Large diameter casing piles, design, testing and monitoring

Pieux à grand diamètre tubés forés, conception essai et surveillance

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ABSTRACT

The railway extension project between three of the major Dutch cities, The Hague, Rotterdam and Utrecht, was commissioned by the Dutch railway authority Prorail in 2005. In the original client design all bridges had foundations that consisted of thick concrete slabs with a large number of driven prefab concrete piles as are commonly used in the Netherlands. Since the bridges themselves were supported by columns of 1,2 m diameter an alternative design was made using bored casing piles with a diameter of 1,65 m, one pile below each column. The piles should be capable of handling a design pile load of 12.000 kN, but should also have a vertical deformation less than 10 mm as a train passes by. Since bored piles normally have a rather feeble load-displacement behaviour, it was deemed necessary to equip the piles with a grouting device that was injected after hardening of the concreted piles.

The use of these kind of techniques was a first in the Netherlands. Therefore it was decided to use CPT's as a way of checking the influence of the installation of the pile on the surrounding soil, to install three instrumented piles to be tested on site by means of a static load test and to monitor the deformation of all piles during and after construction.

In 2008 the second stage of the project started with the installation of an additional 17 piles. In order to get information on the pile behaviour under even larger loads two extra piles were tested by means of a Statnamic load test with a 16 MN device.

RÉSUMÉ

En 2005, l autorité néerlandaise responsable de chemins de fer Prorail a passé une commande de l'élargissement de la voie ferroviaire entre trois des principales villes du pays, La Haye, Rotterdam et Utrecht. Selon des plan des ponts, faites par le client, les fondations des colonnes étaient au debut des semelles de béton épaisses avec un nombre important de pieux en béton préfabriqués. Depuis que même les ponts étaient soutenus par des colonnes de 1,2 mètre de diamètre une conception alternative a été introduite avec l'utilisation de pieux forés et enveloppés de 1,65 de diamètre, chaque pieu sous chaque colonne. Ils doivent pouvoir supporter une charge de 12 000 kN, et être assez rigid (une déformation de moins de 10 mm) lors du passage d'un train. Comme les pieux forés sont plutôt assez souple, il a été jugé nécessaire d' equipper leurs pointes d'un dispositif de joints qui a été injecté sous une grande pression après le durcissement du béton.

L'utilisation de ce type de procédés a été une première aux Pays-Bas. Il a donc été décidé d'utiliser les CPT comme un moyen de contrôler l'influence des installations de pieux sur les sols environnants, trois pieux ont été testés sur site avec des moyens comme un essai de charge statique et la déformation suivie/contrôlée de tous les pieux durant et apres la construction.

En 2008, la seconde étape du projet a commencé avec l'installation de dix-sept pieux supplémentaires. Pour plus d'informations sur les réactions du pieu sous la pression de fortes charges, deux pieux plus volumineux ont été testés avec un essai de charge statnamic avec du béton 16 MN.

Keywords : bored piles, tip injection, casing piles, monitoring, Statnamic pile testing

1 INTRODUCTION

The railway extension project between three of the major Dutch cities, The Hague, Rotterdam and Utrecht, was commissioned by the Dutch railway authority Prorail in 2005. Near the city of Utrecht the extension includes the realization of a new embankment for 4 railroad tracks and a total of 20 new bridges. As a result of these bridges a safe passage for the local residents is provided in the new residential area of Leidsche Rijn.

For the first time in the Netherlands large diameter casing piles have been installed successfully. During the first phase of the project in 2005, a total of 83 piles were installed. In the second phase of the project in 2008, the last 17 piles were installed. This Article describes the characteristics of this pile system by means of the chosen execution method and several checks of the final result. At each bridge site a number of Cone Penetration Tests (CPT's) were performed prior to pile installation in according to the Dutch geotechnical standards. After pile installation additional CPT's were carried out to supervise the installation method of the piles. At bridge number 6, three piles were instrumented with vibrating wire strain gauges and static applicability tests were carried out. After installation all piles have been monitored during construction and also in a period after finishing the construction of the bridges.

The sub-surface along the route consist of a Holocene clay and peat layer that varies in thickness from 1 m to 7 m based on a pleistocene sand layer with a thickness of more than 40 m. The cone resistance in the sand layer varies from 5 MPa (loose sands) to over 15 MPa (medium dense to dense sands).

2 PILING SYSTEM

In the original client design all bridges had piled foundations. The foundations of abutments and supports consisted of thick concrete slabs with a large number of driven prefab concrete piles as are commonly used in the Netherlands. Since the bridges themselves were supported by columns of 1,2 m in diameter an alternative design was made to use bored casing

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piles with a diameter of 1,65 m, one pile below each column. Instead of using 80 prefab concrete piles, the supports could be founded on 6 of these casing piles. Also the heavy concrete slab (including drainage and additional temporary constructions) could be omitted.

The alternative foundation had to meet the strict client requirements. The piles should be capable of handling a design pile load of 12.000 kN, but should also have a vertical deformation less than 10 mm as a train passes by. Since bored piles have normally a rather feeble load-displacement behaviour, it was deemed necessary to equipped the piles with a grouting device that was injected after hardening of the concrete of the piles.

3 PILE EXECUTION

The bored casing piles were bored without a stabilising fluid such as bentonite. During drilling and removing the ground inside the casing it was therefore essential that a higher water level was maintained in the casing than the dominating groundwater level at the pile tip. To minimise the risk of disruption of the ground at the pile tip the piles were equipped with a grouting device that was injected after hardening of the concrete of the piles. By filling the grout device under high pressure is was possible to pre-stress the pile tip (and hence the entire pile) to guarantee a stiffer load-settlement behaviour.

The execution method of the casing piles is presented in Figure 1.

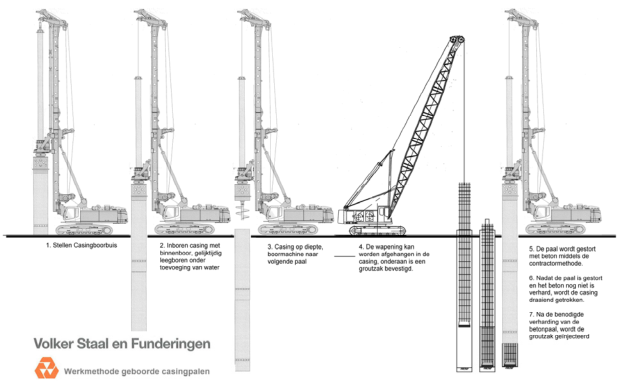

Figure 1. Pile execution method.

4 PILE DESIGN

4.1 *Bearing capacity*

In the Netherlands the calculation of all piles is based on the Dutch standards NEN670 and NEN6743-1. A typical calculation of the bearing capacity is included in EN 1997-2:2007 (E) Annex D7. This method is based on application of α_p (point) and α_s (shaft) factors. These factors are given in the standards for a limited number of piles and are based on static tests that been performed on piles over the last 30 years. The piles mentioned in the standards are:

- soil displacement type piles (driven piles)
- piles with limited soil displacement
- soil replacement piles (bored piles)

For soil displacement piles a typical value of the factor α_p is 1.0 and a typical value of factor α_s is 0.010 – 0.012. For soil replacement piles these factors are 0.6 – 0.8 and 0.005 – 0.006 respectively.

For the casing piles there were no test results available in the Netherlands. Outside the Netherlands the bearing capacity of these piles is normally established based on a combination of experience, ground conditions and static pile load tests. There was no knowledge available on the correlation between CPT results and the obtainable pile load. If there are no pile load tests available it is common practise to compare the installation method of the pile system with the pile systems that already mentioned in the Dutch standards and Eurocode 7. Based on a report provided by Deltares, the original design was made for the casing piles. Based on the pile execution method the following factors for α_p (0.8) and α_s (0.010) were chosen.

4.2 *Load-displacement behaviour casing piles*

For three types of piles the load-displacement curves are presented in the Dutch standards. These curves are also based on pile load tests and are available for same pile types as mentioned above.

For the casing piles there were no test results available in the Netherlands. In order to examine weather the casing piles had the required stiff load-displacement behaviour, three suitability test have been carried out. On two piles a load of 6000 kN, equal to the service load, has been applied. The third pile was loaded to the design load of 8000 kN.

5 DESIGN BASED ON CPT'S BEFORE AND AFTER PILE INSTALLATION

In order to establish the influence of the pile installation on the ground conditions at each bridge site four CPT's were carried out at a very close distance to one of the piles. By comparing the CPT results before and after pile installation it is also possible to calculate the actual theoretical bearing capacity of the piles. The Dutch standards mention that under certain conditions this is an accepted calculation method. When the results of CPT's are used that have been carried out after the installation of the pile, the factor of α_p is 1.0 and of α_s is 0.010. One of the conditions is that the CPT at the surface has to be carried out within a distance of one meter from the pile.

As a result of "normal" slope deviations of the CPT rod however, we do not consider this requirement strict enough. We believe that the CPT must be within the influence area of the pile (2D of the pile). For this reason the CPT's have been carried out equipped with a double inclinometer.

As a result the exact position of the cone in the depth is known. At all locations the CPT's started at a distance of approximately 0.25 m from the edge of the pile. Based on the results of the inclinometers it was established that the CPT results were obtained within a relevant distance to the piles.

From the results of the CPT's it could be concluded that the piles have a neutral installation behaviour, this means on average there was only a limited increase or decrease of the cone resistance along the pile length. It should be stated that some variation in cone resistance is normal. In sandy deposits the standard deviation in the Netherlands is normally around 0.12 and at this specific project site it was approximately 0.15.

In Figure 2 the result of a CPT prior pile installation is shown (black), in combination with the result of four CPT's that have been carried out after pile installation.

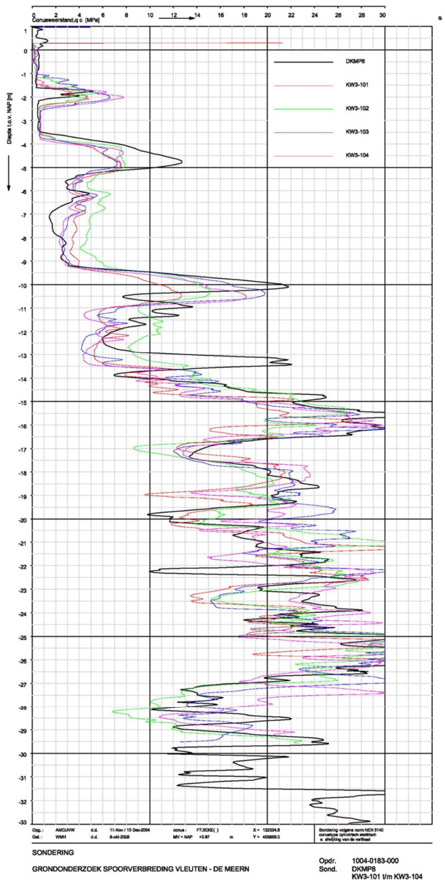

Figure 2. CPT's before and after pile installation

6 PILELOAD TESTS

At bridge number 6 a row of three, 17.85 m long, 1.65 m diameter piles at a centre to centre distance of 3.75 m where individually tested. The goal of these tests was verification of the load displacement behavior up to 8000 kN. At three levels 3.6, 12.6 and 17.35 m below the pile head 3 vibrating wire strain gauges were installed. On top of the piles a pressure cell was installed. Vertical displacements of the pile heads were measures by high accuracy leveling. At a level of 12.6 and 17.35 m below the pile head tell-tales were installed. The reaction frame with a deadweight of 1000 kN was anchored by 8 Gewi-anchors with a capacity of 1250 kN each.

Prior to pile installation at the centre of each pile one CPT was performed; the cone resistance of these CPT's show a significant spatial variation in vertical and horizontal direction this reflects the nature of these sands. After pile installation 4 CPT's were performed at 4 sides of each pile to detect production process anomalies. These CPT's started at GL at 0,25 m distance of the pile shaft and the average deviation from the pile shaft at pile tip level was 1.1 m. The average cone resistance of the CPT's executed after pile installation was over the pile length 20 - 60% higher and at the level just below the pile tip level the average cone resistance was 20% less that the CPT's executed prior to pile installation. The reduction of 20 % is within natural variation of these sands but the local increase with 60% is not. It is concluded that there is no proof of anomalies during execution of the piles but there is a noticeable improvement of the soil conditions over the pile length. Based on the 3 CPT's executed prior to pile installation the ultimate bearing capacity of the piles is estimated at 20000 kN.

The piles were loaded in steps of 1000 kN. The load was then kept constant for 1 hour, a time that was extended if the deformation speed was more than 0.3 mm/h up to a maximum of 4 hours. At a load of 6000 kN the piles were unloaded to 4000 kN and reloaded to 6000 kN in steps of 1000 kN. Only one of the piles was loaded with an extra 2 steps of 1000 kN up to 8000 kN.

7 MEASUREMENTS

The measured load at the pile head versus the pile head displacements are presented in Figure 3. The shaft friction over the two sections between the strain gauges is presented as the shaft force versus the pile tip displacement measured by the lower tell-tale in Figure 4. The top section is from 3.6 to 12.6 m below the pile head and the lower section is from 12.6 m to 17.35 m below the pile head. During the loading of one pile the maximum measured vertical pile head displacement of the other 2 piles was during loading of pile VI-86 was 0.44 mm, VI-87 was 0.32 mm and VI-88 was 0.36 mm.

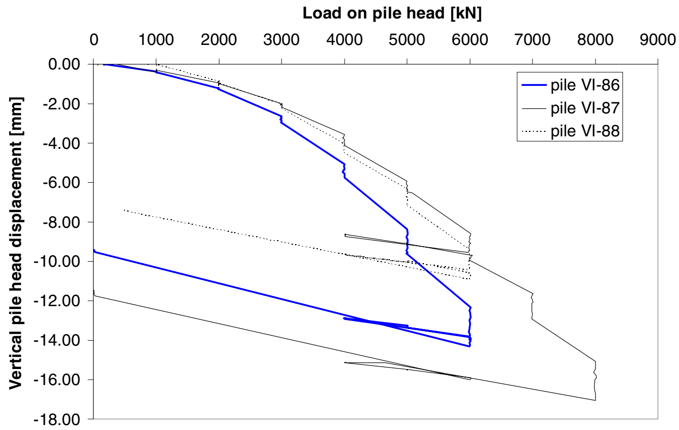

Figure 3. Load displacement curves of the pile heads.

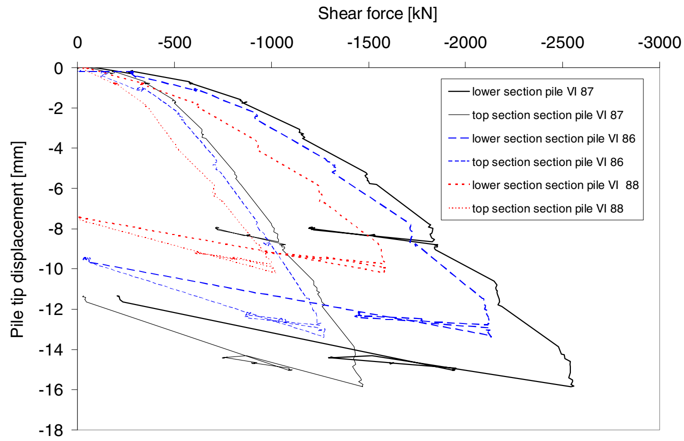

Figure 4. Load displacement curves of pile shaft sections.

At 6 bridges the vertical deformation of the piles have been monitored on the long term. The total vertical deformations after 1 year of train passages are given in Table 1 .

Table 1. Average settlement after 1 year of train passages.

Bridge	Best estimate updated prediction [mm]	Measured [mm]	Ratio Predicted /measured
3	2.3	2.8	0.82
4	3.9	5.6	0.70
8 West	4.2	5.6	0.75
8 East	3.1	2.8	1.11
9	1.9	2.2	0.86
12	4.2	2.9	1.45
		Average	0.95
		CV	0.28

8 EVALUATION

The observed average pile group interaction (=settlement of a pile due loading of an adjacent pile) was a factor 16 lower than predicted by NEN6743 for a single loaded pile. This observation is in line with the expectation as the NEN6743 method is based on large strain stiffness and end bearing piles. At the lower stress range the piles in this project are expected to act as friction piles and the strains are limited.

The observed average unloading stiffness during full unloading is 2.8 times higher that the virgin stiffness in the load range 0 to 6000 kN.

The observed average reload stiffness in the load range of 4000 to 6000 kN is 4.8 higher that the virgin stiffness.

The average observed load displacement curve of the pile head is plotted in Figure 5 together with the prediction based on the preliminary design starting points (α_p is 0.8 and of α_s is 0.010) and the prediction based on the worst case design starting points used in the final design (α_p is 0.6 and of α_s is 0.008). For the prediction the 3 CPT's made prior to pile installation in the center of the test piles were used. As the pile type does not exactly fit the Dutch design code NEN6743 two sets of starting point were used during the design process. During the pile load tests the piles were not loaded to failure. So no new set of starting points for the NEN6743, α_p and α_s and normalized load displacement curves could be defined. A practical approach was chosen to make an updated prediction for the other bridges. As all the piles in the project have a similar ratio between shaft and end bearing capacity it was suggested to use a load displacement curve between the best estimate predictions for 6 bridges, based on this updated load displacement curve and the lower pile group interaction are presented in Table 1. The average ratio between the predicted and the measured settlement after 1 year under deadweight of the bridges is 0.95 and the coefficient of variation (CV) of the ratio is 0.28. This means that the average updated best estimate prediction was reasonable good and the CV is good in line with the expected CV for deformation of 0.25 given in the Dutch code NEN6740.

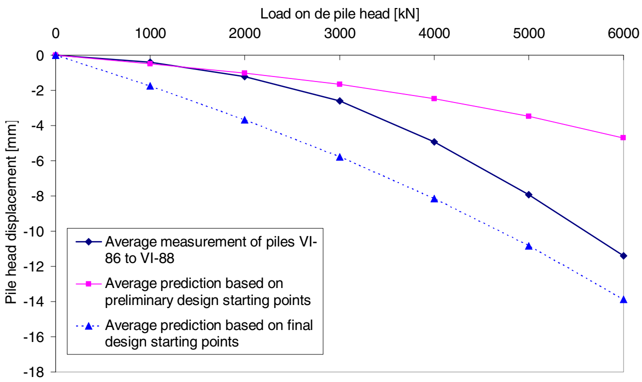

Figure 5. Load displacement curves pile head

9 STATNAMIC LOAD TESTING

In november 2008 two Statnamic load tests were carried out on test piles that had been installed in 2005. Originally it was intended to test these piles to refusal by means of a static load test. Such a test would have required a load of approximately 20000 kN, even though the piles have a limited length of 13 m.

The introduction of a 16 MN Statnamic device in the Netherlands by Fugro made it possible to test the piles to loads that would approach the ultimate bearing capacity of the piles. In a Statnamic load test pile loading is achieved by launching a reaction mass. This mass is only 5% of the weight needed for a static load test. The loading is perfectly axial, the pile and the soil will be compressed as a single unit and the static load-displacement behaviour of the pile is obtainable if a series of tests is performed.

Given the fact that the information of the static load test up to a load of 8000 kN was already available, the two test piles were only tested once with the maximum load of 16 MN. A typical result of a Statnamic load test is presented in Figure 6.

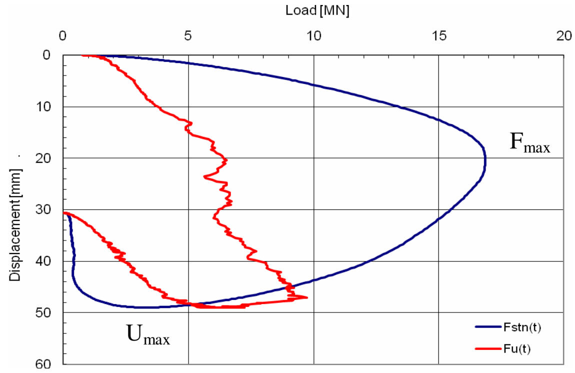

Figure 6. Results of the Statnamic load test where Fstn(t) is the measured load on the pile head and Fu(t) is the derived static pile resistance.

The results of the Statnamic load tests were analyzed using the Unloading Point Method. Together with the results of the static load tests and the theoretical method using the CPT-tests a very good understanding was reached concerning the ultimate bearing capacity and the load-settlement characteristics of the casing piles.

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