LATENT POTENTIALS OF AUTOMATION FOR DEEP STABILIZATION MACHINES AND WORKING PROCESSES

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Abstract

The paper introduces and discusses some results of a large active research project in Finland. In this part of the research the aim was to develop an automated total process for deep or column stabilization. Based on work studies and other practical researches an economical analyze of latent economical benefits of automation for deep stabilization was made. Automation was found to have remarkable latent economic benefits in the development of deep stabilization. The evaluations and statistical calculations showed up to 20% of the direct costs could be saved by utilizing advanced techniques and methods in deep stabilization. Time savings, energy savings and environmental benefits were also remarkable.

KEYWORDS: 3D, automation of deep stabilization, soil strengthening

1 INTRODUCTION

1.1 Background

The integration of an overall functional process of foundation engineering with column stabilization work is currently very minor. The functional process of the column or deep stabilization method is still completely at the 2D level, including some automation and manual machine control routines. For the time being, no data is being transferred from the planning stage to the control systems of deep stabilization machines. The driver operates in accordance with the site markings and must keep a record of the columns made, mostly to facilitate his own work. Typically, the stabilizing column fields include a great number of stabilizing points (columns), which are marked on the site by the measuring group with pile positioning. 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 current process.

Continuous control of the binder feed has been found to be a significant deficiency and development need. The current 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.

Figure 1. Example of current 2D deep stabilization plan with columns to be stabilized between 1.25 m intervals (left), traditional Piling Process (right): no 3D positioning for the machine, instead wooden target sticks, only 2D drawings available, manual control system for any movements of the machine, quite stable (constant) feeding of stabilization material per point, poor measurement and saving of machine parameters during the work, poor as-built documentation and non-homogenous columns demand cases using special PDA measurement technique.

In the POHVA I study, the opportunities providing geophysical measuring methods to generate site investigation data (3D 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. In pile driving, it is essential to know the location of the bearing soil layer, which, in addition to probing, are also seismic methods. In the POHVA II project, the piling work itself supplements the site investigation with continuous measurement. (Juvankoski *et al.*2007).

From the electric methods, the resistivity sounding and induced polarization (IP) methods have been tested by field tests (part of the tests was still continuing during the summer of 2007). Between the electric resistivity and ground water content there is a model under development, with which the results of the resistivity measurements are converted into water content. Induced polarization gives potential additional information on the soil layers because the method also reacts to grain size changes. (Juvankoski *et al.*2007).

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.

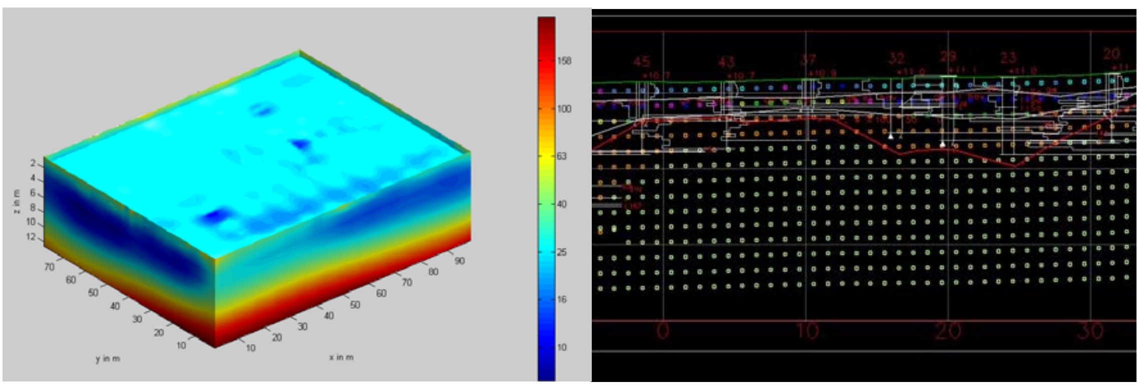

Figure 2. Results of the POHVA I study: on the left, 3D representation of electric resistance of Vanttila's test site; on the right, continuous 3D soil model interpreted following the inversion of the input data measurements, including 3D representation of water content, data of stratigraphic layers and soil types (POHVA I, Centroid Sito Oy).

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 in the POHVA I study. Also, the applicability of these has been evaluated for the automation of the overall functional process of the foundation engineering automation. (Juvankoski *et al.*2007).

A new type of continuous 3D ground mapping method based on the electric tomography measurement has been created in the POHVA I research part. 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. (Juvankoski *et al.*2007).

1.2 Objectives

The main objective of the research project "Development of Automation for the Foundation Engineering of Building and Infra Construction – POHVA-II" was to develop a 3D functional process for foundation engineering utilizing automation needed in the sub-areas of pile driving, mass and column 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. The partial objectives enabling the achievement of the main objective were:

- completion of the necessary specific scientific research and development tasks for the development of the overall functional process,
- modeling of the overall functional process for implementation of full-scale test projects, and
- implementation of the experimental automation overall functional process in actual construction projects.

The target automation process of the POHVA-II research in the application area of deep (column) stabilization includes several different parts and phases:

- measurement of continuous 3D representation of soil model and water content clay, mud) using point-specific, sampling and continuous site investigation technologies
- 3D 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
- connecting opportunities for real-time measurement characteristics of the input data for cutting blade of machine
- Optimization of feeding stabilization binder for the column field, 3D machine control model
- Automated 3D control of the work machine
- Continuous measurement of the realization data
- Real-time evaluation of the column-specific soil composition relative to target
- Automatic documentation of the implementation process, wireless data transfer for obtaining machine control and for sending realization data

In this paper, the focus was to evaluate and report the economic potentials of this type of automation in deep stabilization process. The aim of this research part was to recognize potentials of automation in foundation engineering. The potentials were compared with traditional foundation engineering by the site case studies. The thesis concentrated to the waste, environmental impacts and effects to the project control.

2 METHOD

First, the economic potential of the automation of deep stabilization process was evaluated using an excel sheet developed by the University of Oulu. With collaboration of the main industrial companies (a deep stabilization contractor as well research organizations) evolved into deep stabilization process in Finland. Any of the present unit cost information was gathered from the same companies.

Second, the same potentials were evaluated and compared more statistically based on some site case studies. On financial, time and quality wastes were studied in traditional and automated column stabilization processes. The prices of the traditional and automated processes were calculated using @Risk program developed by Palisade Corporation (http://www.palisade.com/risk/default.asp). Environmental impacts where calculated using Life Cycle Assessments (LCA). Impacts of the automated process for project control were studied by a questionnaire study. The aim was to recognize the problems and development possibilities of project control in foundation engineering.

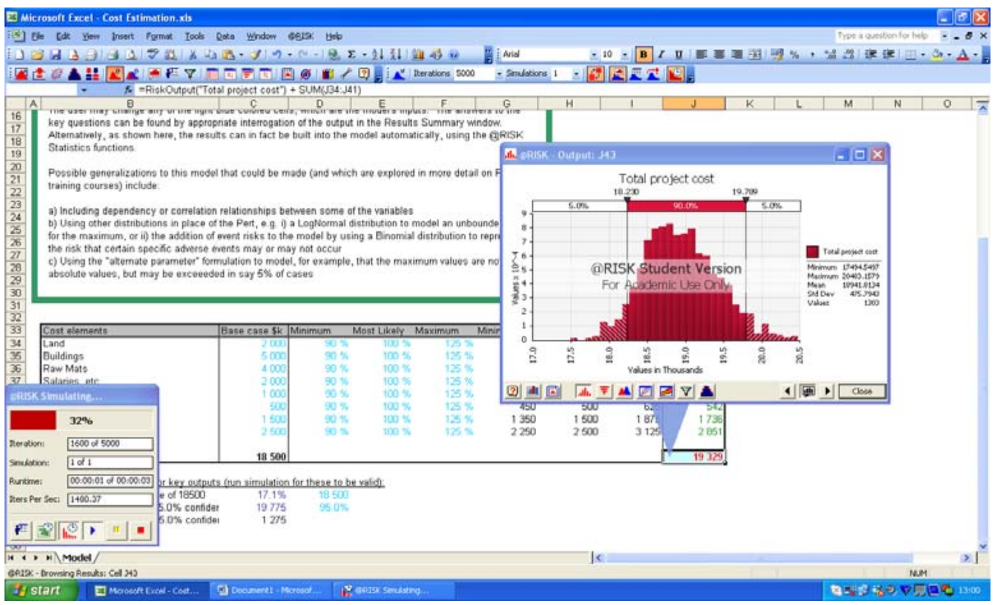

Figure 4. The economic calculations were made using @Risk program and Monte Carlo Simulation.

In the statistical calculations, chalk-cement (50%/50%) was used as stabilization material manufactured by Nordkalk Oy Ab in Lohja City. The source information about energy consumption was directly received from the same company. The calculations made by VTT (Hakkinen *et al.* 1997) was used for the determination of the energy consumptions and emissions of cement. The environmental profiles of the transportation, stabilization work and the use of an excavator were calculated using the energy information provided by VTT (VTT 2009).

3 RESULTS

Based on the direct costs evaluation by the excel sheet developed, near 20% of the costs of deep stabilization could be saved using the determined type of automation in deep stabilization process (Tab. 2). In Finland, this would mean about 2.7 million eur annual saving in deep stabilization works. The key factor enabling the savings is the possibility to avoid waste deep stabilization material trough the utilization of measured 3D water content.

Table 1. An evaluation of the economic potential of deep stabilization (University of Oulu).

stabilization costs	unit	traditional stabilization	automated stabilization	saving
driven metre	[eur/m]	6.99	5.63	1.36
construction site	[eur]	4,472,500.00	3,600,700.00	871,800.00
Total in Finland	[eur/year]	13,976,563.00	11,252,188.00	2,724,375.00

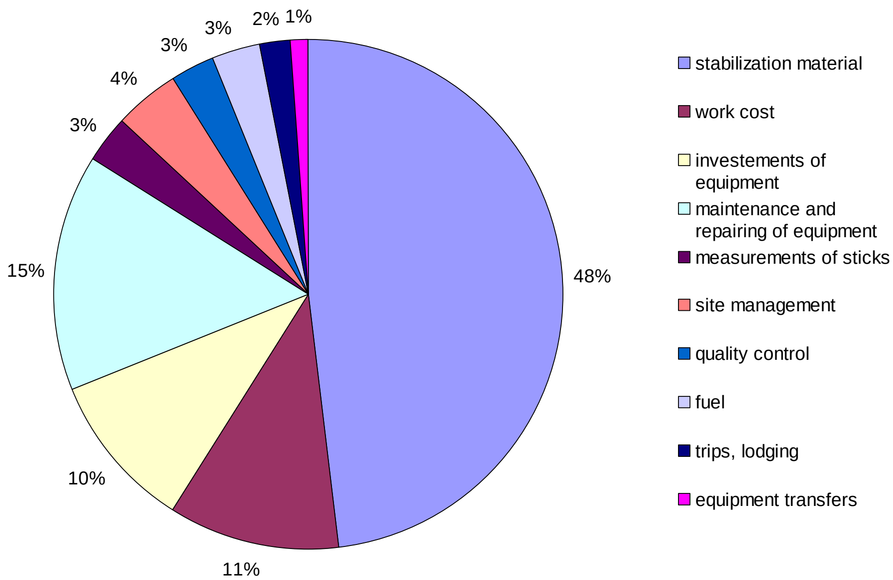

Figure 5. Typical proportional costs of deep stabilization.

In the statistical calculations using the @Risk program and Monte Carlo Simulation, the automated deep stabilization process was 3 % cheaper than traditional process concerning a small site and 18 % cheaper a big site. One real stabilization construction site completed earlier (in Espoo Suurpelto area in Finland) as well as a computational site having one year duration were used as reference information. Binder consumption had the biggest influence for the whole price of the site. Developing automation for the control at binder feeding has biggest financial saving opportunity.

Table 2. The initial data of two deep stabilization construction sites used for the statistical analyze (University of Oulu).

construction site	unit	Suurpelto Espoo	One year Site
column points	number	2000	64000
column depth	m	10	10
column diameter	m	0.7	0.7
stabilization material	kg/m	29	29
labour productivity	m/work day	600	600
duration of the site	work day	33	267
number of machines	number	1	4
distance between site and factory	km	50	50

In the reference project used, 33 working days were needed to complete the work using the traditional process. Using the automated process, 31 working days would have been needed when using one work machine. Annually there are 267 working days, and when using four work machines there would be needed 232 working days to complete the work using the automated process. The annual saving of time would be 35 working days.

Table 3. Effects of annual savings in stabilization material in a typical deep stabilization project (University of Oulu).

saving in stabilization material	traditional [eur]	automated [eur]	saving [%]
0-50%, average 15%	4,886,850	3,997,886	18
0-30%, average 15%	4,886,850	4,274,774	13
0-20%, average 10%	4,886,850	4,554,036	7
0-5%, average 2.5%	4,886,850	4,770,738	2

In the big column stabilization site the use of energy was reduced by 20 631 GJ and carbon dioxide release by 2135 tons. Automation process reduces remarkably the environmental impacts.

One part of the project control is to be aware of the risks and adapt to changes on sites. Some risks can be removed or reduced using automation process. This is a direct advantage for project control.

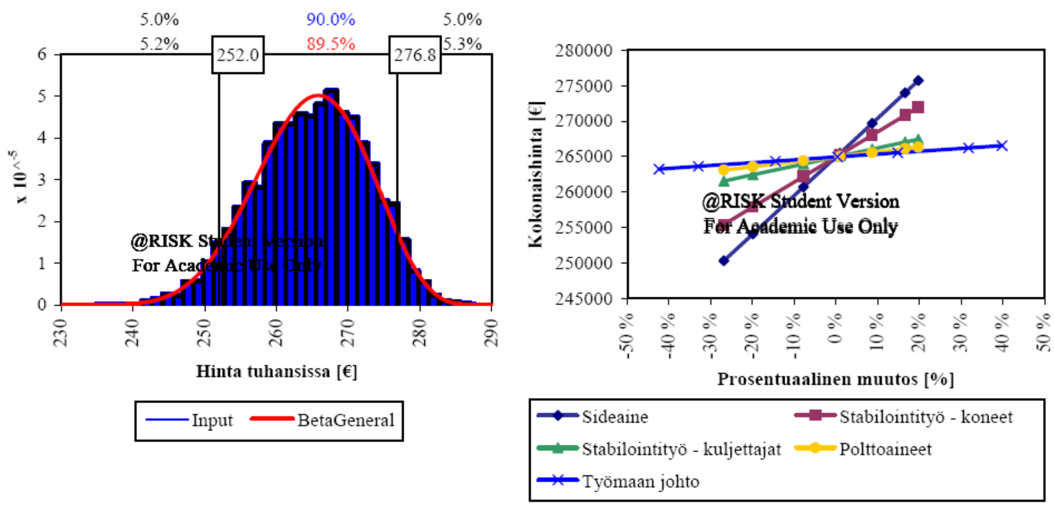

Figure 6. Evaluation of the benefits by @Risk program ("hinta tuhansissa" = costs in thousands euros, "sideaine" = stabilization material, "stabilointityo - kuljettajat' = stabilization work - operators, "stabilointityo - koneet" = stabilization work – machines, "polttoaineet" = fuel).

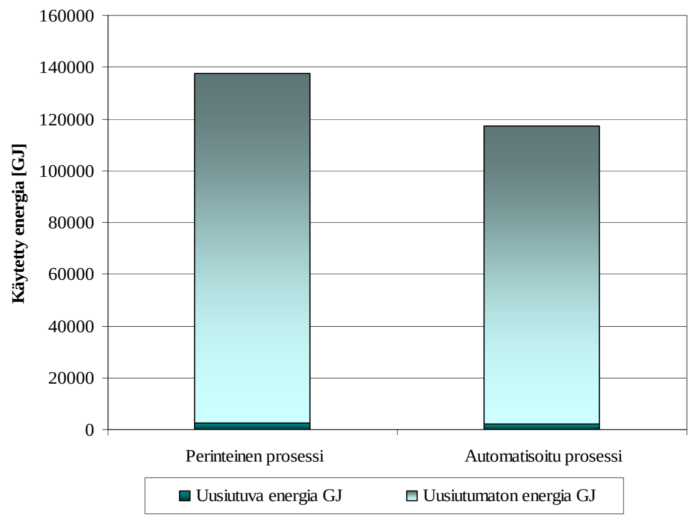

Figure 7. Evaluation of the energy savings by @Risk program (traditional process - left, automated process – righ, “kaytetty energia” = energy used, “uusiutuva” means renewable energy source, “uusiutumaton” nonrenewable energy source).

In the large-size deep stabilization site (one year), energy consumption was reduced by 20631 GJ and carbon dioxide release by 2135 tons. In all, 287 single family houses could be heated by this saved energy for one-year period in Finland. The saved carbon dioxide equals the release from 164 commercial flights from Oulu to Helsinki (about a one-hour flight) assuming the aircrafts are full of passengers. The automation process remarkably reduces the environmental impacts. The time saving in one-year site was about 35 work days. An important part of project control is to be aware of risks and adapt to site changes. Some risks can be removed or reduced using the automation process. This is a direct advantage for project control.

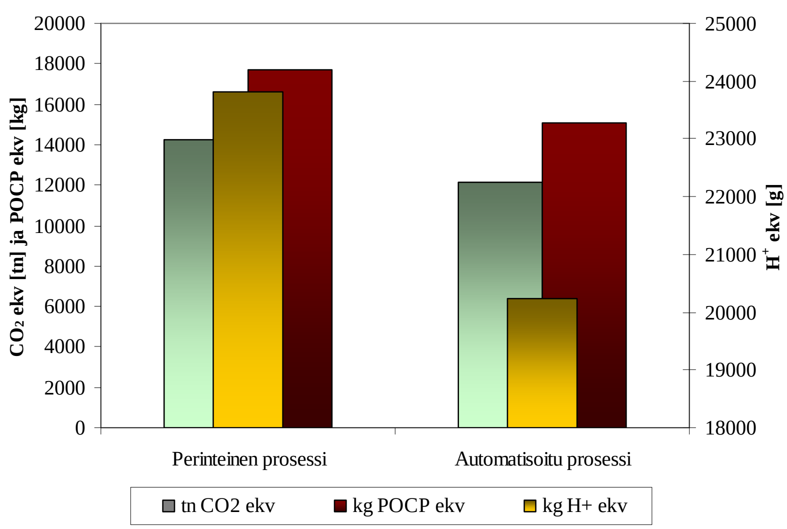

Figure 8. Evaluation of the environmental effects by @Risk program (traditional process - left, automated process - right).

4 CONCLUSIONS

Automation has remarkable latent economical benefits in the development of deep stabilization. Up to 20% of the costs of deep stabilization can be saved using the new type of automation in deep stabilization process. Binder consumption had the biggest influence for the whole price of the site. Developing automation for the control at binder feeding has the biggest financial saving opportunity. Automation process also reduces remarkably the environmental impacts. Thus, the development of more automated process for column stabilization is one of the very potential means to promote remarkably sustainable and green development in foundation engineering.

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