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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 ft<sup>2</sup> 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 yd<sup>2</sup> at different points, cushions of 1,0 yd<sup>2</sup> 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

pressure of the rock soil, the cushions are arranged in the rock in two parallel slits. The distance between the two slits then corresponds to the thickness of the test sample.

Very often it will be possible to leave these appliances where they are after the construction has been completed and to continue to use them to ascertain the changes in tension occurring in the soil. For this it is only necessary to give the pressure cushions filled with a compressed liquid a degree of elasticity in the direction of the load, identical with that of the material surrounding the pressure cushion. For measuring strain in the soil or the material of a construction a concrete dam for example, special appliances (regulators) are used which make it possible to regulate the elasticity of the pressure cushions without any difficulty. The tension in the soil or the material of the construction can then be deduced from the degree of the pressure of the liquid in the pressure cushion. As such appliances can remain in use for years, changes of tension can be continuously registered over a long period of time.

In order to give the pressure cushion a particular degree of elasticity, it is attached by means of a pressure conduit to a regulator, for instance an iron pipe of particular dimensions closed all round. If the cushion filled with a liquid is then exposed to pressure from without, the liquid is subjected to tension. As a result of the pressure of the liquid, the above-mentioned pipe expands elastically in a special way and compressed liquid flows over into the pipe from the pres-

sure cushion. As, when the exterior load on the cushion changes, the tension of the liquid contained in it also changes, it is quite easy, by measuring the pipe to produce a particular degree of elasticity in the pressure cushion.

If suitable methods of construction are employed to ensure the tensile strength of the connection between the cushion and the surrounding material the degree of tensile stress occurring in the material can be ascertained by means of the appliance. It is then only necessary to measure the reduction in pressure of the liquid contained in the cushion.

The cushions employed are suitably gauged prior to use, the pressure of the liquid in the cushion being measured for a particular load and a particular change of volume. Cushions which have two smooth parallel surfaces for transferring the load (see fig. 1 and 2) can be gauged very simple by means of testing machines which contain parallel pressure plates.

The attached figures 1 and 2 show illustrations for the use of the devices described above.

In fig. 1 two parallel slits (1,2) are shown in the rock one on top of the other and a certain distance apart, into which pressure cushions have been inserted, the spaces between the cushions and the rock having been filled with compressed mortar.

In the upper slit (Section A-A) the length of the cushion (10) corresponds to the depth of the slit. In the lower slit (2) several pressure cushions (11) are arranged one

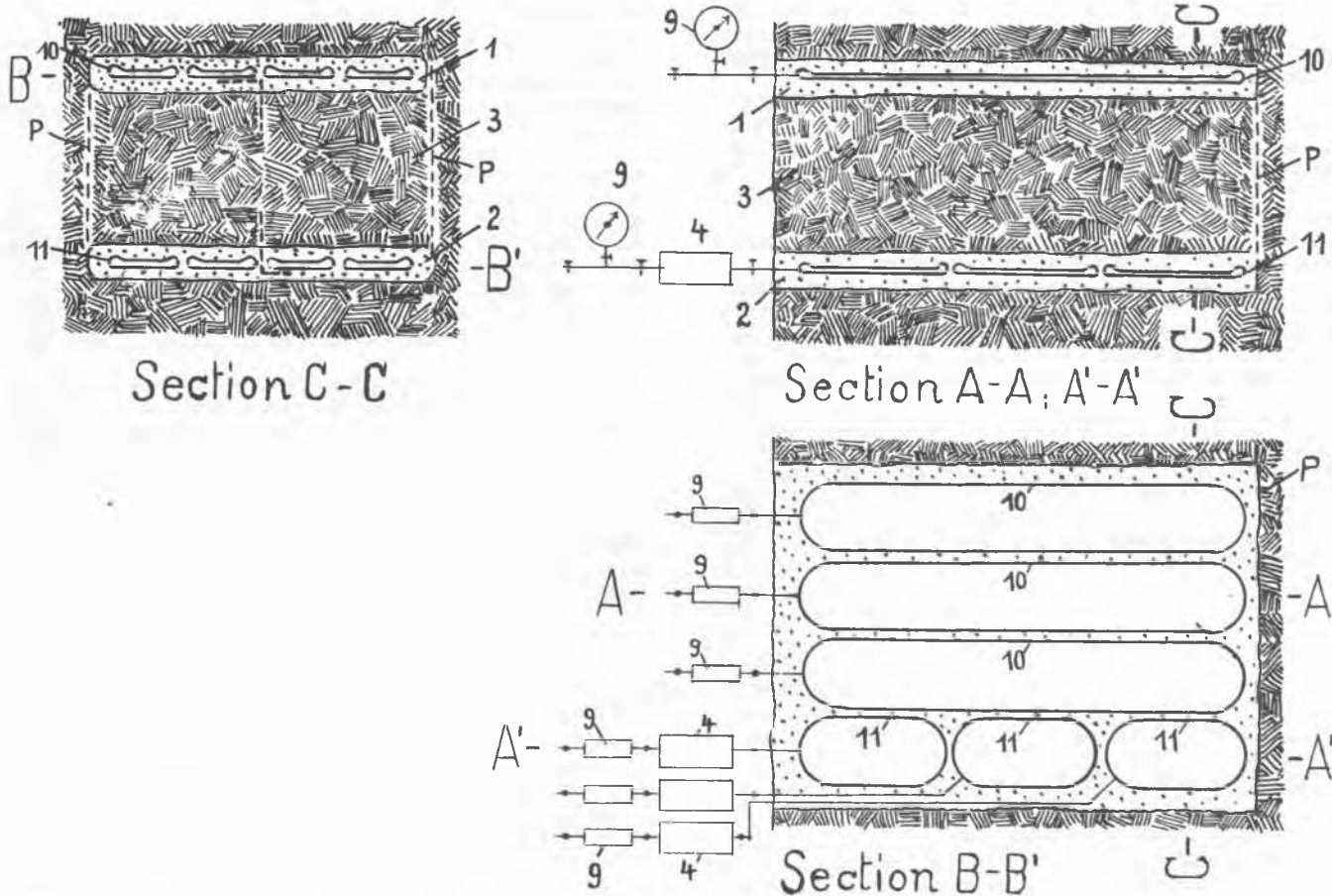
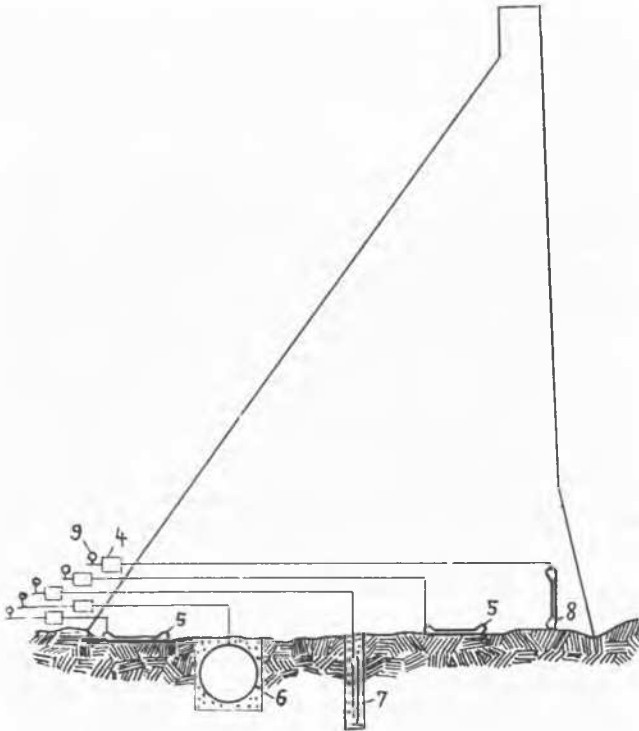


FIG.1



Pressure cushions not  
according to scale

FIG. 2

behind the other, so that the deformation of the rock can be ascertained for each section on the strength of the quantity of the liquid introduced into the various cushions.

If the slits are for instance 10 yards wide by 10 yards deep these 100 square yards of area can be filled with 20 cushions of 10 yards in length and  $\frac{1}{2}$  yard in width. After the compressed mortar inserted between the cushions and the rock has become hard, compressed liquid is introduced into the different cushions of for instance 5 atmospheres. The quantity of liquid introduced into each cushion is exactly measured and registered. Thereupon the pressure is increased by, say, 5 atmospheres more and the quantity of liquid introduced into each cushion is again measured. In this way it will be possible to ascertain the degree of contraction of the rock resulting from the increased inpressure of 5 atm. If the pressure of the liquid is similarly increased by the 5 atm. at a time and the contraction is measured at each degree of pressure on the basis of the quantities of liquid introduced, a very good general idea of the

capacity of contraction of the rock can be obtained. By gradually imposing and removing loads, it will be possible to ascertain the elasticity of the rock. If the imposition and removal of loads are also effected in the case of the cushions of the lower slit (2) of fig. 1 particular tests with loads can be made in this way with the part (3) of the rock between the slits (1,2).

The accuracy of the result of the test can of course be increased by appropriately separating this part (3) of the rock from the rest along lines P of fig. 1 but even without this separation these tests can produce valuable results if as large areas as possible covered with cushions are chosen.

If the loading of the rock is carried out within the limits of elasticity of the rock material, these appliances can be used during construction and after the completion of the structure for ascertaining the tension of the soil. At the same time the above-mentioned regulators (4) and tension meters (manometers) (9) are attached to the cushions and the extent of the tension in the soil can then be deduced from the pressure of liquid in the cushions. Such regulators (4) attached to the cushions are shown in the lower slit (2) of fig. 1 Sections (A<sup>1</sup> - A<sup>1</sup>, B - B). For better control the regulators (4) and manometers (9) are arranged outside the areas to be tested.

For measuring the tension in the soil, it will often be sufficient to use round cushions of a diameter of say 0.4 by 0.8 yd. In fig. 2 such cushions (5-8) are arranged in the joint between the soil and the concrete of the construction (dam). The cushions can be placed straight on the soil (5) or in a vertical position in the plane of section of fig. 2 (6) or perpendicular thereto (7,8). By means of the arrangement indicated in fig. 2 the strain occurring in the three principal directions can be ascertained (5,6,7). There is of course no reason why the cushions should not be arranged in any other way.

The pressure cushions can naturally be arranged deeper underneath the foundations of a construction. If this is done, the cushions are sunk and concreted, together with the pressure conduit, in small shafts and slits, before the construction is erected. The pressure conduit of each cushion is then directed to the observation room and there provided with the regulator (4) and the tension meter (manometer) (9).

For measuring the strains in the masonry of the construction the cushions (8) of fig. 2 are appropriately built into the masonry during construction or sufficient room is left for inserting the cushions subsequently. In this way, the tension both in the soil and in the construction can be ascertained by means of fairly simple devices as shown in fig. 2 for a concrete dam.