Model tests in laboratory using dry mixing method

Les essais sur modèle réduit dans laboratoire en utilisant la méthode de mélange sec

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ABSTRACT: To clarify the effect on strength properties and homogeneity of the cement treated soil columns the shape of the mixing tool, the lifting and rotation speed of the shaft and the immediate loading of the columns after manufacturing, has been investigated in model tests in the laboratory of Soil Mechanics and Foundation Engineering at the Helsinki University of Technology. This paper is a description of test arrangement and test procedure for manufacturing cement columns in the laboratory using the dry mixing method.

RÉSUMÉ: Pour clarifier l'effet sur la propriété de résistance et l'homogénéité de colonnes traitées avec ciment on a fait des investigations dans le laboratoire de l'ingénieur de mécanique des sols et fondation dans l'Université de technologie d'Helsinki. On a investigué le forme de l'instrument de pétrissage, la vitesse de levage et de rotation de la barre ainsi que la charge immédiate des colonnes après la production. Cet article est une description des arrangements d'essai et la procédure pour produire les colonnes de ciment en utilisant la méthode de mélange sec.

1 INTRODUCTION

The dry mixing method is an in situ stabilization method, which is commonly used in Finland. The DM method has been applied to increase the bearing capacity and to reduce the settlements and the deformations mainly in the different types of embankment structures.

The quality of manufactured columns depends on different components: soil properties, mixing efficiency, penetration speed of the stabilizer, and quantity and quality of the stabilizer.

The constant feeding and thorough mixing of the appropriate stabilizer along the column height will ensure the homogeneous and competitive ground improvement method in various infrastructure constructions.

This research work has been done in the laboratory of Soil Mechanics and Foundation Engineering at the Helsinki University of Technology and is part of the larger research project: "Deep Stabilization – quality, design methods and quality control". The main purpose of this work is to investigate the effectiveness of the shape of the mixing tool on the degree of mixing and strength properties of the cement-soil column manufactured dry mixing method. The effect of lifting and rotation speed, mixing energy, amount of air and loading of the columns after manufacturing were carried out too.

Several series of construction tests on soft soil were performed in the laboratory by using an apparatus simulate the insitu dry mixing. The cement powder was mixed with the clay to construct the columns 20 or 30 cm in diameter and 100 cm in height.

2 TEST ARRANGEMENT

2.1 The dry mixing model apparatus

The mixing machine consists of four main components: a hydraulic unit of force, a mixing unit, a binder feeder and a control unit. The apparatus and its main specifications are shown in Figure 1.

Table 1. The classification properties: main road 7 (VT7 clay) and the secondary road in Espoo (Otaniemi clay).

Classification property	VT7 clay 1.7-2.7 m	Otaniemi clay 1.4-2.4 m
Water content [%]	70-75	90-95
Clay content [%]	60	55
Density [g/cm^3]	1,6	1,5
Specific gravity [g/cm^3]	2.76	2.77
Plastic limit [%]	25	22
Liquid limit [%]	70	65
Undr. shear strength [kPa]	15	6
Sensitivity [-]	10	12
Organic matter [%]	< 1	<1

2.2 Soil properties

The soft clay was placed in the big PVC-barrels by using a heavy excavator. In this way the samples were as undisturbed as possible.

There were two sampling sites: the VT 7 site – a reconstruction site of main road 7 near Porvoo and the Otaniemi reconstruction site of a secondary road in Espoo. The classification properties of the soil on about 100 square metres sampling areas are shown in table 1.

First the dry crust and the harder clay layer below it were removed. The strong plastic barrels of 560 mm in diameter and 1000 mm in height were pushed down into the soft soil and then lifted up with a bucket excavator (figure 2). The clay samples in the barrels were from a depth of 1.7 – 2.7 m in the first VT 7 site and from 1.4 - 2.4 m in the Otaniemi site.

After fastening the caps on the barrels they were transported by lorry to the laboratory. Altogether 26 clay barrels, weighting 400 kg each, were stored in the humidity room at a temperature of +6 °C.

Just before mixing the cement to clay the sample tubes of 50 mm in diameter were taken from every barrel. From these continuous samples the amount of organic matter and water content were controlled in function of depth.

Parameter	Specification
Output	15 kW
Force (pressing down)	30 kN
Force (uplifting)	50 kN
Lifting speed	0 - 18 m/min
Rotary speed	0 - 200 rpm
Rotary moment	0 - 590 Nm
Lifting capacity	1,20 m
Feeding capacity	0-3500 g/min

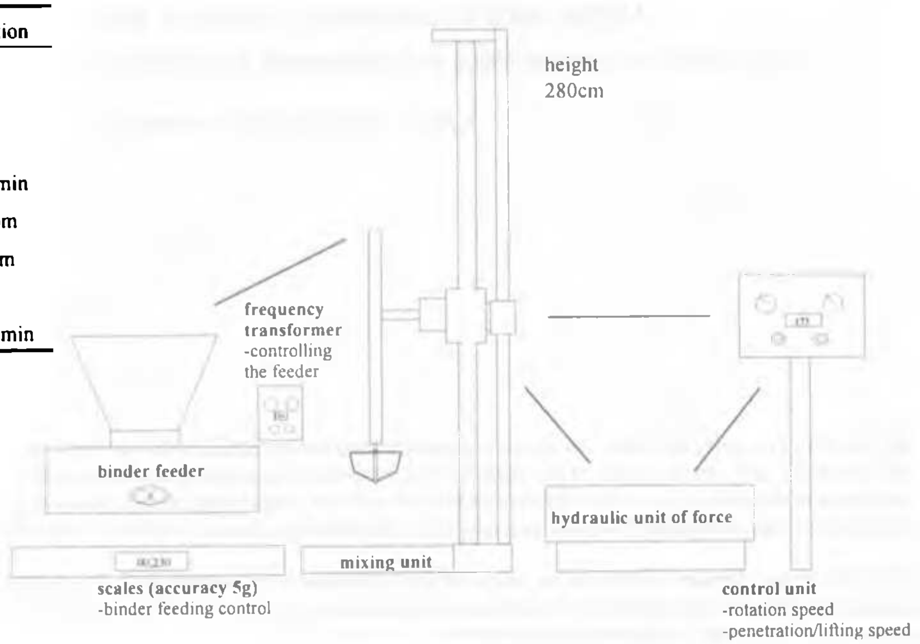

Figure 1. The outline of the laboratory mixing apparatus.

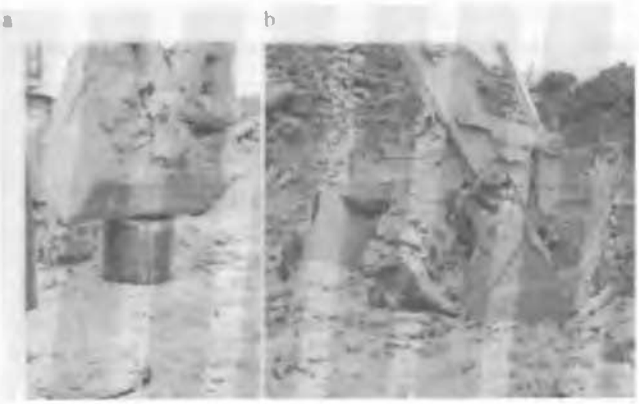

Figure 2. a) The plastic barrels were pushed down into the soft clay b) and then pulled up with the help of a bucket excavator. Pictures from main Road 7 (VT 7).

2.3 Mixing tools

Seven different mixing tools of 200 mm diameter each were used in the mixing process. The tools are shown in figure 3.

The mixing tools were divided into two categories: cone and pot type. Attention has been paid to the mixing, the shearing and the compaction effect by using a multiple number of blades, different shapes of blades and different angles on the blades, teeth on the blades and special blades (screw plate).

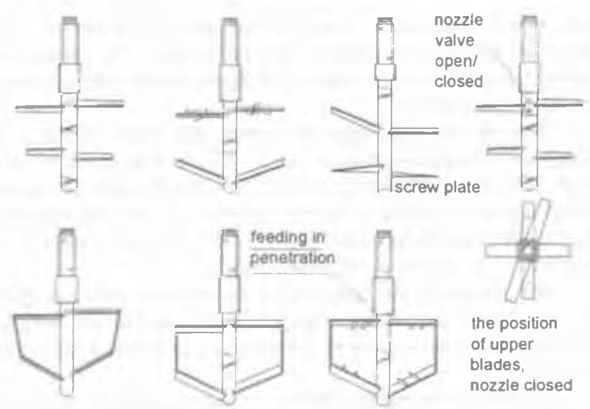

Figure 3. Seven different mixing tools of 200 mm diameter used in model tests of DM.

To reduce air content in the columns a valve system was used in the nozzle of one cone type mixing tool. In the case of one pot type tool the cement feeding was done during penetration.

The laboratory mixing machine is scaled down to 1/3 the actual in-situ dry mixing machine with a mixing tool of 600 mm in diameter (commonly used in Finland and Scandinavia). The mixing tool of the laboratory apparatus, with a nozzle of 10 mm in diameter is connected to the shaft, which has a rounded quadrilateral cross section, with a side length of 40 mm.

3 LABORATORY TESTS

3.1 The first test series – VT 7 clay

Before starting the first test series the pressurised feeder (connected to the stabilizer transportation hose) was calibrated with compressed air for ensuring the smooth feeding of the standard cement. The cement feeding was controlled by a constant amount of air.

The amount of air coming out of the nozzle was calibrated by manufacturing pre-model columns. The compressed air in the pre-model columns was 70, 100 and 150 l/min. The cross-sections of these columns are presented in figure 4. The amount of air, 70 l/min, used in the actual tests was chosen on the base of homogeneity of the pre-model column.

The rotating speed of the mixing tools was 120 r/min. The penetration and withdrawal speed was 5 mm/r., which corresponds the 15 mm/r. speed in the full scale apparatus (equal mixing energy per volume when the full scale mixing tool is three times larger).

With every mixing tool of 200 mm in diameter three model columns were manufactured in barrels (three barrels, one for each column). After mixing the barrels were taken back to humidity room and stored at a temperature of +6 °C for 28 days.

After four weeks of storage the cement columns and surrounding clay mass was pushed out with a special machine with a large piston. The columns were excavated carefully out and the middle parts of the columns were cut to a cylinder shape to pro-

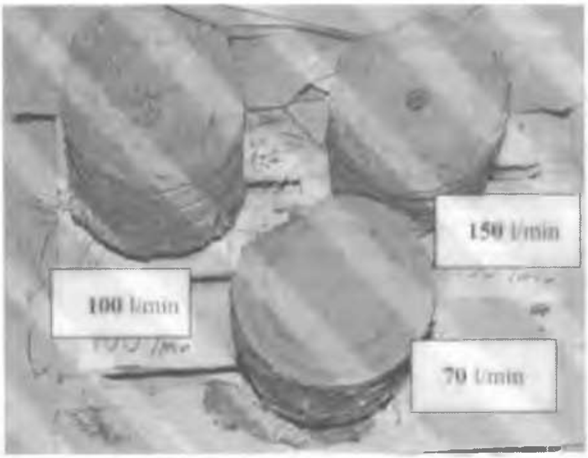

Figure 4. The amount of the air in pre-model columns was 70, 100 and 150 l/min.

Figure 5. The different mixing tools create visible differences: air caves, irregularity of the surface, homogeneity of the column.

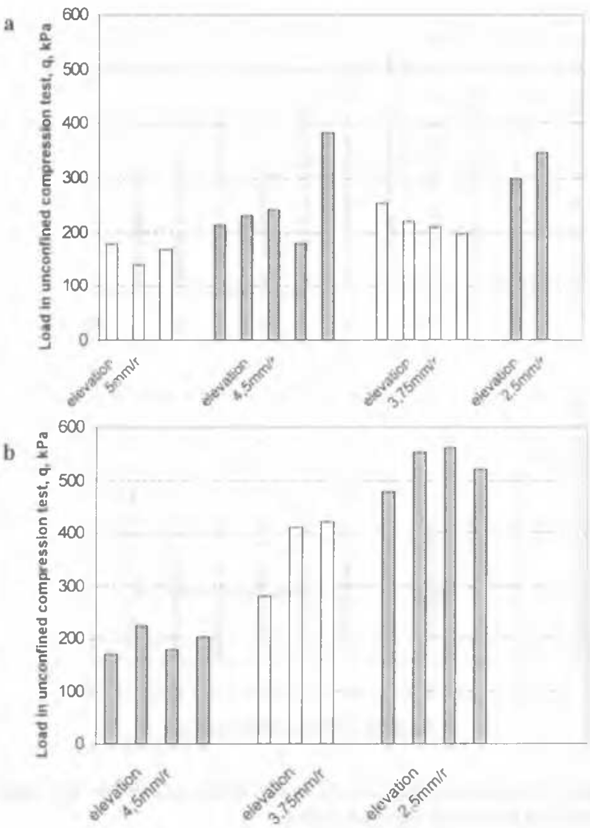

Figure 6. The unconfined compression strength vs. mixing energy a) without and b) with 40 kPa load during hardening time (anchor-pot type mixing tool).

duce samples of 200 mm in diameter and 300 mm in height. All of the samples were loaded using the unconfined compression test. The parts below and above the compressed sample were tested using the falling cone test for the homogeneity of the cross section. In figure 5 is shown some special characteristics of the columns made with different types of mixing tools.

In respect to the strength and the homogeneity of the columns the "best" mixing tool (anchor-pot type with teeth; the second from the left in figure 3) was chosen for further analyses: the mixing energy was increased by lowering the withdrawal speed to 4.5, 3.75 and 2.5 mm/r and part of the columns were loaded 40 kPa load during hardening time. The results of the unconfined compression tests are shown in figure 6.

3.2 The second test series – VT 7 clay

After the first test series the constant amount of air controlled feeding was changed to a constant pressure controlled system and the penetration speed was accelerated to four times higher than the lifting speed (v_{pen}= 20 mm/r.). Instead of standard cement, rapid cement was used for a faster hardening time (now one week) and inert iron oxide (20 %) was added to the cement for a better visual indicator of the homogeneity.

Two pot and two cone types of mixing tools of 200 mm diameter each were chosen for the second test series and in all six columns were manufactured with each tool. The average values of unconfined compression tests are shown in table 2.

Table 2. Unconfined compression test data from the second test series.

Mixing tool type	Unconfined compression strength [kPa]
Pot 1	55
Pot 2	30
Cone 1	104
Cone 2	109

Columns made of the cone type tool, had higher compression strengths and smoother distributions of the binder in the cross section, this was visually detected. The falling cone test data of 24 cross sections are shown in figure 7.

To check on the scale effect of the mixing tools, one Pot 1 and one Cone 1 type were manufactured with a diameter of 300 mm. Three columns of each were investigated using the falling cone test. The falling cone test data of 19 cross sections are shown in figure 8.

3.3 The third test series – Otaniemi clay

Now the third period of laboratory construction tests is in progress. The water content of the Otaniemi clay is higher and the shear strength is lower than that in the VT 7 clay; the Otaniemi clay is in a more liquid form.

The influence of different lifting and rotating speeds and the effect of the teeth and pins on the blades are under investigation. New types of mixing tools are also being engineered (for instance the dough mixer type).

After these laboratory construction tests, the research project is continuing with the in-situ tests where about five different type of mixing tools will be manufactured to full scale. The quality of in-situ mixed columns will be tested by traditional column test and by the cone penetration test (CPT) and 60 % of the columns will be lifted up for more accurate laboratory analyses.

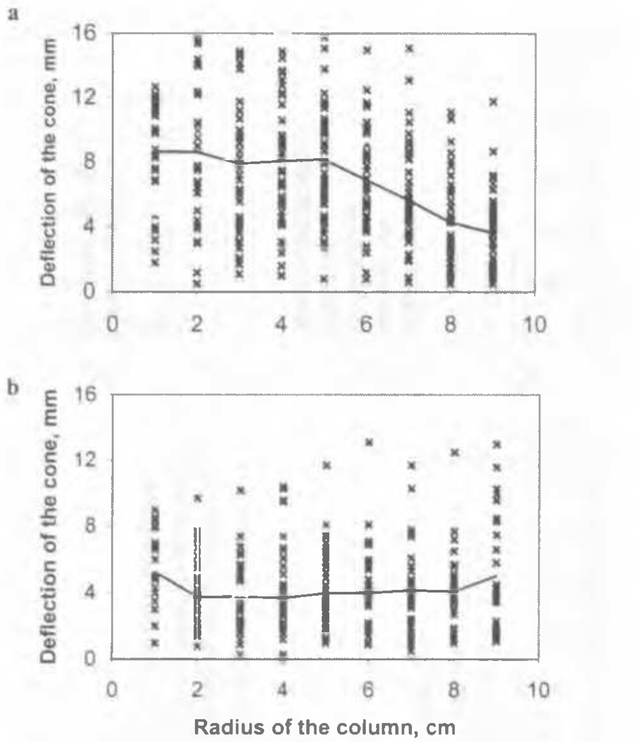

Figure 7. Deflection of the cone vs. radius of the column (d= 200 mm). The mixing tool **a)** Pot 1 and **b)** Cone 1.

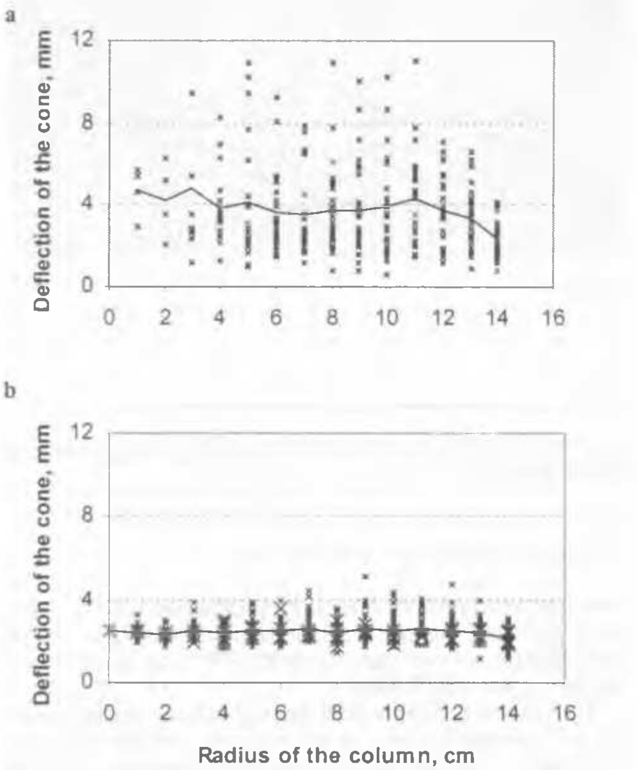

Figure 8. Deflection of the cone vs. radius of the column (d= 300 mm). The mixing tool **a)** Pot 1 and **b)** Cone 1.

4 CONCLUSION

Since now some conclusions can be drawn on the base of the laboratory construction tests:

- The used amount of air has a considerable effect on the strength and the homogeneity of the columns,
- We get stronger and more homogeneous columns using the cone type mixing tool,
- During manufacturing the columns the pot type mixing tool tends to lift up the soil mass easier than the cone type tool,
- Loading the columns (40 kPa) during the hardening time increases the strength of the columns and
- By lowering the withdrawal speed and thus increasing the mixing energy we get stronger columns when the columns are loaded.