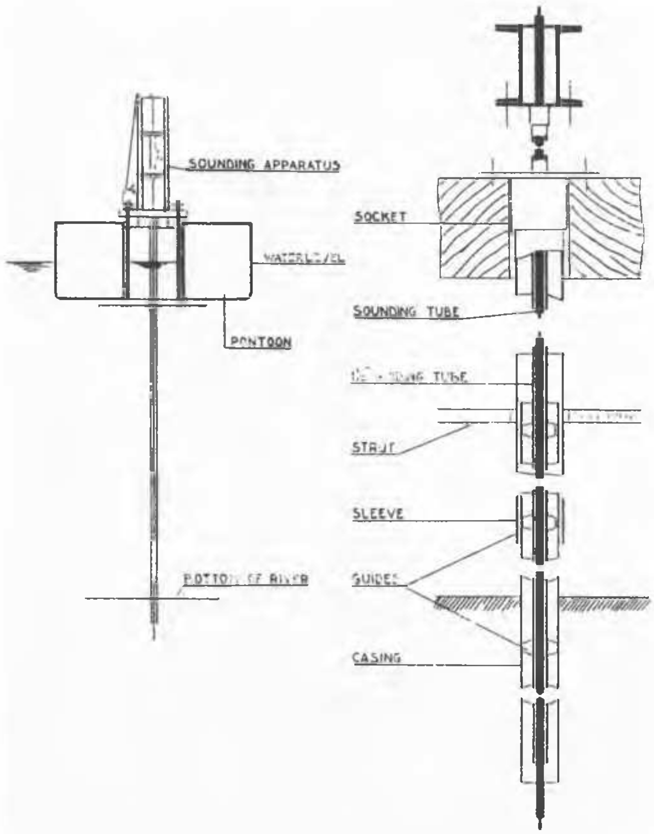

FIG.15

of the river was covered with debris from the destroyed quay walls. The City Engineer's Department succeded in developing a method of deep-sounding, working from a pontoon barge, solving the problems arising out of the rise and fall of tidal water. The 300 ton barge is shown in fig. 15. A deep-sounding apparatus is set up above the cylindrical opening in the pontoon. The sounding proceeds as follows:

Working from the deck, first a 4" casing is placed to about 2 m under the river bottom. The top is then at about 20 cm above low water. Enveloping this casing, a 5" sleeve pipe is lowered, which is connected to the pontoon and takes part in the vertical tidal movement. The sounding tubes are prevented from buckling by a 1½" guiding tube, which finds support against the casing by means of welded guides. All pipes together are secured against buckling by wooden struts in the hole in the pontoon.

During the sounding the rise and fall of ebb and flow is registered by a levelling apparatus set up on the shore and, with the aid of these readings, the results of the sounding are subsequently corrected.

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2) Ir.G.Plantema, Construction and Method of Working of a new Deep-sounding Apparatus, Proc. 2nd. Int.Conf. Soil Mech. 1948. Vol. I paper III b 6.
3) Laboratory of Soil Mechanics Delft. The predetermination of the required length and prediction of toe resistance of piles. Proc. Int. Conf. Soil Mech. 1936. Vol. I I-1

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SUB-SECTION III c

MEASUREMENTS OF PRESSURES AND DEFORMATIONS

EXPERIENCE GAINED IN THE MEASUREMENT OF PORE PRESSURES IN A DAM AND ITS FOUNDATION

III c 1

MILTON G. SPEEDIE, M.C.E.

INTRODUCTION.

Fifteen piezometers have been installed in the embankment and foundation of the Eildon Dam, Victoria, Australia, to record pore pressures and so provide basic information for the design of an enlargement of this structure. It was necessary to select instruments suitable for installation through about 100 feet vertical thickness of rock and clay embankment and which would permit pressure reading to be made at the level of the embankment crest. They are of two types designated 1 and 2 as shown on drawing No. 1, and have been located in two cross-sections of the dam.

LOCAL CONDITIONS.

The dam was originally constructed in the period 1915 to 1929 and consists of a zoned clay and rock fill embankment with a central concrete core wall extending from the foundation rock to the top of the bank. For the most part the interbedded sandstones, slates and shales of Silurian age which form the foundation rock are overlaid by alluvial deposite consisting of about 6 feet of sandy gravel which in turn is covered by 15 feet of medium clay. Typical mechanical analynes of these materials are shown on drawing No. 3 and physical properties of the clay are as follows:

Physical Properties of clay.

	6 feet above Piezometer 4	4 feet above Piezometer 7	Average Values
Wet Density lbs. per cub.ft.	124.6	118.3	125
Dry Density " " " "	99.7	86.4	102
Moisture Content %	24.9	36.7	
S.G. of Particles	2.72	2.74	2.72
Permeability Ft. per yr.			0.003

Only sufficient of the foundation materials were excavated to enable the core wall to be keyed into the rock. Immediately upstream of the concrete wall a clay blanket wall was constructed from the surface of the foundation clay to an elevation 5 feet below top of embankment, having a thickness of about 17 feet at the top and an upstream slope of 6 on 1.

The whole of the downstream and remainder of the upstream portions of the bank were composed of rock fill placed directly on the clay. This material is very permeable and free draining with an average density of 125 pounds per cubic foot.

An extensive subsidence occurred in the upstream portion of the embankment during a rapid draw down of the reservoir in 1929 when construction had been practically completed. This subsidence and the subsequent dam reconstruction involving the placing of much additional rock filling were described in detail elsewhere. (1) The greatest subsidence occurred at chainage 1550 feet for which the present profile is as shown in drawing No. 3 together with the locations and recordings of the piezometers installed at this cross-section. The present location of the clay zone does not agree with that previously reported on account of slow continuation of the subsidence for some time after completion of the original exploratory boring in the embankment.

PIEZOMETER INSTALLATION.

Two types of piezometers were installed, their constructions and details of the installation being as shown in drawing No. 1.

Piezometers type I closely follow a design used by the United States Bureau of Reclamation and consist essentially of a bronze body in which is mounted a diaphragm, subject to the hydrostatic pressure on its underside. A copper tube enclosing an insulated wire connects the upper portion of the body with the recording panel and air pressure is applied through the tube to the cell until deflection of the diaphragm breaks an electric circuit (through insulated wire, contact button, diaphragm, body, tube, lamp and battery) and extinguishes a lamp, the pressure of air being recorded by a Bourdon pressure gauge.

Piezometer type 2 is of similar construction but has two tubes instead of one thus permitting flushing out of any water which may leak past the diaphragm or condense from the air.

The piezometers were mounted in a steel tube fitted with a pointed shoe to assist driving. Coarse sand was packed around the piezometer heads and the voids filled with water. The remainder of the steel tube was filled with concrete, rubber discs being provided at intervals to ensure that copper tubes retained their correct positions and did not contact the outer tube.

When placing the assembly in the clay wall or foundation the tube was jacked into position. No pilot hole was bored where the clay was soft but in hard or stiff clay a pilot hole was necessary and this was made at least an inch smaller in diameter than the tube. All copper tubes at each cross section were led to a panel mounted on the top of the embankment and fitted as shown in drawing No. 1 and illustrated in photographe No. I and II. Air pressure is supplied by an electric motorcompressor unit illustrated in photograph No. III, and air pressure measurement is by means of a calibrated Bourdon gauge.

PRECAUTIONS.

The following precautions were taken:

1) The use of dissimilar metals in the installation was avoided. Experience (2) with other equipment showed that a sealed galvanized pipe filled with water generated hydrogen by galvanic action, thus producing high pressures. For this reason the piezometers and copper tubes are insulated from the steel tube by rubber discs.
2) Diaphragms and contact buttons were carefully adjusted, and the cell subjected to pressure to test its operation and watertightness, prior to installation.
3) Each piezometer was calibrated to determine the pressure difference required to break the circuit. This varied from 1 to 4 feet of water and 8 feet for Piezometer No. 7, all corrections to be subtracted from air pressure readings to give pressure below diaphragm.
4) Copper tubes were joined by compression couplings or brazing. Sweating with solder was avoided.
5) Air pumped into the tube when taking readings was first dried by passing through calcium chloride crystals. It is doubtful whether this procedure provides adequate desiccation.

METHOD OF MAKING READINGS.

1) Air pump and gauge are connected to the large tube leading to piezometer. This is done by closing relief valve and connecting rubber tube to valve fitting.
2) Electric circuit is completed through piezometer battery and lamp by burning control knob to appropriate contact on multiple switch.
3) Valve on air line is slightly opened and air pressure very slowly built up until lamp is extinguished. Pressures at which lamp flickers or becomes dim are also recorded.

Front View

PHOT. 1

Rear View

PHOT. 2

4) Air pressure is slowly reduced until lamp again glows brightly. Dim and flicker pressures are again noted.
5) Tubes are dewatered by opening return tube to atmosphere and building up an air pressure of 150 feet head of water (65 lbs. per sq. inch) at top of down tube.
6) If the tubes are found to contain water repeat steps 1 to 4 above.

The first set of readings is used unless water is found in the cell, in which case the second set is adopted. Where the breaking of the circuit is not definite the points at which the lamp changes from bright to dim, or vice versa, are considered to indicate deflection. Flickering of the lamp shows instability of the diaphragm and when confirmed by recordings on other dates may indicate pore pressure.

EXPECTED PRESSURE VARIATIONS.

At the time of installation the soil disturbance due to forcing steel tubes into it must produce high local pore pressures. These would dissipate gradually while the pressure inside the tubes will build up until they attain that of the pore water in the soil. The pressure of the pore water and the water in contact with the piezometers will then still further reduce, until the effect of the soil disturbance disappears. Thereafter the pore water pressure should be governed by water level variations although this condition can only be definitely recognized when pressure recordings show increasing pressures for the second time.

The pore water pressures can vary with water level for two reasons.

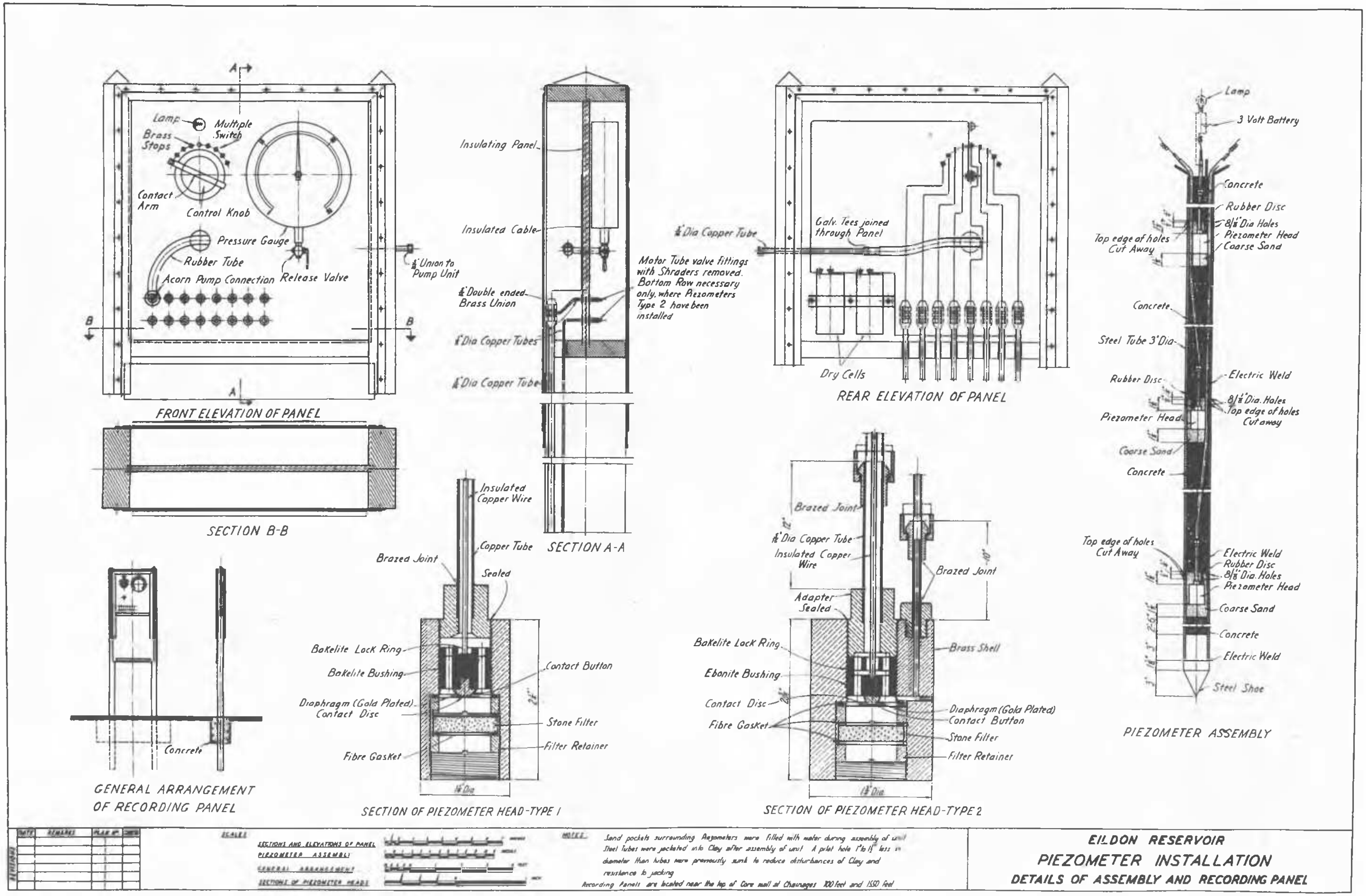
1) The loading on the surface of the clay varies and portion of this variation would be transmitted to the pore water. Where there is no rock filling the variation in water level represents the change in pressure on the clay expressed as hydrostatic head. Where rock fill overlies the clay to an elevation above water level the change in vertical pressure equals the weight of water contained in the voids of the filling within the range of water level variation i.e. about 27% of hydrostatic pressure variation. In addition to the vertical loading there will be a lateral component due to the embankment slope; this would be greater for low water levels than for high.
2) Hydrostatic pressure changes can be transmitted through the pore water of the clay mass. Pressure variations transmitted in this way are likely to exhibit a time lag with respect to the water level changes producing them.

RECORDINGS.

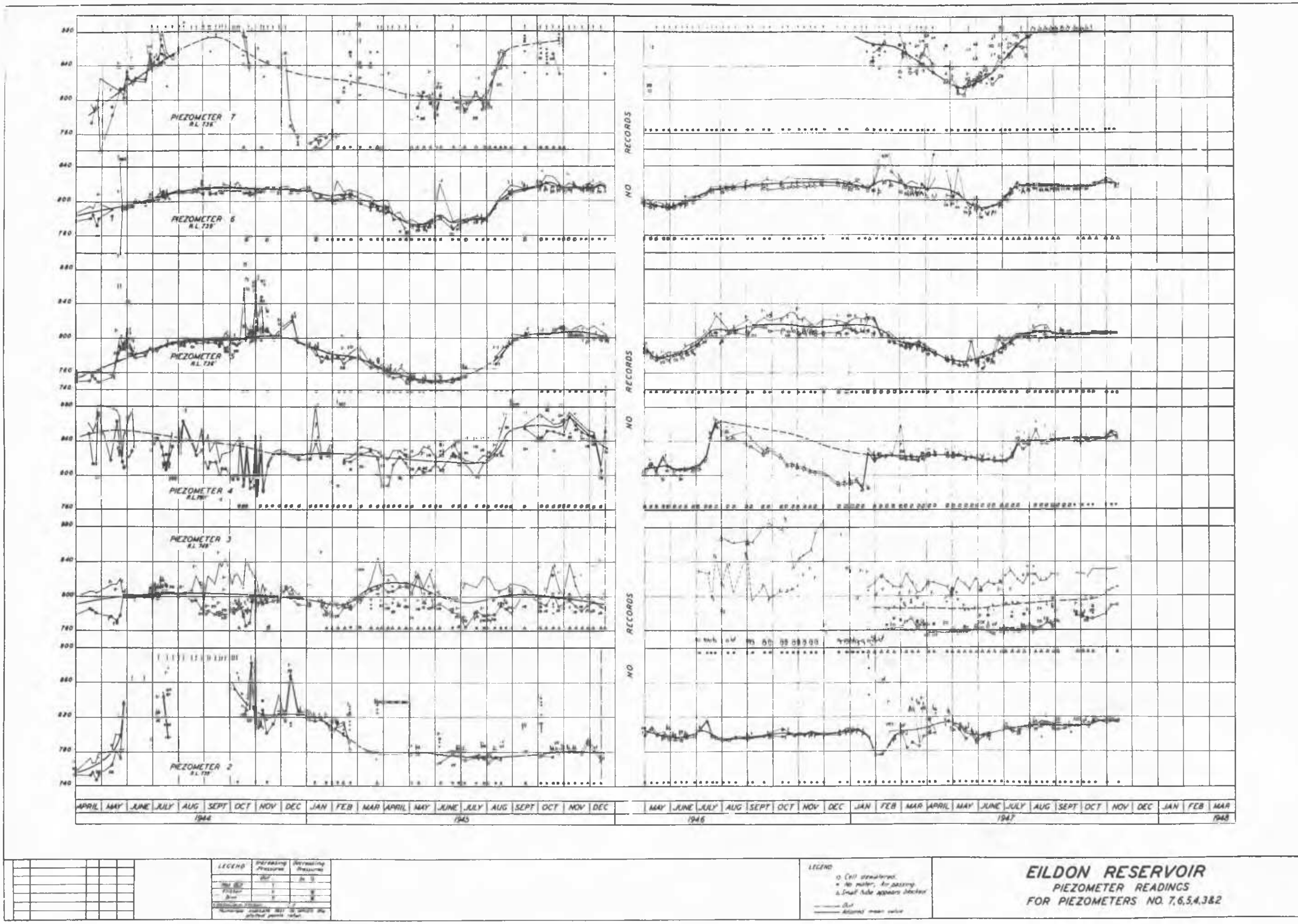
Details of the locations and recordings of type 2 piezometers are shown on drawings Nos. 2 and 3. Type 1 cells were placed at another location in the dam and their readings have been more consistent and showed lower pressures than for type 2 piezometers but are considered unreliable as stated below so the readings are not recorded here.

Recordings of type 2 cells show -

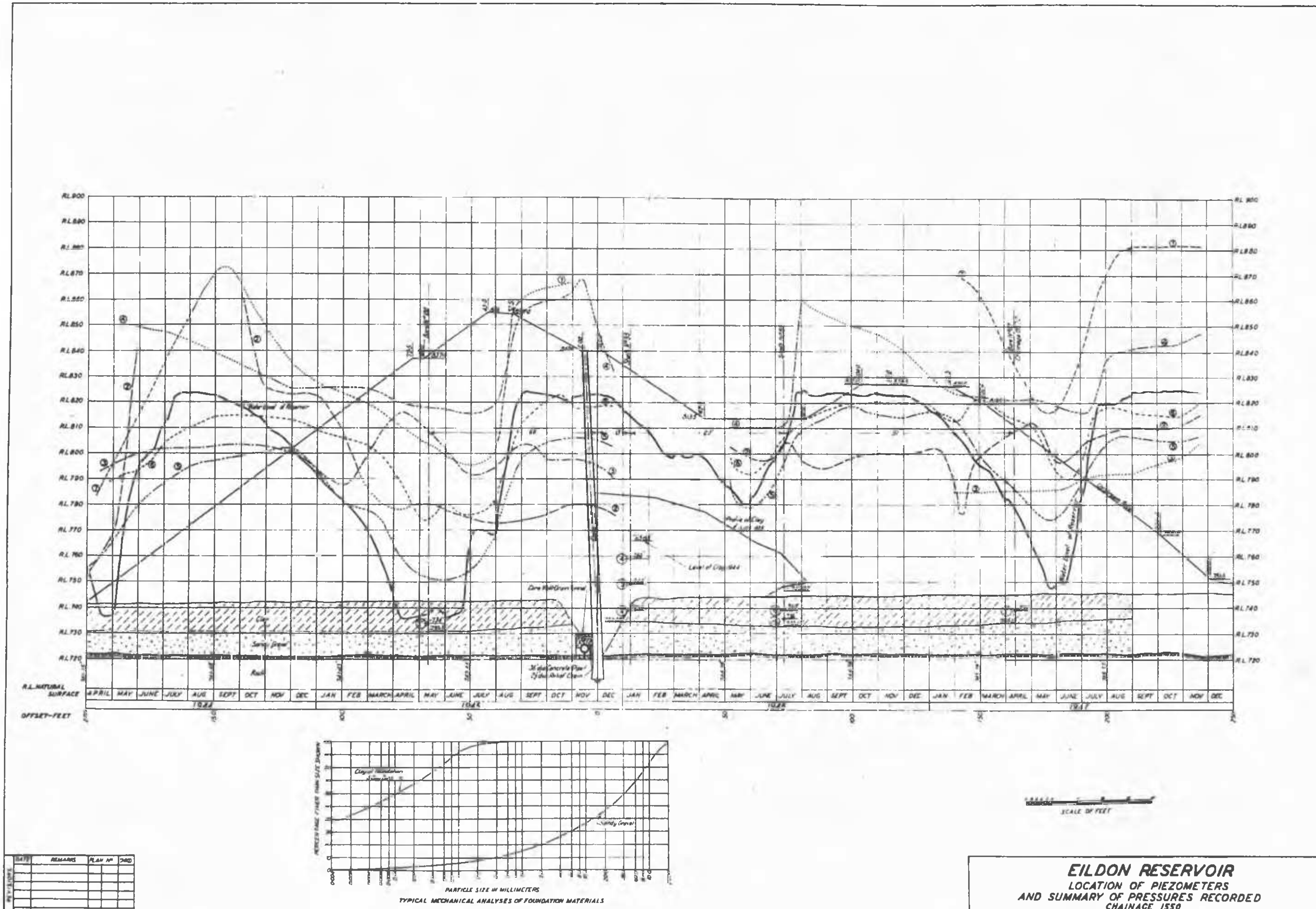
a) About 15 months after installation the piezometers indicated increasing pressures for the second time. This is thought to make the


Lamp
Multiple Switch
Brass Stops
Contact Arm
Control Knob
Pressure Gauge
Rubber Tube
Acorn Pump Connection
Release Valve
¼" Union to Pump Unit
FRONT ELEVATION OF PANEL
SECTION B-B
Insulating Panel
Insulated Cable
¼" Double ended Brass Union
¼" Dia Copper Tubes
¼" Dia Copper Tube
Motor Tube valve fittings with Shraders removed. Bottom Row necessary only, where Piezometers Type 2 have been installed
SECTION A-A
¼" Dia Copper Tube
Galv. Tees joined through Panel
Dry Cells
REAR ELEVATION OF PANEL
Concrete
GENERAL ARRANGEMENT OF RECORDING PANEL
Insulated Copper Wire
Copper Tube
Brazed Joint
Sealed
Bakelite Lock Ring
Bakelite Bushing
Contact Button
Diaphragm (Gold Plated) Contact Disc
Stone Filter
Filter Retainer
Fibre Gasket
SECTION OF PIEZOMETER HEAD-TYPE 1
Brazed Joint
¼" Dia Copper Tube
Insulated Copper Wire
Adapter Sealed
Bakelite Lock Ring
Ebonite Bushing
Contact Disc
Fibre Gasket
Brass Shell
Diaphragm (Gold Plated)
Contact Button
Stone Filter
Filter Retainer
SECTION OF PIEZOMETER HEAD-TYPE 2
Lamp
3 Volt Battery
Concrete
Rubber Disc
8/⅛" Dia Holes
Piezometer Head
Coarse Sand
Top edge of holes Cut Away
Steel Tube 3" Dia
Electric Weld
Steel Shoe
PIEZOMETER ASSEMBLY
DATE
REMARKS
PLAN Nº
CHKD
REVISIONS
SCALES
SECTIONS AND ELEVATIONS OF PANEL
PIEZOMETER ASSEMBLY
GENERAL ARRANGEMENT
SECTIONS OF PIEZOMETER HEADS
NOTES
Sand pockets surrounding Piezometers were filled with water during assembly of unit
Steel Tubes were jacketed into Clay after assembly of unit. A pilot hole 1" to 1½" less in diameter than tubes were previously sunk to reduce disturbances of Clay and resistance to jacking
Recording Panels are located near the top of Core wall at Chainages 700 feet and 1550 feet
EILDON RESERVOIR
PIEZOMETER INSTALLATION
DETAILS OF ASSEMBLY AND RECORDING PANEL

DRAWING 1


EILDON RESERVOIR
PIEZOMETER READINGS
FOR PIEZOMETERS NO. 7,6,5,4,3&2
PIEZOMETER 7
PIEZOMETER 6
PIEZOMETER 5
PIEZOMETER 4
PIEZOMETER 3
PIEZOMETER 2
NO RECORDS
APRIL MAY JUNE JULY AUG SEPT OCT NOV DEC JAN FEB MAR APRIL MAY JUNE JULY AUG SEPT OCT NOV DEC
1944
1945
MAY JUNE JULY AUG SEPT OCT NOV DEC JAN FEB MAR APRIL MAY JUNE JULY AUG SEPT OCT NOV DEC JAN FEB MAR
1946
1947
1948
LEGEND

DRAWING 2


RL 900
RL 890
RL 880
RL 870
RL 860
RL 850
RL 840
RL 830
RL 820
RL 810
RL 800
RL 790
RL 780
RL 770
RL 760
RL 750
RL 740
RL 730
RL 720
R.L. NATURAL SURFACE
OFFSET—FEET
APRIL
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
JAN
FEB
MARCH
Clay
Sandy Gravel
Rock
Core Wall Grout Curtain
Level of Clay 1944
Water Level of Reservoir
SCALE OF FEET
Clayey Foundation
Sandy Gravel
PARTICLE SIZE IN MILLIMETERS
TYPICAL MECHANICAL ANALYSES OF FOUNDATION MATERIALS
DATE
REMARKS
PLAN Nº
REVISIONS
EILDON RESERVOIR
LOCATION OF PIEZOMETERS
AND SUMMARY OF PRESSURES RECORDED
CHAINAGE 1550

DRAWING 3

Portable Air-Compressor Unit.

PHOT. 3

commencement of the first definitely representative readings of pore water pressures in the embankment.

b) Thereafter the pressure recordings increase and decrease with water level. Particular comments on individual cells are given below.

c) Piezometer 1 has shown zero pressure as would be expected downstream of the core wall.

d) Piezometer 2 has given readings which are generally consistent regarding pressures at which the diaphragm deflects with increasing and decreasing air pressure. No correlation with water level has been possible.

e) Piezometer 3 recordings have been very irregular and no conclusions can be drawn.

f) Piezometer 4 has given fairly consistent readings but considerable quantities of water have collected therein. In the period August 1946 to January 1947 water accumulated in the tubes as a result of inadequate flushing by an inexperienced operator. In January 1947 well over a pint of water was flushed from the tubes which would account for the whole of the 50 feet rise in pressure at that time.

g) Piezometer 5 has been consistent and pressures have varied with water level, generally with a small lag. The variation amounting to 45% to 87%, average 58%, of change in water level, is greater than the variation in vertical pressure on the clay surface.

h) Piezometer 6 also gave consistent readings with variations of 39% to 71% (average 55%) of change in water level. When the reservoir is full the hydrostatic head given by both piezometers 5 and 6 approximates that to water level.

j) Piezometer 7 has recorded very high pressures. For a long time the electric circuit could not be broken with air pressures up to 150 feet head of water and it was thought to have a short circuit or other fault. However, in 1944 a large quantity of water (estimated at 70 feet depth) collected in the tubes and some readings were then obtained again. During 1947 pressures were recorded and they varied with water level but were about 60 feet greater than hydrostatic from reservoir level.

Slight upstream movements of the rock fill observed during draw down of water level are consistent with high pore pressure.

The high pressures might be interpreted as indicating a condition of partial consolidation in the clay, but the large variation with water level seems inconsistent with this interpretation. Lateral pressures should be greatest with low water level and might be expected to limit the pore pressure reduction during drawdown of water level. However, no such limitation has occurred.

CONCLUSIONS.

It is concluded that -

1) The diaphragm type of piezometer has given consistent readings over a period of 3½ years.

2) Water has been found to accumulate in the piezometers due to condensation from air pumped into the tubes, and/or as a result of leakage, consequently type 1 cells which are not capable of being cleared of water are considered unreliable and will give misleading readings.

3) The pressures in the foundation clay are high.

4) The variation in hydrostatic pore pressure in the foundation clay is less than the variation in reservoir water level but considerably more than the variation in total pressure (rock fill plus water) on the foundation.

ACKNOWLEDGEMENT.

The Author wishes to thank Mr. L.R. East, M.C.E., M.I.C.E., M.I.E.Aust., Chairman, State Rivers and Water Supply Commission, Victoria, for permission to publish the paper. All designs and investigation work are carried out under the direction of Mr. R.G. Knight, M.C., M.C.E., M.I.C.E., M.I.E.Aust., Chief Designing Engineer.

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SUMMARY.

Piezometers of two types, totalling fifteen in number, have been installed in the embankment and foundation of the Eildon Dam, Victoria, Australia, and readings are available for a period of 3½ years.

The dam consists of a zoned embankment of clay and rock fill with a central concrete core wall extending from the foundation rock to the embankment crest. The clay and rock fill embankment rests on a natural clay strata overlying sandy gravel and rock.

In both types of piezometers pore pressure is transmitted to the underside of a diaphragm while air pressure is applied to the top until deflection breaks an electric circuit and indivates equality of air and pore pressure. Type 2 cells differ from Type 1 in that two tubes lead to the upper side of the diaphragm and so permit removal of any water that accumulates there.

Precautions taken in manufacturing and installing the cells are listed together with the method of making readings. Illustrations give details of the equipment, installation, and readings, the latter being briefly discussed in the latter press.

Pore pressures were disturbed by installation of the piezometers but, after an adjustment period, consistent recordings were obtained

which varied with water level, but to an extent greater than the variation in total pressure on the clay surface and somewhat less than the corresponding variation in reservoir level. In general, the maximum pressures for each instrument corresponded with or were greater than hydrostatic from spillway crest level.

It is concluded that the diaphragm type of piezometer has given consistent readings over a period of 3½ years and that provision must be made for removing water which accumulates in the cells by leakage or condensation. Results obtained from cells without such provision are unreliable.

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III c 2

SOME RESULTS OF WATERPRESSURE MEASUREMENTS IN CLAY-LAYERS

E. DE BEER and H. RAEDSCHELDERS
Ghent (Belgium)

INTRODUCTION.

To control the stability of deep cuts in clay-layers several waterpressure measurements were performed. Most of the tested clay-layers are situated between an upper and a lower sand layer or limestone layer, having a different hydrostatic pressure. Beforehand one should believe that the waterpressure in the clay-layer would be a mean between the upper and the lower watertable. The results of the measurements are often quite different from this expectation.

CANAL CUT AT GODARVILLE FOR THE CANAL BRUSSELS-CHARLEROI.

To allow navigation for 1350 ton ships, a deep cut of a depth of 43 m has to be constructed at Godarville. At this location the following layers are generally found, starting from the surface of the ground:

1) loam or loamy fine sand.
2) more or less sandy clay.
3) clayey sand.
4) more or less sandy clay.
5) limestone.

The physical properties of a typical sample of each of these layers are given in tableI None of the layers can be considered as homogeneous.

The loam or loamy fine sand (layer 1) belongs to the pleistocene, the layers 2 till 4 belong to the tertiary ypresian formation (y_2 - y_{1b} - y_{1a}). The limestone is of secondary age.

In some borings there was a sand layer belonging to the tertiary Lutetian formation (B_1) between the pleistocene top-layer and the tertiary Ypresian sandy clay-layer. In one boring (group 605) a sand-layer of the secondary Wealdien formation (W) was found between the limestone and the Ypresian clay formation.

A certain number of borings were performed. During the borings the water-level was accurately recorded, especially at morning before continuing the boring. Depending on the permeability of the soil the water had opportunity to come more or less to hydrostatic equilibrium. In this way the points indicated by a single circle in the fig. 1 are obtained and the points corresponding to a same boring are connected with a dotted line. In these figures the depth underneath the soil surface is taken as an ordinate, and the piezometric waterheight corresponding to this depth as an abscissa.

The pressures so measured during the borings are not necessarely exact, because it is not sure that in one night the hydrostatic equilibrium has been reached. But from their variation with depth can be deducted how many independent watertables were met during the boring. Thus when a boring was finished, at a mutual distance of at least 2 m., there were performed a certain number of complementary borings, at least as many as different watertables were recognized. During the execution of these complementary borings the variation of the waterlevel was recorded as for the primary boring. The complementary borings were ended at different depths, and almost in different soil layers. Open tubes, 2" diameter, were put in place.

In these open tubes the fluctuations of the waterlevel were controled during several months, thus giving a more exact value of the piezometric height at the level of the bottom of the tube. The so recorded values are indicated by crosses and a letter in the fig. 1.

Group of borings 601.

There is a different water-level in the loam layer and in the limestone layer. The pipes b and c, located at different depths in the sandy clay indicate that the waterpressure in this layer increases hydrostatically with depth, according to the water level in the loam. During the boring 601-a the waterlevel starts to drop underneath the level + 115. Thus it is as if a more impervious skin existed near this level.

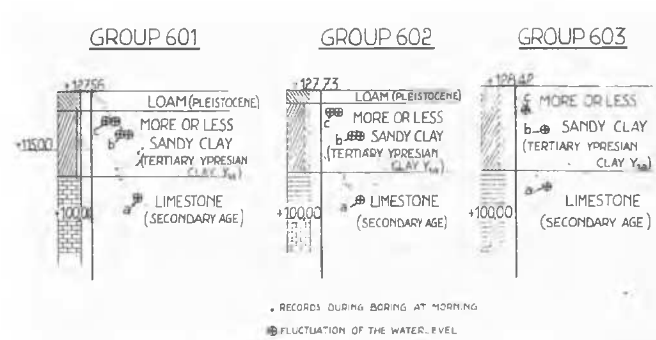

FIG.1