Bending Moments in Piles Due to Lateral Earth Pressure

Moments fléchissants dans les pieux sous l'effet de la poussée des terres latérale

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Summary

When constructing embankments close to existing buildings, it is possible that-owing to lateral displacements of a soft subsoil-heavy horizontal loads may be imposed on the foundation piles.

In order to determine the stresses in the piles as a function of the distance from an embankment, tests were carried out on a building site in Amsterdam in 1959.

Three test piles, each with a length of 12·5 m, were driven at 5 m centres into a sub-soil of peat, clay and sandy clay, the whole covered with a sand embankment 2 m deep. The toes of the piles were driven into a firm stratum of sand; the heads of the piles were held in place by struts. The test piles were steel tubes with a rectangular cross-section having the same strength in bending as concrete piles of equivalent dimensions.

On one side of the pile-row an embankment was constructed with a height of 7 m and at a distance of 30 m from the piles. It was extended in the direction of the piles by steps of 5 m.

The stresses in the piles due to this load, were measured by means of strain gauges. The bending moments were determined from strain gauge readings.

The strain gauges gave excellent service for the 6 months that the test lasted. At the same time the deformations in the sub-soil, the pore water pressure in the clay layer and the forces in the struts were measured.

The tests showed that piles of normal dimensions can be overloaded considerably by these horizontal forces. At a distance of 10 m between the piles and the toe of the embankment bending moments up to 14 ton metres were measured. Horizontal displacements in the sub-soil occured down to a depth of 10 m below ground level.

Sommaire

Pendant la construction de remblais le long de bâtiments existants des forces horizontales peuvent agir sur les pieux de fondation par suite de déplacements latéraux dans le sous-sol mou.

Pour déterminer les tensions dans les pieux en fonction de la distance au remblai, des essais furent effectués en 1959 sur un chantier à Amsterdam.

Trois pieux d'essai, long de 12,50 m, furent battus dans un terrain composé de tourbe, d'argile et de sable argileux et recouvert d'une couche de sable de 2 m. La pointe des pieux était enfoncée dans une couche de sable dur; la tête des pieux était maintenue en place par des étais. Les pieux étaient des tubes d'acier à section rectangulaire et de même résistance à la flexion que des pieux en béton de dimensions égales.

Un remblai de sable de 7 m de haut fut construit à 30 m de la rangée de pieux et rapproché de ceux-ci par étapes de 5 m. Les tensions résultantes dans les pieux furent mesurées avec des extensomètres électriques; en même temps les pressions d'eau interstitielle dans la couche d'argile et les forces d'appui contre les étais furent enregistrées.

Les essais ont démontré que les tensions admissibles dans des pieux normaux peuvent être largement dépassées par l'effet des forces horizontales du sous-sol. Des moments de 14 tonne-mètres furent mesurés pour une distance de 10 m entre pieu et remblai. Des déplacements du sol furent observés jusqu'à 10 m de profondeur.

Within the building area of the city extension of Amsterdam are high level roads founded on sand embankments. Some of these embankments will not be constructed before the surrounding buildings, all on pile-foundations, have been completed. As the sub-soil of most of the building areas concerned is composed of soft peat and clay layers down to a depth of at least 7 m, a considerable amount of lateral earth pressure against the existing pile foundations must be expected during construction of the sand embankments with an average height of 5 to 6 m. In order to design the concrete pile foundations of buildings adjacent to the future high level road embankments, an accurate estimate of bending moments in the piles as the result of lateral earth pressure has to be made.

The theoretical approach to this problem proved to be unreliable due to the number of assumptions that had to be made concerning stress distribution in the various subsoil layers. It was therefore decided to perform a full scale test by measuring the actual bending moments in test piles as a result of lateral earth pressure from a sand embankment at different distances from the piles. This test could be undertaken during the construction of a road-embankment in the southern part of the city extension of Amsterdam where the soil conditions are similar to these encountered in most of the new building areas of the town.

Fig. 1 shows the soil layers at the site of the test; on top of the peat, which formed the original surface layer in the polder, a sand embankment 2 m deep has been recently applied for consolidation of the soft subsoil. The reference level indicated on the drawings is the Normal Amsterdam Level, (N.A.L.). The groundwater level is 1·20 m below N.A.L.; the peat and the underlaying clay layers are all saturated with water. After an original settlement of approximately 0·70 m by the weight of the 2 m sand embankment the ultimate total settlement will reach an average value of 0·90 m in a consolidation period of 25 years. The diagram of the cone penetration test (Fig. 2) shows a layer of relatively high bearing capacity at a depth of 11 m, this is the sand layer in which the foundation piles are usually driven; those piles with an average length of 12 m are encased at the top in the foundation beams of the buildings; the toes of the piles are firmly embedded in the sand layer.

As concrete piles are unsuitable for accurate stress measurements, it was decided to use three identical steel tubes with a rectangular cross-section of 30 by 30 m and a length of 12·50 m. Those test piles should have the same bending

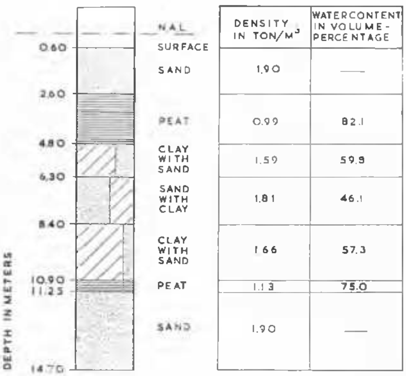

Fig. 1 Boring profile at test site.
Profil du sol à l'endroit des essais.

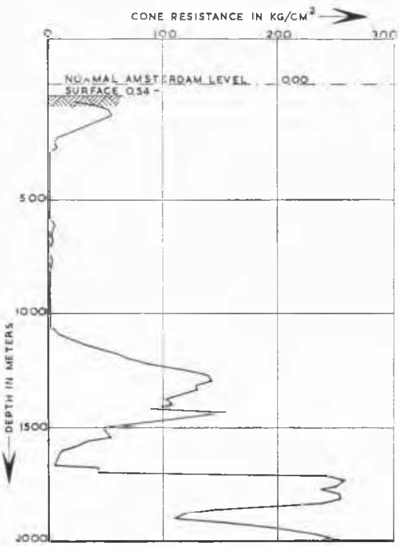

Fig. 2 Cone penetration diagram.
Profil de sondage au pénétromètre.

strength as concrete piles of equivalent external dimensions, which resulted in the use of 6 mm thick steel plate for their construction. For each test pile two *U* shaped profiles were especially made, then welded together and closed by steel plates at both ends. Before welding, electrical strain gauges were fixed at 4 places on the inside of each half pile, making 8 measuring points per pile. The largest earth pressure being expected in the upper soil layers, the measuring points were concentrated in 4 cross-sections of the upper part of the piles. In each of those 4 sections the stresses due to longitudinal forces and bending moments can be measured at two points diametrically opposite each other. The electrical strain gauges are of the Hottinger type FB I with 120 Ohm resistance, connected in complete Wheatstone bridges with two active strain gauges. Fig. 3 shows

Fig. 3 Test pile with strain gauges during fabrication.
Pieu d'essai avec extensomètes électriques pendant la fabrication.

the open piles with the strain gauges before welding. In each pile a small steel plate is fixed by a single bolt, supporting an additional measuring point, that will remain without stress throughout the test and serves as check point for the measuring device. After completion, the test piles were gauged by means of a bending test as a horizontal girder on two supports.

On the building site the three piles were carefully driven to the same depth; they were placed in one line at 5 m centres. Then a 7 m road embankment was constructed by hydraulic fill with the toe of the embankment slope at a distance of 30 m from the piles. The heads of the piles were propped up at ground level against a heavy concrete beam founded on 8 batter piles, so they could not move in the direction of the lateral earth pressure; the test piles were

Fig. 4 Disposition of strain reading instruments in the shed.
Disposition des instruments de mesure.

thus under conditions similar to those of normal concrete foundation piles.

Pressure boxes were mounted between the propping up and the heads of the piles for measuring the reaction forces. Near the piles and between the piles and the embankment several electrical pore water pressure meters were placed in the clay layer immediately under the peat. In alignment with the piles, four flexible tubes were placed in the ground by which the displacements of the subsoil could be measured with a Plantema type inclinometer. All the cables of the strain gauge measuring points, coming out of the piles near the top, were brought together in a shed where they were permanently connected to the reading instruments. All the readings of the pore water pressure meters the reaction force pressure boxes and the deflectometers could also be made in the shed.

For test purposes the embankment, made by hydraulic fill at a distance of 30 m from the piles, was progressively extended in the direction of the piles by steps of 5 m, as indicated on Fig. 5. Each step was followed by a period

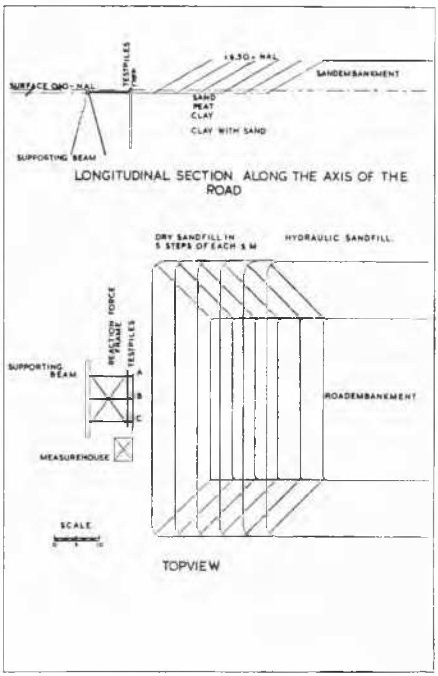

Fig. 5 Schematic plan of tests with steps of embankment extension.

Plan schematique des essais avec phases d'avancement du remblai.

of rest of two or more weeks. When the toe of the embankment was extended to a distance of 10 m from the piles, the bending moments reached nearly 14 ton metres which was about the maximum the piles could stand without permanent deformation that could have disturbed the strain gauge measurements.

In order to keep the piles intact, two were pulled out at this stage of the test; the zero readings proved that the measuring points were still in good condition after more than 6 months' use. The third pile was submitted to a last test by extending the embankment another 5 m. Due to an artificial lowering of the pore water pressure with vertical sand drains in the interval between the last two steps, the measured stresses in the third pile did not exceed those of the previous stages. Fig. 6 gives a general view of the test site seen from the top of the embankment.

Fig. 6 General view of test site.

Terrain d'essai vu du haut du remblai.

Figs. 7 to 10 show the results of the test. Fig. 7 gives the relationship between the measured bending moments in the test piles and the distance from the piles to the toe of the road embankments; the measuring data obtained with the three piles proved to be in very close agreement. The maxi-

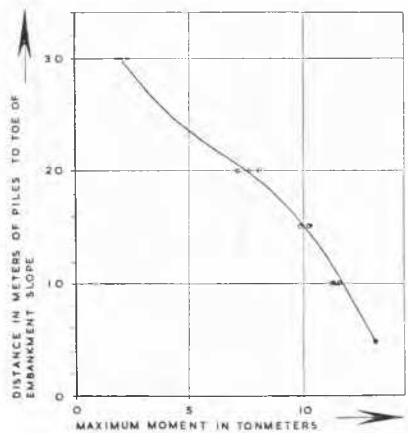

Fig. 7 Bending moments in piles related to distance from embankment.

Moments fléchissants dans les pieux en fonction de la distance au remblai.

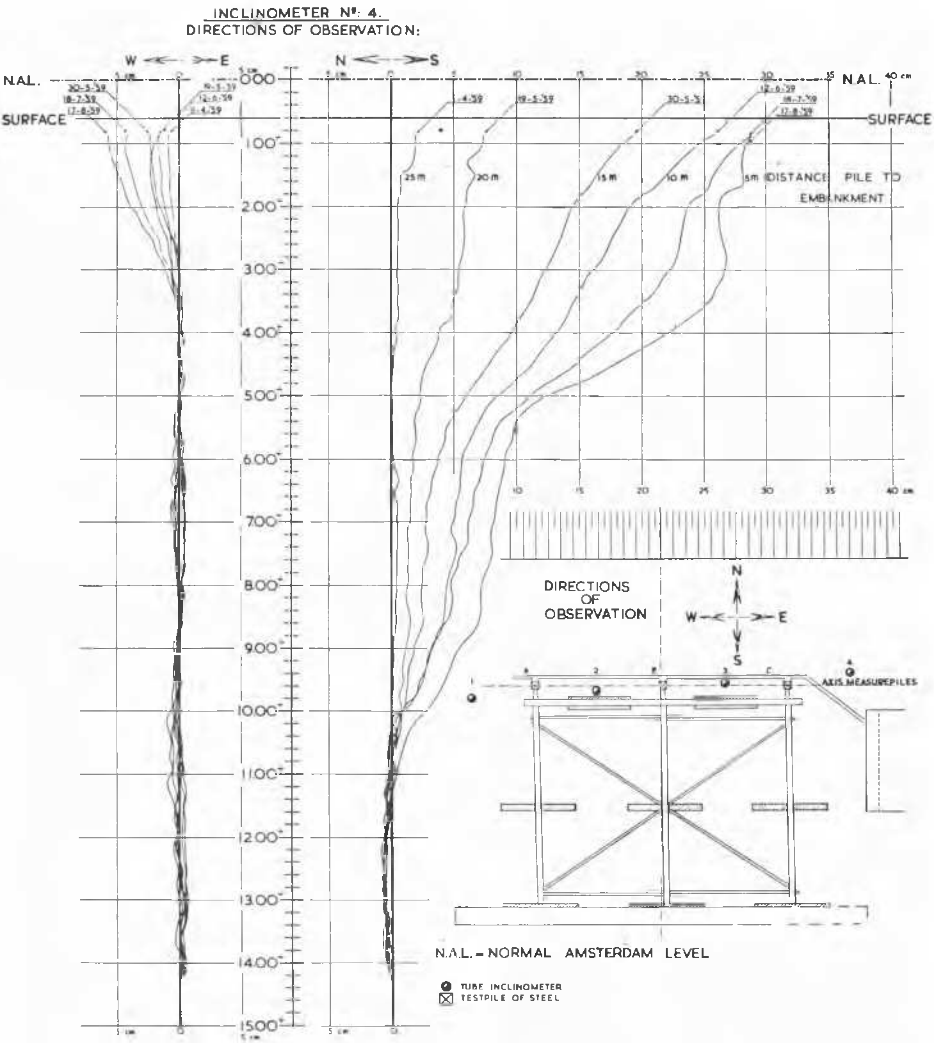

Fig. 9 Horizontal soil displacements measured with inclinometer.

Déplacements horizontaux du sous-sol mesurés avec l'inclinomètre.

mum bending moment was observed at a depth of about 2·50 m, that is approximately the level of the separation between the sand and peat strata. Fig. 8 shows the relationship between the horizontal reaction forces at the head of the piles and the distance to the toe of the embankment. In normal building practice this horizontal force will not cause special problems : the stiffness of the whole pile foundation will usually be sufficient to withstand it ; if necessary, batter piles can be used.

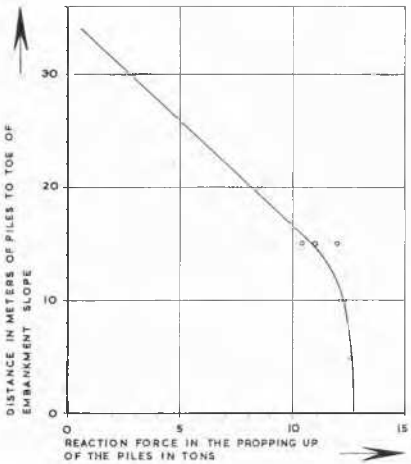

Fig. 8 Horizontal strut reaction related to distance from embankment.

Force de réaction horizontale en fonction de la distance au remblai.

Fig. 9 shows the displacements in the subsoil measured after each consecutive step of the extension of the embankment. After the third step (distance 15 m) the horizontal displacement increased more than during the first steps and reached 20 cm at ground level. The largest displacements were measured at the surface ; they diminished with increasing depth. Below the level of 5 m, in the sandy clay, the displacements were relatively small ; in the firm sandlayer below 11 m depth no displacements have been recorded. Fig. 10 shows the observed pore water pressure in the clay layer near the piles as a function of the corresponding highest

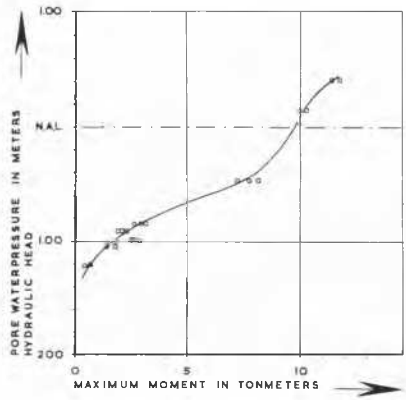

Fig. 10 Maximum bending moment related to pore water pressure in clay layer.

Moment fléchissant maximum en fonction de la pression d'eau interstitielle dans l'argile.

bending moments in the piles. The pore water pressure in the diagram is referred to the Normal Amsterdam Level (N.A.L.). The overpressure of pore water as a result of the construction of the embankment has to be measured from the initial ground water level at 1·20 m below N.A.L. For a distance of 15 m between pile and toe of embankment, when the bending moment was 10 ton metres, the pore water pressure in the clay was 1·40 m, that is 0·20 m above N.A.L. Below the top of the embankment, with 7 m of sand, the highest overpressure was 7·20 m, decreasing only very little during the test period.

The conclusion from the above test results is that, for soil conditions similar to those of the test site, special precautions shouls be taken if high embankments are constructed at less than 25 m distance from existing pile foundations, the maximum permissible bending moment in normal concrete piles with shaft dimensions of 30 by 30 cm being about 5 ton metres.

In Amsterdam, in all cases where pile foundations have to be made for buildings located at less then 25 m from future embankments, the use of especially reinforced piles is recommended. If bending moments of 10 ton metres or more are expected as the result of lateral earth pressure. piles of special design are used ; the bending resistance of those piles is increased by additional steel reinforcement and by enlargement of the pile shafts.