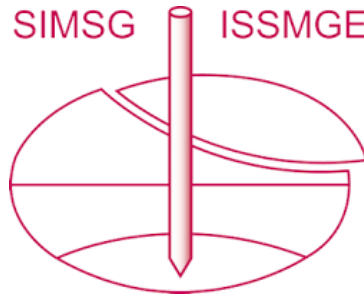


INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING



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III b 4

A PRACTICAL METHOD OF RAPID MEASUREMENT OF SOIL MOISTURE AND ITS APPLICATIONS

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Japan

I. THE METHODS USED BEFORE AND NEW METHOD.

It is essential to measure the content of soil moisture in the course of research or practise on soil mechanics. The oven-dry method has been used, but it takes at least a day or more before we can know results.

A few methods have been proposed for rapid measurement of soil moisture; for example, a method of measuring the electric resistance of soil sample and of measuring the temperature rise by mixing sulphuric acid with it, but none of which has been in common use because of the requirement of special instruments or because of the difficulty or inaccuracy of the process.

A new method of rapid measurement of soil moisture based on a physical principle can afford results in about ten minutes with ample accuracy for engineering purposes.

Principle of the method is very simple as well known, and is based on the fact that the net specific volume or the net volume per unit weight of a sample excluding air void changes in linear proportion to the percentage in weight of moisture to the total soil sample.

A practical procedure was devised by author for measuring the net specific volume of soil sample, which is to be called the index of moisture.

Equipments required for this method are not special made, but we can find them all on the shelf in our laboratory, such as flask, funnel, beaker, glass tube and balance, etc.

It is very easy to exercise this method both in laboratory and in field, and we can know results at once.

If the apparent specific density of soil is known, the index of dry density can be determined, which proportionates in linear relation with the dry density. In this case, the saturation curve can be drawn in the simplest form with no relation to the specific gravity of soil particles.

A number of results have been obtained successfully by this method both in laboratory and in field, especially in the field of compacting soil to obtain the maximum density at optimum moisture. Some examples of the results observed are reported in this paper.

II. PRINCIPLE AND PRACTICE OF NEW METHOD.

Let the specific gravity of soil particles be equal to 2.50 and that of water to 1.00, then the value of net specific volume of perfect dry soil sample is 0.4 and that of water is 1.0, and the corresponding percent-

ages of moisture content are zero and 100 respectively. In the case of mixing both in equal weight, it amounts to 0.7, corresponding to 50 percent of moisture content. We can know that the net specific volume of a soil sample has a linear relation to the percentage of moisture content to the total weight of sample. In general, if we use the following designations, G_s =specific gravity of soil particles
 W =weight of a soil sample
 V =net volume of the soil sample, excluding air void

W_w , W_s =weights of water and soil particles contained in the soil sample

w =percentage of soil moisture to the total weight of the sample

Ω =net specific volume of the sample (index of moisture)

G_a , G_d =apparent specific gravity and dry density of the sample

Γ =index of dry density

then we get the following relations

$$w = W_w / W_s \times 100 \text{ and } \Omega = V / W = W_w / W + (W - W_w) / G_s W \quad (1)$$

Therefore

$$w = (\Omega - 1/G_s) / (1 - 1/G_s) \times 100 \quad (2)$$

We know from (2) that the moisture content w is in linear relation to the net specific volume Ω , which is to be called the index of moisture.

If the apparent density of soil sample is known, the index of dry density can be defined by

$$\Gamma = (1 - \Omega) G_a \quad (3)$$

hence

$$G_d = (1 - w/100) G_a = \Gamma / (1 - 1/G_s) \quad (4)$$

We can know that the dry density is in linear proportion to the index of dry density.

In the case of saturating the voids of a soil sample by water (no air void), the moisture content and the dry density stand in a relation of

$$w = 100(1 - G_d/G_s) / (1 + G_d - G_d/G_s) \quad (5)$$

which gives the different saturation curve with the different value of G_s . Using the both indexes Ω and Γ in the new method, we can express the saturation curve by

$$\Gamma = 1/\Omega - 1 \quad (6)$$

which has a simplest form easy to remember.

The equipments to be prepared for this method are as follows (Photo. 1):

Quantity Unit Equipment

- | | | |
|---|------|--|
| 1 | each | glass flask, 400l ltr., slender necked |
| 1 | " | glass funnel, 45 mm dia., with a sharp point |
| 2 | " | glass beakers, 100 c.c. and 500 c.c. |



Equipments for the new rapid method of measuring soil moistures.

PHOT. 1

- 1 " glass tube, 3 mm inner dia., 15 cm long
- 1 " balance, 200 gr. capacity, 0.1 gr. sensibility
- 1 " steel wire rod, 2 mm dia., 25 cm long
- 1 " tin-plate funnel 7 cm dia., for throwing soil sample in a flask
- 1 " brass spoon of a large size

If the apparent specific density of a soil sample is to be known, its volume must be measured. An equipment of shaving type consisting of a ring frame and a shaving blade has been used by author conveniently for this purpose (Photo 2).



Shaving equipments for getting a fixed volume of soil sample.

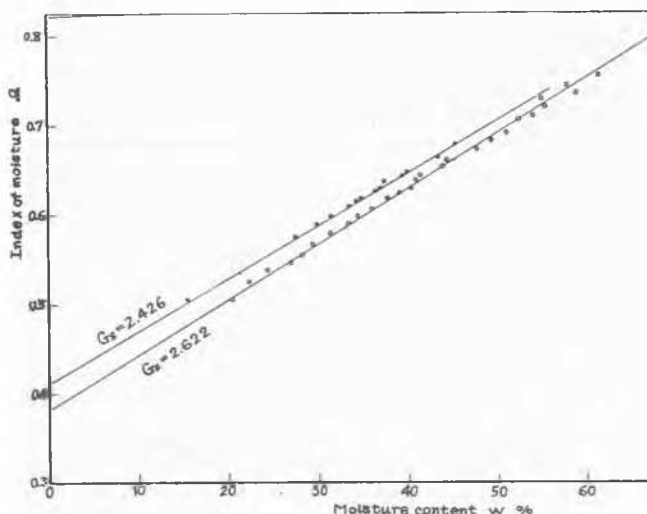
PHOT. 2

Practice of the new method is done in the following order.

Pour clear water in a flask up to its bottle neck. Adjust the level of water to coincide with the lower point of a funnel inserted, holding the flask in a right position. A glass tube can be used for adjusting a small quantity of water. We can suspend or release a drop of water in it by shutting or opening its upper opening with a finger. After a precise adjustment of water level, take out a part of water from flask to a beaker and throw a weighed sample of soil (about 100 gr.) into the flask, then stir up the mixture rotating the flask or inserting a steel wire rod moistened before. Remove the bubbles or lighter dirt risen up from soil sample to the surface of water into a glass tube filled with a bit

of water through its lower opening and then transmit them to the beaker. Rest the flask on a support for a while until the upper portion of contained water becomes clear. Then adjust again the level of water in the equal height in the same manner as before, adding water in the beaker to the flask. During the course of process, even a drop of water must not be lost. Measure the weight of water remained in the beaker, which represents the net volume of soil sample free from contained air void. The index of moisture or the net specific volume can be determined by dividing the weight of water in beaker by that of soil sample.

The data obtained by the new method were compared with those by the oven-dry method and the results showed the ample accuracy for engineering purposes (Fig. 1).



Accuracy of the new rapid method compared with the oven-dry method.

FIG.1

III. APPLICATIONS OF NEW METHOD.

The new method of rapid measurement is applicable to all fields in soil mechanics when it is necessary to measure the soil moistures; but it is most useful when a lot of results are to be known in a very short time, especially in field works. Because of the easy receipt and lightness of equipments and the simple procedure of measurement, we can exercise the new method in any place at any time. Those jobs executing soil compactions will be most benefited by this method as we can know the moisture contents of soils quickly and precisely in the field and can adjust them to the optimum moisture for compaction.

Some examples of the results obtained by author are as follows:

- 1) Effects of drying and hydrating soil sample on the compaction and the strength of test piece.

It is a well known fact that the dry density of test piece compacted under a certain static pressure becomes heavier by mixing water to the soil sample and reaches to a maximum value at optimum moisture.

Experiments on the effects of drying and hydrating soil samples were done with a red loam soil in Chiba, Japan, physical properties of which are shown in Table 1.

Table 1.

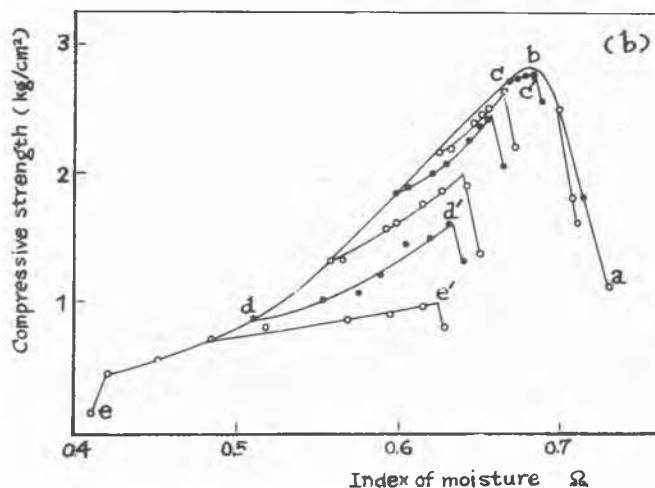
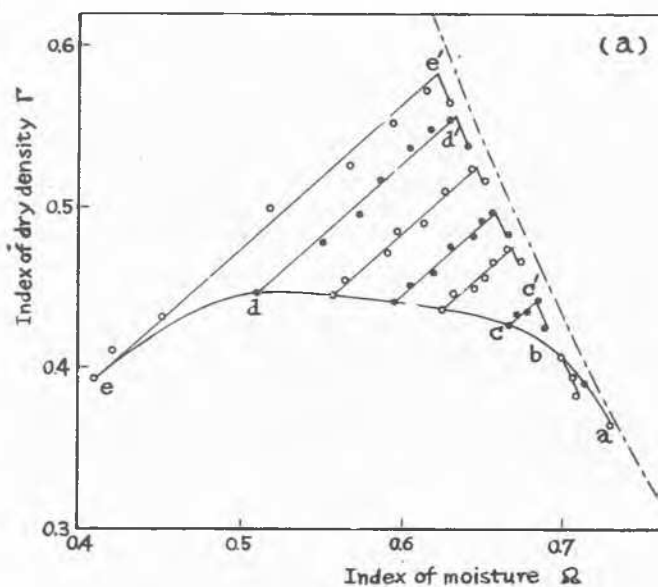
Items	District	Chiba
Mech. Analysis		
Sand (coarser than 0.074 mm)		41.3
Silt (0.074 mm - 0.005 mm)		21.4
Clay (finer than 0.005 mm)		27.3
Specific gravity		2.67

The results of both compaction and compression tests are as follows:

Test pieces, 5 cm dia., 10 cm high, were compacted in a brass cylinder under a 10 kg/cm² static pressure.

Both indexes of moisture and dry density of each test piece were measured.

Compaction of dry samples gives a moisture dry density curve abcde expressed by both indexes (Fig. 2a), on which points a, d, and e correspond to the no dry, air-dry, and oven-dry states separately. The dry density slightly increases by drying until air-dry, but decreases adversely by absolute dry. Mixing water to the dried samples gives a group of



Effects of drying and hydrating soil sample on the compaction and the compressive strength of the test piece.

FIG.2

straight lines cc', dd', ee', and so on. At optimum moisture is obtained the maximum density, which fairly differs each other by the degree of drying (c', d', or e'). Absolute maximum dry density can be obtained by absolute dry sample (e').

The compressive strength of each compacted test piece was measured. (Fig. 2b). With the reduction of moisture by drying, compressive strength rises steeply at first, and reaches to a highest value near a point b, then reduces gradually and comes to a lowest point e at absolute dry state. By mixing water, the compressive strength increases slightly and reaches to a maximum at optimum moisture (c', d', or e'). The higher degree of drying corresponds to the lower compressive strength, though it corresponds to the heavier dry density. It is to be noticed that the degree of drying gives a soil sample the quite different physical properties, and that to gain an absolute maximum compressive strength, the soil sample must not be dried in excess degree, though the absolute maximum dry density can be obtained by absolute dry sample.

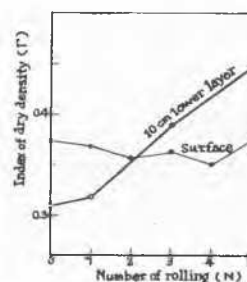
2) Effects of rolling soils observed both in a job and in a field.

The effects of rolling a natural soil layer by 10 ton macadam roller were observed in a job in Chiba district.

Results obtained are as follows:

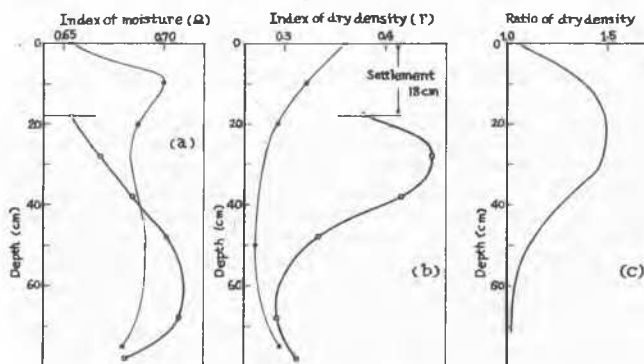
The effect of rolling did not appear on the ground surface, where the soils were rather in dry state and had already heavier densities by being stamped. But it appeared clearly in the 10 cm lower layer, giving heavier dry density with the repetition of rolling. (Fig. 3).

Vertical distributions of moisture and dry density of soils before and after rolling varied distinctly (Fig. 4a and b). The degree



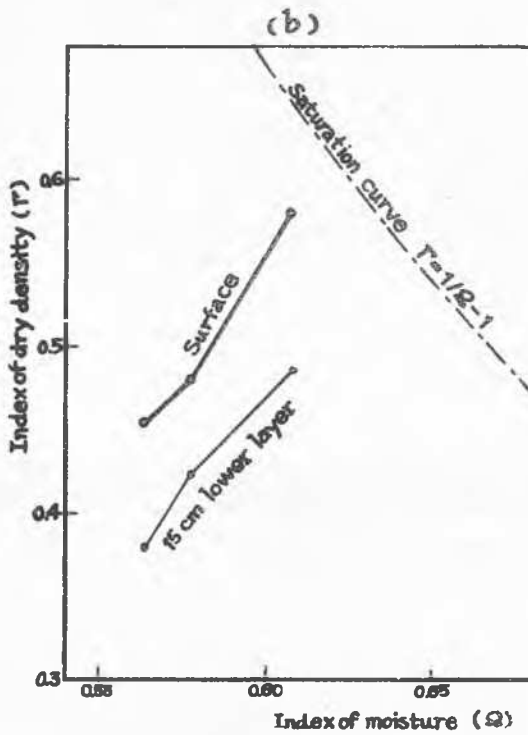
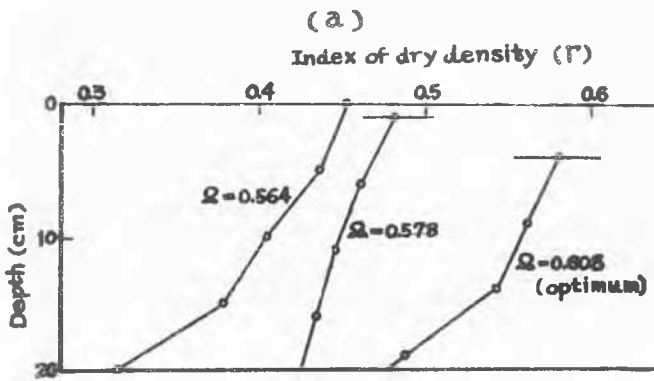
Effects of rolling a natural soil layer (number of rolling and depth).

FIG.3



Do (vertical distributions of moisture and dry density).

FIG.4



Effects of rolling moistened soil layers (moisture).

FIG.5 a b

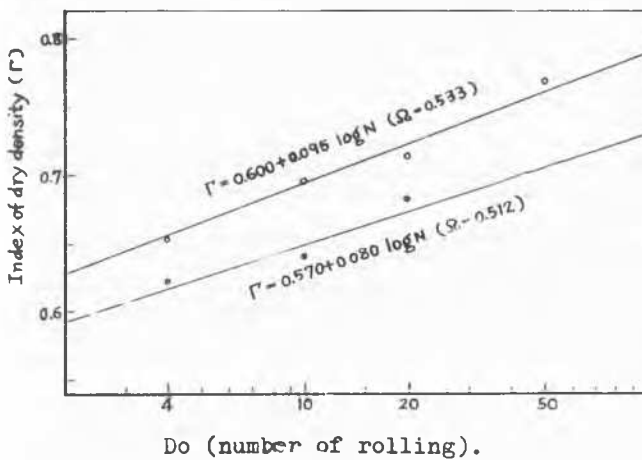
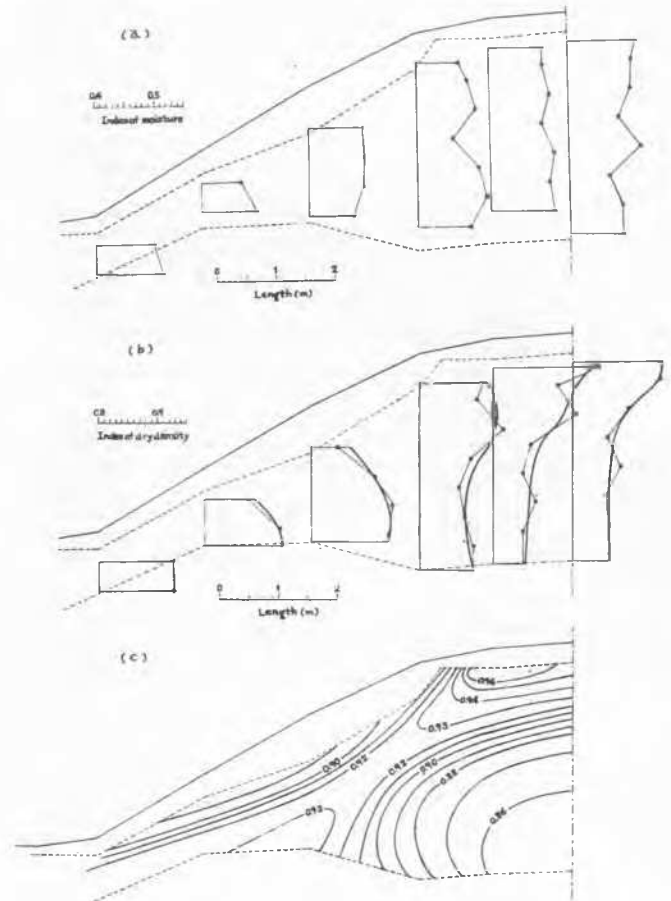
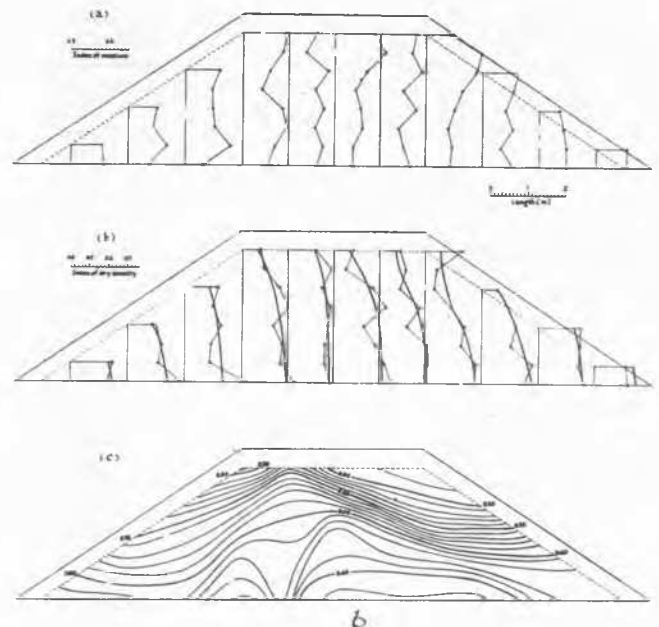


FIG.6



Distributions of moisture and dry density in the interior of an aged embankment.

FIG.7



Distributions of moisture and dry density in the interior of a new embankment.

FIG.8

of compaction in each depth of soil layer was calculated and the maximum value of the ratio of both in dry density before and after rolling was obtained at the 20 cm lower layer (Fig. 4c).

Another experiment of rolling soils by 375 kg hand roller in a field in Chiba city clearly showed the effects of mixed water and number of rolling (Figs. 5, 6).

We can know that the maximum rolling effect of uniformly moistened soil layer is obtained when an optimum moisture is given for the maximum density at the surface of layer corresponding to the number of rolling and that the rolling effect reduces gradually with the depth.

3) Distributions of moisture and dry density in the interior of embankments.

Distributions of moisture and dry density on the cross section of railroad embankments were measured at both fields in Mie and Fukushima districts, Japan. The former embankment has been compacted under traffic loads for about fifty years, the latter was executed only two years ago, being charged with no load yet.

At each point in the cross sections, two or three samples of a fixed volume were shaved and their indexes of moisture and dry density were measured in the field. The mean va-

lues of observations were plotted and the lines connecting the points of equal density were drawn in Fig. 7 (a) (b) and (c) for Mie and in Fig. 8 (a) (b) and (c) for Fukushima.

The upper portion of an aged embankment has heavier dry densities compacted by traffic loads in a long period, which may be assumed to be a main factor for the settlement of embankment. New embankment has loose densities in the upper layers and heavier densities in the lower layers being charged by its own weight only.

The physical properties of soils prevailing in both cross sections are listed in Table 2.

Table 2.

Items	District	Mie	Fuku-shima
Mech. Sand (coarser than 0.074mm)		58.0	84.8
Anal. Silt (0.074 mm - 0.005 mm)		29.0	14.4
Clay (finer than 0.005 mm)		13.0	00.8
Specific gravity		2.63	2.65
Liquid limit		35.0	54.0
Plastic limit		24.7	50.0
Plastic index		10.3	4.0

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TESTING OF THE ELASTICITY AND STRESS PROPERTY OF ROCK SOIL

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According to the known methods for the establishment of the elasticity and stress property of rock, which serves for example as rock soil for dams, test samples are cut out of the rock, or partly separated from it and then subjected to the usual tests. They are relatively small, as already a crosscut of 5 ft² needs extraordinary high pressure tests, which up to the present can be made with complicated special appliances, which are very expensive. It is therefore necessary to confine oneself when testing the rock to the small test samples. The results of these tests indicate very roughly the real conditions of the above mentioned soil.

According to the author's proposal the tests on the rock itself are carried out with "pressure cushions" without bulbs. These cushions were developed by the author and already employed with success in 1934 for grid potential of the soil and later also for testing the strength of materials for great pressures.

The above mentioned cushions of pressure are flat, hollow bodies made of thin sheet metal and closed on all sides, which can be provided with pads at the edge. In the case of great compressibility of the rock, a number of cushions is placed one upon another, so that even when very high pressures are used a proportionately thin sheet may be employed. Each cushion possesses devices for admitting the pressure of a liquid and at the same time

expelling air.

To introduce such a cushion into the rock one or more large slits are made in the rock by means of boring or otherwise. These slits may have a depth and breadth of several yards and a height of a few inches. There is no difficulty in making cushions of 10 and more yards by 0.5. These are inserted in the slit side by side after which the free space between the cushions and the rock is filled up with cement mortar (pressed mortar).

After the hardening of the mortar the pressure of a liquid will be introduced into the cushions. As they can easily lose their shape, the pressure of the liquid is carried directly over on to the rock.

The elastic compressibility of the rock can then be exactly ascertained from the quantity of pressure liquid introduced into the cushion.

This quantity is ascertained during the testing of the different pressures.

If great value is attached to ascertaining the compressibility for example per 1.0 yd² at different points, cushions of 1.0 yd² are employed whereby each receives a separate feed pipe.

The duration of the particular testing can be spread over several days, months or even years without any difficulty. This is of a great importance.

In order to ascertain the resistance to