SUB-SECTION VII b

HORIZONTAL PRESSURES ON PILE FOUNDATIONS

VII b 1

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A. INTRODUCTION.

In the Western part of Holland the subsoil mainly consists of alternative layers of clay and peat resting on thick layers of sand.

Around Rotterdam the sand layers are found at a depth of 16 à 17 m - N.A.P. (datum level) above which clay occurs from about 8 to 16 m - N.A.P. There above layers of alternatively clay and peat exist.

All structures in these parts are founded on piles, whereas roads are usually constructed on sand fill.

This fill increases the water-pressure in the clay and peat layers and may result in substantial horizontal pressure on the abutments of bridges and their foundations (fig. 1).

It was been noticed that this pressure sometimes led to slight horizontal movements in the clay and peat layers, resulting in deflection and even breakage of the piles.

B. SURVEY OF A FEW CASES:

1. Bridge over the marshalling yard near the "Stadion" in Rotterdam (fig. 2).

The abutments consist of a reinforced concrete structure, 29 x 77 m. The latter dimension perpendicular to the axis of the bridge, included the wide stairs leading to the sports ground (fig. 2). The fill consisted of sand and earth and to a minimum level of 7 m above ground. The entire abutment moved a few cm, point A 3 cm and B 13 cm.

To reduce the horizontal earth pressure, no end wall was erected, the piles consequently being especially affected by this pressure. The piles were reinforced concrete with a cross section of 0.40x0.40m. No vertical movement could be recorded. Water pressure cells indicated a considerable increase in water pressure, which could not be reduced by sand cores. When the earth fill was replaced by coarse debris, with an average weight of 1 ton per m^3, the movement stopped.

2. The Vlaggemansbrug over the Noorderkanaal, Rotterdam (fig. 3).

This is an archbridge with reinforced concrete ties. No abutments were necessary. In 1926 the site was filled in with sand up to El. + 0.35 m. In 1936 the foundation pit was excavated and after the piles were rammed in, the concrete arch constructed and filled in with sand up to El. + 3.39 m. Finally the tierods were concreted. No movement of the soil was observed during erection. After water had been admitted to the canal a counter pressure developed, which. in the opinion of the authors, would eliminate all danger of soil movement.

At that time, little was known about water pressure in clay in Holland.

During the winter of 1938/1939 however, it proved that the piles on one side of the bridge were snapped off at El. - 7.35 m causing a settlement of more than 0.30 m.

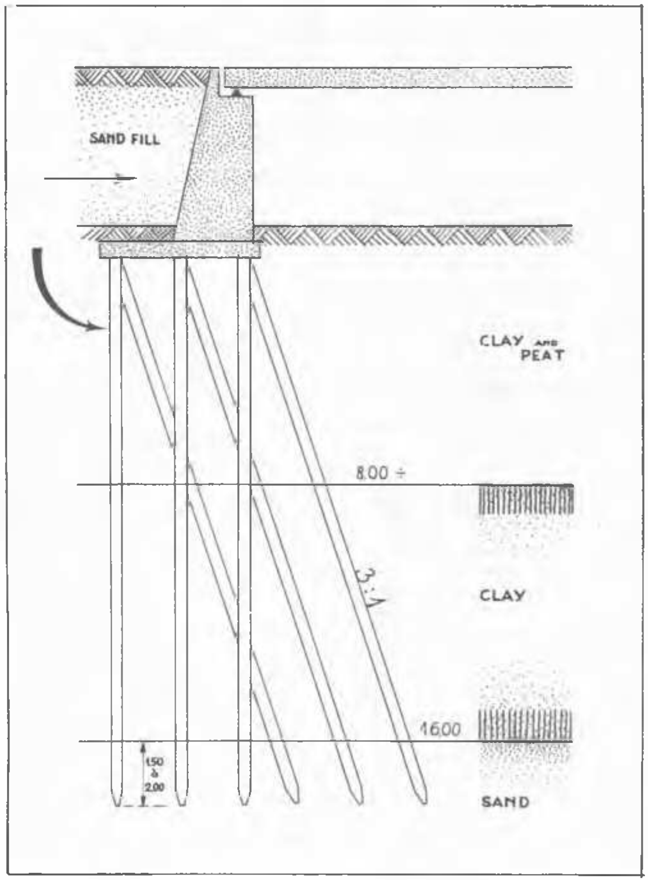


FIG. 1

A steel tube, 0,60 m in diameter, with holes closing like a sliding sash, was used for examination. This tube was sunk into the earth behind a pile; a sliding sash was opened and a hole was dug out through the peat and clay layers in horizontal direction, as far as the pile. A photograph of the fracture was taken (fig. 4.).

During examination the horizontal soil and water pressure unexpectedly cracked the tube. The row of piles on the other side of the canal were apparently not damaged.

An analysis made by the Laboratory for Soil Mechanics at Delft showed that the cause of this accident could be attributed to the increased water pressure, whereby the soft layers had suffered a horizontal plastic movement, finally leading to breakage of the piles.1). The deep sand layer and the sand fill were not affected by this horizontal movement, but only the peat and clay layers in between. The extent of this movement depended on the shearing resistance of this type of soil and on the horizontal pressure, caused by the difference in level between the fill and the bottom of

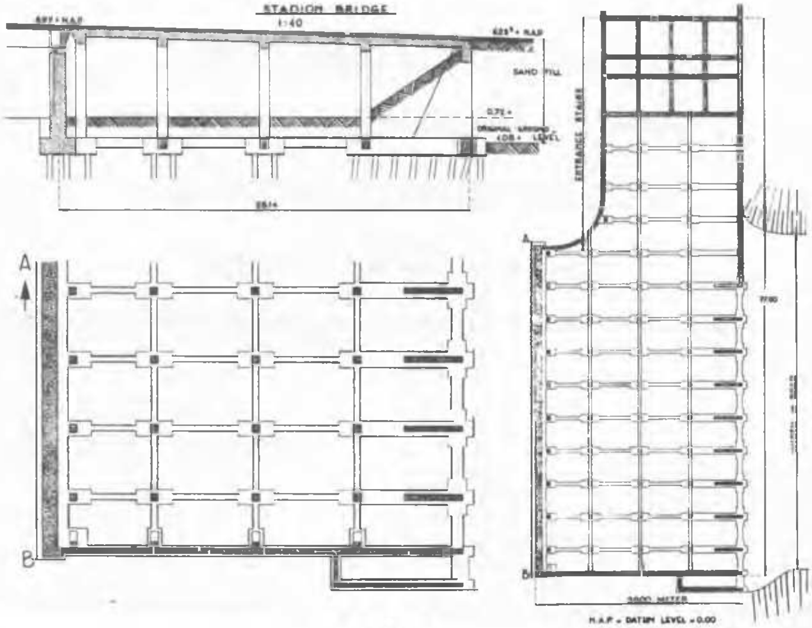


FIG. 2

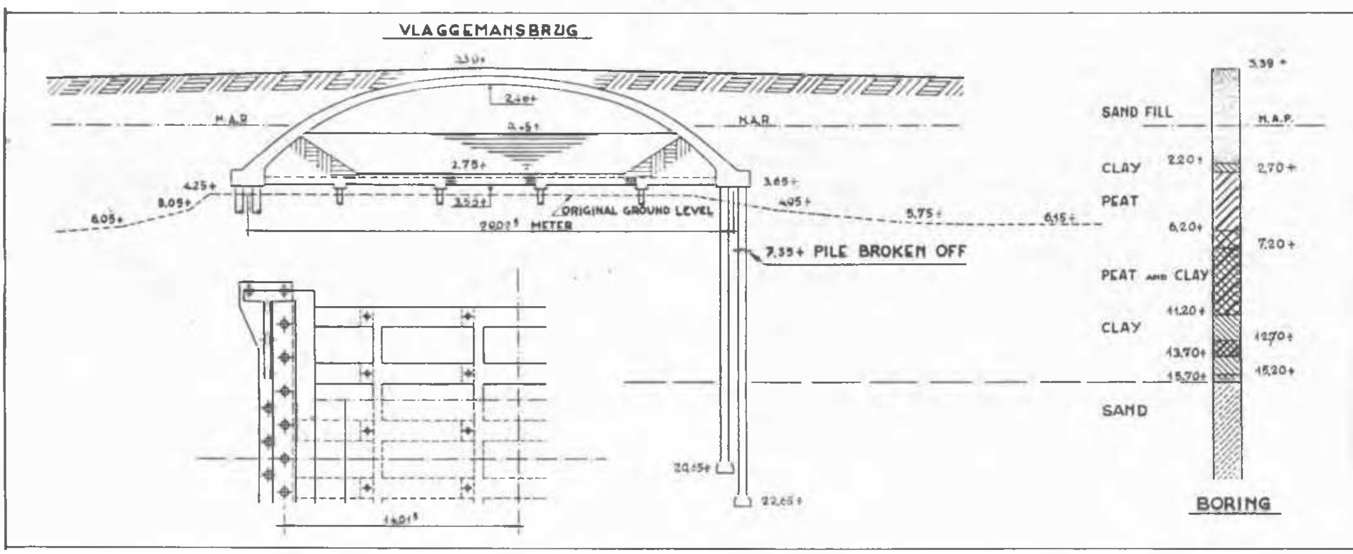


FIG. 3

the canal. There was no loss of equilibrium in this case. As the bottom of the canal did not rise the soil must have been compressed horizontally. This phenomenon might be called horizontal settlement.

3. Highway viaduct at Sliedrecht (fig. 5).
The abutments of this viaduct consist of a single crossbeam supported by reinforced concrete piles. After the concreting had been finished, the pit under the viaduct was excavated and the sand behind the abutments filled in.

From the date of filling (May 1939) until the beginning of 1947 the distance between the abutments decreased about 14 cm.

At the beginning of 1947 the roller bearings (fig. 5) were readjusted in order to prevent tilting over.

From May 1939 up to February 1942 records of the horizontal movement were made (fig. 5). Due to the war this could not be continued, but during the period from Febr. 1942 up to the beginning of 1947 this movement is believed not to have been more than 2 cm.

The diagram shows that the displacement

FIG. 4

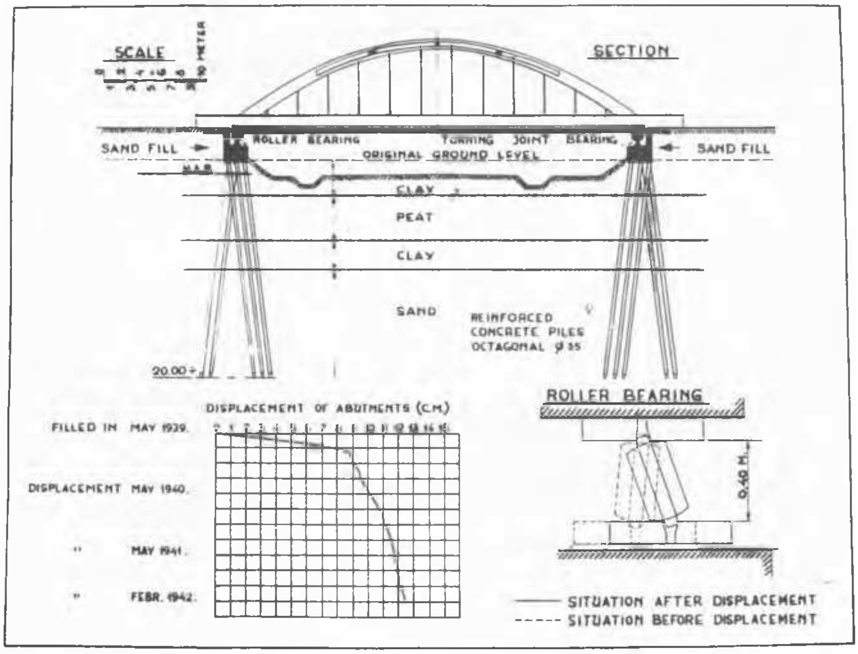


FIG. 5

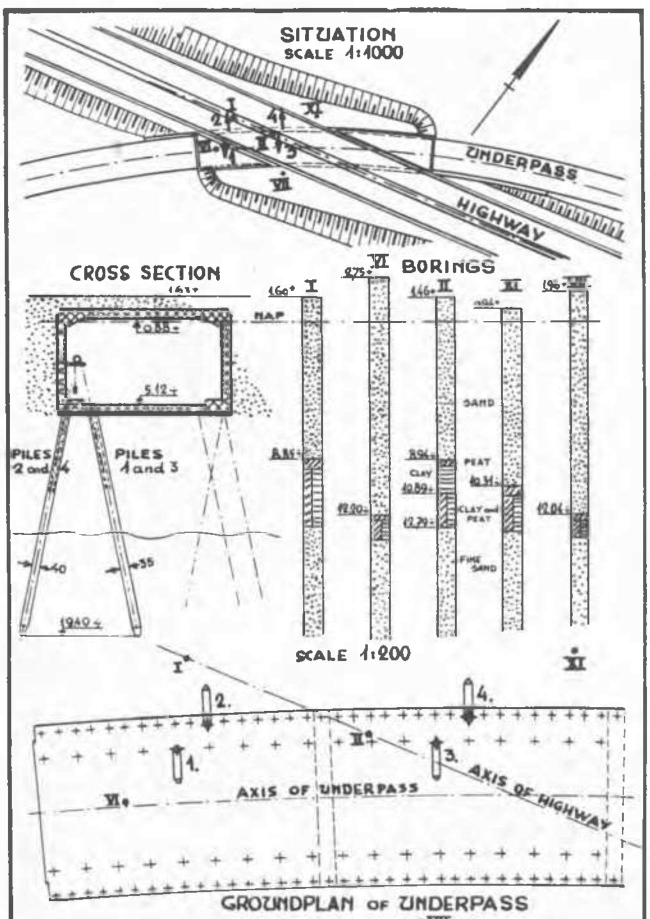


FIG. 6

during the first 3 or 4 months was substantial (about 9 cm). Afterwards it gradually decreased.

Investigations made by the Laboratory for Soil Mechanics at Delft proved that the water pressure under the fill surpassed that in the layers under the midspan of the structure. The displacements were attributed hereto.

It will be clear that in this case a horizontal pressure was acting on the piles, forcing the pile heads to move inwards.

Owing to this action the piles must have been subjected to bending with the possibility of breakage. In our country highway viaducts are as a rule constructed after preliminary soil improvement, the site being filled in with sand, the weight of which causes a lateral displacement of the soft layers. One to two years later the pit is excavated and building operations start.

In the above case this method could not be followed for special reasons.

In Holland the abutments of bridges show a tendency to horizontal movement even in cases of soil improvement. On designing this fact must be taken into account. Movable bearing allow some displacement of the abutment. Between abutment and bridge deck an expansion joint should be applied, allowing a displacement of the abutment to a large extent.

4. Underpass in the highway Utrecht-the Hague (fig.6).

The cross section of this underpass shows a rigid concrete structure. The method of soil improvement has been carried out here. However, the possibility that the deep layers of clay and peat would affect the concrete piles horizontally still existed. It was then decided to examine the behaviour of these piles with regard to bending. A measuring device was designed in collaboration with the Laboratory for Soil Mechanics at Delft. For this purpose a steel tube was cast in in the core of the test piles and a steel wire fixed at the bottom of the hole in the centre of the pile. At the upper end the steel tube was closed with a plug with a centre hole. The steel wire passed through this hole and was stretched by means of a pulley and counter weight. The pulley was movable, see the particulars of fig. 7.

The horizontal movement "a" was calculated by measuring the displacement of the pulley permitting the wire to pass free through the centre of the hole.

Batter piles 1 and 3 (diam 35 cm) were driven with an inward and piles 2 and 4 (diam 40 cm) with an outward inclination.

The records of these tests are shown in

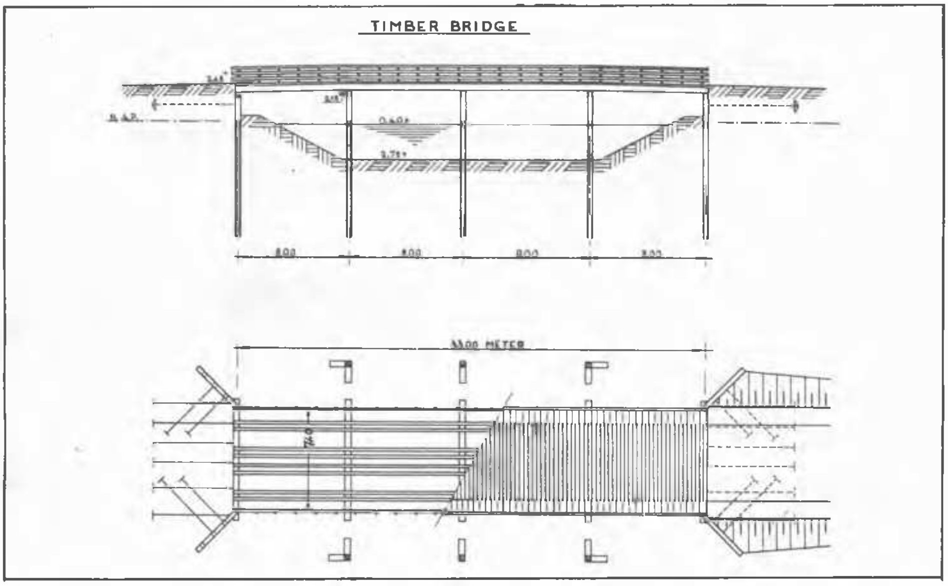
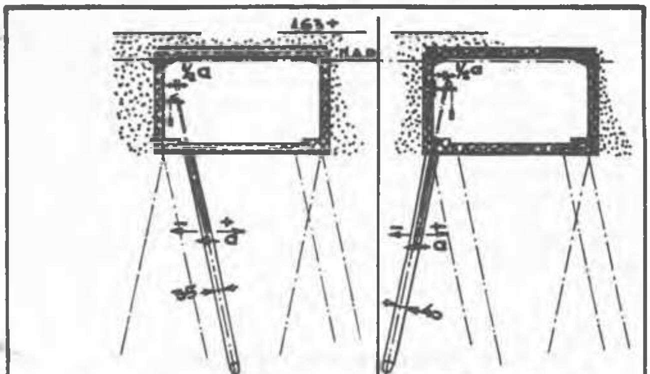


FIG. 8



DATE	PILE 1	PILE 3	PILE 2	PILE 4
	a in m.m.	a in m.m.	a in m.m.	a in m.m.
7 APRIL '38	–	–	+6	+5
3 MAY '38	–5	+17	+12	+5
18 JULY '38	+2	+36	+18	+40
4 NOV. '38	0	–	+20	–
15 FEBR. '39	–2	+46	+23	WIRE BROKEN
22 SEPT. '39	WIRE	BROKEN	+30	
20 SEPT. '40			+36	
14 SEPT. '43				

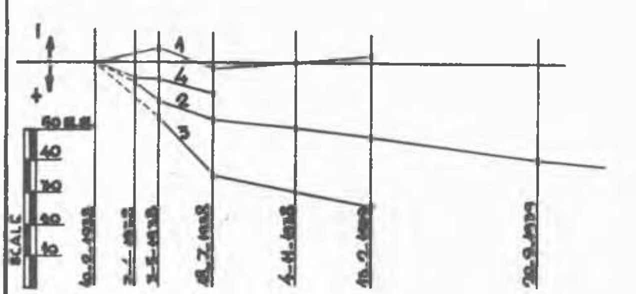


FIG. 7

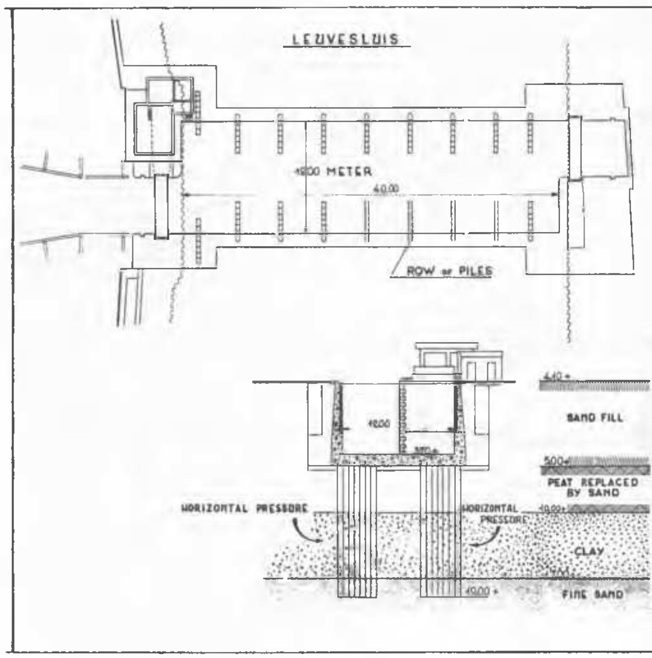


FIG. 9

fig.7. Unfortunately the wires of piles 1, 3 and 4 broke after some time. Only the test on pile 2 could be continued for a longer period. A deflection in the direction of the soil and water pressure is indicated with + ; a deflection in the opposite direction with - .

During the first 4 or 5 months pile 2 was subject to important bending forces due to the horizontal soil and water pressure on the pile, fig. 7. Thereafter the bending did not increase very much.

With reference to the inward inclination of batter pile 3 it was expected that the weight of the overlaying sand fill would cause this pile to bend in the negative direction. The diagram however shows a deflection in the positive direction, due to a considerable increase of soil and water pressure.

The weight of the overlaying sand layers and the horizontal pressure on the piles 2 and 4 are acting in the same direction (+).

Although the figures show some discrepancy, it is clearly shown that piles in this position are subjected to considerable deflection and that an additional dead load may finally lead to breakage.

C. MEASURES TO PREVENT HORIZONTAL MOVEMENT.

1. The best method, but very often the most expensive, is to replace the soft layers, or at least part thereof by sand; this method is called "soil improvement". It is applied a.o. in highway and railroad construction near Rotterdam. Whenever the deep sandlayers are not far below the ground surface this method must be recommended.
2. Since movement of the soil may cause breakage of piles, (which movement cannot be resisted by a normal concrete pile) it may be advisable to use timber piles in some cases, as timber piles are far more elastic. The total length of the timber piles pulled out in the destroyed centre of Rotterdam amounted to more than 2200 km. Thousands of these piles have been used again for reconstruction purposes. A great many, however, were too much bent to be used again, but only very few piles proved to be broken.

The Vlaggemansbrug (see B2) has been replaced by a simple timber bridge with timber abutments (fig. 8). Built in 1939 it is expected that this bridge will last several years before collapse. The water pressure will then have decreased to such an extent that a permanent structure can be built.
3. A third method is to construct relieving floors. Behind the abutment and not connected to it, floors on timber piles are constructed for supporting the fill. With older structures the length of these floors (measured along the centre line of the road) is from 50 to 60 m. In course of time the most backward row of piles will fail, after that the next row and so on; until eventually the water pressure will have decreased sufficiently. For numbers of years this method has been applied successfully, especially for railroad embankments. In view of the latest experiences this old method deserves again our entire attention.
4. In order to prevent increase of water pressure a fill of a low specific gravity might be used, for instance debris or compressed peat. This peat, mechanically compressed into blocks of ± 11 cu.ft. is sold in Holland for agricultural purposes. It also has been applied successfully in constructing streets, where a sand fill, owing to its heavy dead weight, would cause more settlement than a peat fill. On being compressed the blocks are tied together with wire, so that they are already prestressed before being used as filling material. The bearing capacity of these blocks is low however.
5. Sometimes a steel sheet piling is driven behind the abutment in order to protect the piles against horizontal soil pressure. The bridge itself than acts as a strut. Technically and economically this method is only then advisable, when the soft layers are not too thick.
6. The piles have greater resistance against bending when they have a rectangular cross section with the longitudinal axis in the direction of the pressure.
However, when piles with a length of 18 m and more are used it will be almost impossible to handle them with the standard pile driving equipment, as they are far too heavy.

This method is therefore especially suitable for rather thin soft layers, requiring piles of comparatively short length.
7. Better results may be obtained by driving the piles in rows. The direction of the rows must correspond with the direction of the soil pressure. It will be advisable to choose the distance between these rows as wide as possible, so that the soil in between, may move freely.
With these types of foundations the most backward piles will fail first, then the next ones etc. This fact should be taken into account into account on designing a foundation. The water pressure will gradually decrease.
8. It will even be better to drive the piles in closed rows. This method is used with the lock "Leuvesluis" in course of construction in Rotterdam (fig. 9). First the layers of peat were excavated and replaced by sand. After the lock will be filled in, the height of the height of the total layer of sand will amount to 14 m. The layers of clay, from El. - 10 to El. - 17 under this sand fill will settle horizontally.

The piles have a cross section of 0.40 x 0.60 m and a length of 14 m.
9. If, in cases of bad soil conditions, absolute safety in connection with horizontal soil and water pressure is required, caissons may be considered. On the whole this method is more expensive than a pile foundation. Nevertheless for this purpose caissons have often been used with great success in Holland.

REVERENCE.

1)E.C.W.A.Geuze,Horizontal pressure against a row of piles.
See following paper No:VII b 2

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VII b 2 HORIZONTAL EARTH PRESSURE AGAINST A ROW OF PILES

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INTRODUCTION.

The construction of the Vlaggemans-bridge, a road-bridge, was completed in December 1936. In February 1937 the groundworks including the digging of the canal, the sand fills and the embankments were finished.

During the winter of 1938-1939 large cracks were observed in the superstructure. An investigation of the cause of these cracks gave the following results:

a) One of the foundation piles of the row at the southern end of the bridge had subsided, others on the same side of the row apparently too.
b) Consequently one corner at the southern end of the bridge showed a considerable settlement.

The Delft Soil Mechanics Laboratory was