Automated-driven concrete piling: Latest developments and experiments in Finland

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Purpose POHVAII is a large research project carried out in Finland between 2007 and 2011 to develop and test a new automated process for concrete driven piling. We also describe recent developments in the Finnish industry and evaluate the technology worldwide. **Method** Design, modeling, and an XML-based information transferring tool for structure designer (Tekla Structures) were newly developed, as well as a new 3-D guided piling machine using two GNSS antennas for positioning tasks and a graphical user-interface for the operator. Furthermore we developed a wireless monitoring system of environmental effects such as piling-related shakings and vibrations that could affect other nearby structures, and a system to measure real-time geotechnical bearing capacity of piles during hitting work. In the automated working process the main aim was to design, measure, save, transfer, and utilize all the different useful data using 3D-information models throughout the whole working process of the driven piling. **Results & Discussion** Several practical tests and experiments were carried out during the POHVAII-project. We will give a short introduction to the most important results of our 3D-guidance testing: the monitoring system for generated vibrations and the geotechnical bearing capacity measurements. We analyze the new automated piling process and compare it with the traditional process used in most developed countries. Great economical saving and environmental benefit potentials are reported and evaluated.

***Keywords**: 3D, automation, deep stabilization*

INTRODUCTION

Background

The traditional functional process of the column or deep stabilization method has been at the 2-D level. No 3-D data has been transferred from the planning stage to the control systems of deep stabilization machines. The driver has operated in accordance with the site markings and must keep a record of the columns made, mostly to facilitate his own work. After every three to five column stabilizations on average, the deep stabilization machine must be brought close to the tank car for filling of the binder tank. During working, the measuring sticks do not remain in place and the location of the column already pile-driven into the muddy terrain is not always easy to find. Reliable documentation is required so that each column point located in the field can be stabilized in accordance with the plan. This is not necessarily the case with the traditional process.

Fig.1. Traditional process of deep stabilization.

Also the traditional process functions on the so-called ”constant binder feed principle”, which wastes valuable binder and at the same time increases stabilization work consumption and costs. Unlike the current solution, the measurement of the quantity of the binder would be located as close as possible from the feed and mixer head, which would enable the control of accurate and real-time binder flow as a function of mixing depth. In addition to depth-oriented control, documentation concerning the success of the mixing work is also insufficient. Problems related to the mixing work and its management are revealed in practice as a measured non-homogeneity of the columns (so-called hour-glass phenomenon), which increases implementation costs and reduces the work quality, reliability and broader applicability. With reliable documentation of the mixing work and binder feed, the quality of the end product can be controlled, unlike with the current established quality control.

Objectives

The main objective of the research was to study and develop a 3-D functional process for deep stabilization, and the sub-technologies and methods needed for these, in which the efficiency and quality of the measuring, planning, implementation and realization measuring process can be improved.

METHODS

Model for 3-D Automated Deep Stabilization

The target automation process of the research in the application area of deep (column) stabilization includes several different parts and phases (see Fig. 2):

(1) Measurement of continuous 3-D representation of soil model and water content clay, mud) using point-specific, sampling and continuous site investigation technologies.
(2) 3-D planning of the stabilizing column field (stabilizing area, quantity of required columns, length and diameters of columns, distances between columns), targeted strengths and settlement properties.
(3) Connecting opportunities for real-time measurement characteristics of the input data for mixing blade of machine.
(4) Optimization of the feeding of stabilization binder for the column field using 3-D machine control model.
(5) Automated 3-D control or guidance of the work machine.
(6) Continuous measurement of the as-built data.
(7) Real-time evaluation of the column-specific soil composition relative to target.
(8) Automatic documentation of the implementation process, wireless data transfer for obtaining machine control and for sending realization data.

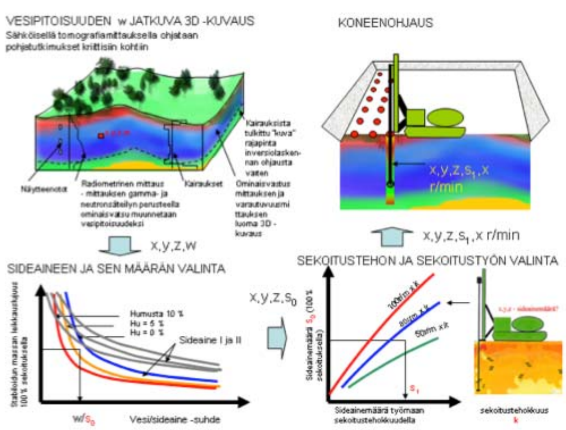

Fig.2. Principal idea of the 3-D automation for deep stabilization.

Experiments

The development possibilities of initial data surveying was tested using an electric tomography measurement system to observe electric resistivity of ground. The results were converted into 3-D water content model. The development of design process was tested using Citycad software as a base modeling tool, and by programming the need additional tools for enabling the initial data conversions. Furthermore, continuous 3-D soil model interpreted following the inversion of the input data measurements, including 3-D representation of water content, data of stratigraphic layers and soil types. A 3-D plan of deep stabilization columns including also the optimized binder amount calculation was designed and created. The 3-D machine control process of deep stabilization machine was studied by observing the use of two new different commercial 3-D control systems in real construction sites. The development possibilities of the feeding of stabilization material was studied by testing the measurement of the rotating moment of mixing blade as well as the force need to lift or press down force of the blade. In addition, a measurement test of stabilization material flow was done using a Solidflow sensor of SWR Engineering.

RESULTS

Observations about the development of initial data surveying

The opportunities providing geophysical measuring methods to generate site investigation data (3-D input data model) for the stabilization and piling needs were clarified. Electric, seismic and radiometric methods have been evaluated in the study, with the main emphasis on the electric methods. In stabilization, it is essential that the water content of the ground can be measured with electric and radiometric measurements. Electric measurements are a non-destructive method. With radiometric logging, the resistivity of the ground is converted into a continuous water content tomography (Fig. 3-4).

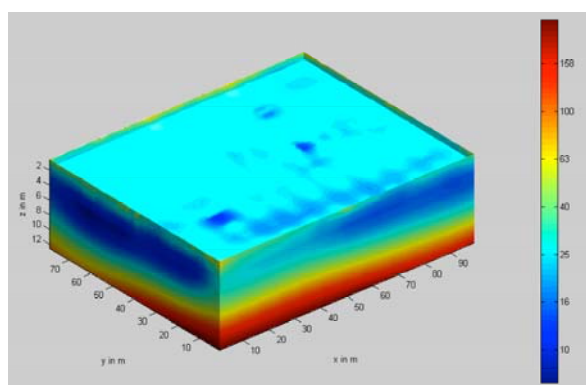

Fig. 3. 3-D representation of electric resistance of Vanttila's test site

From the electric methods, the resistivity sounding and induced polarization (IP) methods have been tested by field tests. Between the electric resistivity and ground water content there is a model, with which the results of the resistivity measurements can be converted into water content. Induced polarization gives potential additional information on the soil layers because the method also reacts to grain size changes[2].

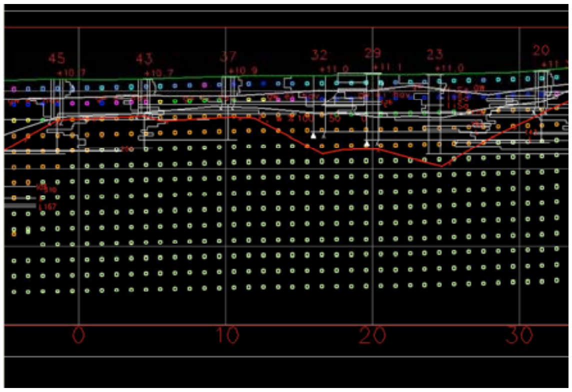

Fig. 4. Continuous 3D soil model interpreted following the inversion of the input data measurements, including 3D representation of water content, data of stratigraphic layers and soil types

Data obtained from electric measurements is not useful for soil interpretation as such; a so-called inversion model must be performed for the data. The apparent resistivities and IP values obtained from the measurements are calculated by inversion as real resistivities and IP values. In the inversion, the most suitable model is applied to the measured data using the multidimensional method of the smallest sum of the square. Also, the layer data obtained from conventional probing and possible seismic sounding can be included as part of the inversion process to obtain more distinguishable results. Interpretation and conversion into other quantities, such as water content, are performed on the data obtained from the inversion. It is also essential that the inversion be made so that the surface variations of the measuring range, i.e. topography, are taken into account.

Conventional reflection and refraction seismic surveys produce soil layer data with ±10 % measuring accuracy. Furthermore, the SASW method (Spectral Analysis of Surface Waves), radiometric logging, TDR method (Time Domain Reflectometry) and NMR method (Nuclear Magnetic Resonance) have been examined.

A new type of continuous 3-D ground mapping method based on the electric tomography measurement has been created in the research. A discordant description of stratigraphy created by sampling the probing and spot type is complemented with electric resistance and charge reversal measurement in the method and is changed into a continuous 3D representation of the water content. The water content has been established as the determining characteristic regulating the stabilized soil material strength and the required binder quantity. With the help of the water content and empirical water/binder ratio, the shear strength to be achieved with stabilized mass can be estimated. Furthermore, data on the organic content of the ground is required because part of the binder quantity must be used to neutralize the humus acid before the desired strength target can be achieved. Based on the strength targeted, the most suitable binder type is selected. Following the binder type selection, the mixing work quantity required (mixing head type and mixing efficiency), as well as the binder quantity to be fed to each place (x,y,z), are specified.

Observations about the development of design process

Design process was started by importing the initial data models into Citycad software. The design of soil improvements by deep stabilization was any time considered as a part of wider road or facility area design. A transformation of tomography measurements into a continuous 3-D representation of the water content was made. The 3-D topography of a test site was measured. Designer determined the needed stabilization columns and their demanded geotechnical resistance (Fig. 5-6). Furthermore, the optimal amount of binder material was calculated to every columns varying freely trough total column length. A new LandXML based transformation format extension was developed for the open information transfer in the research.

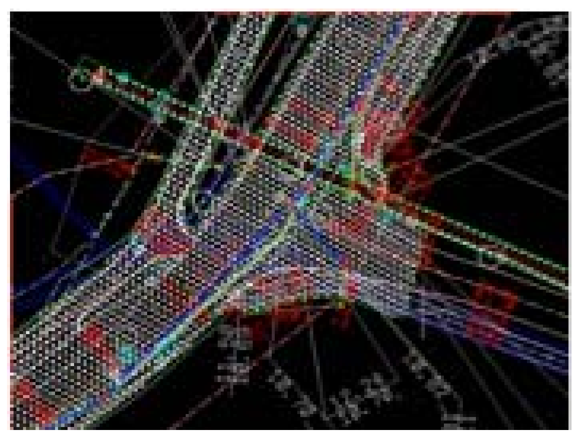
Fig. 5. A 2D scene of the Deep Stabilization Plan for a Road Construction Project in Finland (CityCAD, Sito Oy).

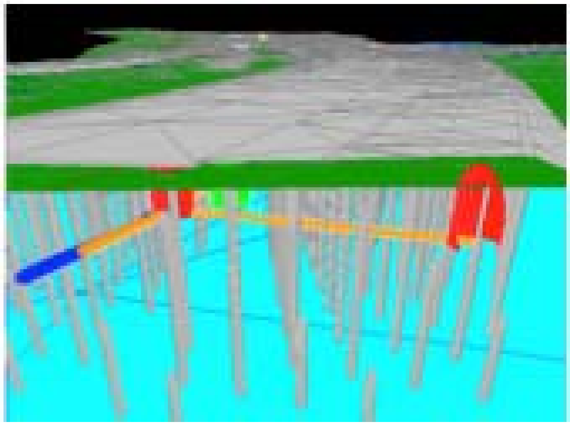

Fig.6. 3-D Deep Stabilization Work Model for a Road Construction Project in Finland (CityCAD, Sito Oy).

Observations about the use of 3-D control system in deep stabilization machine

During the last few years two different 3-D control systems for the control of deep stabilization machines were developed in Finland (Novatron Oy and Scanlaser Oy). Two GNSS antennas were used for the positioning of the machine (Fig. 7-8). The researchers of POHVAII project executed several work studies in different sites to observe the new features and efficiency of 3-D guidance in practical stabilization work. Four studies concerned the traditional work processes and two studies of 3-D controlled sites were executed. The direct work time consumptions of these two methods were not significant. However, several other benefits were observed: no wooden sticks were needed to be measured and installed before machine work and no waiting for measurements were any more needed. Furthermore, the use of 3-D machine control systems in deep stabilization machines was fast increased in Finland and Sweden during the last years. In Finland, about 50 % of machines has been evaluated to been equipped with 3-D system today.

Fig. 7. A 3-D Controlled Deep Stabilization Machine.

Fig.8. An user-interface of the 3-D control system for deep stabilization machine.

Results of soil resistance measurements

Based on the measured rotating moments and down press forces, it seems to be possible to identify and determine the features of soil layers and different material properties. The main results are shown and illustrated in the Figures 9 and 10.

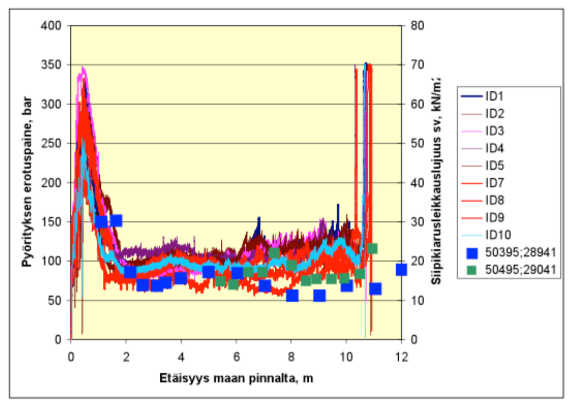

Fig. 9. Comparison of test results with soil survey results.

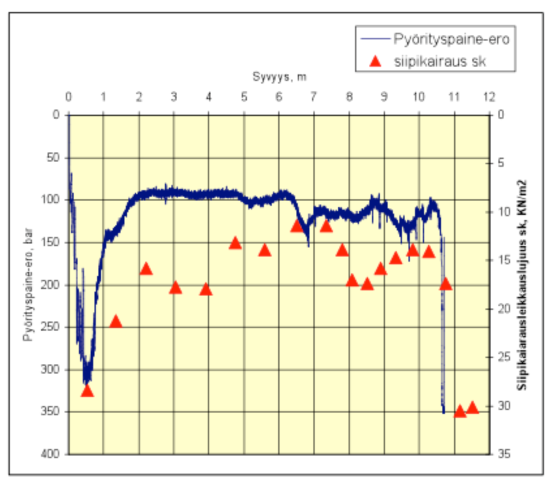

Fig. 10. Comparison of test results with soil survey results.

Results of the tests of binder flow

The pressure sensors installed into the feeding pipe of stabilization material can be utilized in the identification of possible blockages inside the pipe. The tested Solidflow sensor did not work in the material flow measurement due to the insufficient measurement range of the sensor. The main results are shown in the Figure 11.

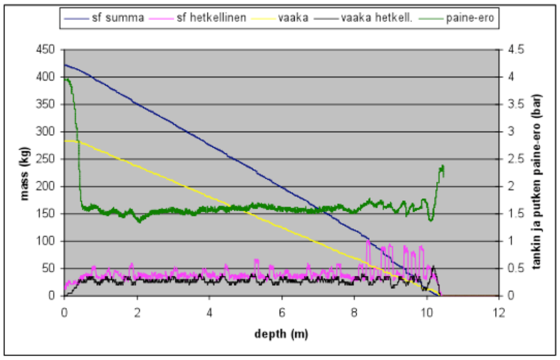

Fig.11. Test results of binder flow test using Solidflow sensor compared with the weighing results of the binder tank.

CONCLUSIONS

The automated process of deep stabilization was to be developed and tested having several different test methods including. Partly the tests indicated the full utilization possibilities of the process model and some parts, partly some of the tests indicated the functionality of the model and some parts could not to be verified. The automated process model was, however, decided to be introduced.

In the new automated visionary process model of deep stabilization, the traditional soil surveys are to be supplemented by electric tomography measurement in 3-D, with which the spatial water content of the object soil bed is to be determined. As a part of 3-D design process, the optimal amount of stabilization material to be feeded into the object soil is to be calculated. Deep stabilization machine is to be controlled using a 3-D control system having the guidance working principle. Traditional marking measurements with wooden sticks are not yet needed. The control system measures continuously the amount of fed stabilization material and adjusts the feeding according to the machine control model. During the work process, the rotating resistance as well as the press down force are measured using the special sensors needed. At the same time, the system calculates and re-models more accurately the soil model, differs the different soil material layers and their shear resistances. All of the key information of the completed stabilization work is to be saved, documented and further shared with the owner, general contractor and stabilization contractor enabling also the full realization of the billing of the project. The further orders of stabilization material are also automatically sent based on the saved as-built information. This process model includes strongly the idea of real-time adjustment of the construction process.

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