LATERAL SOIL PRESSURE AND NEGATIVE FRICTION ON PILES

LES CONTRAINTES LATERALES ET LE FROTTEMENT NEGATIF SUR DES PIEUX

БОКОВОЕ ДАВЛЕНИЕ ГРУНТА И ОТРИЦАТЕЛЬНОЕ ТРЕНИЕ СВАЙ

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SYNOPSIS. The computation of the lateral soil pressures on pile foundations is a very complicated matter. It can only be done in an approximate way assuming elastic behaviour of the loaded soil mass. In order to adapt these calculations to more realistic circumstances an extensive program of tests with special instrumented piles is carried out in the Netherlands. These piles are provided with devices for measuring bending moments, negative skin friction, deflections and soil pressures on the shaft. The piles are situated near the edge of a 9 mtrs thick sand embankment for a road. The compressible layer underneath has a thickness of 9 mtrs and consists of clay and peat. Some of the measuring piles are placed in a group of 10 piles of which the results are compared with those of 2 instrumented "single piles". One of the aimes of the investigation is to determine the effect of the application of vertical sand drains on the lateral pressure and the negative skin friction. The results of the measurements are correlated with the results of computations and laboratory tests on undisturbed samples.
In this paper a review is given of the set-up of the investigation. Some results will be discussed in detail and will be compared with the results of computation.

INTRODUCTION

When viaducts and similar structures are built in areas where the subgrade consists from the original ground level downwards of soft and compressible layers several metres thick, horizontal earth pressures come into action on the foundation piles of the abutments. As a result of these horizontal earth pressures, bending moments will occur in the piles. Their size depends mainly on:
a. the deformation properties and the thickness of the soft layers beneath the fill;
b. the composition and thickness of the fill;
c. the degree of consolidation of the soft layers under the load caused by the fill;
d. the resistance to bending of the piles;
e. the location of the piles in respect of one another and of the fill, and can be determined by means of a calculation method developed by the Delft Soil Mechanics Laboratory. (Begemann, H. and De Leeuw, E.H., 1972).

To check whether there is reasonable agreement with the moments actually occurring, extensive field tests are at present being conducted.

For this, piles have been placed at the edge of a sand fill some 9 m thick that is resting on a highly compressible subgrade. A number of piles have been fitted with measuring equipment for determination of the deflection, negative skin friction, bending moments and earth pressures.

Owing to the structure of the subsoil in the Netherlands, especially in the western part of the country, the problem of horizontal pile pressures is of frequent occurrence. As a result, special, costly measures are often required to avoid damage to the structures.

DESCRIPTION OF THE SITE

The test site consists of two sections each of about 25 x 55 sq.m. In one section vertical sand drains have been installed to accelerate the process of compression. The interval between the sand drains is 3 m.

The level of the site has been raised to 6 m above New Amsterdam Datum (N.A.P.), partly by hydraulic fill and partly by dry fill. The slope gradient is 1 in 1½.

Fig. 1 shows the situation of the test sections and of the nature of the soil, which was determined by means of borings and soundings. In the laboratory tests have been made on undisturbed samples to determine the properties of the soil, whose average values are shown in the table below.

Kind of soil	Compression constants $1/c_p$*)	$1/c_s$*)	Permeability coefficient k in cm/sec	Angle of internal friction φ	φ'
sandy clay	0.025	0.002	5.10^{-5}	24°	28°
peat	0.220	0.036	5.10^{-7}	16°	20°
organic clay and peat	0.110	0.017	5.10^{-7}	8°	22°

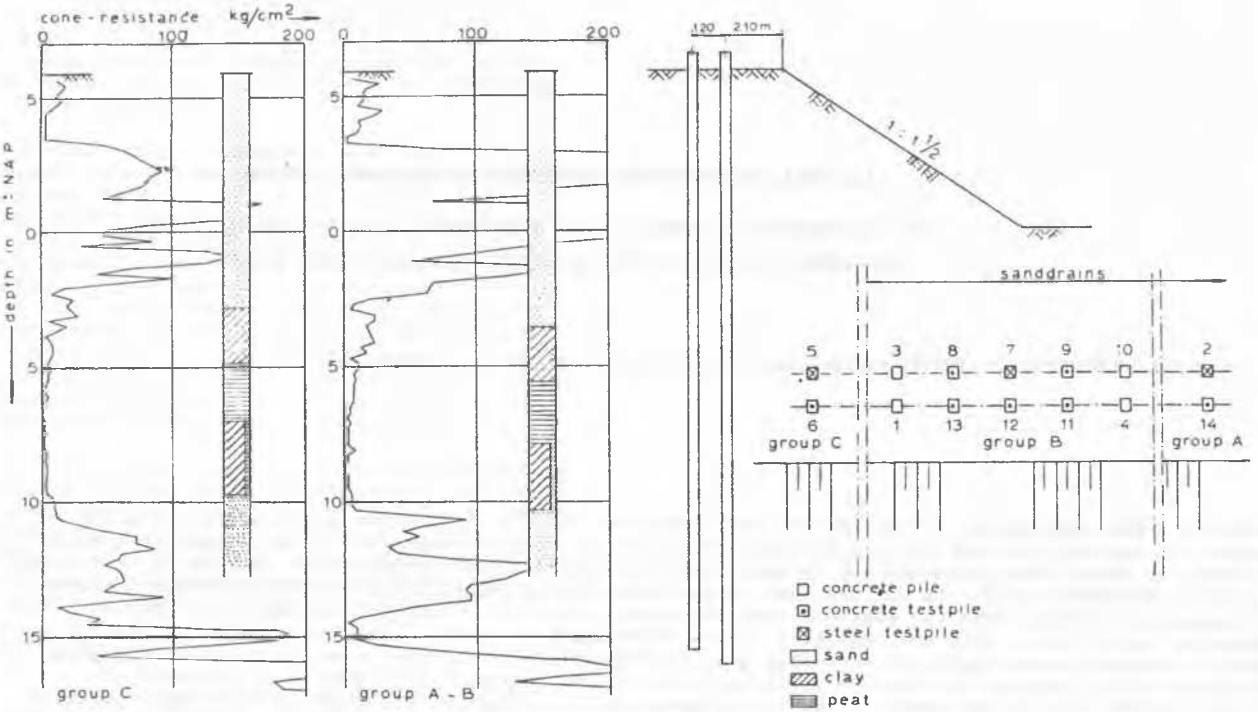

FIG. 1. SITUATION AND NATURE OF THE TEST SITE

*) $1/c_p$ is a criterion of the initial settlement, and $1/c_s$ of the secular settlement;
$\frac{1}{c} = \frac{1}{c_p} + \frac{1}{c_s} \log t$, in which t is the time in days and c the compression constant. The subsidence of the fill and of a number of points in the compressible layer is measured by means of markers.

Fig. 2 shows the result of the subsidence measurements in the section with sand drains and in that without. The trend of the water pressure in the various layers is also measured.
The movements of the soil in a horizontal direction are measured by means of inclinometers.

PILES

Near the edge of the fill 14 piles have been driven, divided among three measuring set-ups A, B and C. The location of these piles is shown on the general view of the site in Fig. 1.
The piles are numbered in the order of driving.
Measuring set-ups A and C represent the most elementary problem, in which the horizontal earth pressures act on two piles placed behind one another without disturbing neighbouring piles.
The calculation methods here are based on the situation in accordance with set-up C (without sand drains), although in practice sand drains will be used in most cases with such a structure of the subsoil.

Measuring set-up B represents a configuration of foundation piles more in accordance with practice. Each measuring set-up contains one steel measuring pile (Nos. 2, 5 and 7) of which the resistance to bending and the surface area at right angles to the direction of the horizontal pressures are

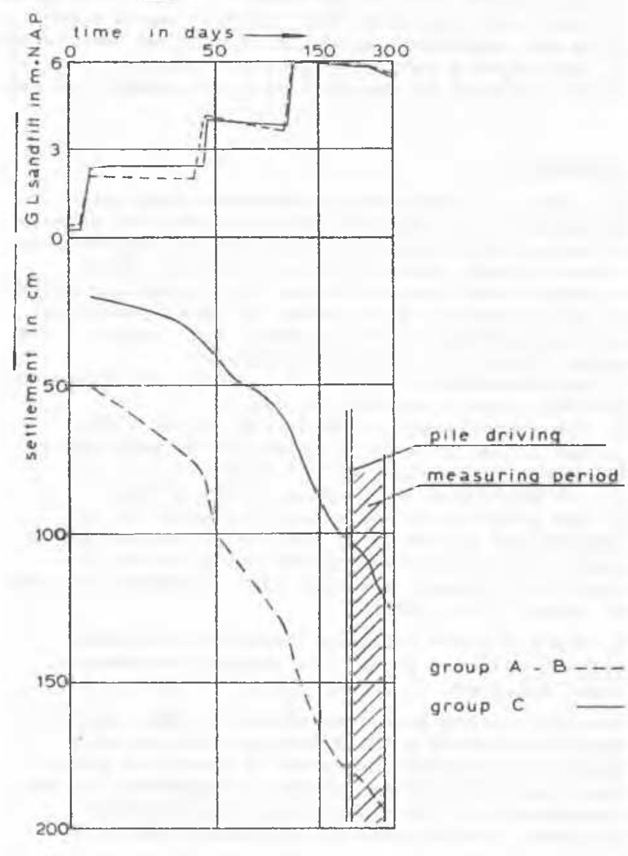

FIG. 2. THE TIME-SETTLEMENT CURVE OF THE FILL

equal to those of the concrete piles used: EI = 7500 tm^2 and the width is 40 cm.

To make it possible to build in equipment, the pile has been fabricated in two halves which have then been welded together after incorporation of the equipment mentioned below.

At seven different levels electrical strain gauges have been installed, in both the tension and the pressure zones of the pile. These measure the strains or moments occurring locally in the pile shaft.

From the same seven levels to the pile head conduits of the type used to carry electric wires are attached, being welded at the bottom to a steel support fastened to the pile wall. By measuring the change in length of a conduit in respect of the pile head the average normal stress or moment over the length of the conduit is determined.

Moreover, in the steel measuring piles steel tubes are fastened to the pile wall, of which the deflection curve is measured by means of an electrical inclinometer.

At four different levels earth pressure measuring cells are fitted in the pile wall on both sides of the pile.

The concrete measuring piles (Nos. 6, 8, 9, 11, 12, 13 and 14) have been located in set-ups A, B and C in such a way that immediate comparison with the behaviour of a steel measuring pile is possible. A 20 m long plastic tube has been cast into these piles beforehand, in which the horizontal movements in respect of the pile head are recorded by means of an optical method. (Lousberg, E.,and v.Milaan, 1965).

Moreover, in group B four normal concrete piles have also been driven (Nos. 1, 3, 4 and 10). The piles were all vertically driven by means of a diesel hammer with a drop weight of 2250 kgf at a maximum output of 6300 kgm. The pile-driving was done at the beginning of December 1971.

With the aid of a recording accelerometer attached to the pile head the accelerations occurring during driving have been measured on each pile. In this way the whole pile-driving process was checked in such a way that the chance of damage being done to the measuring equipment was minimized. As maximum admissible acceleration approx. 200 g was adhered to at first.

By experimenting with varying heights of drop and the composition of the pile helmet packing, data are obtained on the most favourable manner of pile-driving. Nevertheless, the mechanical strain gauges on steel measuring pile No. 2 have been completely destroyed and those on measuring pile No. 5 partly destroyed.

In view of this, measuring pile No. 7 of group B was driven in a bored hole.

The rest of the measuring equipment has remained intact, so that the planned programme of measurements can be performed in its entirety.

RESULTS OF MEASUREMENTS

For the following discussion of a number of important results of the measurements, only the data measured over a period from the beginning of December 1971 to mid February 1972 (80 days) are available. The measurements will continue for some considerable time yet.

The first measurements clearly showed that quite soon after driving of the piles a great load occurred through negative skin friction. The trend of this negative skin friction on pile No. 2 is shown in Fig. 3.

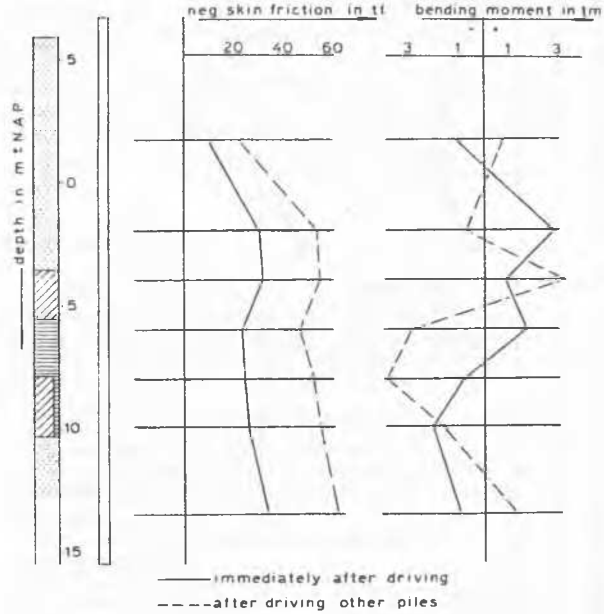

FIG. 3. MEASUREMENTS ON PILE NO. 2 DURING DRIVING

Moreover, during driving of the pile great initial bending moments already occurred, as can likewise be seen from Fig. 3.

Through the driving of a pile in the immediate vicinity an increase in the load through negative friction occurred, while the bending moment distribution also changed considerably.

Immediately after driving all piles had an initial deflection away from the slope of a maximum 7 cm.

Fig. 4 shows for the measuring piles the trend of the load through negative skin friction and the bending moment 20, 40 and 80 days respectively after termination of pile-driving.

Differences between the results of the measuring piles are bound up with the following circumstances: Measuring pile No. 2 in group A was driven through a fairly solid surface layer of sand (see Fig. 1), while in the soft layers the degree of consolidation under the load from above was already fairly considerable at the moment of driving: approx. 70%.

Measuring pile No. 7 in group B is situated in the middle of a group of piles in a prebored hole, while the degree of consolidation at the moment of driving was just as great as for group A.

Measuring pile No. 5 was driven from the underside of the layer of sand fill after a hole had been prebored in the sand packet; at the moment of driving the degree of consolidation was approx. 45%.

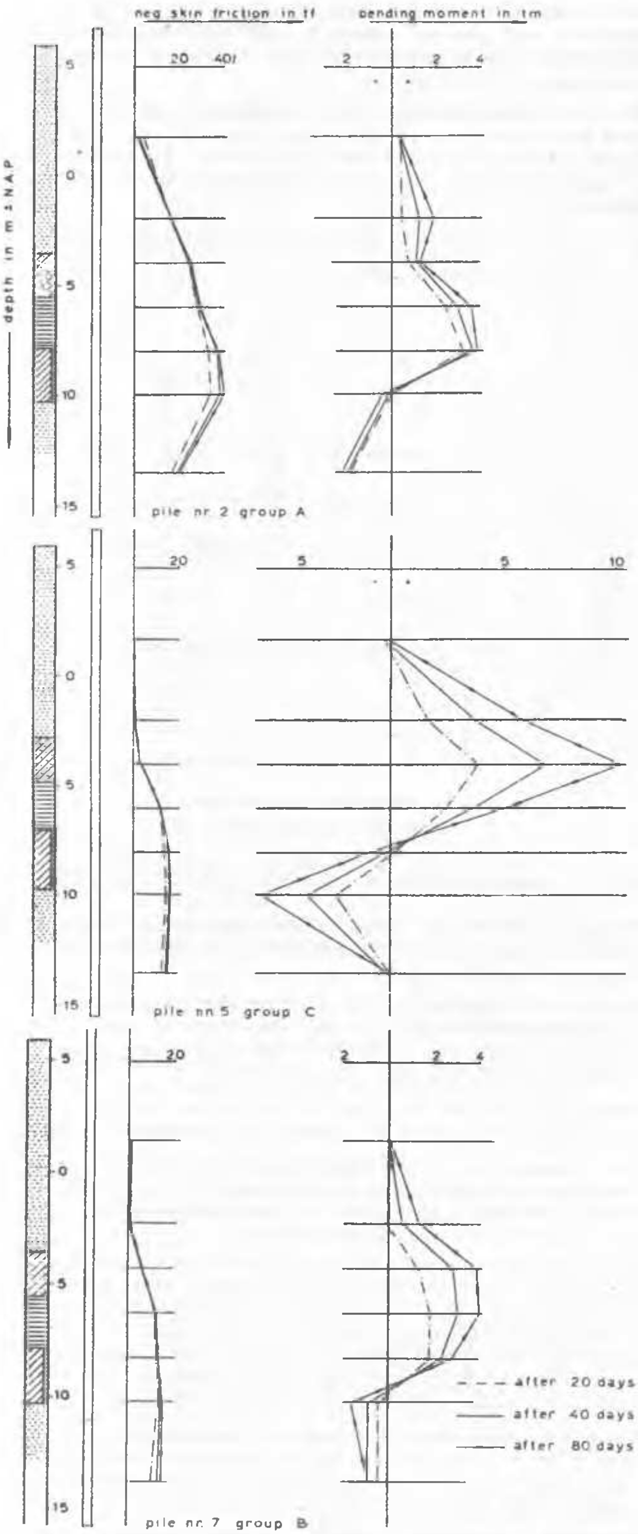

FIG. 4. MEASUREMENT OF PILES NOS. 2, 5 AND 7 AFTER TERMINATION OF PILE-DRIVING

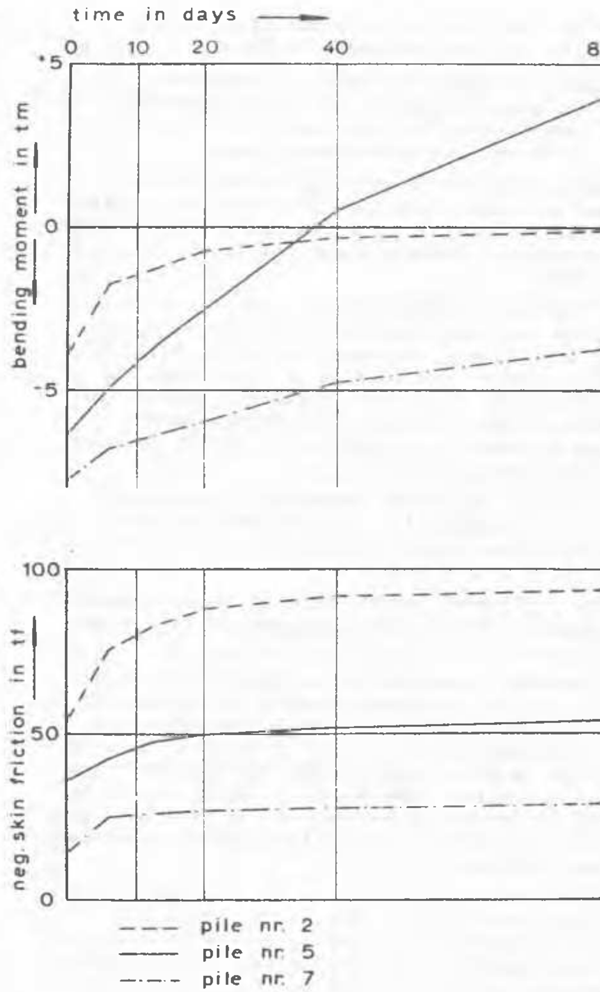

FIG. 5. SIZE OF AND INCREASE IN THE MAXIMUM BENDING MOMENT AND THE MAXIMUM NEGATIVE SKIN FRICTION

Next, Fig. 5 shows for the three steel measuring piles the trend of the maximum bending moments and negative skin friction actually occurring over the above-mentioned period of 80 days.
In this measuring period all the piles proved in addition to undergo a deflection which entirely or partly cancelled out the deflection caused by driving. In Fig. 6 this phenomenon is illustrated for piles Nos. 7 and 12 of group B, which stand behind one another.

In the period of measurement stated the pile heads likewise displayed a horizontal displacement away from the slope, as Fig. 6 also shows.

COMMENTS

The results of measurements and experience in the above-mentioned pile-driving and measuring period show that the most interesting phenomena occur during and immediately after the driving of the piles, so that a high frequency of measurement is required in that period.

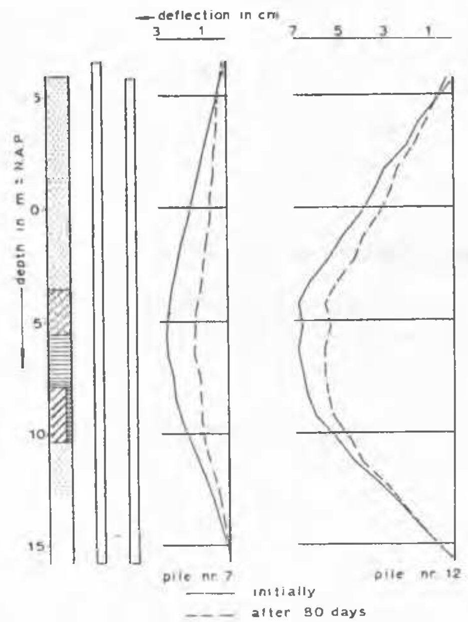

FIG. 6. DEFLECTION CURVES OF PILES NOS. 7 AND 12

In that connection the increment curves of Fig. 4 must also be considered. These are plotted against a zero position recorded after termination of pile-driving. However, pile No. 2 was driven nine days before that date and piles Nos. 5 and 7 seven days before.

With the aid of the calculation method developed by the Delft Soil Mechanics Laboratory the maximum moments in piles Nos. 2 and 5 were calculated before commencement of the test with the aid of data available at that time and estimated constants as regards soil properties.

There followed for measuring pile No. 2 a maximum bending moment of 5 - 10 tm and for pile No. 5 of 10 - 15 tm. The measured increases in the bending moments were, according to Fig. 4, approx. 4 tm and 10 tm respectively after 80 days. As has been made clear above, these values may be higher in view of the fact that the zero position was recorded a few days after the piles in question had been driven.

The degree of consolidation has practically no effect on the size of the maximum negative friction; on the other hand, it is of great importance to the maximum moment occurring in the foundation piles.

The deflections occurring as a result of pile-driving are often larger than and in an opposite direction to those resulting from the development of the horizontal earth pressures.

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