Investigation of soil-machine interaction during deep vibro compaction

Analyse de l'interaction sol-machine lors du processus de vibrocompactage profond

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ABSTRACT: Deep vibro compaction (vibroflotation) is a method, which was patented by Keller in the 1930s and since then it has been successfully used worldwide for deep compaction of granular soils. The methods for quality control of the compaction works are largely empirical in nature and therefore often unreliable. In a current research project fundamental experimental investigations on real-time quality control for the deep vibro compaction are executed. Large scale test measurements were performed to investigate the three-dimensional vibrator movement during the compaction process. This paper presents selected results of the large-scale tests; moreover, possible indicators in the measured data for the changing soil conditions are discussed.

1 INTRODUCTION

1.1 *Soil improvement by deep vibro compaction*

The deep vibrator is essentially a rotating cylindrical steel tube with external diameters usually between 300 and 500 mm. Horizontal vibrations are induced by an eccentric weight at the bottom of the vibrator body, which rotates around its vertical axis. Figure 1 displays the compaction process and the compaction device, the deep vibrator schematically.

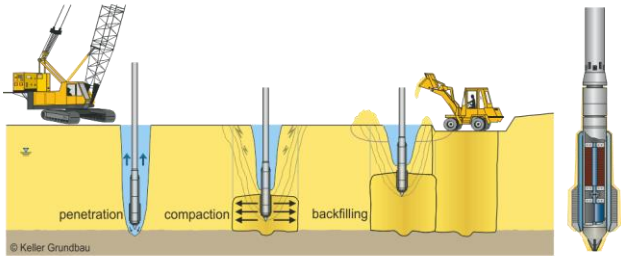

Figure 1. Compaction process during deep vibro compaction and the deep vibrator.

The compaction process is carried out bottom up either by vibrating at a constant depth for a fixed time or by withdrawing the vibrator by 0.3 to 1.0 m, then lowering again by about the half the withdrawing depth (back-step method).

There are nowadays basically two principle ways to estimate the success of vibro compaction. On the one hand site investigation methods such as dynamic probing, on the other hand by deriving performance factors from monitored machine parameters.

1.1 *Vibrator movement as indicator for the compaction state*

The three-dimensional movement of the deep vibrator is determined by the interaction between the compacted soil and the compaction device. Thus, an increase of the soil stiffness during the compaction process causes changes in the vibrator movement. Therefore, the vibrator movement together with certain process parameters can be used for a work-integrated indication of compaction state, which would provide the machine operator with valuable information on site and would be a valuable tool for the quality assurance of the compaction works.

The connection between the movement of the deep vibrator and the compaction state of the soil was first analyzed by Fellin (2000) on the basis of simple physical models. Model tests were performed in saturated sand by Nendza (2006). However, reliable vibrator instrumentation and a comprehensive measurement campaign could not be realized so far.

A pioneering basic research project was initiated to investigate the three-dimensional dynamic movement of deep vibrators comprehensively, including large-scale experimental tests and complementary theoretical investigations based on numerical simulations. This research project is a collaborative effort between the Institute of Geotechnics at the TU Vienna, the Keller Grundbau GmbH, the VCE Vienna Consulting Engineers ZT GmbH, and the Unit of Applied Mechanics at the University of Innsbruck.

2 IN-SITU TESTS

2.1 *Test area*

Figure 2. Test area near Fisching (Austria), divided into several subfields.

The three-dimensional movement of the deep vibrator during the compaction process has been investigated in large-scale experiments. A test area was prepared and equipped in a gravel pit near Fisching (Austria). Down to the exploration depth of 20 m, the subsoil was classified as well graded sandy gravel, therefore ideally suited for deep vibro compaction.

2.2 *Measuring technique*

To investigate the three-dimensional vibrator movement several sensors were installed on the vibrator body, which were exposed to very high demands during the compaction process. The installed sensors had to be protected against possible mechanical damages caused by soil grains and against water penetration, too. Furthermore, they had to be protected against estimated temperature up to 170°C on the vibrator body. Therefore, a novel specific monitoring and data recording system was developed for the experimental field tests.

Heavy duty triaxial accelerometers were installed (see Figure 3) to measure the accelerations of the vibrator tube in three orthogonal directions at the vibrator tip and the coupling.

The triaxial accelerometers were mounted in thick-walled steel cylinders to protect them against mechanical damages and water penetration.

Figure 3. Triaxial accelerometer on the vibrator body (left), sensor installation in steel cylinders (right).

Additionally, a special self-developed pulse emitter was used to determine the phase angle between the current position of the rotating eccentric mass and the vibrator movement. The vibrator movement can be characterized completely by means of the accelerometer measurements and of the phase angle.

In addition to the vibrator movement numerous process parameters were recorded during the compaction process.

3 SELECTED RESULTS OF THE EXPERIMENTAL FIELD TESTS

An extensive test program could be implemented within the scope of the experimental investigations. A part of the vibro compaction points was compacted without any specifications with respect to the process parameters at the discretion of a skilled machine operator in standard operation mode. Selected vibro compaction points were processed with predetermined non-standard process parameters, wherein a variation of different compaction parameters was obtained in the highest possible range.

3.1 *Compaction in standard operation mode*

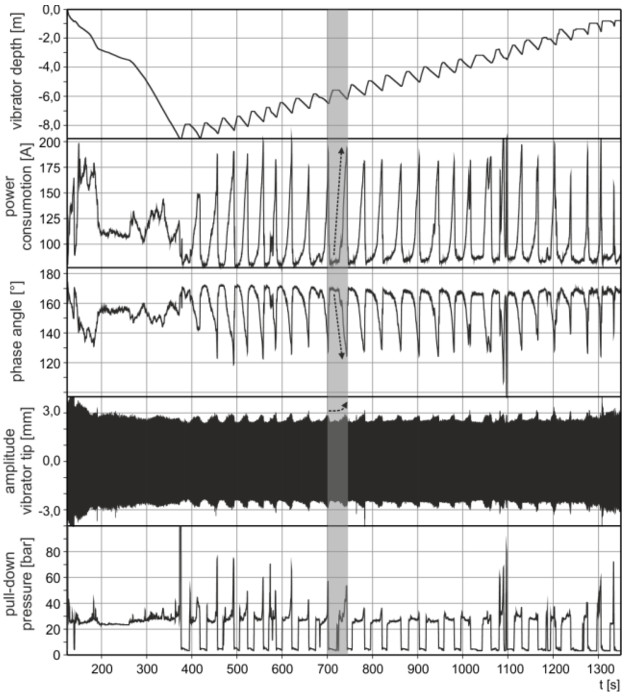

Figure 4. Time history of the vibrator depth, current power consumption of the electric engine, amplitude of the vibrator tip, phase angle, pull-down pressure during deep vibro compaction in standard operation mode.

Figure 4 shows selected process parameters and the vibrator movement during the compaction process at constant vibrator frequency of 50 Hz. The time history of the vibrator depth and current power consumption of the electric engine are parameters used by Keller together with the amount of backfill material for quality assurance of the compaction works.

The vibrator was lowered to the depth of 9.0 m, the compaction was performed bottom up sequentially using the back-step procedure by withdrawing the deep vibrator by 0.9 m and lowering again about by 0.5 to 0.6 m. During the lowering process the soil was compacted and displaced laterally and downwards due to vibration and penetration of the vibrator cone. In Figure 4 such a pilgrim step is highlighted exemplarily. During the lowering process the power consumption of the vibrator increases with increasing resistance of the soil, while during withdrawing it drops again quickly. During increase of the power consumption significant changes in the three-dimensional vibrator movement can be observed (increasing amplitude of the vibrator tip and decreasing phase angle). Figure 5 shows the horizontal movement of the vibrator tip at the beginning and at the end of the lowering process during the highlighted pilgrim step. In both cases the vibrator tip describes almost a perfect circular shape; however, at the end of the lowering process the amplitude of the vibrator tip is higher than at the beginning and the movement becomes more irregular.

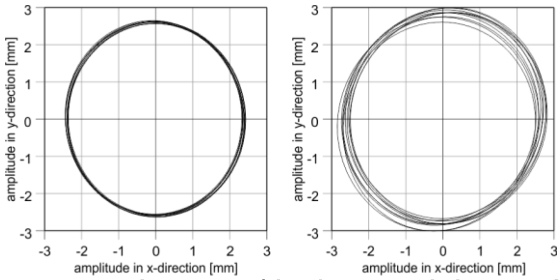

Figure 5. Horizontal movement of the vibrator tip at the beginning (left) and at the end (right) of the lowering process during the highlighted pilgrim step.

The changing vibrator movement and the connection between the discussed process parameters and the vibrator movement indicate that the rising contact pressure between soil and vibrator cone has a significant impact on the vibrator movement and generally influences the compaction process. The outcomes of the discussed test confirm that the changing compaction state of the soil has a decisive influence on the vibrator movement.

4 CONCLUSION

The presented study demonstrates selected results of fundamental experimental investigations of deep vibro compaction. The outcomes of the experimental investigations disclosed numerous previously less known mechanisms of the vibrator-soil system. The measurement results show generally high reproducibility of the vibrator movement and essential process parameters. Consequently, there is a high potential for the development of a real-time, work-integrated quality control system based on the three-dimensional vibrator movement and on particular process parameters.

5 REFERENCES

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