Field studies on bearing capacity of vibratory and impact driven piles

P. Lammertz
Institut of Soil Mechanics and Foundation Engineering,
University Essen, Germany

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Abstract
The mean topic of the research project is to compare vibratory and impact piles concerning bearing capacity and to derive a design concept to vibratory piles. Measurements during pile-driving and geotechnical information of the site constitute the basis for our following research.

Introduction
Vibratory driving is a dynamic method to install piles into the ground. Compared to impact pile driving it is extremely economical and reduces noise pollution. Unfortunately vibratory driving is still fraught with uncertainties. One of the foremost question is bearing capacity of the installed piles. It has been still required that the vibratory driven pile is redriven with an impact hammer for acceptance as a bearing pile. But this process disturb the advantage above mentioned of the vibratory driven piles. The main objective of the present research project is to derive a relation between measurements during the installation and the bearing capacity of vibro-driven piles, subjected the knowledge of the properties of the soil. The projekt aims to clarify the primary factors influencing the bearing capacity of vibro-driven piles. It is sponsored by the German Society of Research (DFG) and directed by Prof. Dr.-Ing. W. Richwien.

Vibratory technics
When eccentrical supported masses (combined eccentric mass m) spin at a rotational frequency $\Omega$, their centrifugal force is $F_{dyne}=m\Omega^2\cos(\Omega t)$. This force is transmitted through the eccentric mass bearings to the oscillator and thus to the pile. Only vertical components of the centrifugal force are transmitted to the pile because pairs of eccenters are spinning in opposite directions. Normally the vibratory frequency is between 20 and 40 Hz and the displacement amplitude is approximately 1-20 mm (depend on the vibrating mass).

Comparison of bearing capacity of vibratory and impact driven piles
A literature research was conducted to find as many pile test programs as possible that had direct comparisons of vibratory and impact driven piles. Even though the vibratory technique is global, there are very few publications dealing with the bearing capacity of vibratory driven piles. The lack of publications in the area reveals both the lack of knowledge and the potential for further research. In Figure 1, the failure load for the vibratory driven piles is plotted versus the failure load of the impact driven piles found in the literature. The diagonal line in the plot represents a one-to-one correspondence between the impact and vibratory capacity; points below this line show a greater capacity for vibratory driven piles, and the points above this line show a greater capacity for impact driven piles. This plot show that, for the majority of the pile tests, the vibratory-driven piles have less capacity than impact driven piles. A common and possible explanation for the reduced capacity for vibratory driven piles is that the vibratory driving process results in less compaction at the pile tip, thus lowering the tip capacity. The analysis of the literature revealed that many questions concerning the bearing behavior of piles are not sufficiently clarified. It was ascertained that equal piles in equal soil reached deviations in the bearing capacity.

![Figure 1 comparison of impact and vibratory driven piles](image-url)
Field studies

The piles tested are part of pile foundation for a pier construction of the Port of Emden. It is situated in the North-Sea on the western border of the German Bight in the Ems River estuary. The pier is founded on continuous flight auger piles, a combined sheet pile wall and steel piles. Figure 2 shows a photograph during construction. The piles tested are open-ended steel piles, 31.3 m in length, 914.7 mm in diameter and 12.7 mm thick. The soil investigation consisted of CPT, SPT, boring and soil sampling at different levels. Furthermore there are conducted laboratory tests to determine the soil classification and stress-strain behaviour of the soil. The soil are sandy clay and peat down to 8 meters, overlying medium to dense sands. The piles are installed using a Müller MS 32 HF var high frequency driver with variable eccentric moment and a IHC Hydrohammer S 70. The instrumentation mounted on the vibrator is manufactured by the German Thyssen Krupp and the French Lutin company. The vibrator instrumentation consists of five sensors for monitoring the following vibratory parameters: eccentric moment, driving frequency, penetration depth, oil pressure and the acceleration of the vibrator. The observation during impact driving contains the common parameters: penetration depth, blows per distance, total blows, energy and blows per minute. Dynamic testing with stress-wave measurements are performed on all piles tested to determine the static pile capacity and its distribution along the shaft and on the toe.

In the following one part of the test results will be presented. Note that the measurements haven’t been still finished. One pair of piles was installed at a distance of 4.3 meter using respectively vibrator and hammer. The vibro-driver proved to be extremely efficient for the penetration into saturated sand. The pile was driven from -14.3 mN to a depth of -24.5 mN with a mean penetration rate of 40 mm/s under the total weight of the pile and the vibrodriver (i.e. no crane uplift being applied). The driving frequency and the eccentric moment were held constant to 35 Hz and 24 kgm respectively. The oil pressure depends on driving frequency and resistance to drive the pile into the ground, namely all losses of energy during the penetration. The second pile was then impact driven using a IHC S70 at an energy of 56 kNm, and a penetration speed of 14 mm/s. Figure 3 depicts the oil pressure of the vibrator during the installation and relating driving energy of the impact pile.

The pair of piles was dynamic tested after a delay of two weeks. The results of the dynamic test show that the vibratory pile has a slightly higher capacity (2286 kN) than the impact driven pile (2054). The tip capacities for both are only 550 kN and reveal that both piles were unplugged.

Summary

Brief descriptions of the results of the measurements will be presented orally. Note that the measurements still haven’t been finished. One of the main issues related to use of vibratory driving for installing bearing piles is the estimation of the setup of the shaft friction after it has been considerably reduced during pile installation. Furthermore it is important to elaborate links between the results of the cone penetration tests and the driving log of vibratory piles.