AUTOMATIC CONTROL SYSTEMS APPLIED WHILE PERFORMING SOIL TREATMENT TECHNIQUES USING DEEP VIBRATORS (VIBRO-REPLACEMENT, VIBRO-COMPACTION)

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Abstract. Presentation of the in-use automatic control systems while performing soil treatment techniques using deep vibrators (vibro-replacement, vibro-compaction); For the control of the process there are defined the parameters that allow the proper control of performed works and the automatization process that has been established by the Keller Group in order to develop automatic data registers for the management of the gathered information. Example of the data register and interpretation are shown, which allow to conclude on the accuracy of the process regarding either the used hardware or the used interpretation methods.

Keywords: Deep Vibrators, Stone Columns, Vibrocompaction, Automatic Control Systems.

1 Introduction: Deep Vibrator Techniques

The performance of soil treatment by vibroreplacement/stone columns was introduced in the 1960's, after several technical improvements made on the deep vibrator tools developed by German company Keller in the 1930's [2]. At the beginning of use of this technique, only the concept of vibrocompaction was known, being used to densify granular to coarse soils while applying vibration to the soil.

The soil treatment by stone columns was then developed in order to expand the application of this technology to fine graded soils. A large number of references can be found related to process description [1] [2].

2 Control of Parameters

The in-use equipment for the execution of this works comprises automatic computerized control systems, named M4 and M5, which acquire and process the several execution parameters which are obtained in real time while the works are being performed. The registered parameters are, usually, the elapsed time, depth, gravel consumption and electric intensity while compacting the gravel (in the case of stone columns) or the sand (in the case of vibrocompaction). Additionally other information is registered as the rig movements and the standard information's regarding site (number, name, place, date, time, rig operator, identification of performed columns/point, etc). These parameters are then registered as graphical outputs, as per below:

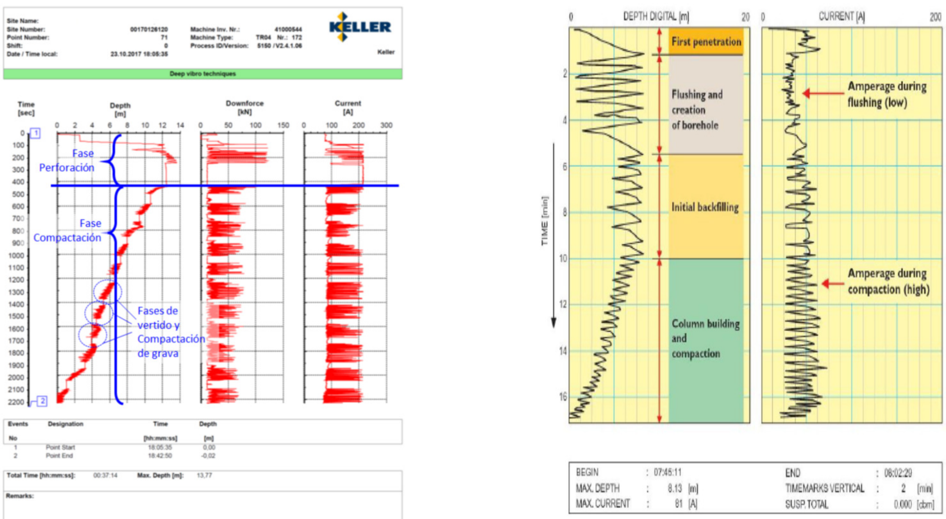

Fig. 1 – Graphical outputs – Stone Columns and Vibrocompaction

3 Automatization Process

In the last 15 years the Keller Group is undertaking an intense program of I&D together with several European universities, aiming a full automatization of the control of the deep vibration works.

The target is to allow that the process adjusts to the real in situ soil conditions, optimizing the use of energy during the soil treatment. As a consequence, the equipment that it is presently being developed includes additional devices for the monitoring of it's use, which include accelerometers, positioning sensors (GPS, energy measuring devices, etc.), who allow to achieve the densification levels in an automatic and optimized way.

The fundamental principle of this automatization and optimization is based in the adjustment of the vibration frequency induced by the vibrators, in order to assure that it is similar to the soil own frequency, aiming to generate a resonance effect, which can be used to reach a pre-defined dynamic response of the soil. In the studies made by Wehr [4] it was verified that if the frequency of a vibrator is kept constant, the resonance with an optimal amplitude only occurs in certain depths. This effect depends on the soil's relative density and, in a minor case, of the water table level. If the vibration frequency changes, the resonance can occur in different depths and in different relative density values. There are, anyhow, limits to the resonant frequencies, and not all of them are valid. Typical interval limits are a 15-20 Hz lower limit where the density cannot be lower than the lowest material density, and an upper value in the cases where the soil is on it's denser state. Some investigations call this phenomenon the "frequency of soil resonance", even though it could be more precise to identify it as "resonance frequency of the interaction soil-vibrator".

It is very important to mention that the soil does not have only one resonance frequency and that the resonance frequency of the system soil-vibrator is not constant, once it depends of the vibrator type, soil density and treatment depth. Also to mention is that, without a strict and sophisticated frequency control, it is not possible to maintain the resonance in the soil, which can then occur only in aleatory events.

Aiming to improve that control, Keller is in a continuous I&D process, being relevant the scale model under study in the University of Erfurt (Germany) that allows the verification and cross checking of the results from the theoretical studies.

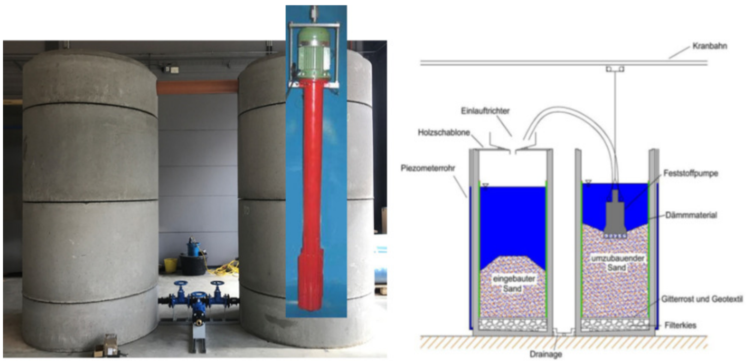

Fig. 2. Scale model, Erfurt University

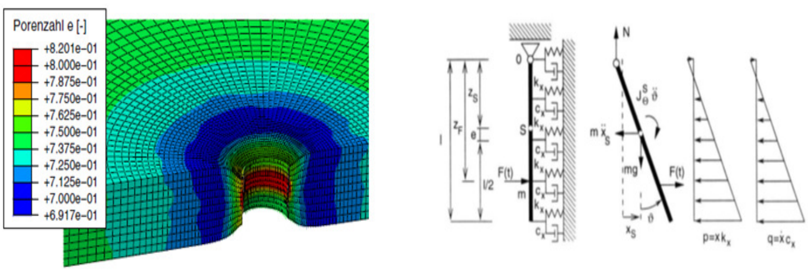

Fig. 3. Numeric models to study the interaction soil-vibrator.

4 Processing Systems: Data, Management and Control

Considering the control registries for each stone column or vibrocompaction point, a large data base is generated, offering valuable information in order to reach an optimized quality control system.

For quality system purposes, Keller uses the so-called QPM (Quality Production Management) which manages all the available data obtained from the operating plant. A "Data Mining" process is used over that data in order to filter and organize data interpretations. It is possible to have a quick view of the soil behavior, being also possible to make a special interpolation of the information obtained on each point in order to have a general overview for the whole area (Fig. 2).

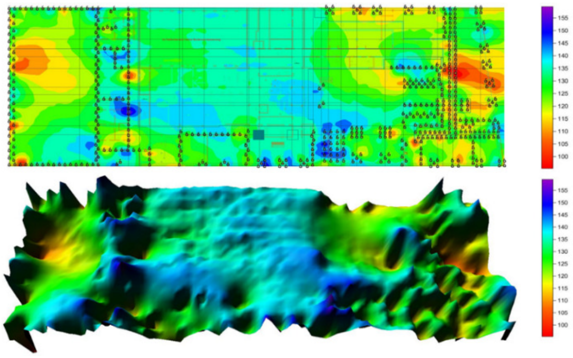

Fig. 4. System output – data processing

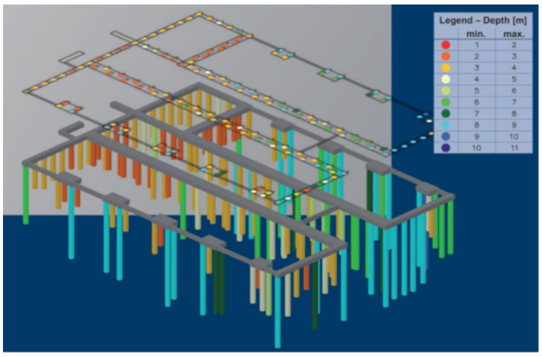

Fig. 5. System output – treatment with soil columns

5 Conclusions

- Deep vibration techniques (Stone columns, Vibrocompaction) are performed with similar equipment's that induce the same level of vibrations over soil
- Existent equipment's allow the performance of this soil treatment up to 60 m depth (for both on and off shore works), including those with latest technology "bottom feed" systems
- Those equipment's use computerized systems that allow real-time register and control of execution parameters
- I&D studies are ongoing aiming the optimization and automatization of execution processes, namely controlling working frequencies
- With the in-use automatized devices it is possible to gather and manage information of the whole sites, allowing to take short term decision times and leading to an increase of quality control.

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