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.

-o-o-o-o-o-o-

III c 2

SOME RESULTS OF WATERPRESSURE MEASUREMENTS IN CLAY-LAYERS

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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.

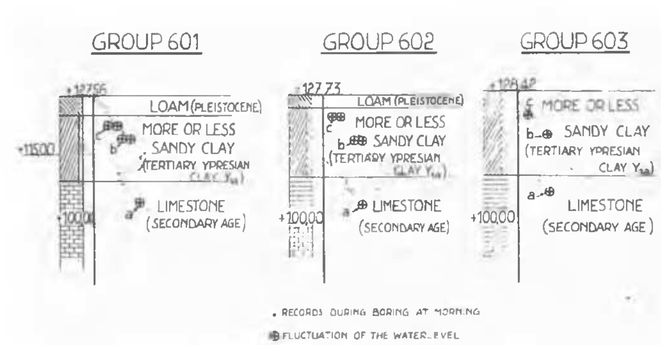

FIG.1

Group of borings 602.

There is a different water-level in the loam and in the limestone. The pipes b an c, and also the waterlevel variations recorded during boring a, indicate that the waterpressures in the sandy clay layer follow a hydrostatic law according to the waterlevel in the loam.

Group of borings 603.

Same conclusion as for group 602.

Group of borings 604.

Here the piezometric height in the limestone is nearly the same as that in the loam. Thus one gets a nearly hydrostatic law through all the layers.

Group of borings 605.

The pipes c,d give a hydrostatic law in the sandy clay with respect to the water-level in the loam. The pipes a and b both in the sand give a hydrostatic law in the sand. It is worthwhile to note that during the boring a, the recorded levels in the sandy clay follow an hydrostatic law, the fall of pressure being located in the sand.

Group of borings 606.

A sandy clay layer is located between a loam- and a clayey finesand layer, having distinct water-levels. Pipes b and c indicate a hydrostatic law in the sandy-clay layer with respect to the water-level in the upper loam layer.

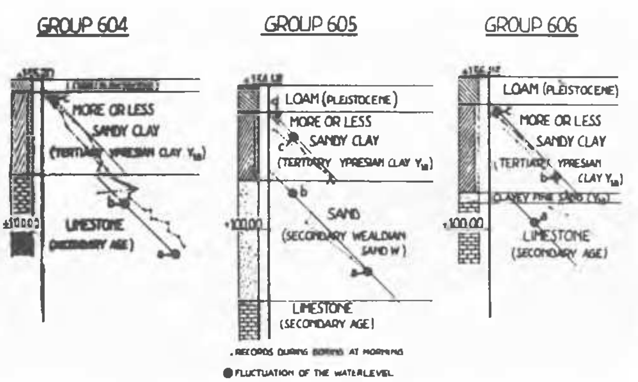

FIG.1

Group of borings 607.

This group is composed of 5 pipes and shows 5 distinct layers, and 3 distinct watertables. The variations of the water-levels recorded during the borings themselves are rather erratic, but the measurements in the pipes give very concording results.

The pipe d placed at the top of the clayey sand layer, sandwiched between the two sandy clay layers shows zero pressure. Pipe e shows a hydrostatic law in the upper sandy clay layer in respect with the open water-level found in this layer. Pipes b and c give a hydrostatic law in the lower sandy clay layer with respect to the water-level in the clayey sand layer.

Group of borings 608.

Pipes d and e show a hydrostatic law in the upper sandy clay with respect to the open water-level found in this clay. Pipes b and c in the lower sandy clay layer, and also pipe a in the limestone show a hydrostatic law with respect to the water-level in the clayey sand layer. In this case there should be no distinct water-level in the limestone.

Group of borings 609.

The waterpressures in the lower sandy clay layer and in the limestone seem to follow the water-level in the clayey sand.

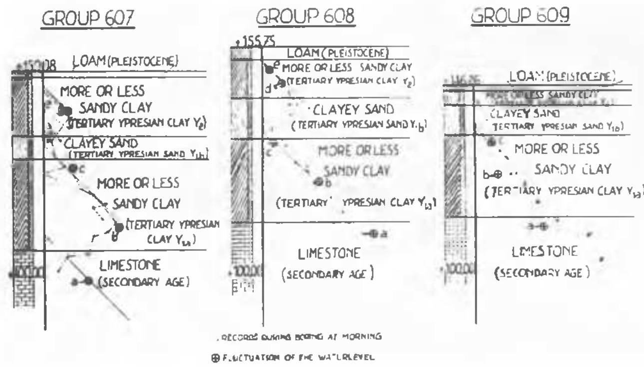

FIG.1

Group of borings 610.

The hydrostatic law in the lower sandy clay layer in respect with the water-level in the clayey sand layer, is shown by the pipes b and c, and also by the records during the boring 610a.

Group of borings 611.

The pipes b and c show a hydrostatic law in the lower sandy clay layer in respect with the water-level in the clayey sand layer. It must be noticed that the records during the borings themselves are very different from one boring to another especially in the clayey sand layer. Of course these records have only a relative value, as already has been explained.

Group of borings 612.

The only difference from the other groups is, that here a fine sand layer between the lower sandy clay-layer and the limestone has been encountered.

All other groups of borings and pipes of the cut at Godarville give analogous results.

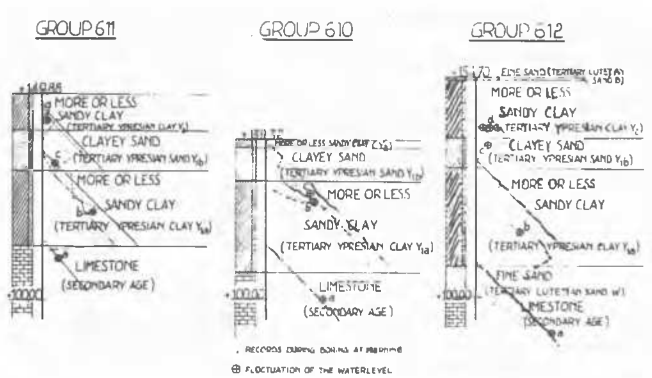

FIG.1

CANAL CUT AT EIGENBILZEN FOR THE ALBERTCANAL.

To cut the crest between the basins of the Meuse and the Scheldt a cut of a maximum depth of 29 m was dug at Eigenbilzen for the Albertcanal. At this location the following layers are generally found, starting from the soil-surface:

1) loam
2) in some places cobblestones, in other hill-sidewaste.
3) a pleistocene layer of fluviatil origin (Pl_2)
4) a pleistocene gravel (Pl_1)

SECTION 1a (LEFT BANK)

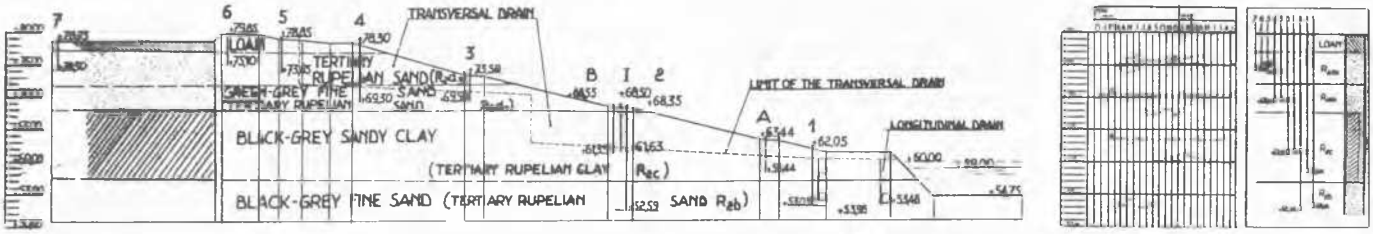

FIG.2a

SECTION 1a (RIGHT BANK)

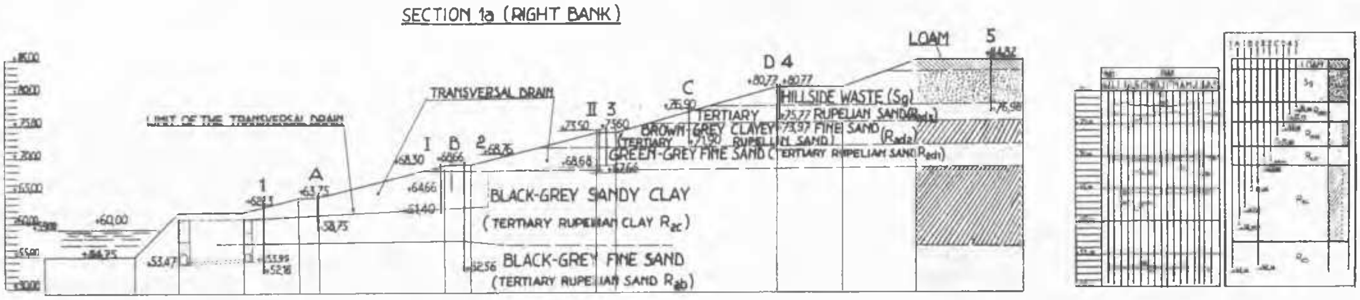

FIG.2b

SECTION 51 (RIGHT BANK)

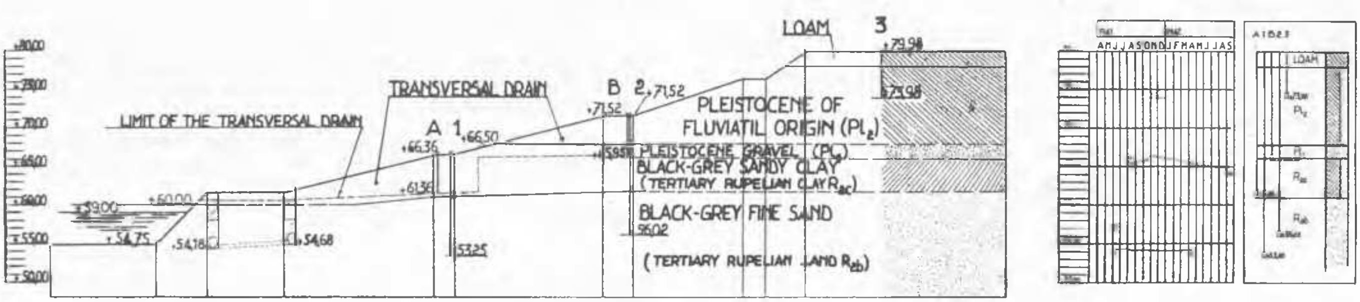

FIG.2c

SECTION 41 (LEFT BANK)

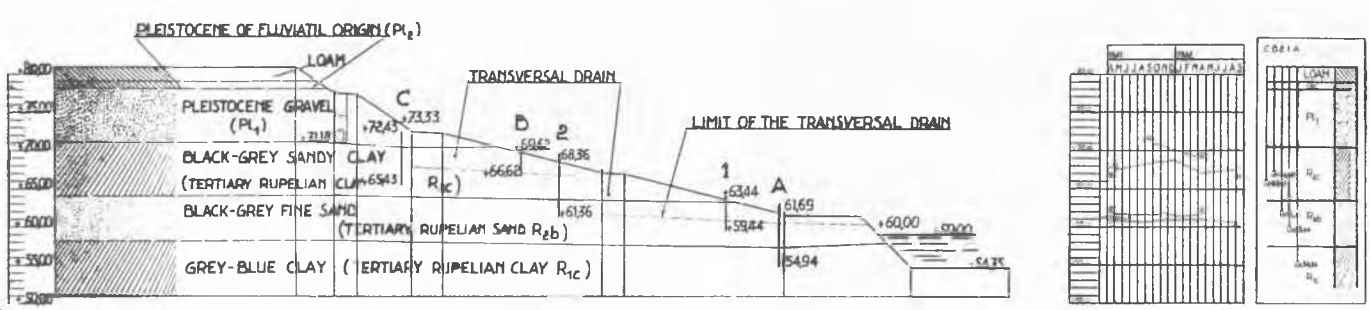

FIG.2d

CANALCUT AT EIGENBILZEN FOR THE ALBERTCANAL

SECTION 34 (LEFT BANK)

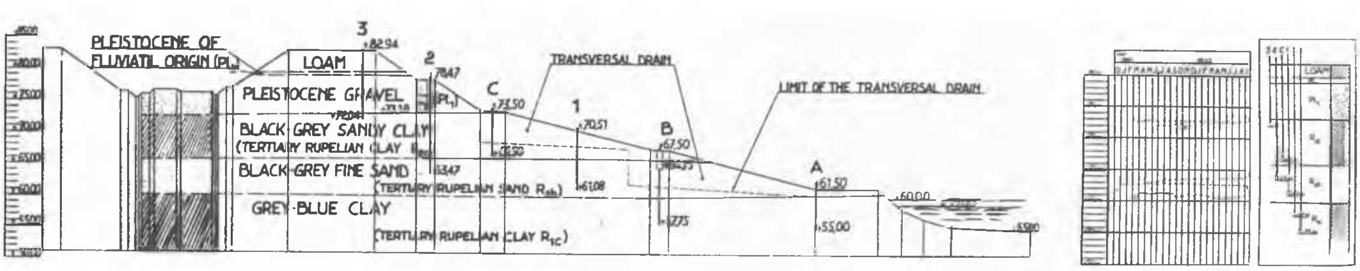

FIG.2e

5) a grey fine sand belonging to the teriary Rupelian sand R_{2d3}.
6) a brown-grey clayey fine sand belonging to the tertiary Rupelian sand R_{2d2}
7) a green-grey fine sand belonging to the tertiary Rupelian sand R_{2d1}
8) a black-grey sandy clay belonging to the tertiary Rupelian clay R_{2c}
9) a black-grey fine sand belonging to the tertiary Rupelian sand R_{2b}
10) a grey-blue clay belonging to the tertiary Rupelian clay R_{1c}

There, where the Rupelian sandlayers R_{2d1}, R_{2d2} and R_{2d3} are found, the Pleistocene formations Pl_1 and Pl_2 don't exist.

The physical properties of a typical sample of the principal layers are given in table II.

To obviate the waterpressures in the different layers longitudinal and transversal drains were provided, as indicated on the sections of the figures 2. The transversal drains are located on mutual distances of about 20 m.

After the canal cut existed already several years, 34 piezometers were put in place, as indicated on the figure 4. Twenty piezometers have their end in more pervious layers and are of the open type; fourteen others have their end in clayey layers and are of the closed type.

The open piezometers are steeltubes with an internal diameter of 2". The end of each of the piezometers is perforated with holes and surrounded with a metal gauze over an height of 25 cm. After the tubes have been lowered in the hole of the boring, the filtering end is surrounded with clean coarse sand. Above the sand clay was put around the tubes and carefully compacted, while the boringtubes were extracted.

The closed piezometers consist of ½" diameter steel tubes, connected to a capillary mercury gauge. At their end the tubes are perforated over an height of 15 cm and surrounded with metal gauze. A scheme of the closed piezometers is given in figure 3. The open piezometers are indicated by numbers, the closed by capital letters.

Before putting the 34 more accurate piezometers into place, some 4½" diameter tubes already had been put. The latter are indicated by Roman numbers.

Section 1 a (Left Bank) fig. 2a.

There are independent water-levels in the sandlayers R_{2dI} and R_{2b}. The open tube I and the closed piezometers A and B are put in the clay layer R_{2c}. The recorded waterpressures in this clay-layer are much higher than those corresponding to the water-level in the lower sand layer R_{2b}. The waterpressures recorded with the closed piezometer B are higher than those recorded with the open tube I altough located nearly at the same spot. In the fine sand layer R_{2d3} there is a water table independent from that in the fine sand layer R_{2dI}.

It is worthwhile to note that the locations of all the piezometers are not more distant than maximum 10 m from the transversal drains.

Section 1 a (Right Bank) fig. 2 b.

There are independent watertables in the sand layers R_{2d3}, R_{2dI} and R_{2b}. In the brown-grey clayey finesand layer R_{2d2} are located the closed piezometers C and D. The waterpressures of these piezometers are not influenced by the waterlevel in the lower sand layer R_{2dI}. The waterpressure given by D is even higher than that corresponding to the waterpressure in the upper sandlayer R_{2d3}, and the piezometer C, though located at the base of the clayey layer R_{2d2} gives practically a hydrostatic pressure in respect of the watertable in the sandlayer R_{2d3}.

In the claylayer R_{2c} are located the closed piezometers A and B, and the open pipe I. The recorded waterpressures don't correspond to the watertable in the lower sandlayer R_{2b}. The waterpressures given by the closed piezometer B are higher than those deducted from the open pipe I, although having nearly the same location.

Section 51 (Right Bank) fig. 2c.

There are independent waterlayers in the layer Pl_2 of fluviatil origin, in the pleistocene gravel Pl_1 and in the sandlayer R_{2b}.

In the claylayer R_{2c} was put the closed piezometer A. Although located at the base of the claylayer, the piezometer is practically not influenced by the waterlevel in the lower sandlayer R_{2b}.

Section 41 (Left Bank) fig. 2d.

There are independant watertables in the layer Pl_1 of fluviatil origin and in the sandlayer R_{2b}. In the claylayer R_{2c} are put the closed piezometers B and C. The waterpressures in them are not influenced by the watertable in the lower sandlayer R_{2b}.

In the claylayer R_{1c} is put the closed piezometer A. The recorded pressure is nearly

TABLE I

Sample	Nature of soil	Depth underneath soil surface	Granulometric size Fraction					Limits of Atterberg			Organic content	Chalk content	Volume weight	Dry weight	Water content	Percentage of voids	Penetration value
			IV ∅ 2 mm	III_b ∅ from 2 to 0,074 mm	III_a ∅ from 0,074 to 0,02 mm	II ∅ from 0,020 to 0,002 mm	I ∅ 0,002 mm	Liquid limit	Plastic limit	Plasticity index							
		m	%	%	%	%	%	%	%		%	%	t/m^3	t/m^3	%	%	kg/cm^2
27749-266-4	loam	1,50		5	47	31	17	34,4	18,1	16,3	0,3	3,8	2,010	1,625	23,5	38,6	4,1
31549-266-640	loamy fine sand	4,45		51	35	8	6	35,8	23,4	12,4	0,5	2,4	1,920	1,510	27,1	43,0	6,2
31534-266-1567	more or less sandy clay	3,25	1	21	39	18	21	69,7	30,2	39,5	0,6	3,2	1,768	1,265	39,5	52,5	7,7
27772-266-1308	clayey sand	9,80		75	20	2	3	29,7	21,6	8,1	0,5	0,5	1,600	1,320	21,2	50,1	1,2
31521-266-1322	more or less sandy clay	16,20	9	50	10	11	20	49,8	19,3	30,5	1,1	4,4	1,950	1,625	19,8	38,6	14,5

TABLE II

Sample	Nature of soil	Depth underneath soil surface	Granulometric size Fraction					Limits of Atterberg			Organic content	Chalk content	Volume weight	Dry weight	Water content	Percentage of voids	Penetration value
			IV ∅ 2mm	III_b ∅ from 2 to 0,074 mm	III_a ∅ from 0.074 to 0,02 mm	II ∅ from 0.020 to 0.002 mm	I ∅ 0,002 mm	Liquid limit	Plastic limit	Plasticity index							
		m	%	%	%	%	%	%	%		%	%	t/m^3	t/m^3	%	%	kg/cm^2
1689-22-17	Clay R_{Ic}	4,30	1	23	17	28	31	61,4	20,5	40,9	0,53	6,5	2,090	1,730	20,7	34,7	41,2
4390-22-41	Sand R_{2b}	7,00	13	71	4	6	6	23,6	no	no	1,5	2,8	1,850	1,680	10,0	36,6	6,9
4388-22-38	Clay R_{2c}	3,00	1	38	18	18	26	43,2	20,2	23,0	2,1	1,4	2,020	1,660	21,5	37,4	15,8
1900-22-29	Sand R_{2d}	3,50	5	82	3	3	7	26,2	no	no	-	-	1,930	1,680	14,6	36,6	5,9
4386-22-36	Sand S_g	5,00	6	77	5	5	7	25,4	no	no	0,65	2,5	1,980	1,860	10,7	29,8	5,5

hydrostatic with respect to the water-level in the upper sandlayer R_{2b}.

Section 34 (Left Bank) fig. 2e.

Independent watertables are found in the layer Pl_1 of fluviatil origin and in the sandlayer R_{2b}.

In the claylayer R_{2c} was put the closed piezometer C. Although located very near the base of the claylayer, it doesn't show any influence of the waterlevel in the lower sandlayer, but the recorded pressure is nearly hydrostatic with respect to the waterlevel in the upper pervious layer Pl_1.

In the claylayer R_{1c} were put the closed piezometers A and B, which give nearly hydrostatic pressures with respect to the water-level in the upper sandlayer R_{2b}.

GENERAL REMARK.

All of the piezometers are not more distant than max 10 m from the transversal drains, Some are even located at only 4 à 5 m. from these drains. In spite of these very short distances, the piezometers located in the claylayers, and even those located in the clayey layers, are practically not influenced by the existence of these drains. At the contrary the waterpressures in all the sand- and gravellayers are very influenced by the same drains.

GENERAL CONCLUSION.

The waterpressure measurements performed at Godarville and Eigenbilzen indicate that in case of claylayers located between more pervious layers, in which exist two independent water-tables, the waterpressures in the claylayer are practically not influenced by the water-level in the lower pervious layer, but are generally nearly hydrostatic with respect to the water-level in the upper more pervious layer. These results are surprising, because the waterpressure in the clay should be expected to be a mean between the upper and the lower watertable. The much higher recorded waterpressures are a very peculiar fact for the stability of slopes in claylayers. When deep cuts are to be made in such layers it is thus suggested to control the waterpressures in the claylayers by means of closed piezometers.

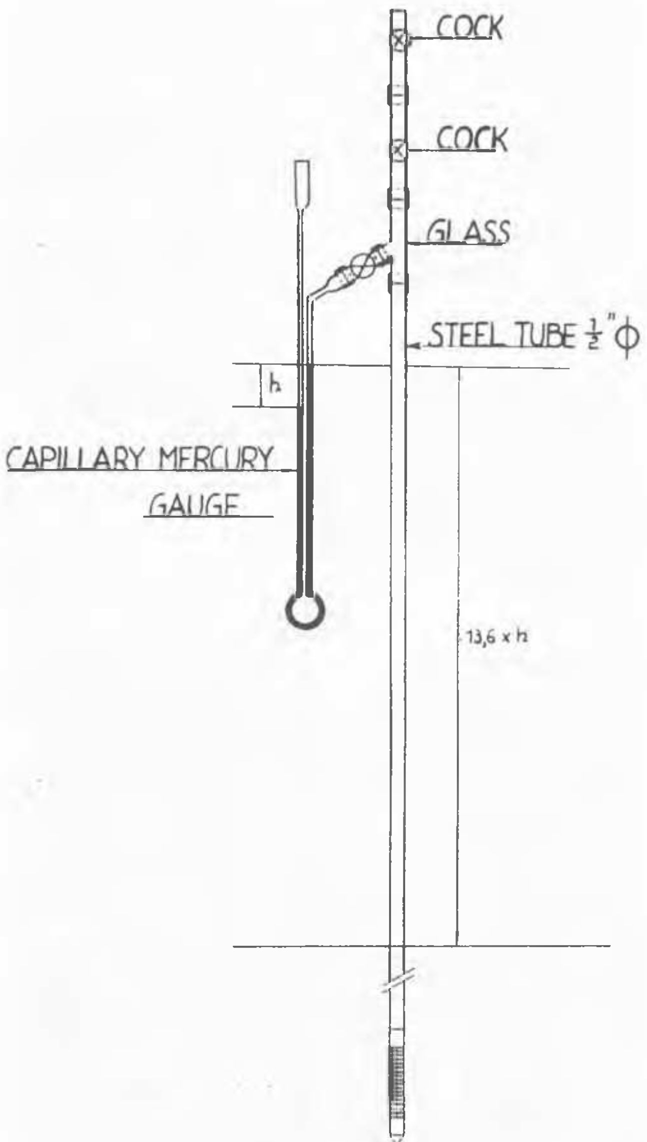

FIG.3

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III c 3

LOADING TESTS ON CLAY

STEN ODENSTAD
The Royal Swedish Geotechnical Institute.

SYNOPSIS.

This report deals with the strength of clay. In certain borderline cases, where ground rupture has occurred at a known load, the strength according to computation by tentative sliding surfaces is compared with the strength obtained in the laboratory by nonconfined compression tests and by Swedish cone tests on undisturbed soil samples taken from the same ground. A hypothesis is stated for the relation between the strength of the soil sample and that of the native soil, indicating in principle how strength of soil may be obtained.

INVESTIGATIONS.

In the laboratory, nonconfined compression tests are made on "undisturbed" soil samples according to fig. 1. The vertical normal stress is increased from zero until either real rupture occures, usually in an inclined sliding surface, or the height of