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Correlation of machine parameters, boundary conditions and soil properties using vibro compaction technology

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Introduction

Vibro compaction is a vibratory compaction technique, where vibrations emanating from the depth vibrator reduce the friction between the soil particles so that they can rearrange into a denser state under their own weight. However, design and quality control of compaction in cohesionless soils have remained almost entirely empirical on the base of project specific compaction trials, since several machine and soil parameter influence the compaction result. This is why the achieved density is usually determined by soil investigation tests which offer reliable but only spot-like testing after compaction. Relatively recent research has however shown, that recorded machine parameters such as the movement and the power consumption of the vibrator may indicate the compaction state of the soil during compaction which could make vibro compaction more efficient.

Influencing Factors on Compaction Result

The resulting degree of volume reduction and the corresponding soil density of vibro compaction depends on the soil properties, the applied energy, which mainly depends on the chosen design parameters for the compaction procedure and the characteristics of the vibrations, which are emanated from the vibrator.

Design Parameters & Vibro Compaction Procedure

1. The oscillating vibrator sinks under its own weight into the ground to the design depth, by using air and water jets as penetration aid.
2. During compaction, the vibrator is held at a constant level for a specified holding time before its stepwise retraction towards the surface with intervals from 0.5 m –1.0 m. A longer holding time and smaller depth interval leads consequently to a denser soil.
3. Backfill is added of up to 1.5 m³/ m compaction depth from the top, to maintain a constant contact of the vibrator with the ground, which is required for energy transmission.

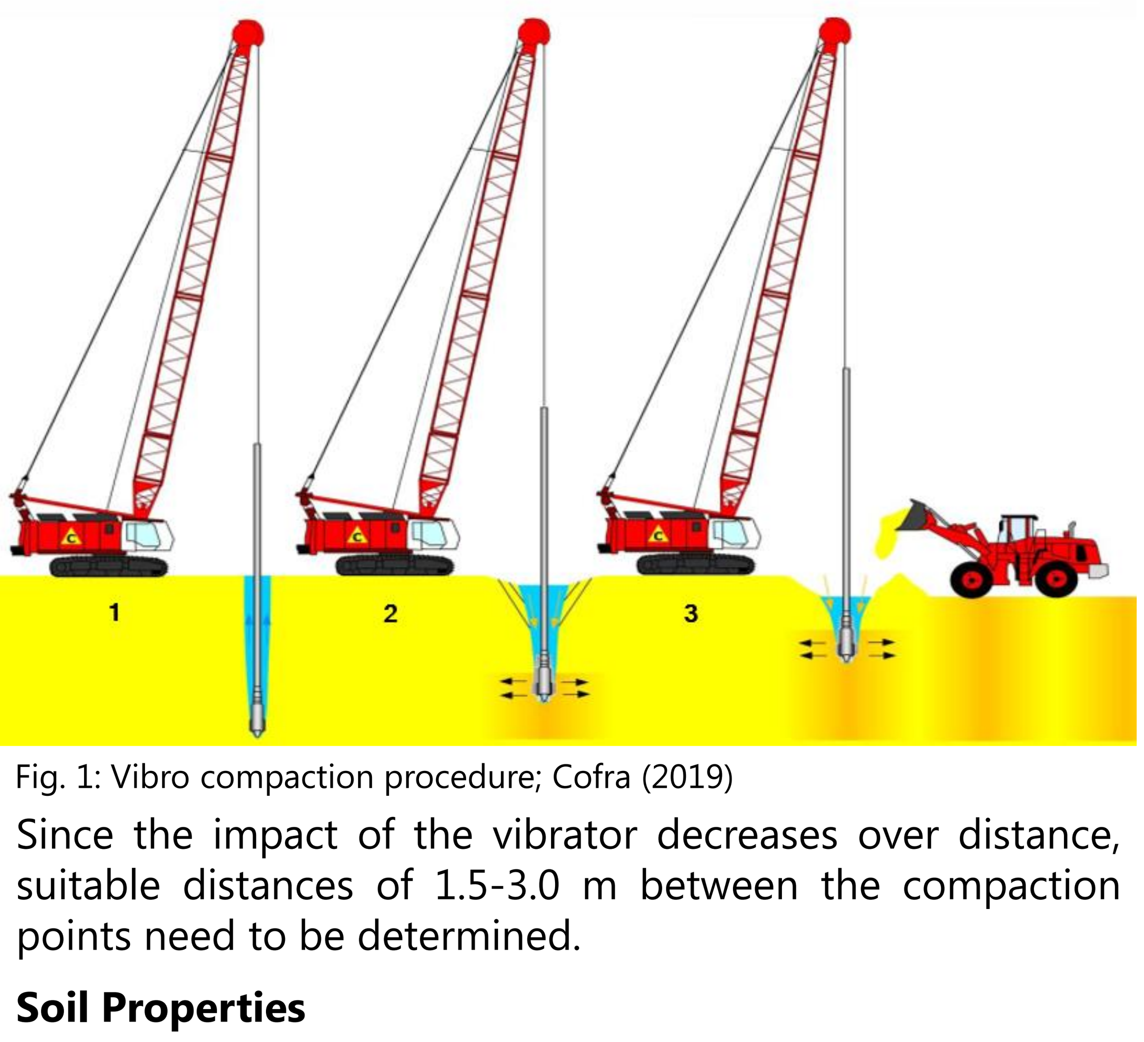

Fig. 1: Vibro compaction procedure; Cofra (2019)

Since the impact of the vibrator decreases over distance, suitable distances of 1.5-3.0 m between the compaction points need to be determined.

Soil Properties

Cohesive soil particles are more difficult to rearrange and dampen the vibrations, wherefore a maximum fines content of 10-15 % is recommended.

Depth Vibrator

The depth vibrator contains an eccentric weight with the mass *M* which rotates around its vertical axis with a given eccentricity *e* and angular frequency ω, causing the vibrator to oscillate horizontally with the corresponding double amplitude *2a*.

The horizontal vibrations can be expressed by the centrifugal force *F*.

$$F = M \cdot e \cdot \omega^2 \qquad (1)$$

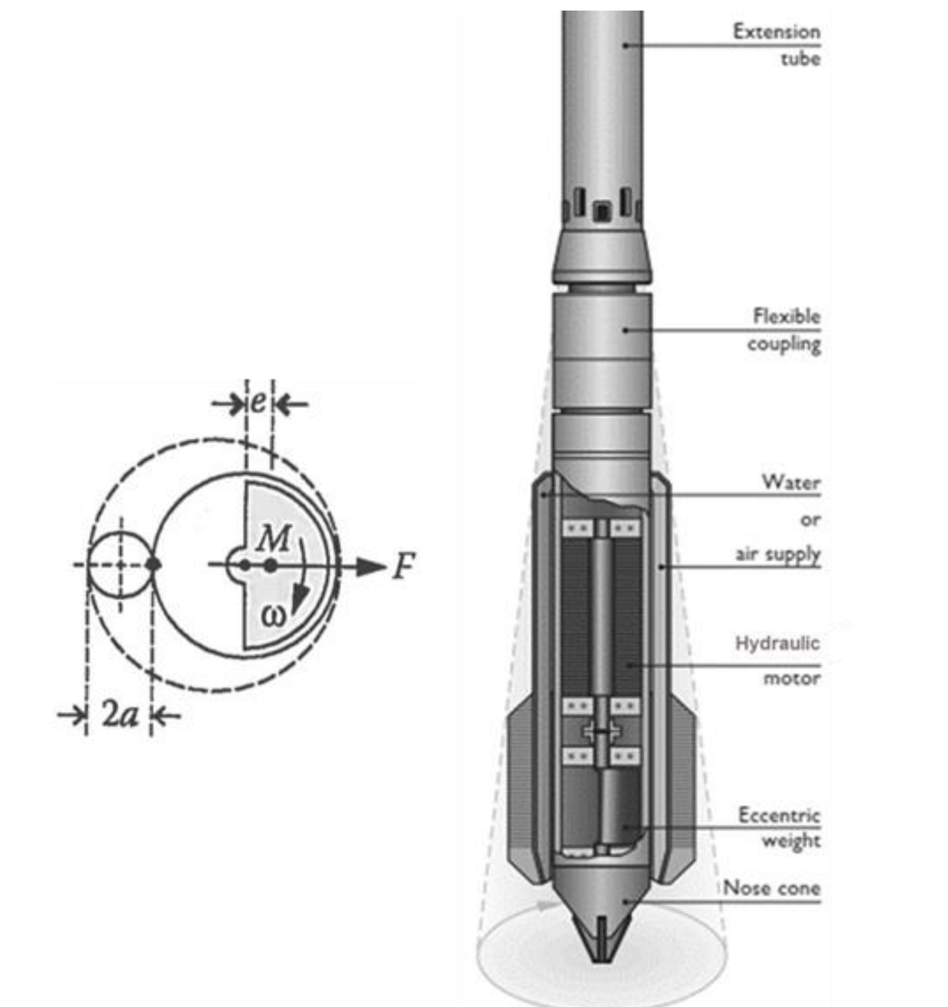

Fig. 2: Cross section and operating mode of the depth vibrator; adapted from Keller (2019) and Kirsch (2017)

Quality Control during Compaction

A denser soil causes more resistance to the vibrator motor and consequently reduces its rotational speed, wherefore the power consumption (hydraulic oil pressure) of the vibrator needs to increase accordingly, to maintain a constant rotational speed. Since the soil compaction occurs during holding of the vibrator, it is assumed that the recorded hydraulic pressure can indicate the compaction state of the soil during the holding times. Moreover, the movement of the vibrator, which is characterized by the oscillation amplitude and the position of the eccentric weight over time, are assumed to indicate the soil state. [2]

Correlation Analysis of Makassar Trials

To investigate the correlation between the hydraulic oil pressure and the soil state, a realized vibro compaction project in Makassar, Indonesia has been used. The recorded machine parameters and performed CPT's derive from several compaction trials on carbonate sand. An example of recorded machine parameters can be seen in Fig. 3.

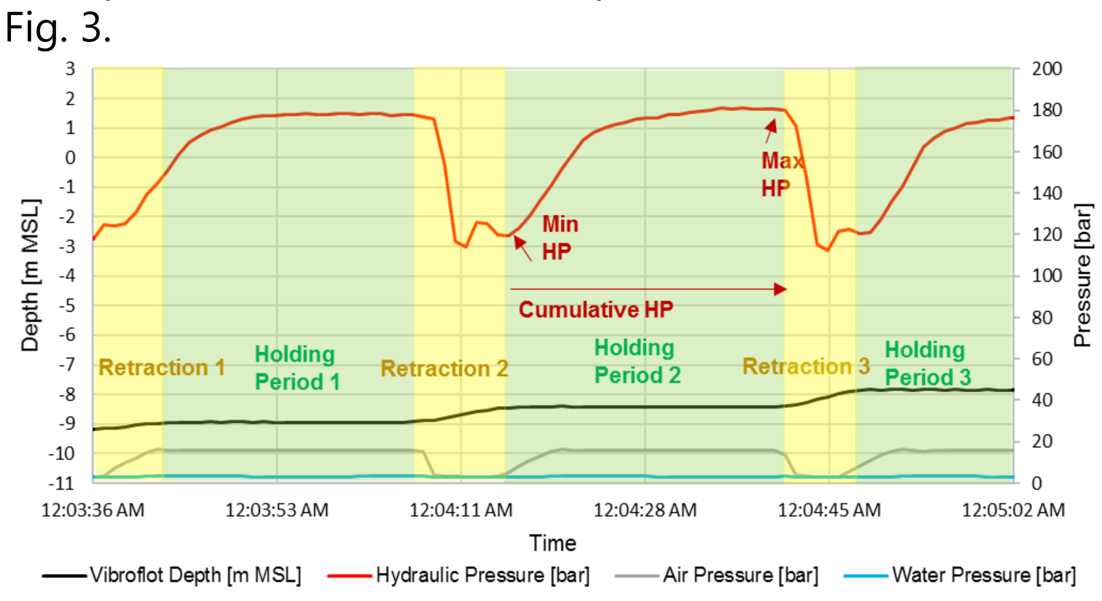

Fig. 3: Typical time history of the vibrator depth, hydraulic pressure, air pressure and water pressure during holding and retraction

Assumptions

1. The hydraulic pressure is depth-independent
2. With the chosen grid spacing of 3.5 m, the surrounding compaction points have no significant influence on the hydraulic pressure of one compaction point
3. The depth vibrator impact decreases with distance from the compaction points, wherefore only adjacent CPT's shall be used to determine the soil state
4. The minimum hydraulic pressure per holding time corresponds to the Ø before compaction q_c of the subsequent depth interval
5. The maximum hydraulic pressure per holding time corresponds to the Ø after compaction q_c of the subsequent depth interval
6. The cumulative hydraulic pressure per holding time corresponds to the Ø Δ q_c or respectively to the Ø after compaction q_c of the subsequent depth interval

Results

For the minimum hydraulic pressure (red) no distinct correlation was found, which may be owed to the fact that the soil has been disturbed by means of penetration of the vibrator, wherefore the before compaction CPT does not display the surrounding soil state of the vibrator during compaction.

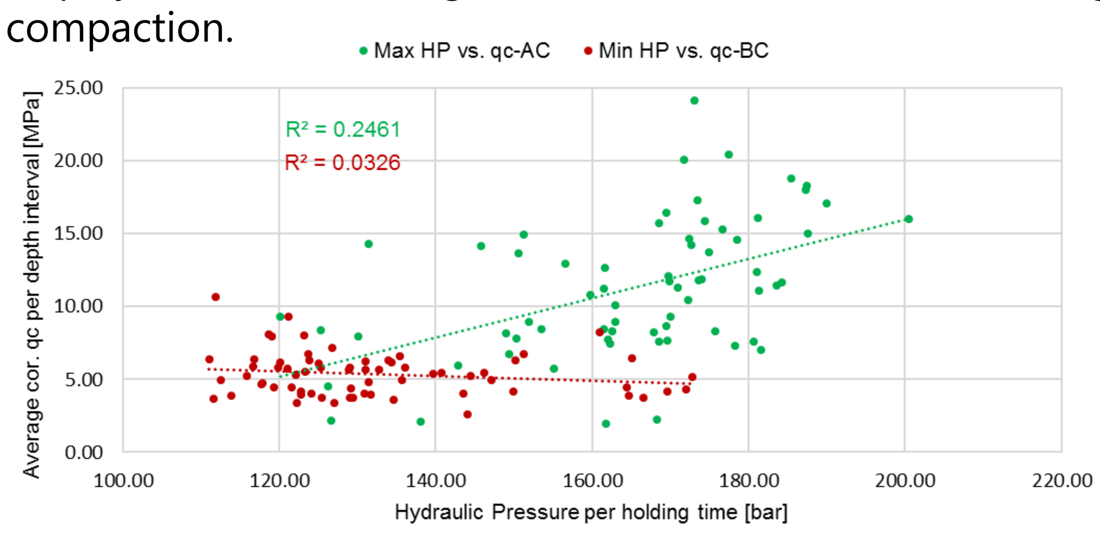

Fig. 4: Correlation between minimum hydraulic pressure and before compaction q_c (red) and correlation between maximum hydraulic pressure and after compaction q_c (green).

For the correlation between the maximum hydraulic pressure and the after compaction q_c (green), more distinct trendlines were found but still display a significant scatter.

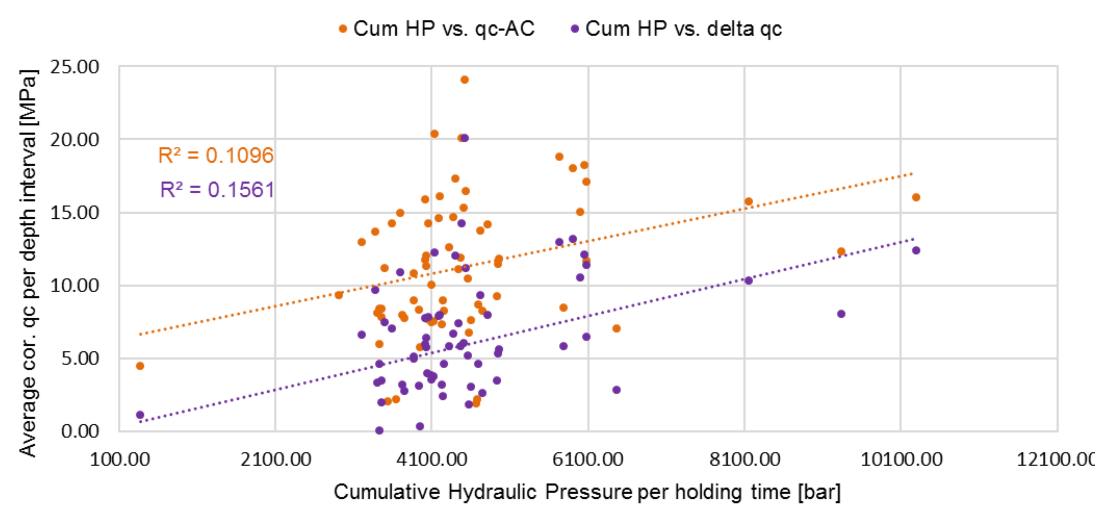

Fig. 5: Correlation between cumulative hydraulic pressure and after compaction (orange) or Δ q_c (purple).

For the correlation between the cumulative hydraulic pressure and the after compaction (orange) or respectively Δ q_c (purple), it was found that a significantly high cumulative hydraulic pressure corresponds to a denser soil, but since the holding time varied mostly around 30 s, a wider scatter of cone resistance was found for the same hydraulic pressure. Moreover, the trendline of the soil improvement correspond to the final soil conditions due to the homogenous initial soil conditions.

Summary

Based on the findings from the correlation analysis, it has been confirmed that the vibro compaction result is influenced by the soil properties, the duration of the compaction procedure and the vibrations. Regarding the use of the hydraulic pressure to predict the soil state, no distinct correlation was found, which may be owed to the use of carbonate sand, local soil variability and multiple changing design parameters during the trials. Further analysis with only one changing parameter is therefore recommended. Moreover, it is recommended to record the vibrator movement on site to validate the findings of other researchers.

Bibliography

[1] Kirsch, K., „Ground Improvement by Deep Vibratory Methods", CRC Press Taylor & Francis, 2017

[2] Fellin,W., „On-line Verdichtungskontrolle bei der Rütteldruckverdichtung", Messen in der Geotechnik, 2002

Project
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