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considered as a kind of framework under pressure in the earth, at the sampling the soil sample is injured in the manner that the "bars" of the framework, the grains, to some extent turn and slide one on another, whereby the average grain pressure sinks from p^1_a to p_a and, according to fig. 7, the shear strength from τ^1_B to τ_B. This statement conforms also with loading- tests which have been carried out.

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MEASUREMENT OF PORE WATER PRESSURE

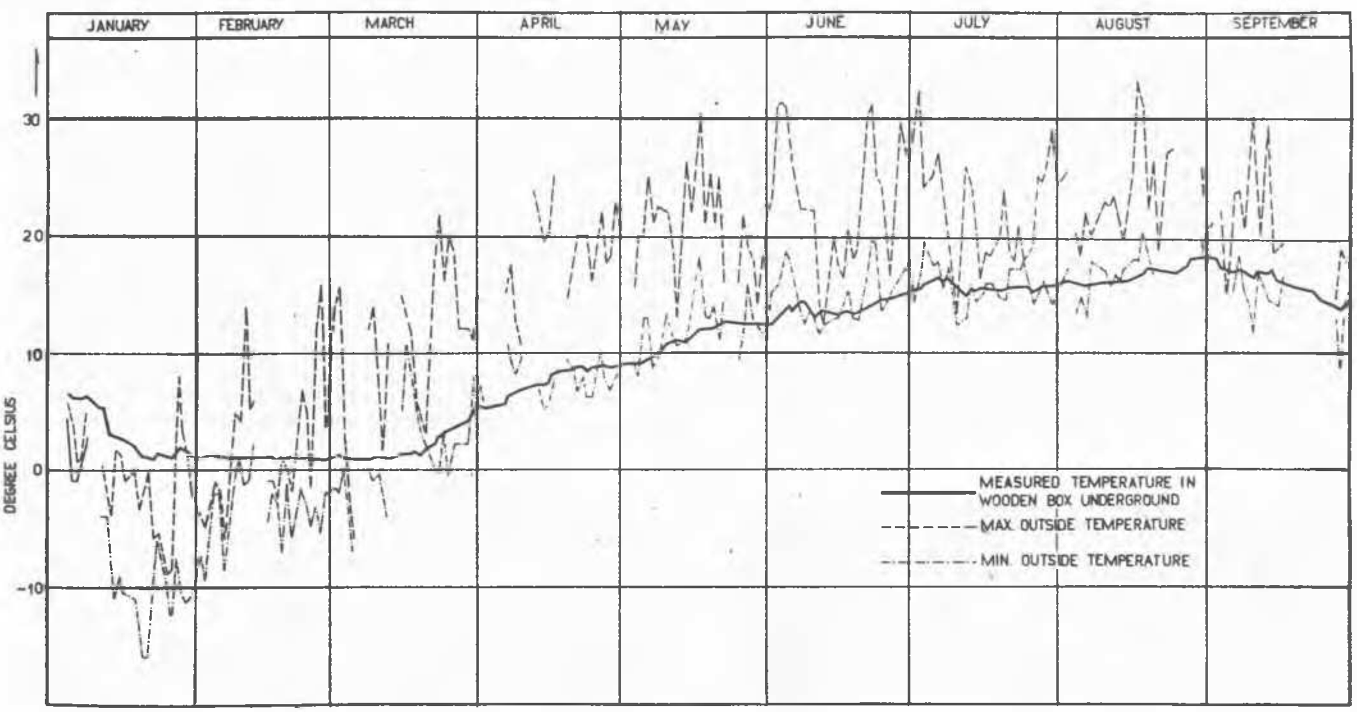
Ir. T.K. HUIZINGA
Director of the Soil Mechanics Laboratory, Delft, Holland

INTRODUCTION.

In the Proceedings of the First Conference on Soil Mechanics Ringeling and Biemond reported on the measurement of pore water pressure in peat and clay layers (F 8, F9). The importance of such measurements in view of the preparation, the design or the construction of civil engineering works needs hardly be stressed nowadays. Since then many measurements have been carried out in the Netherlands, in most cases under the guidance or under the supervision of the Laboratory. In the course of these measurements we encountered various difficulties which had to be overcome, resulting in the gradual improvement of the apparatus.

OBJECT.

The measurements may serve several objects, e.g. to collect the necessary data for the estimation of the probability of earth failures in excavation works, both for a con-



Measured temperatures in 1942

FIG.1

stant and a variable hydrostatic pressure in the underlying layers of sand, to calculate the stability of slopes and hence to control the construction speed in earth works, to predict the continued settlement of a fill at any time after construction, to estimate horizontal forces on pile groups under abutments or other retaining walls, to evaluate pile driving data, for research, etc.

CONSTRUCTION.

At first the filters were placed in a previously made borehole and embedded in suitable graded sand in the same way as when installing ordinary water gauge pipes. Because it is to be feared that the soil fill in the borehole may permit communication with layers of different pore water pressure, nowadays the pipe with the filter is forced into the ground, resulting at the same time in less disturbance in the neighbourhood of the filter. Owing to the displacement of the soil round the filter, some initial excess pressure in the pore water will develop, so that one must wait one or more days before the correct value can be read. In the beginning the filter pipe was connected by means of a hollow lead-cable to a mercury pressure gauge erected away from the construction works. It appeared however that the cables were not sufficiently watertight. Now the pressure gauge is once more directly connected to the filter pipe.

EFFECT OF TEMPERATURE.

The mercury pressure gauges installed on the surface are in a vulnerable position and are liable to freeze during frost periods. To counteract this, they were at first placed in wooden boxes, which were heated during the winter. An other way was to use oil or liquid parafine instead of water in the upper portion of the pipe. This required much attention and therefore nowadays the filter pipes are placed with their tops 80 cm to 1 m under the surface and an ordinary Bourdon type pressure gauge is used, the whole being covered by an insulated plate. Even during long and severe frost periods the temperature in the thus enclosed box did not drop below 0^{o} C, due to the transfer of heat from the earth. The curve in fig. 1 shows the relation between recorded temperature in the box and above.

At the same time this arrangement reduces the rise of temperature due to the radiation of the sun, which would have caused expansion differences between the material of the pipe and the water, with the ensuing observation errors.

EFFECT OF GASCONTENT OF THE SOIL.

In soils containing gas, trouble has been experienced from gas bubbles rising in the pipe. The gas accumulates in the upper portion of the pipe, causing a time lag in the readings. To avoid this an air lock is provided, consisting of a glass tube in which the amount of gas present can be clearly seen. This gas can be locked out without appreciable change in the water pressure. In some cases the large amount of gas caught in the pipe necessitated frequent lock-out operations, resulting in unreliable readings. Furthermore, in fine grained soils it has been found that the soil particles entered the pipe through the filter. To counteract this a porous pot was placed inside the filterpipe. In this way we have reverted to the tensimeters of Schofield, used by him since long in agricultural work and by means of which even pressures above the phreatic water table can be measured down to a pressure of about ¾ atmospheric pressure. Thus the water pressure meter has become a vapour pressure meter by means of which at the same time easily the relative humidity in moisture laden spaces can be measured. Fig. 2 shows a photograph of the described apparatus.

The most important advantage of a water pressure meter as compared to an open water gauge pipe is the improved registering of changes in pore water pressure, owing to the smaller amount of in- or out flowing water required.

VARIOUS INFLUENCES ON THE GROUNDWATER TABLE.

In the course of our observations we often found certain readings difficult to explain. Such readings do not necessarily result from faulty construction or arrangement of the apparatus because in the ground appreciable fluctuations of water pressure may occur, and we must also take account of the influences of temperature, atmospheric pressure, etc. When using Bourdon type pressure gauges or electrical pressure gauges we should remember that we measure the difference of pressure with the

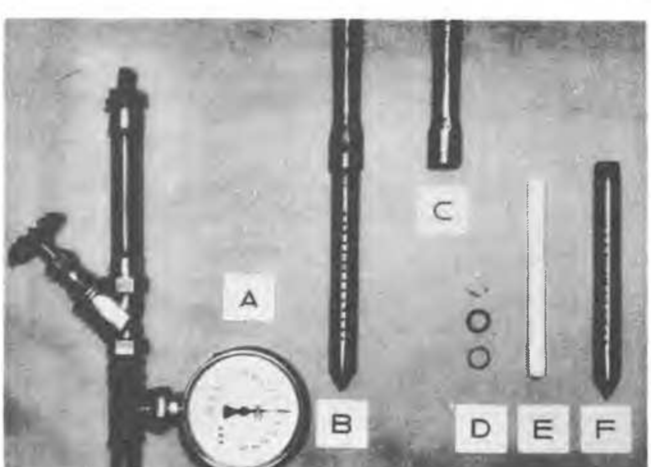
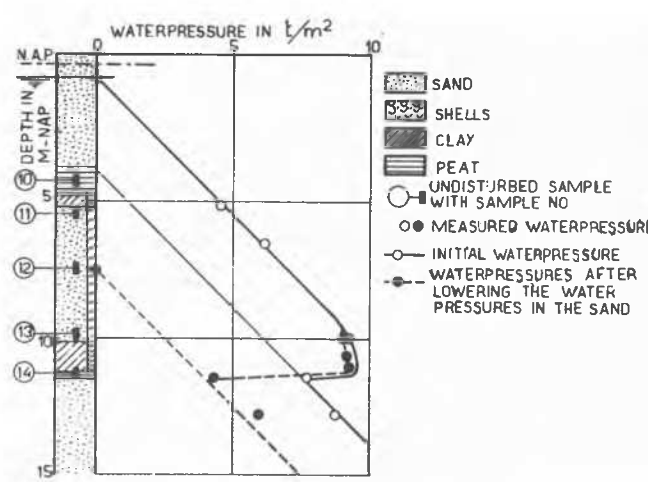
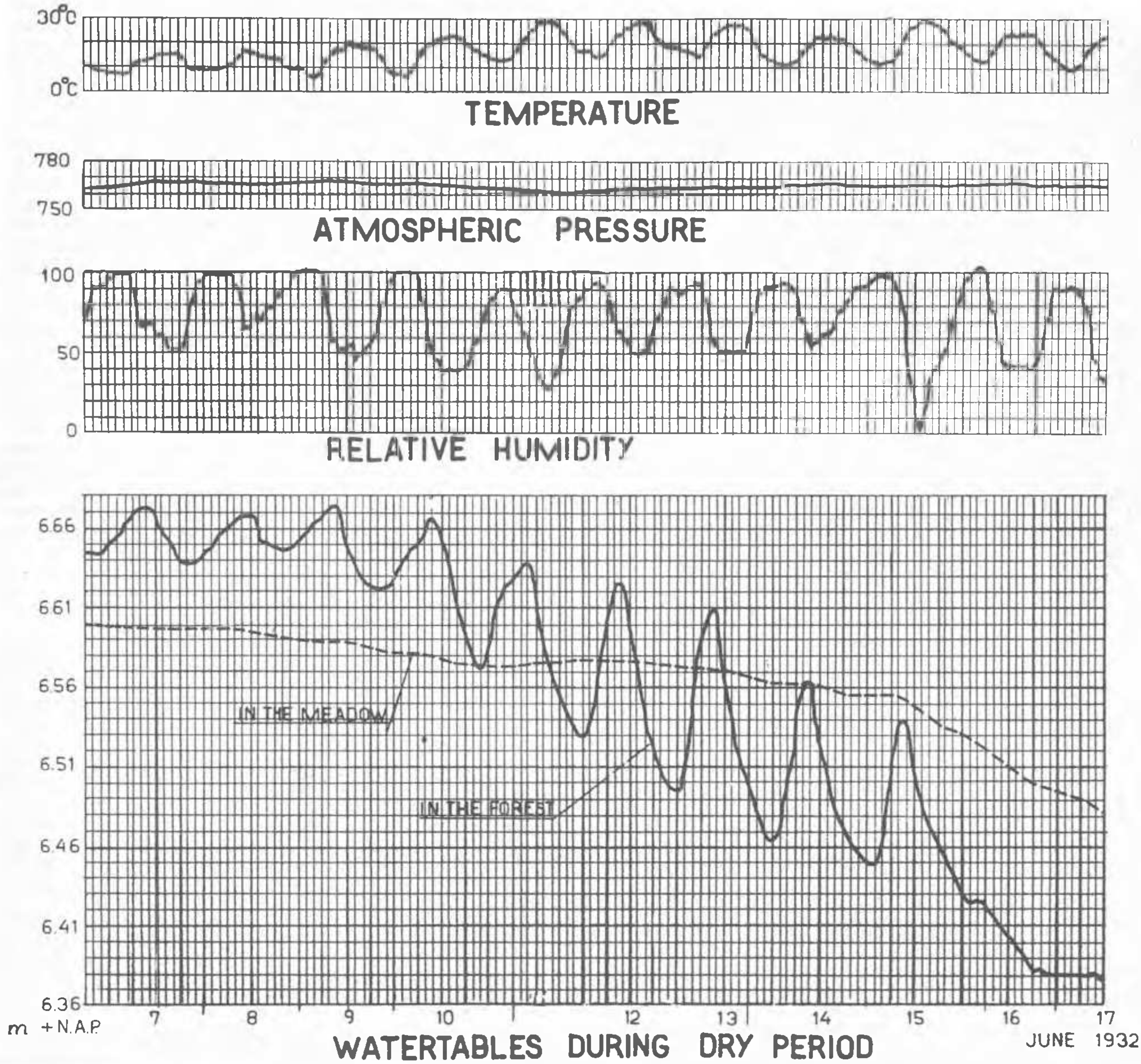


FIG.2



Measured waterpressures at Amsterdam

FIG.3



Observations of groundwater table at Wageningen

FIG.4

atmospheric pressure obtaining at the time of the calibration of the gauge.

It is useful to form a clear idea of the various factors influencing the level of the phreatic water table or generally speaking the pore water pressure.

1) The soil conditions. Soils are composed of heterogeneous materials; they are built up from layers of different permeabilities giving rise to apparent water tables and to water pressures that sometimes do not correspond to the hydrostatic pressure. This may be associated with

2) The flow of the pore water. If the pore water pressure does not follow the hydrostatic law, the water is caused to flow through the soil. An example is furnished by the readings taken at Amsterdam and shown in fig. 3. It appears that a very thin layer of peat practically prevents communication between the two layers with different water pressures, so that drainage of the underlying sandlayer will have little effect on the pressures in the layer above. Also in dewatering or irrigation works a vertical flow may be caused. A result of this can be that temporarily thicker or thinner capillary layers occur.

3) Excess hydrostatic pressure. Besides the excess water pressure caused by forcing the apparatus into the ground, we know excess pressure caused by loads on the surface, pile driving , etc. Here too the water will flow, mostly in several directions. Dependent on the depth of the filter and the time of placing, the readings will vary.

4) Strains within the soil. When measuring pore water pressures in the neighbourhood of pile groups in soft layers on which an overburden has been placed, we must be aware of the fact, that a certain friction may develop between the soil and the piles. The resulting displacements in the soil may take place rather irregularly causing corresponding sudden fluctua-

tions in the readings.
5) Rainfall. Dependent on the conditions of the soil and the amount of water entering the soil, rather sudden changes in ground water pressure may occur. An example of this is furnished by the so called Lisse-effect where it is assumed that between the zone of capillary rainwater entering from above and the existing capillary zone the air in the voids is compressed, causing a sudden rise of the phreatic watertable. This rise is limited both by the height of capillary rise in the upper layer and by the weight of this saturated layer which finally may burst, so that part of the compressed air can escape. An other example is the Wieringermeer-effect, where the soil is completely in a state of capillary saturation. A slight rainfall will break up the menisci causing the phreatic watertable to rise to the surface.
6) Relative humidity. Experiments of Professor Thal Larssen at Wageningen show that even the very slight amount of water resulting from dew may effect an appreciable rise of the phreatic watertable (fig. 4). On the other hand dessiccation of an upper layer consisting of several thin sub-layers, each with their own different heights of capillary rise, may result in sudden fluctuations of the phreatic watertable.
7) Frost action. It is well known that during frost periods the pore water pressure decreases appreciable. Observations made below the frost depth show that the relative humidity there is very low, perhaps due to the diffusion of the moisture upwards in the form of vapour with subsequent condension and freezing. Wells run dry until immediately after the onset of the thaw when they start flowing again even without previous rainfall. Also in the drinkwater producing areas in the dunes this fact is well known although a satisfactory explanation has not yet been given.
8) Atmospheric pressure. It is also well known that with a fall of the atmospheric pressure wells may start flowing even without rainfall. A theoretical explanation may be found only when we associate this phenomenon with the presence in the water of gas bubbles or dissolved gases.

These water pressures vary fairly suddenly. For the proper study of these phenomenons a quick registering water pressure meter is needed. It might be advisable therefore to use a meter, where the water volume remains practically constant.

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AN ELECTRICALLY OPERATING PORE WATER PRESSURE CELL

R.G. BOITEN

Research-Engineer T.N.O. Dept. Stress-Analysis, Delft

G. PLANTEMA

Engineer of Public Works, Dept. Soil Mechanics, Rotterdam

SUMMARY.

For the solution of various soil mechanical problems exact and reliable water-pressure-meters are required. Up till now, the Dept. of Public Works of Rotterdam have made measurements by means of filters driven into the ground, provided with pipes, with Bourdon gauges, on which the water pressure can be read. As the use of this measuring system always forms an obstacle to the works being carried out, as it cannot be read at a distance, and has several other technical defects, an attempt has been made to develop another measuring system.

In this report a waterpressure meter is described which can be read electrically, and does not have the defects of the system in use up till now, and nevertheless is of such small size that it can easily be driven into the soil without using a bore hole, so that the subsoil is disturbed as slightly as possible, Moreover the meter is very robust, and can be read in a simple and exact way.

Hitherto Public Works of Rotterdam have determined water pressures in the subsoil by means of a filter, which is driven into the subsoil to the desired depth and is connected with a Bourdon gauge by ¼" tubes. After these tubes have been completely filled with water and connected with this gauge, the height of water or of suction which corresponds with the watertension around and in the filter, can be read on it. (fig. 1). 1)

However, several difficulties arise in using this system, such as:
a) the being of an obstacle for the work being carried out;
b) the impossibility to registrate at a distance, which is so troublesome that in certain cases, the experiments were given up, although they could have yielded valuable data;
c) the possibility of leakage in the connections of the pipes, so that the measurements become unreliable;
d) the freezing of accessories during a frost-period;
e) on the one hand faulty indications owing to pressure differences in the water, on the other hand owing to differences in temperature of the water in the pipe, caused by differences in the temperature outside;
f) faulty indications by the Bourdon gauge, in consequence of the overloading of the deforming torus 2).

In view of these difficulties, a water-