the same time measured by the soil stress gauge
embedded in the sample and the strain meter,
respectively. Figs. 4 (a) and (b) show the typical
records of the stress and the strain forms recorded
by a synchroscope. The observation depth, and
the ratio of the proportional constant k between
the differential voltage and the capacity to the
initial capacity C_0 as expressed in Eq. (8) are
entered in that figure. Although the phenomena
of the stress and strain in this wave propagation
test by the shock tube are considerably rapid, it
is found that the responsibility of this condenser-
type strain meter is excellent.

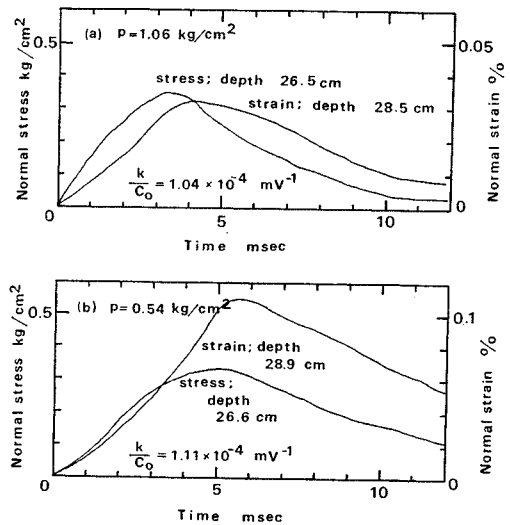Fig. 5 shows the stress-strain curves which are

Fig. 4 Typical records of the stress and the
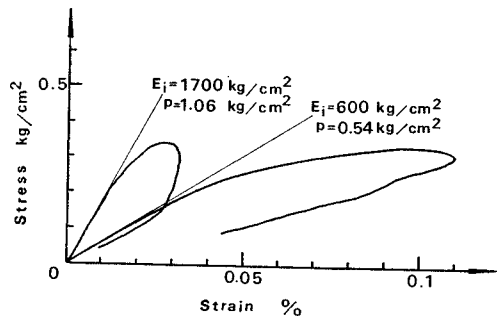   strain forms.

Fig. 5 The stress-strain curves.

constructed by picking up the stress and the strain values corresponding to the same instant of time in Figs. 4 (a) and (b), respectively. Though each stress-strain curve expresses a large hysteresis loop for a given dynamic stress cycle, the plastic deformation does not seem to occur. Consequently, the physical behavior of the clay sample is considered viscoelastic at the range of a given strain level less than 10^{-3}. The initial tangent moduli E_i obtained from the stress-strain relationship are 1700 kg/cm² in the case of $p=1.06$ kg/cm² and 600 kg/cm² for $p=0.54$ kg/cm², respectively, while the Young's moduli E calculated from rod velocity c_R and density ρ by the following equation;

$$E=\rho c_R^2 \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots(9)$$

are 1730 and 695 kg/cm², respectively. E_i and E are almost identical, in both cases and it is considered that this type of strain meter has an enough confidense.

5.2 Unconfined Compression Test

A distribution of normal strain in soil sample in unconfined compression test is observed by using this type of soil strain meter. The procedure of the strain meter is same as that described in **5.1**.

In order to know the strain distribution in soil sample, needles are in each test embedded in one of upper, middle and lower parts of soil sample as shown in Fig. 6. Fig. 7 shows the relationship between the local strain measured by the soil strain meter and the average strain by dial gage. The soil samples used are relatively soft clay with 5.2 cm in diameter and about 10 cm in
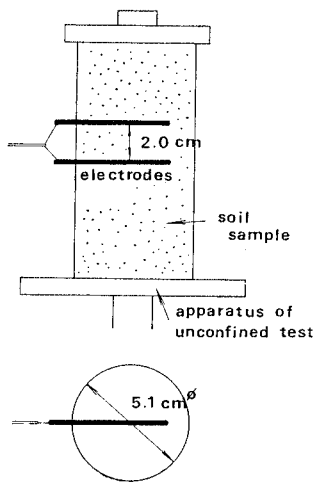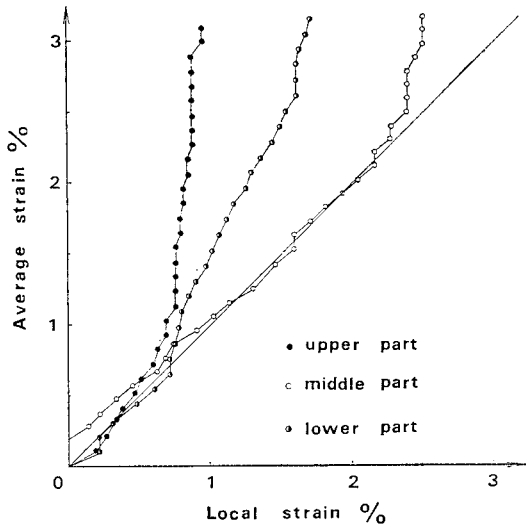
Fig. 7 The relationships between the local strain and the average strain in soft clay samples.

height. Their failure forms are ductile. It is found from this figure that the distribution of normal strain is nearly uniform up to the strain of 0.8%, and non-uniform for much more strain. The local strain in a middle part of sample is same as the average strain up to about 2.5%, and much more compressed, the local strain does not increase and the soil in this part flows in lateral.

Fig. 8 is the results for a relatively stiff clay.

Fig. 6 The manner of embedding needles into the sample of unconfined compression test.
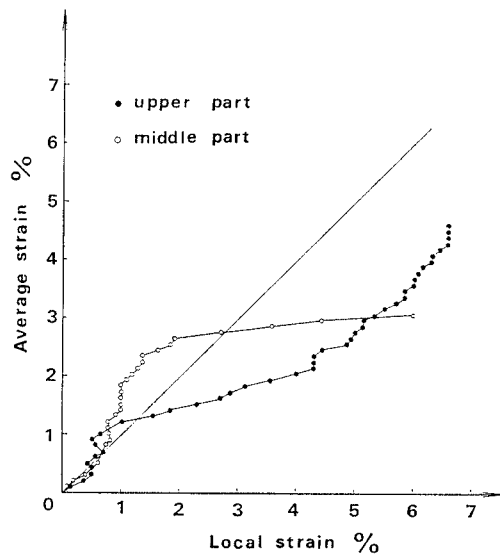
Fig. 8 The relationships between the local strain and the average strain in stiff clay samples.

Failure form in this case is brittle. The strain distribution is also uniform up to strain 0.8% same as above described one. Under further compression the local strain in middle part increases gradually and the one in upper part increases rapidly. This is due to that the samples are broken down.

6. CONCLUSIONS

It is found through this study that the condenser-type infinitesimal displacement meter can be used to measure the one-dimensional normal strain in soil. By using the thin needles as the electrodes of a condenser embedded in soil, the disturbance in soil sample can be decreased and the soil strain can be measured much more accurately. The troublesome calibration test described the previous paper[1] is needless and when a pair of needles is embedded in soil, it does not need to read the initial spacing of them, provided the initial capacity C_0 and the constant k are examined from Eq. (8). Since the responsibility of this meter is excellent even in higher frequency range, it is suitable to measure the dynamic strain in soil.

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