
Paul Hölscher
Deltares


Victor Hopman
Deltares


Aukje Veltmeijer
Delft University of Technology

DEVELOPMENT OF ADVANCED PILE INTEGRITY TEST METHODS FOR CAST IN-SITU PILES

1. Introduction

Traditional sonic testing of cast-in situ foundation piles is cheap and reliable. However, for deeper or less pronounced defects the reliability is limited. Measurements often lead to discussion on the question whether the defect is acceptable or not. To solve this, additional more accurate independent methods to determine the real size of the defect is desired.
New methods are suggested (e.g. [2][5]) but the reliability of these methods is unknown. In this research we tried to get more insight, by comparing the results of all methods on 20 test piles with intentionally created defects. Two new methods are discussed in more detail.

2. Field-test

A field test with 20 cast in-situ piles had been created. The site is located at the office of Deltares in Delft. The soil profile has about 8 m soft soil with some peat and clay layers above a sand layer of about 4 m. The piles (10 m length) had their toes in this sand layer, but had been designed for testing only, not for bearing capacity.

Seventeen piles had one or two realistic defects such as bulges, necks and fractures. The bulges were created by injection of concrete through in advance installed pipes. The necks were prepared by tires filed with clay that were placed in the pile during installation. The fractures were created by a heavy lorry that hits the pile softly.

The piles were prepared for application of several advanced inspection methods (see Figure 1):

- Sixteen piles had a single tube in the centre of the pile. This facilitates Single Hole Sonic Logging (SHSL, see e.g. [5]) and Seismic Tube (ST). The seismic tube will be discussed in Section 4.
- Four piles had three equidistant holes facilitating Cross-Hole Sonic Logging (CHSL).
- All piles had one or two deep accelerometers for Deep Acoustic Check (DAC). This method will be discussed in Section 3,
- Some piles had Discrete Temperature sensors (DT) and Fibre Optics (FO) to measure temperature.
- The distance between the piles was large enough to facilitate pushing a seismic cone along the pile to test Parallel Seismics [2].
- All piles were tested by traditional sonic testing by several experienced companies.

Based on the measurements all involved parties made a blind judgement of all piles, using their own methods. Based on the comparison of the predictions and the created defects, and experience of the field test the applicability of methods is discussed.

- The traditional PIT with one transducer and a hammer blow at the pile top turned out be the most reliable.
- The temperature measurements by the fibre optics and the acoustic SHSL give comparable results. The temperature method requires the installation of a fibre in the pile, the SHSL method requires a central hole. Both methods did not yet give additional information on the size of a defect. The temperature method is very fast, it measures during the curing. This gives the shortest response time after pooring the pile, since there is no need to wait for pouring of the concrete.
- The PS gave reasonable results, under the condition that the transducer is not coupled to the rod. This requires an uncoupling mechanism, that can coupled again in the soil, or the measurement should start at sufficient depth. The advantage of the method is that it doesn't require preparation in the piles, but the site must be accessible for heavy equipment.
- ST, DAC and CHSL didn't give results. ST measurements required additional interpretation. DAC was hindered by failure of the transducer that was used at the pile head. The number of piles with three tubes was too low to give a judgement over CHSL.

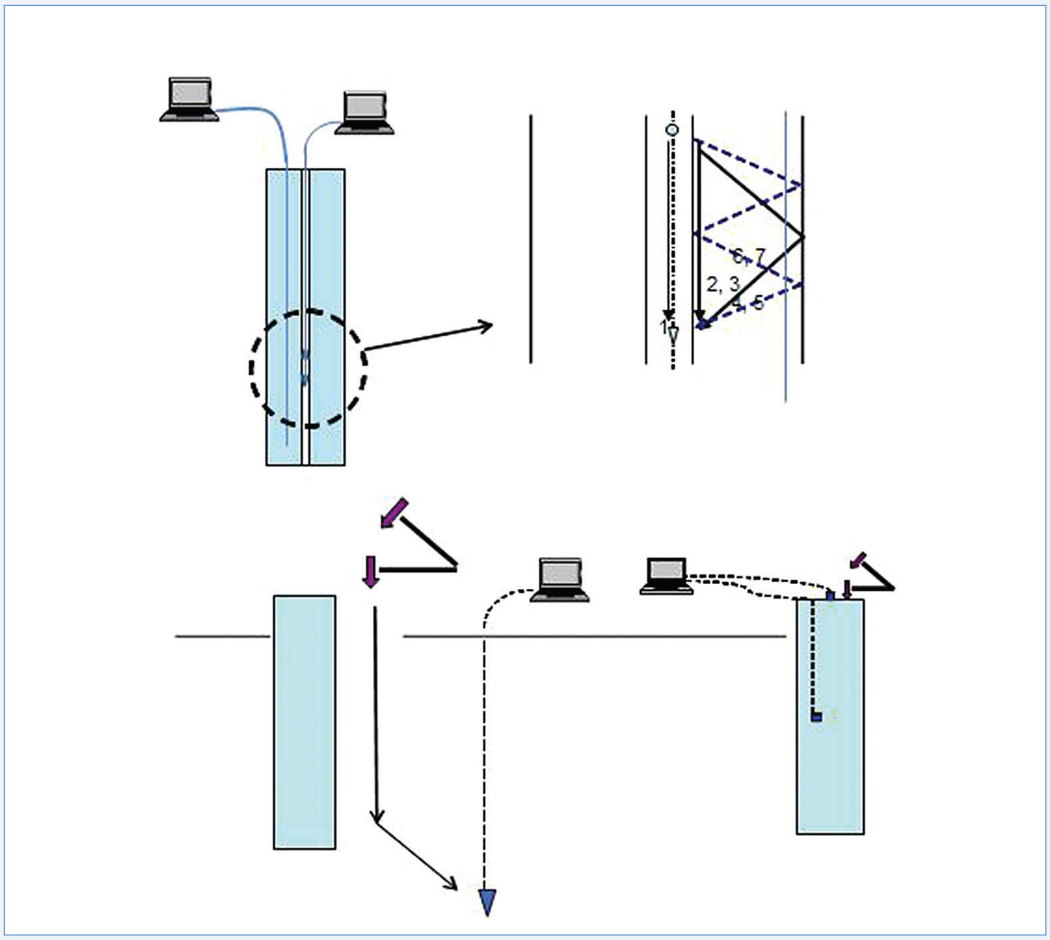

Figure 1 – Overview of the methods that are tested.

SUMMARY

Cast in-situ piles are sensitive for defects during installation. Therefore, integrity of the pile-shaft must be tested. Traditional sonic testing often leads to discussion on the acceptance of piles. More advanced methods that give reliable information on concrete quality and diameter of the pile at distrusted locations are required. This paper describes a field test in which several of these methods have been evaluated. Two methods (Seismic Tube and Deep Acoustic Check) are presented in more detail.

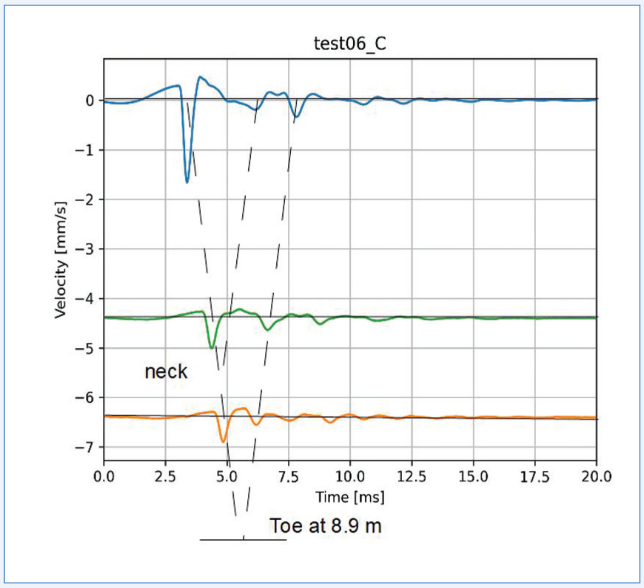

Figure 2 – Results of Deep Acoustic Check at pile 6.

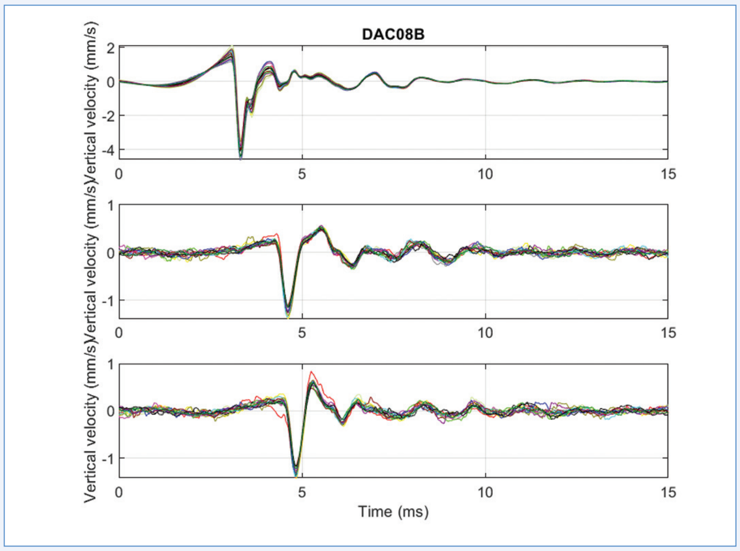

Figure 3 – Results of Deep Acoustic Check at pile 8.

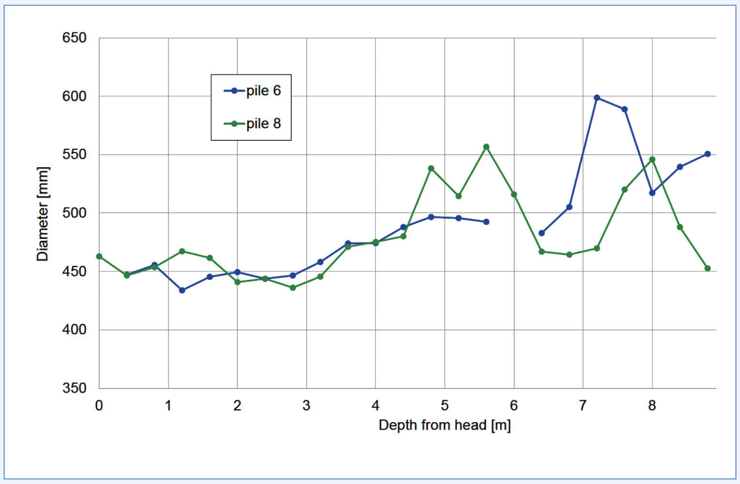

Figure 4 – Diameter of piles from measured circumference for pile 6 and pile 8.

After the tests, seven piles have been removed. The selected piles had the largest difference between the intended defect and the defect detected by the measurements interpretation or had very different answers from the measurments. After removal, these piles were inspected visually and (later on) the circumference has been measured. It shows that the creation of a neck with a rubber tire worked well, although some tires were damaged and felt down to the toe of the pile. Injection by concrete to did create some bulges but was hampered by blockage of the pipes. It turns out to be important to regain the piles to check the defects precisely.

3. Deep Acoustic check

The basic idea of the Deep Acoustic Check is to add cheap (lost) transducers (Mems) deep in the pile. The signals that are measured by these deeper transducers, can be interpreted by similar methods as the traditional transducers at the pile head.
The method has been tested experimentally in the field-test after the initial work. The applied Mems accelerometers are sufficient sensitive to get (after integration) velocities in the pile that can be interpreted.

Table 1 shows a summary of the defects in two piles that were excavated and inspected after testing. The piles had been selected on discussion about the real defects. This inspection showed that the intended defects were often not as expected.

Table 1 – Summary defects in piles

Pile	6	8
Length pile [m]	8.94	9.15
Depth transducer 1 [m]	4.4	5.7
Derived wave speed [m/s]	4541	4341
Depth transducer 2 [m]	6.4	6.7
Derived wave speed [m/s]	4451	4376
Shallow defect	none	none
Deep defect	bulge	bulge
Depth defect [m]	7.5	8.0

Figure 2 shows an example of a measurement on Pile 6. The figure is presented as a seismogram, with on the horizontal axis the time, and on the vertical axis the position and amplitude. Pile 6 has one transducer at the pile head and two deep transducers at 4.4 m and 6.4 m under the pile head. Figure 3 shows similar results for pile 8.The signal of the transducer at the head suffers from the integration. This suggest that for this position the mems require a very high sampling rate to be able to integrate to velocity. A traditional transducer might be preferable. Deeper transducers have less influence of this aspect, presumably since the very high frequencies are damped during propagation.

Figure 2 shows that the actual wave speed can be determined accurately. The determined propagation of the waves is shown by dashed lines. For this short pile this is not very relevant, but for longer piles the uncertainty on wave speed hinders the accurate determination of pile length. The deep transducers solve this quandary.

Figure 4 shows the diameter on depth for both pile 6 and 8. The circumference had been measured,

Figure 5 – The seismic tube is placed in the hole in a pile.

and under the assumption of a circular cross-section, the diameter is derived. Pile 6 has a clear bulge close to the toe. The transducers are well above the defect, but this defect is close to the toe. The toe reflection hinders the interpretation. Pile 8 has two bulges. The two transducers are in the highest (closest to the pile head) bulge. This complicates the interpretation.

The interpretation shows that the transducer should be located a sufficient distance above the defects. This distance should be at least the length of the impact wave in the pile. In this case, the wave speed is 4500 m/s and duration of the blow is 0.7 ms. The length of the wave is thus 3.1 m. The transducer is 1.6 m above the neck, so the incoming wave and reflected wave are interfering. However, the different shape of the measured signal at top and at depth shows that there is a neck below.

Since the bulges in these piles are close to the pile toe, the interpretation is challenging. This shows that tests on short piles have limited value for research, since the signals are interfering too much.

4. Seismic tube

The Seismic Tube has been specially designed to gain detailed information of defects, by the application of high-frequency (about 50 kHz) acoustic waves. The seismic tube has two acoustic sources and 8 equidistant acoustic receivers in between. The idea is based on the methods used for seismic surveys. The presence of two sources makes it possible to use two acoustic signals at one position. The present of 8 receivers makes it possible to create a seismic profile.

The instrument is lowered into a tubular hole in the pile, see Figure 5. By performing the measurement with the Seismic Tube at different heights, a measurement is obtained that is comparable to the Single Hole Sonic Logger. However, the presence of eight transducers (instead of one, as with the SHSL) makes it possible to apply seismic interpretation techniques.

Figure 6 shows a measurement as seismogram, i.e. the time signals are presented at the position where it is measured. The signals are multiplied with a factor that is proportional with the distance between the transducer and the source. This avoids that the decay of the signals makes the signals further away almost invisible.
This figure suggests that the decay is quadratic with distance. However, the cumulative energy in the signals shows that the energy decay is less, about amplitude multiplied with square toot of amplitude.

The signals that had been measured in the test field have been analyzed more in detail by Veltmeijer [4]. One of the methods tested is the well-known surface wave inversion (e.g. MASW), but this did not lead to a useful result. This analysis lead to the conclusion that several wave types are propagating in the pile. They can be picked by the arrival times:

- a direct wave propagating parallel with the pile axis (straight characteristic)
- a "surface" wave (Stoneley wave) propagating parallel with the pile axis (straight characteristic)
- a refraction wave (curved characteristic)
- a reflected wave (curved characteristic)
- a reflected refraction wave (curved characteristic)

Veltmeijer also created an interpretation tool that can be used for picking the waves from the measured signals Figure 7 shows an example.

The tool shows that the complex structure of the waves propagating in the pile can be understood. The first arrivals give information on the wave speed in the concrete and thus the quality of the concrete in the core. To determine the diameter of the piles locally the reflected waves must be determined, while these waves interfere with the direct waves that arrive in positions further away only slightly earlier.

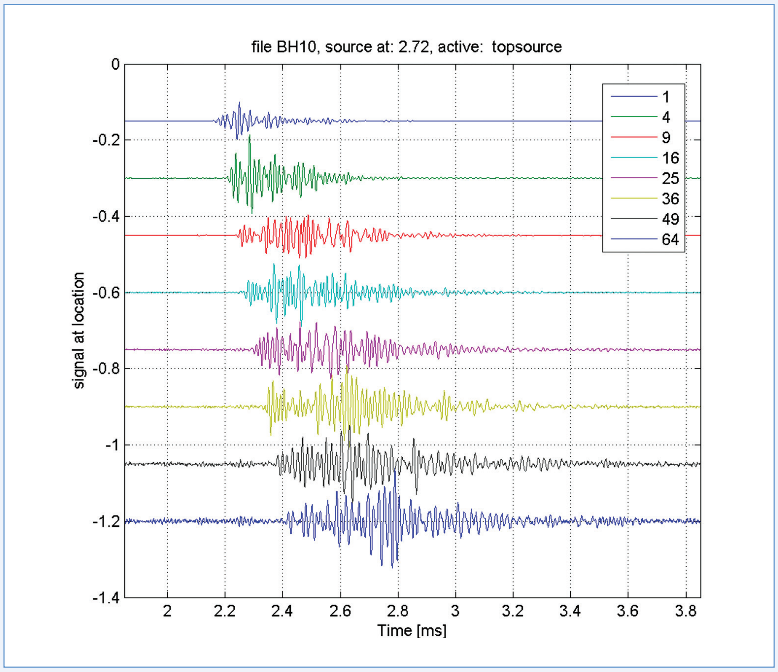

Figure 6 – Measurement in Pile 13 at 5.67 m depth presented as seismogram. The legend presents the multiplication factors for the signals.

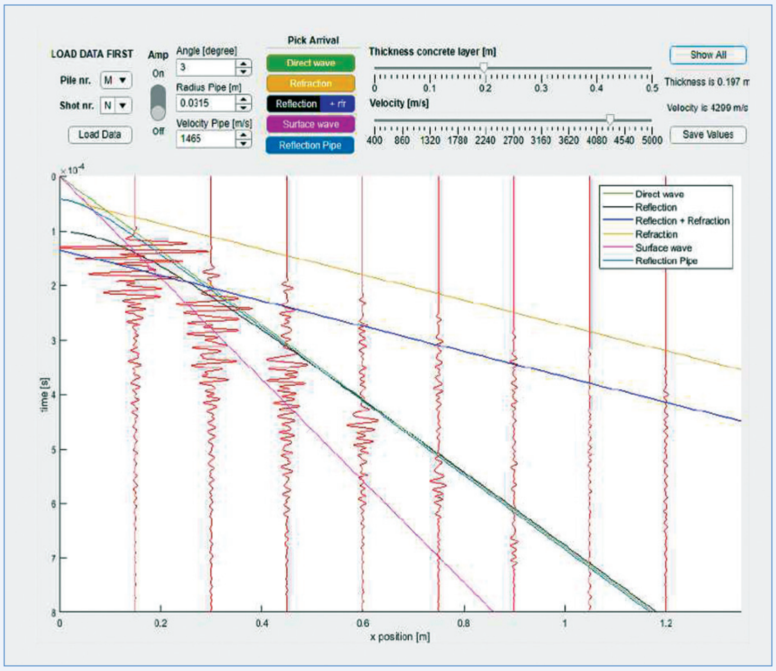

Figure 3 – Example of wave picking tool, showing the complex wave system [7].

This research also shows that the frequency about 50 kHz of applied source of the seismic tube seems sufficient.
The tool was tested for practical engineering but turned out to be too sensitive for user choices. This means that the method has been proven to be possible, but improvement is still required. This can be carried out by improvements of the instrument or automation of the interpretation procedure. Especially an approach which is based on source characteristics. If the direct wave and surface waves are distinguished from the other waves, the seismic tube offers the possibility to get insight in the thickness of the piles.

The results of this analysis also have consequences for the interpretation of Single Hole Sonic Logging, where only one transducer is used. The waves that carries information on the diameter of the pile are the reflected and refracted waves. These waves are not very strong and always in the shadow of the direct waves. This suggests that SHSL is a useful tool for checking the concrete quality, but not for evaluation of the pile diameter. This agrees with the findings by Palm [5]. Application of a seismic tube is expected to give more precise information on quality of concrete.

5. Conclusion

The experience during the installation of the test piles shows that the creation of artificial defects is complicated. Removal of the piles after testing and proper inspection is essential to evaluate the real defects.

The new advanced technologies described in this paper have potence to give more insight than experienced engineers get by traditional PIT. However further development and more experience are needed. The DAC method seems useful for longer piles. The position of the transducers must be optimised for the pile length and the expected positions of the defects. The Seismic Tube gives good information on the concrete quality (from the wave speed). To derive the diameter, the interpretation needs the discrimination of direct waves and waves that are reflected form the edge. This research will start with experimental work at the demonstration day at the Stress Wave Conference in September 2022.

Acknowledgement

This work has been founded by the companies that were participating in the project: van 't Hek, Brem, Hektec, Volker Staal en Funderingen, Fugro, Profound, Leiderdorp Instruments and Directorate-General for Public Works and Water Management and the research program Geo-impuls [3]

References

[1] Hopman, V., Hölscher, P., report Opzet testlocatie voor in de grond gevormde palen - COB, 2016.
[2] de Groot, P.H., report The parallel Seismic detection of defects in pile foundations, MSc report TU-Delft, the Netherlands, 2014 https://repository.tudelft.nl/.
[3] Geoimpuls, see http://www.geoimpuls.org
[4] Veltmeijer, A., Seismic Properties of Foundation Piles, Diameter determination of in-situ created foundation piles using the Seismic Tube, MSc-thesis Applied Geophysics Research, IDEA league Delft University of Technology/Deltares, August 2019
[5] Palm, M., Single-hole sonic logging, A study of possibilities and limitations of detecting flaws in piles, MSc report, Royal Institute of Technology (KTH), Department of Civil and Architectural Engineering, Stockholm, Sweden, 2012, www.diva-portal.org/smash/get/diva2:542054/FULLTEXT01.pdf.