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Early stage elastic wave velocity of concrete piles

Ernst Niederleithinger *, Alexander Taffe

Federal Institute for Materials Research and Testing (BAM), BAM IV.4, Unter den Eichen 87, 12205 Berlin, Germany

Abstract

The low-strain pile integrity testing method is used for quality control of new piles as well as length and integrity check for old piles. If no other methods for calibration are available, the accuracy and reliability of the techniques depend on a good estimation of the elastic wave velocity. In practice it is assumed that piles can be tested 7 days after casting and that the velocity is almost constant in all piles of one kind in a construction project. Recent measurements at the BAM test site in Horstwalde, Germany, showed that the 7 day criterion is not generally applicable.

Keywords: Non-destructive testing; Concrete piles; Pile integrity testing; Foundation

1. Introduction

Concrete piles are important parts of constructions nowadays. If they fail, the entire construction is in danger. Enormous assets rely on proper performance of these deep foundations. As repair or improvement of foundations is difficult and expensive quality control is a major issue. In many countries non-destructive testing (NDT) methods such as cross hole sonic logging (CSL), neutron logging or low-strain pile integrity testing (PIT) are applied on a regular basis, by demand of either the client or the supervising authorities. PIT as the fastest and cheapest method is preferred in most cases.

All methods have serious limitations. For example the CSL method is not sensible to damages outside the reinforcement cage. In the case of PIT there is a lack of resolution (detection of small damages) and an ambiguity between length deviations and quality anomalies. Some aspects of the latter issue are discussed in this article.

2. Low-strain pile integrity testing methods

The *low-strain method*, often referred as pile integrity testing (PIT), is used since several decades [1]. A velocity sensor is placed on top of the pile; a hammer blow generates a force impulse (Fig. 1a and b). The sensor records the resulting movement of the pile head (Fig. 1c). Reflections are caused at major impedance changes in the pile. These changes are present at major increases or decreases of cross-section and/or concrete quality changes (E modulus or density) and of course at the pile toe. The method works, if the acoustic parameters of the surrounding soil differ significantly from the pile concrete.

The pile length L or depth of an impedance change is calculated from the measured transit time Δt and the estimated or known wave speed (WS) in the pile. The other way round (as in this paper) the wave speed c for each pile might be calculated from measured Δt and known length L. Significant differences between the calculated c of different piles give a hint for a quality/integrity problem. Interpretation of reflection shape (e.g. sign, amplitude) gives information on defect type, shape and size. The method is described in several standards [2–5].

3. The test site Horstwalde

In 2005 BAM has built a pile test site at Horstwalde close to Berlin with 10 bored piles in well-compacted sandy (partially silty) soil typical of the Berlin–Brandenburg area (see Fig. 2). Peat layers occur at some locations. The piles of 60 cm diameter have different lengths between 9 and

* Corresponding author. Fax: +49 0 30 8104 1447.
E-mail address: Ernst.Niederleithinger@bam.de (E. Niederleithinger).

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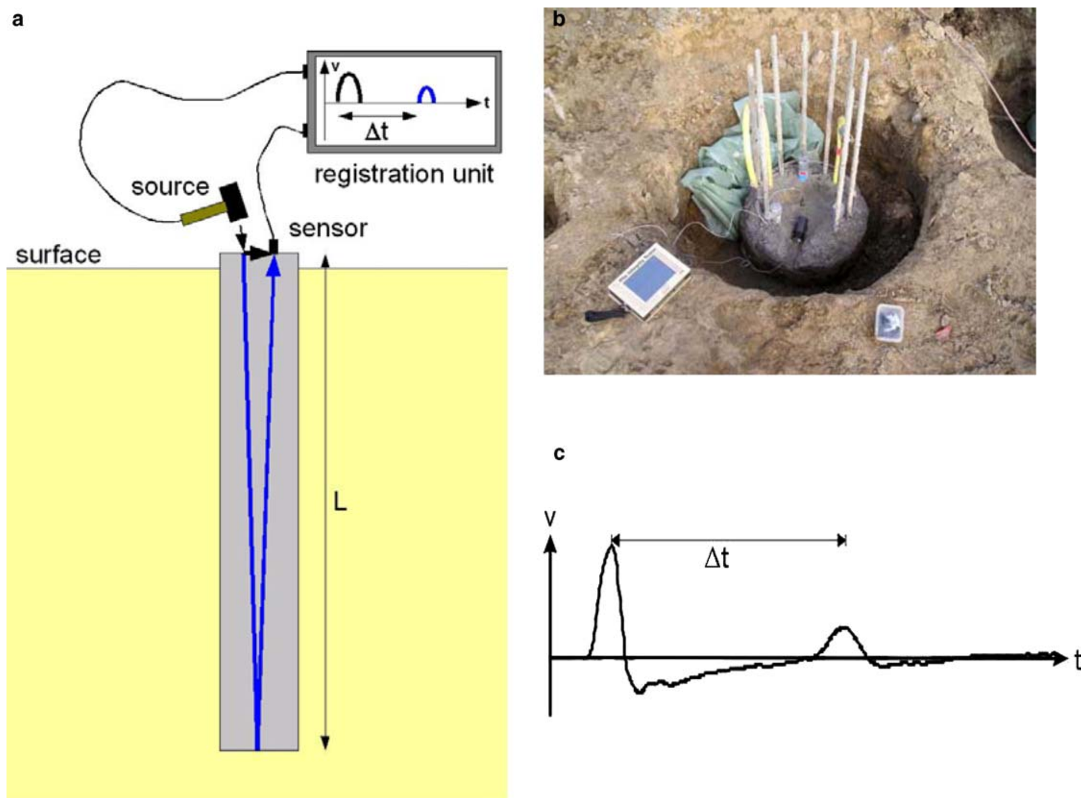

Fig. 1. (a) Principle of the low-strain method and (b) the pile testing device with a sensor and a hammer at the pile top, and (c) example record.

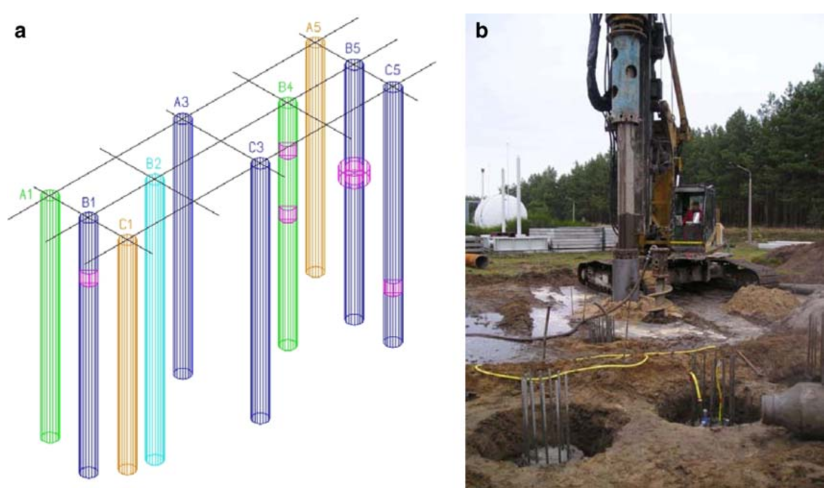

Fig. 2. (a) Drawing of the pile test site with 10 piles and (b) pile test site under construction.

12 m and have been tested with the low-strain method as soon as possible after pouring the concrete. Due to the construction process the pile length was known with an uncertainty of ±10 cm. CEM II Portland composite cement C 25/30 with slow compressive strength development was used.

Some of the piles have artificial defects made by gravel filled geotextile bags or water injection. Observation boreholes near the piles, CSL access tubes and strain gauges allow a large variety of experiments. The test site will be available on a long-term basis for research and education.

4. Measurements and interpretation

Starting directly after casting the piles have been tested as early as possible. Figs. 3–5 show typical early recordings of the pile top velocity versus transit time of a 9.3 m (LE) long pile. The pile length (LE in Figs. 3–8) is known with

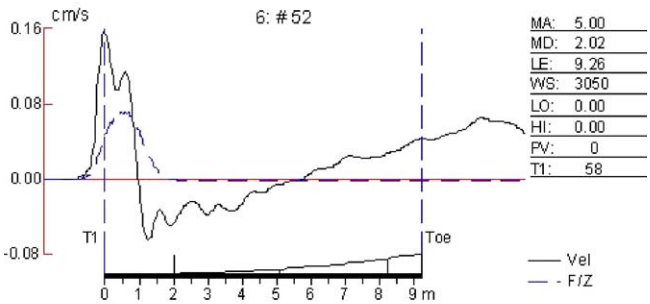

Fig. 3. PIT result pile C3 second day (no clear toe reflection).

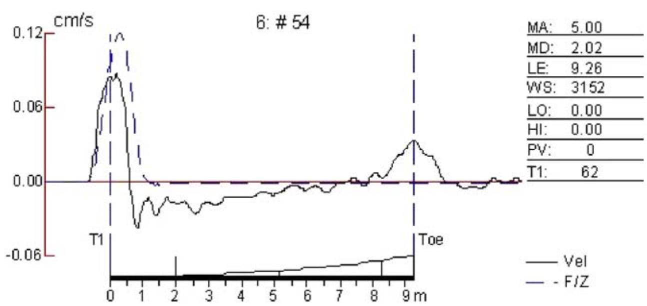

Fig. 4. PIT result pile C3 third day (clear toe reflection, wave speed 3152 m/s).

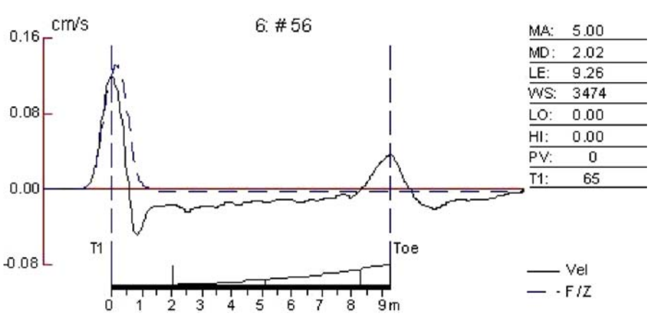

Fig. 5. PIT result pile C3 seventh day (clear toe reflection, wave speed 3474 m/s).

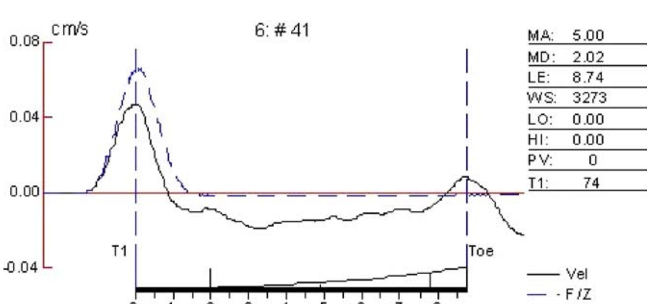

Fig. 6. PIT result pile B4 third day (no defects visible).

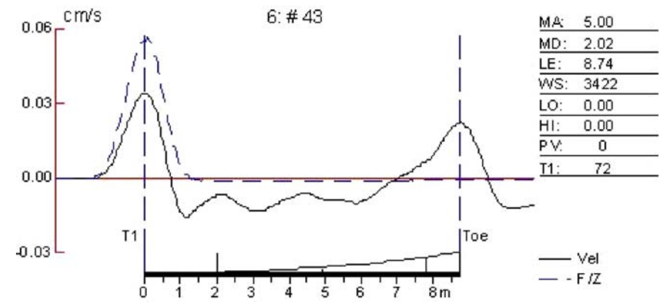

Fig. 7. PIT result pile B4 fourth day (two defects roughly at depth 2 m and 4 m can be guessed).

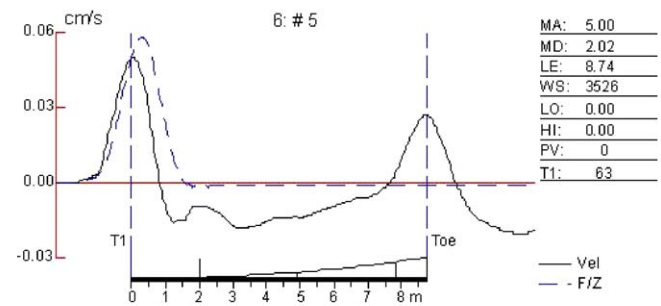

Fig. 8. PIT result pile B4 10th day (the defect at 1.7 m appears clear; the defect at 3.7 m is not clearly visible).

an uncertainty of ±10 cm and was used for further calculations. The horizontal time axis is converted to depth by the interpretation software, the calculated wave speed *c* is noted "WS" among the parameters on the right. WS is obtained by positioning the vertical dotted cursor lines at the impact impulse and the toe reflection. In Fig. 3 (second day) no reading is possible. Figs. 4 and 5 allow readings of WS of 3152 m/s and 3474 m/s. To compare the shape of the curves the processing parameters MA (magnitude of the amplification function of the signal), MD (depth of beginning of the amplification) have been set to the same values. Filter operations LO (low-pass-filter) and HI (high-pass filter) have not been used.

Only one of three piles tested on the second day showed a weak pile toe echo. For the others no pile toe reflection could be observed (Pile C3 as example in Fig. 3). All five piles tested the third day showed a clear pile toe reflection as shown in Fig. 4. No significant difference in this behavior was visible between 8, 10, and 12 m long piles, but may occur on longer piles. The artificial defects, which cause smaller signals, have become visible the fourth day latest if we compare Figs. 6 and 7. But the deeper one of the two defects seems to be more reliable at the early age of 4 days than 6 days later as shown in Fig. 8. Only the upper defect can be read out reliably from Fig. 8 corresponding with its true depth of 1.7–2.0 m. One reason for this invisibility of reflections at early times is the damping of elastic waves in fresh concrete, as described for example in [8]. Due to absorption only a low amount of energy is reflected to the surface. At the same time the *E*-modulus is low, resulting in low velocities.

The change of the wave speed over time is shown in Fig. 9 for four selected piles (others show similar behavior, but have not been tested at an early age). Between days 3

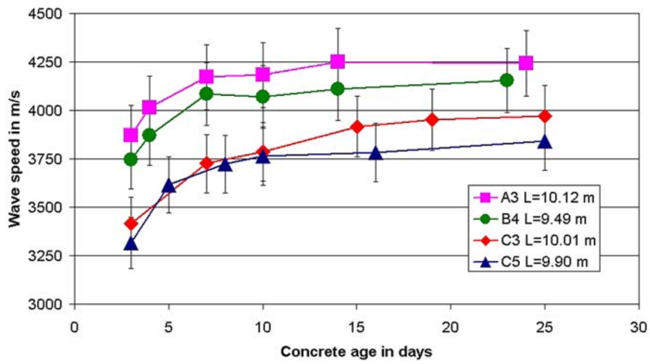

Fig. 9. Development of wave speed related to concrete age for four Horstwalde piles. Error bars correspond to the uncertainty of the method of approximation 4%.

and 7 the increase is around 10%, between days 7 and 14, 2–5% and less than 2% after day 14. After 10 days the velocity change is less than the estimated uncertainty of the method of approximation 4% [7]. The average velocity of all piles in Fig. 9 is around 3750 m/s. The deviation of the measured pile velocities from this average is again less than the estimated method uncertainty of 4%.

The observed velocity development agrees well with results of other authors. Finno et al. [9] have tested several piles with lengths between 12 and 27 m. They have detected slightly larger changes (3% between days 14 and 28) at late times. On the other hand Restrepo found no significant change after day 7 when testing 5 m long sample piles [10]. Several other authors mention velocity increases after a long term (several decades) of 2–3%. The shape of the velocity developments is the same for our piles as well as of those of the other mentioned researchers. The main reason for the velocity increase is the development of the elastic moduli, which itself directly related to the wave speed.

5. Summary and outlook

The early stage measurements at the BAM Horstwalde test site have shown that there is no simple "ready for testing" criterion for concrete piles. The detection of defects (integrity check) seems to be possible after a few days (four at Horstwalde piles) but more reliable after 10 days. Also pile length measurement, which relies on a good velocity estimation, requires longer waiting times our case after 10 days the velocity change was lower than uncertainty of the method. Checking piles with different ages on a construction site may lead to misinterpretation. A systematic deviation of the wave speed has to be taken in the consideration by the tester when young piles of different ages are tested and compared to each other. Piles the under age of 7 days should not be checked for pile length. The qualitative evaluation of pile shape or defects should be handled with care in the first 7 days.

Ways to overcome these problems are testing all piles at the same age, use of a second method for calibration (e.g. Parallel Seismics [6]) and to check at least one pile at each site several times to have an idea on velocity development.

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