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Non-Destructive Quality Check on Cast In-Situ Piles

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Abstract. A test field with 20 cast in-situ piles has been built. Flaws (necks, bulges and cracks) are built in. Existing and newly developed detecting methods have been tested. They show interpretable signals and also some challenges to improve the results. The final phase e.g. excavation of a representative number of piles will lead to final conclusions of the usability of these measurement techniques.

Keywords. Non-destructive techniques, cast in-situ piles, quality control

1. Introduction

On the grounds of Deltares in Delft a foundation was made with cast in-situ piles. After one year, the piles are still there and with the same quality as they were made: too poor to build something on it. But… we are happy with it!

Every year hundreds of thousands cast in-situ piles are made. By default, all cast in-situ piles are acoustically measured with the 'Pile Integrity Test' (PIT) to determine whether the pile shaft meets the requirements. In a significant amount of cases, the current measuring technique does not give a satisfactory answer: the signal cannot be interpreted unambiguously. The cause of this shortcoming of the technique is related to the heterogeneity of the soil surrounding the piles: especially to the irregular structure of the individual layers. It is not possible to determine whether cracks arose after making the pile or that the pile has a neck and is locally too thin. This uncertainty leads to delay in the construction process and entails additional costs with it. An additional non-destructive measurement technic to solve this quandary is required.

In the Netherlands, a joint research project has started to answer the question which techniques are available to get an accurate picture whether the foundation pile meets all requirements. The field test described in this paper is part of this project. Twenty cast in situ piles are installed. The piles has a number of intended flaws. Besdes the traditional Pile Integrity Test, five experimental techniques for the determination of pile integrity has been deployed.

The field test is part of Geo-Impuls (Geo-Impuls, 2014), a research program that aims to reduce 50% of the cost of failure. A reliable pile test method will reduce the discussion in the short term as well as the unnecessary placement of additional piles. On the long term the profit is much bigger: a reliable test method will give rise to a 'natural' selection of the most reliable installation techniques. This will greatly reduce the costly waste of placing additional piles and will lead to a general improvement of pile foundations.

2. Setup test field

The test field exists of 20 cast in-situ piles (length 10 meter, diameter 460 mm) with artificial flaws, such as cracks, necks and bulges. With a mutual pile distance of 5 m, the ability to pull out a number of piles afterwards is taken into account. The test is performed with so-called 'Hek-piles' (Gebr. van 't Hek, 2015). These are concrete cast in-situ piles with a lost tip. A smooth casing is screwed down by axial pressure and a considerable torque. Once the required depth is reached, the reinforcement is placed and the casing is filled with concrete. Then the casing is pulled out with an oscillating motion. In the field test, the reinforcement in the pile is used as a frame that supports the equipment needed for the creation of flaws and the installation of various sensors.

3. Flaws

In total five different flaws are identified as relevant to the pile integrity: a crack, a neck (symmetric and asymmetric) and a bulge (shallow and deep) (see Figure 1).

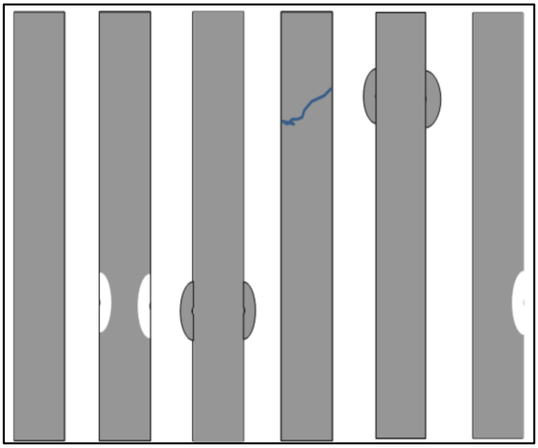

Figure 1: Piles with selected flaws. From left to right: no flaw; symmetrical neck; bulge (deep); crack; bulge (shallow); asymmetrical neck.

An important requirement for the defects is that their location and size are reasonably well defined. Special measures are needed. The following technics are created:

Bulge: special injection channels are installed to the reinforcement. After pouring the concrete, additional concrete is injected into the pile. To force the concrete to move into the soil, a PVC protection ring has been installed in the pile. During injection the volume and pressure are carefully monitored. The creation of a bulge is a delicate process: if the additional grout injection starts too early the cast in-situ pile is not hardened and the injected grout will mix with the concrete instead of creating a bulge. If the grout injection starts too late the concrete of the cast in-situ pile is hardened and the injection tube for the grout injection will be clogged (Figure 2).

Neck: a rubber tire is placed around the reinforcement. It is injected with bentonite after installation of the cast in-situ pile. Creation of the neck must be carried out quickly after pouring the pile, before the curing of the concrete starts. An asymmetric construction is made by filling a half tire with bentonite (Figure 3).

Crack: at the location of the intended fracture two adjacent reinforcement bars were sawn through (Figure 4). During placement of the reinforcement cage in the casing, a steel cable replaces temporarily the missing piece of reinforcement, in order to keep the cage straight. After placement of the reinforcement, but before pouring the concrete, the steel cables were disconnected. After hardening of the concrete, a crack is made by driving cautious against the pile.

Figure 2: Structural adjustment to create flaws. Protection ring and injection tube for bulge.

Figure 3: Structural adjustment to create flaws. Rubber tire and a filled injection tube for neck (bottom right). Top: symmetric neck. Bottom left: asymmetric neck.

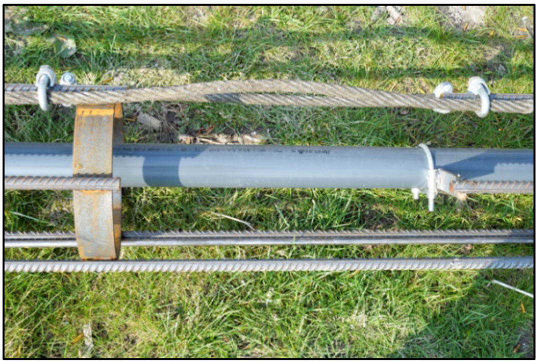

Figure 4: Structural adjustment to create a crack. Sawn reinforcement bias for a crack.

4. Methods and results

This chapter briefly explains the principles of the measurements and the first preliminary results. This article deals specifically with the development of the experimental techniques. Figure 5 shows sketches of the measurement techniques used.

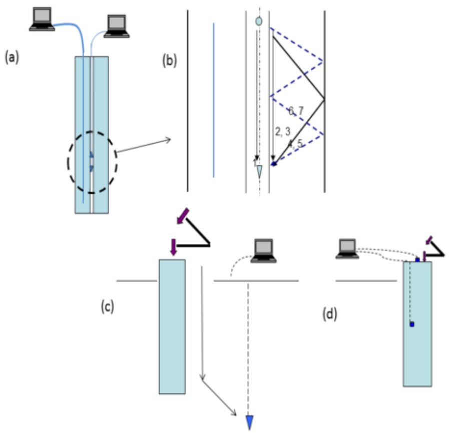

Figure 5: Overview of acoustic measurement techniques: (a) on top, left: fibre optics and single hole sonic logging; (b) on top right: detail of possible wave paths for single hole sonic logging, (c) below, left: parallel seismics (d) below, right: deep acoustic check.

4.1. Single Hole Sonic Logging

In a standard single hole sonic logging, an acoustic source with one acoustic receiver is slowly moved through a measuring channel in the pile (e.g. Hertlein and Davies, 2006; Amir, 2002). This measuring channel can be created during the manufacturing process by including a PVC tube into the pile. The signal emitted from the source will run through the concrete to the receiver. There are several possible paths (see Figure 5b). When the pile has a flaw, one or more paths differs from the paths in the situation without a flaw. This will be visible in the received signals. E.g. a bad spot in the concrete leads to a later arrival time of the signals and usually a smaller signal strength, while a neck leads to an earlier arrival time and a higher signal strength.

A clear picture of the wave propagation around this instrument is still missing. This causes problems in the interpretation of the type and size of a flaw.

In order to clarify the complexity of the wave paths a new device has been build: the seismic tube. The seismic tube is one string with sources and recievers, so it can be lowered in one tube, like the single hole sonic logging device. The seismic tube consists of two sources (one at each end) and eight receivers in between. The mutual distance between the receivers is 15 cm. The eight receivers measure simultaneously response on the signal of one of the two sources. This device gives an image of the spatial wave patterns. The Seismic tube is built for this study, but may later also be used in practice.

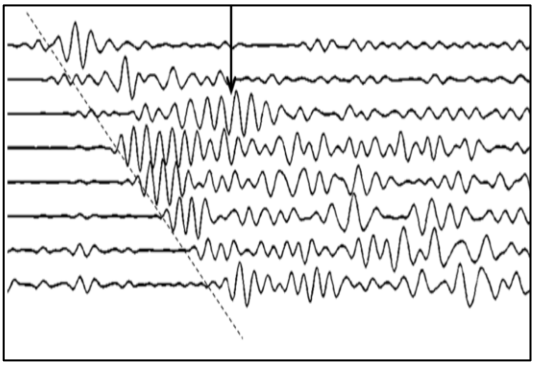

Figure 6: Seismogram of seismic tube. The source is on top of the receivers.

Figure 6 shows a measurement result in the form of a seismogram: the measured signal in a sensor is drawn on the place where the sensor is situated. The active source is located above the receivers. The source gives a short signal. The measured signals are amplified so that a clear signal is visible on each line, with always the same maximum. In reality, the signal falls sharply with distance from the source.

The dashed line indicates the arrival time of the first vibration. However, in the third sensor for example, a very strong vibration is visible, which arrives significantly later. This amplification may have been caused by interference of different waves in the pile, caused by e.g. a bulge in the pile: if the wall is further away, the reflection will arrive later. By carrying out measurements at more depths in the pile, the reason of such an anomaly can be analysed more specific.

4.2. Deep Acoustic Check

The deep acoustic measurement uses a cheap acoustic acceleration sensor which is attached to the reinforcement halfway the pile (Figure 5d). It is a lost transducer.

Figure 7 shows the measured signals in the pile head (upper plot) and deep transducer. In the upper plot, the hammer blow is clearly visible. In the deep sensor registration (lower plot), the passage of the wave in the downward direction is clearly visible. This means that the wave velocity in the pile can be determined. Thus the reflection of the pile tip can be better determined in both the deep sensor and the pile head sensor. A major problem of the standard acoustic is resolved by this.

The measurements in the deep transducer can be interpreted like a transducer in the pile head to check the quality of the pile below the transducer.

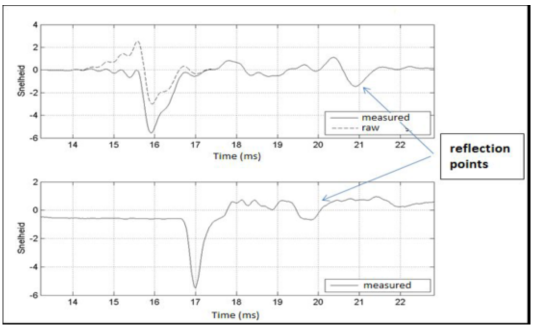

Figure 7: Result of acoustic test with a sensor at the pile head (top) and at 5 m depth (below).

4.3. Parallel Seismics

Parallel seismics is performed by pushing an acoustic sensor (installed in a cone) in the soil close to the pile (Figure 5c) (e.g. Niederleithinger 2012; de Groot, 2014). It is a technique that can be performed without any preparation during the installation of the cast in-situ pile.

After the pile head has been hit with a hammer, waves are travelling through the pile and the soil to the acoustic sensor in the cone. After each measurement the cone is pushed about 25 cm deeper. This produces a seismogram with depth.

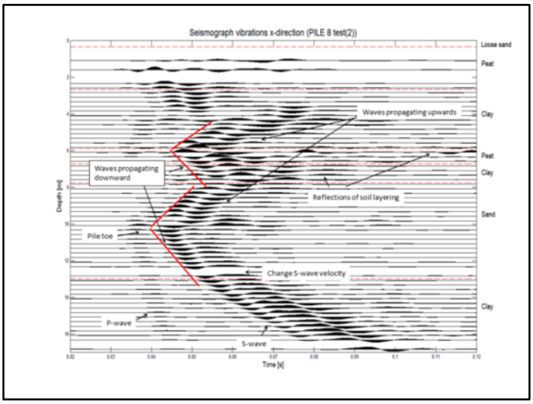

Figure 8: Seismogram of parallel seismics. Cone- pile distance about 2 meter [de Groot 2014]).

Figure 8 shows an example of the seismogram of the measured horizontal vibrations in the bottom immediately next to the pile (de Groot 2014). The wave radiation from the pile tip is clearly visible at 10 m. The reflection of the stress wave in the pile at the pile tip gives a large force on the soil. This force radiates in all directions. A similar radiation pattern is visible at 6 m depth. This is exactly the depth of the transition from clay to peat. This pile has a flaw at approximately 3.8 m. There is a change in the wave radiation, but this effect is too much dominated by the waves of the transition at 3.8 m (or an unknown defect at 6 m depth). This means that for a correct interpretation the waves due to the layer transitions must be removed from the measurements.

4.4. Fibre optics

Distributed Temperature Sensing (DTS) (DeCusatis, 2006) can be used to monitor the curing of concrete in cast in-situ piles. The fibre optic cable is directly attached to the reinforcement. The fibre optics measures the temperature in the pile, that is influenced by the hydration heat from the curing concrete. The measurement starts directly after the pouring of the concrete, and stops after a few days when the hydration heat is fully dissipated.

The measurement is based on a change in temperature profile if a deviating diameter (e.g. bulge or neck) occurs. This leads to a lower or higher dissipation of generated heat. The influence of the surrounding soil has to be taken in account (see Figure 9). This is less complex if more piles are equipped with fibre optic cables (with little additional costs). The temperature measurement can, in addition to classical pile integrity tests, be used to estimate the magnitude of the deviation.

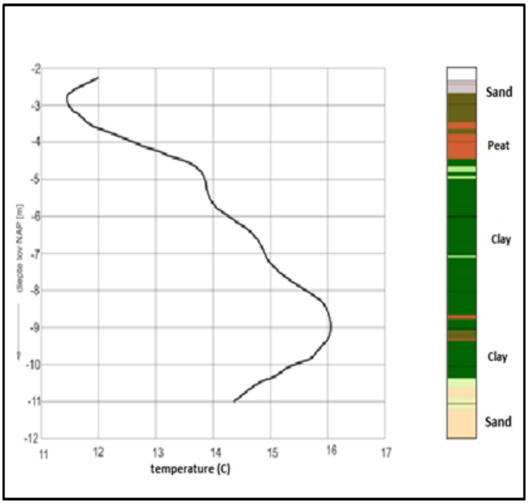

Figure 9: Fibre optics: influence of surrounding soil.

5. Future research

This paper has described the test field and the complexity of constructing piles with various flaws. Methods to obtain piles with well-defined defects were shown. The tested measurement techniques are explained theoretically.

A prerequisite for the application of a technique is that the reliability in the field is known. Nevertheless, the selection of a technique also depends on other aspects such as costs, availability and manageability. The final phase e.g. excavation of a representative number of piles will lead to final conclusions of the usability of these measurement techniques.

6. Conclusions

In the framework of Geo-Impuls, a test field has been built. Existing and newly developed techniques meant to check the quality of cast in-situ piles have been tested. All new techniques show interpretable signals and also some challenges to improve the results.

This research has been initiated by the Geo-Impuls programme in the Netherlands. Geo-Impuls is a five year long, joint industry programme which aims at reducing geotechnical failure substantially in 2015.

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