Rapid load field tests interpreted with the new Guideline

Essais de charge rapide interprétés avec la nouvelle directive

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ABSTRACT

In order to evaluate the draft Guideline for the interpretation of a Rapid Load Test, a field test was carried out. Two instrumented piles were driven and then subjected to both a Static Load Test and a Rapid Load Test. The strain in the piles and the excess pore water pressures during a Rapid Load Test were measured and the results were compared. The draft version of a recently developed Guideline was then used for the interpretation of the Rapid Load Test data. It was concluded that the Rapid Load Test offers good insight in the static behavior of the pile. The application of several methods mentioned in the Guideline on this practical case gives information on the applicability of the methods. The test data also seem to show that the rate factor in sand is defined by the dilatational behavior and the generation of excess pore water pressure during a Rapid Load Test.

RÉSUMÉ

Afin de tester la version provisoire de la directive pour l'interprétation d'un essai de charge rapide, un essai sur le terrain a été effectué. Deux pieux équipés de capteurs ont été enfoncés dans le sol. Les deux ont été testes statiquement et dynamiquement. Les contraintes dans les pieux et les pressions de l'eau pendant un test de charge rapide ont été mesurées. Les résultats sont comparés. La version provisoire de la directive développée récemment est utilisée pour l'interprétation des résultats d'essai des charges rapides. L'essai de charges rapides permet de mieux comprendre le comportement statique. L'application de méthodes théoriques sur ce cas pratique fournit des indications sur les améliorations nécessaires. Le facteur de vitesse dans le sable semble être défini par le comportement en dilatation et la génération de pression négative de l'eau interstitielle pendant un essai de charge rapide.

Keywords : pile, bearing capacity, field test, static load test, rapid load test, regulations

1 INTRODUCTION

The Rapid Load Test (RLT) might be a good and economical alternative for the Static Load Test (SLT) of piles. Examples of this test method are Statnamic (Janes et al, 1991) and Pseudo-Static Pile Load Tester (Schellingerhout & Revoort, 1996). However, the application of this type of test is hindered by the discussion about the interpretation of the test data. This hindrance can be overcome by proper regulation of the test and the interpretation of the test data. An international project has been started with the objective of developing a Standard for the execution of a Rapid Load Test as well as a Guideline for the interpretation of the test (Hölscher, 2009).

The aim of a load test is to demonstrate that a foundation fulfills the specified requirements. Normally, these requirements are specified in terms of the stiffness under working load and the bearing capacity in ultimate limit state. A successful load test provides principals with the assurance that the installed foundation is adequate, and it allows contractors to show that their product fulfills the contractual requirements.

In order to prove the reliability of the calculation rules in the Guideline for the interpretation empirical data are required with the results of an SLT as well as an RLT. Since the results of an RLT need some post processing, the full digital measurement results must be available, and these measurements (the load on the pile head and the displacement and acceleration of the pile head) must have been obtained as specified in the Standard.

This paper describes a field test performed to obtain such a data point, and discusses the application of the interpretation methods in the Guideline on the test results.

2 NEW STANDARD AND GUIDELINE

2.1 *Short description of research*

The Delft Cluster research consists of two parts. The first part focuses on the interpretation of the RLT on piles that get their bearing capacity from a deep sand layer, which is typically the case in The Netherlands. The theoretical studies associated with this part were presented in 2008 (Huy, 2008 and Hölscher, van Tol, 2008). The second part focuses on the creation and validation of documents for practical application. These documents are being created in consultation with an international expert group. The expert group met two times in Delft, The Netherlands, discussing the recent progress in research and the content of the document (Hölscher, van Tol, 2008). Further discussion is being done by e-mail.

The field test described in this paper is part of this research. The objective of the test was to validate the theoretical model for the influence of pore water pressure on an RLT, and to obtain empirical data for validation of the methods described in the Guideline.

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2.2 *Standard for test execution*

The proposed Standard specifies the minimum requirements for the execution of an RLT and the reporting of the test data. A draft of this Standard was presented in 2008 (Chapter 10 of Hölscher, van Tol) and the final document will be reviewed and approved by working group 4 of TC 341.

2.3 *Guideline for interpretation*

The Guideline discusses the aspects that should be considered while interpreting an RLT that is performed in accordance with the Standard.

Three methods of interpretation are described:

- The Sheffield method (Brown, Hyde, 2006)
- The unloading point method (Middendorp, 1992)
- The variable damping method (Matsumoto *et al*, 1994)

The Sheffield method requires some laboratory testing for the rate dependency of the soil, which is very important in the case of clay. The other two methods can be applied without laboratory testing. The Guideline will be published by some institutes as a recommendation.

3 FIELD TEST AND STATIC LOAD TESTS

3.1 *Site description*

The test location was situated near Waddinxveen in the western part of the Netherlands. Figure 1 shows the result of a CPT at the test location. The surface level lies at NAP - 5.07 m (NAP = Dutch reference level). Below grade, Holocene peat and clay layers are found down to a level of NAP -12 m, with the Pleistocene sand layer underneath. This layer consists mainly of medium fine sand. The phreatic ground water level and the piezometric head in the Pleistocene sand layer are found at about NAP -6 m.

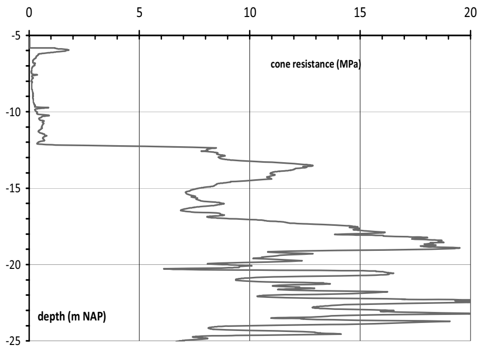

Figure 1. Cone resistance at site

3.2 *Test execution*

Two square precast concrete piles (350 x 350 mm2) were driven about 6 m apart to a level of NAP -15.35 m.

Both piles had been instrumented (before pouring concrete) with strain gauges at three levels: 0.5 m below the head of the piles, 9.5 m below the head of the pile (which will coincide with the transition between Holocene and Pleistocene layers NAP - 13.95 m) and at 0.5 m above the pile toe (two strain gauges at each level). At the toe of both piles, a BAT sensor was installed to measure the pore pressures during the RLT tests. The Bat sensor offers the possibility to install the tip before pile driving and the measurement device after pile driving. In addition, a piezocone was installed after pile driving in the Pleistocene sand layer at a distance of about 0.7 m from Pile 2 at NAP - 15.35 m. Based on an analysis of the CPT data according to Dutch code NEN 6743, the predicted ultimate bearing capacity was about 1340 kN and 1318 kN (Pile 1 and Pile 2 respectively).

Both piles were tested twice: pile 1 was first subjected to an RLT and then an SLT, while for pile 2 this sequence was reversed. The SLT was executed according to EC7/NEN 6745. The piles were loaded by means of a hydraulic jack using water tanks as ballast. The load step was 140 kN for Pile 1 and 175 kN for Pile 2.

Figure 2. The Statnamic apparatus (RLT) and the counter weight (SLT)

3.3 *SLT results*

Figure 3 shows the load displacement curves derived from the SLT of the test piles. From these curves, it was concluded the ultimate static bearing capacity was 1150 kN for Pile 1 and 1120 kN for Pile 2.

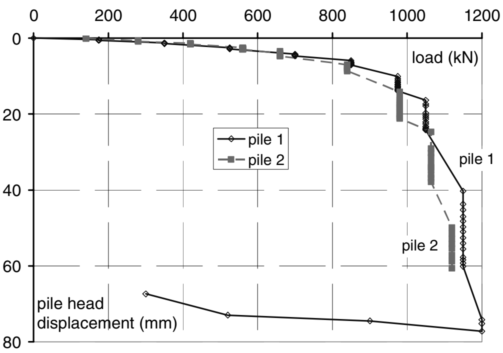

Figure 3. Load displacement diagrams of SLT

3.4 *Results of strain measurements*

During the SLT, the strains were measured at three levels (see Section 3.2).

Figure 4 shows the forces in Pile 2 derived from the measured strain (by the strain gauges) and the estimated pile stiffness. The load measured during SLT and the force derived from the strain gauges correspond well. The shaft carries about 15% of the total load.

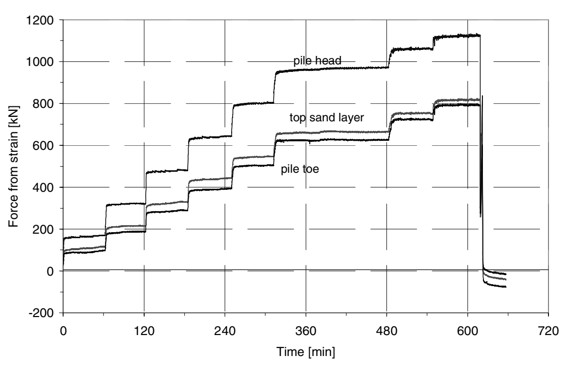

Figure 4. Forces from strain measurements during SLT Pile 2

One of the strain gauges in the head of Pile 1 did not function well. Therefore, Figure 5 shows the results for the deeper levels only. For Pile 1, the friction along the shaft in the sand is higher than the friction along the shaft for Pile 2. The value measured for Pile 1 is more in accordance with our expectation.

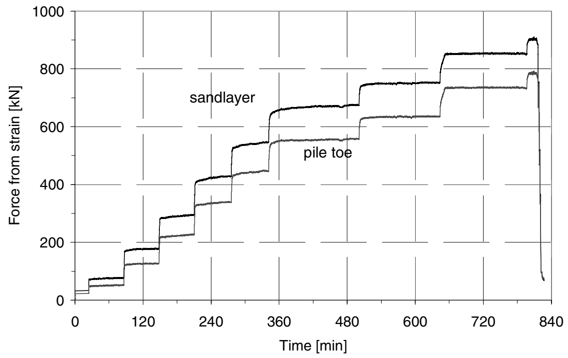

Figure 5. Forces from strain measurements during SLT Pile 1

4 RLT RESULTS AND COMPARISON

4.1 *RLT measurements*

The RLT was carried out using a 4 MN Statnamic apparatus. In accordance with the draft standard the load, displacement and acceleration were measured at the pile head. Additionally, the strains in the piles were measured at 3 levels (see Section 3.2) while the pore water pressure was measured under the pile toe and in the soil close to the pile.

Figure 6 shows the RLT results for the fourth (and last) load step for Pile 2. The graphs in this figure shows the load on the pile (top left - measured and corrected for inertia of the pile), the displacement (top right), the acceleration (bottom left), and the rapid load-displacement diagram (bottom right). For these piles, the inertia correction is very small.

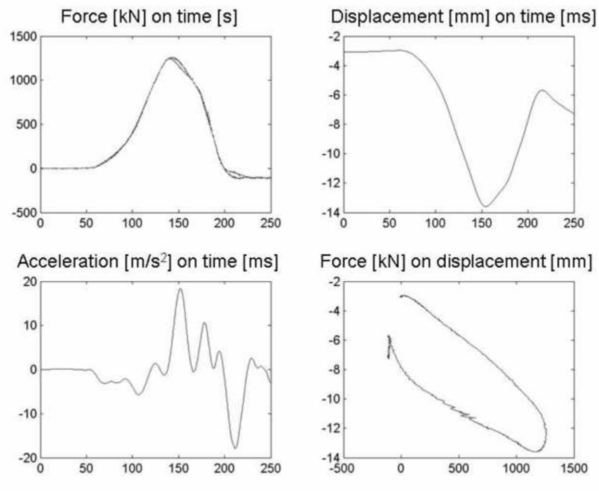

Figure 6. Results of RLT pile 2 load step 4

4.2 *Bearing capacity in accordance with the guideline*

The measurements collected during the RLT were interpreted in accordance with the draft Guideline.

The Sheffield method was not studied, since this method is meant for piles in clay and the required laboratory data were not available. However, the rate effects in sand are small, and therefore the Sheffield method would have resulted in only small corrections.

The variable damping method is also not very applicable given the strong dependency of the method on the initial part of the measurement. This part of the interpretation method must be improved in the draft Guideline.

Initially, the unloading point method focuses on the soil force at the so-called unloading point, the moment at which the direction of pile motion changes. Figure 7 shows the calculated unloading points for both piles at all load steps. The vertical axis shows the displacement at the unloading point (the moment of zero velocity). The horizontal axis shows the load on the pile head corrected for the inertia force (pile mass * acceleration) at the unloading point. Pile 1 almost reached failure (displacement is 10% of equivalent pile diameter). According to the Guideline, the measured soil resistance (corrected for inertia, see Figure 7) must be corrected with a factor (R) in order to obtain the bearing capacity. This factor R is required for the correction for rate effects in clay and pore water pressure effects in fine grained granular materials. Based on empirical data the Guideline suggests for sand a mean value of R = 0.94 (with coefficient of variation 0.15, Hölscher & van Tol, 2008). The derived bearing capacity of this pile is therefore 0.94*1232 = 1158 kN. The RLT results of Pile 2 shows that this pile did not reach failure, and therefore we can only conclude that the bearing capacity will be higher than 1137 kN (0.94*1210 kN).

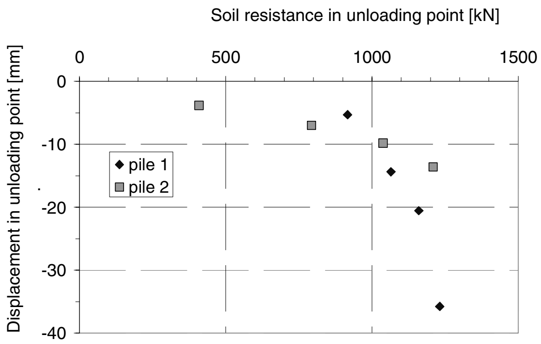

Figure 7. Unloading points for both piles (with correction for inertia, without correction factor R)

Based on the RLT, pile 2 has a higher capacity than pile 1. This is in disagreement with the observation during the SLT.

The measured initial stiffness is presented in Table 1. The stiffness based on the SLT is estimated from the displacement at the load step which passes the 800 kN load. It is noted that Pile 1 is loaded three times with about 800 kN load during RLT. Figure 7 and Table 1 show the results of the first loading. The stiffness's at 800 kN load are in reasonable agreement.

Table 1. Initial stiffness (in kN/mm) at working load values (in kN)

test	SLT	SLT	SLT	RLT	RLT
load [kN]	400	800	800	400	800
case		initial	1 hour		
pile 1	244	143	120	--	170
pile 2	256	120	97	107	113

For initial stiffness, a correction for rate effect in sand is not required, since at the start of the load test, the pore water pressure plays a minor role in the behavior of the sand around the toe and the velocities are small.

An RLT with more load steps gives a reasonable overview of the full load displacement curve. However, at higher loads on the pile, the correction factor R must be included; at lower loads, no correction factor must be included. At this moment, the draft Guideline describes no method to derive the full load-displacement curve from the unloading points taking into account the dependency of the factor R on displacement. For sand, the differences are not that big (since the factor R is almost 1.0), but for silt and clay the differences are much bigger. A method with a smooth transition between uncorrected values at low load and corrected values at higher load (such as the Sheffield method for clay) is required.

4.3 *Strain measurements*

Figure 8 shows the forces measured at the pile head or estimated from the strain gauges for the final load step of each measurement. For the RLT's the values at the unloading point are shown.

It is unknown why the forces from the strain measurements during RLT are 25% higher then the values measured at the pile head. The results of (Stokes & Mullins, 2008) show that a linear stress-strain relationship may be inappropriate for the interpretation of strain measurements if a wide range of strain and strain rates occur in the pile. In this relatively short pile, this is not the case. The linear stress-strain relationship seems applicable and the stiffness of the pile seems to be well estimated, based on the good agreement between the forces in the SLT. The conclusions in this paper are based on the assumption that the externally measured forces during the RLT are correct and thus the forces derived from the strain gauges are incorrect.

The distribution of the shaft and toe resistance differs: during the RLT, the shaft carries more load than during the SLT. This might be due to the rate effect in the soft upper layer. For the sand layer, the effect also exists, although it is smaller.

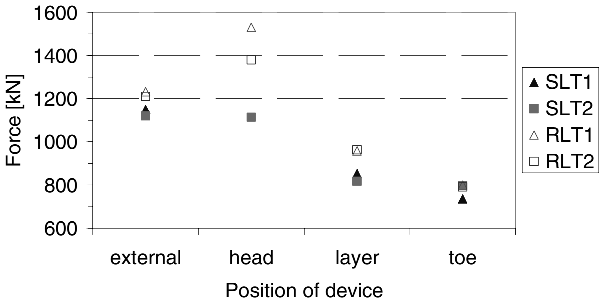

Figure 8. Comparison of forces in the pile from strain measurements and external force transducers (final load step only)

4.4 *Pore water pressure measurements*

The theoretical research showed that excess pore water pressure plays a role in the interpretation of RLT data for piles in sand (Huy, 2008). In earlier research, pore water pressures were measured in the sand close to the pile toe (Hölscher, 1995) (Maeda, *et al* 1998). This field test should provide additional information on this influence by measuring the pore water pressure directly under the pile toe.

Both piles had a pore water transducer at the toe. However, during the first RLT (on Pile 1), it was observed that the pore water transducer was not fast enough to record the actual pressures. Therefore, these measurements have been disregarded here. An additional pore water transducer was installed approx. 0.70 m from the pile toe of Pile 2 before the RLT.

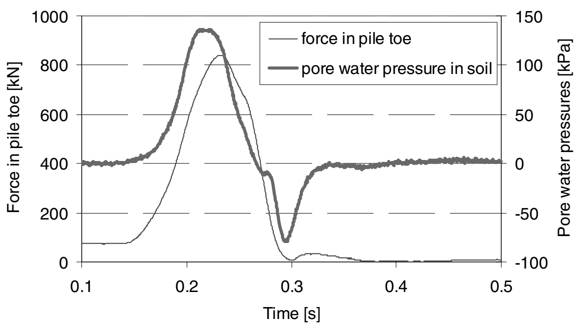

Figure 9. Force and excess pore water pressure in the sand during RLT (Pile 2, load step 4)

Figure 9 shows the results of the dynamic pore water transducer and the strain transducer (expressed as force) in the pile toe during the fourth load step. Due to the distance between the transducer and the pile toe, we expect that the change in excess pore water pressure lags behind the force in the pile toe. During the rise of the force, a minor time lag is observed. However, the pore water pressure decreases before the force reaches its maximum value. During unloading of the pile toe, the pore water pressure decreases strongly. The hydrostatic water pressure is 95 kPa. The minimum value of the excess pore water pressure is -76 kPa.

The decrease of excess pore water pressure during the loading phase of the rapid load test shows that dilatancy of the sand around the pile toe plays a role. This phenomenon was also observed in centrifuge testing (Huy, 2008). This effect explains the rate factor that is observed in sand.

5 CONCLUSIONS

Two instrumented driven piles were subjected to an SLT and an RLT. The test data lead to the following conclusions:

- The bearing capacity based on RLT interpreted with UPM fits well with the static bearing capacity based on SLT.
- The initial stiffness measured by the RLT is practically useful for serviceability state analysis.
- The distribution between shaft and toe in an RLT differs from an SLT, possibly due to rate effects in the soft soil.
- Excess pore water pressures, measured close to the pile toe, confirm the generation of excess pore water pressure.
- The variable damping method must be described in more detail.

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