

Permeability and workability of clay stabilised with small amounts of cement

Perméabilité et usinabilité d'argile stabilisée par un peu de ciment

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ABSTRACT

After excavation from construction sites Finnish soft clay is normally dumped as waste, because in a disturbed state it behaves more or less like liquid. This paper deals with Finnish soft clay stabilised with small amounts of cement (i. e. $C_w \leq 50 \text{ kg/m}^3$) which change the clay's properties adaptable to machinery handling. In addition, a necessary requirement for clay to be used e.g. in mineral liners is that its permeability remains low enough. These properties are tested on samples taken from the site and stabilised in a laboratory, from the on site stabilised clay heap and from a compacted structure.

RÉSUMÉ

Après d'excavation l'argile Finnois est en général transporté à la décharge comme décombres, parce qu'elle comporte plus ou moins comme liquide. L'article rapporte d'argile sensible Finnois stabilisé avec un peu de ciment ($C_w \leq 50 \text{ kg/m}^3$) que change les propriétés appropriées au traitement mécanique. En plus, le condition nécessaire de l'argile usé pour les barrages minéraux est que la perméabilité reste suffisamment basse. Ces propriétés sont déterminées pour les spécimens de sol naturel et stabilisé dans le laboratoire et en le lieu et encore pour les spécimens de la structure compactée.

Keywords : stabilization, permeability, workability, cement

1 INTRODUCTION

Finnish clays in their natural water content, which can exceed 100 %, are so soft and sensitive that they cannot be spread and compacted into structures. Apart from softness and sensitivity, permeability of Finnish clays is very low. They are also durable against detrimental chemicals. Therefore soft Finnish clay is a potential material for clay barriers e.g. in waste disposal sites. Being a material widely available in the country it may be less expensive than manufactured sealing products. After the problem with workability is solved we have a competitive solution for a mineral sealing structure, which meets the requirements of watertightness and durability. For the economical competitiveness it is wise to keep the amount of binder as small as possible.

For a landfill area to be constructed in Helsinki a pilot laboratory project was built up. It turned out that the clay stabilised with small amounts of cement would meet the requirements of both workability and permeability (Palolahti et al., 2003). A clay liner stabilised in this way was competitive both technically and economically. It was selected to be the sealing structure and no major problems were met during construction.

Workability of clay can be evaluated based on its strength and stiffness. A directive requirement for the shear strength of a mineral sealing layer in landfill bottom structure is $\tau_f \geq 50 \text{ kN/m}^2$ corresponding to the compressive strength of 100 kPa (Leppänen 1998). For the control of aqueous liquids there is some international consensus that clay liner materials for landfills should have permeability equivalent to 10^{-9} m/s or less (Cairney and Hobson 1998).

The pilot study carried out for the project discussed above comprised only one specific type of clay and was far too modest for general conclusions. It gave an impulse to investigate further the effect of small amounts of binders on the properties of clay particularly for protection barrier purposes. An extensive project was started in which different clays were tested both from the

permeability and workability points of view. Hassan et al. (2008) studied two clays and one gyttja and Ruohonen (2006) three different clays from Lempola. Test results presented in this paper are obtained from clays collected also in Lempola, located 50 km from Helsinki, where a disposal area for contaminated soil was under construction.

2 LABORATORY TESTING

2.1 Test materials

Laboratory tests were performed on four different clays. Complete index test program was run for the samples denoted by L and S, which were disturbed and homogenised natural clays taken from Lempola. Samples denoted by K were clay stabilised in the field.

Table 1. Some index properties of test materials .

Property	S	L
Water content [%]	58	95
Clay content [%]	60	78
Liquid limit [%]	50	65
Plastic limit	20	23
Plasticity index [%]	30	43
Organic content [%]	1.0	0.4

The cement used in the laboratory to stabilise the collected samples was Portland composite type cement CEM II/B-S 42.5 N (EN 197-1) named Perussementti. Its clinker percentage varies in the range 65-79 % and blastfurnace slag in the range 21-35 % (Finnsementti 2006). The product is widely used for soil stabilisation in Finland. Samples were stabilised using the dry mixing method.

2.2 Testing methods

The principal testing methods were the unconfined compression test and permeability tests in a flexible wall permeameter and a falling head oedometer as described by Tavenas et al. (1983). Three types of stabilised clay specimens were prepared: 1) specimens of 50 mm dia. and 100 mm height for unconfined compression tests and flexible walled permeameter tests, 2) small specimens of 20 mm dia. and 40 mm height for unconfined compression tests to speed up the test program and 3) specimens for permeability testing in an oedometer.

2.3 Stabilisation in the laboratory

Clays S and L were mechanically mixed and homogenised using machines. Mixing of cement was made by hand in plastic bags as described by Hassan et al. (2008). The binder percentages of dry weight A_w , cement amounts C_w [kg/m³] and water-cement ratios W/C are presented in Table 2. In calculating C_w and W/C it was assumed that the clay was fully saturated and its water content and density remained as the same during stabilisation.

Table 2. Binder amounts in the tests. (Leivo 2009)

Property	A_w [%]	C_w [kg/m ³]	W/C
L	5	38.2	19.0
	4	30.6	23.8
	3	22.9	31.7
	2	15.3	47.5
	1	7.6	95.0
S	5	52.7	11.6
	4	42.2	14.5
	3	31.6	19.3
	2	21.1	29.0
	1	10.5	58.0
	0.5	5.3	116.0

2.4 Sampling in the field

In the field clay was stored and stabilised in heaps, Fig. 1. Samples K1 were taken from the heaps on the same day as stabilisation took place and permeability testing was started on the next day. Samples K2 were taken with a tube hammered into a stabilised and compacted layer. Laboratory tests were started one month after the stabilisation.



Figure 1. Heap of stabilised Clay K1.

2.5 Comparison of specimens

The amount of binder in the field stabilisation was 30 kg/m³. As for the binder amount, the comparable laboratory specimens were L with $C_w = 30.6$ kg/m³ ($A_w = 4$ %) and S with $C_w = 31.6$

($A_w = 3$ %). Clay stabilised in the field was mostly dryer than the one in the laboratory. Therefore the water-cement ratio was lower and the clay was stiffer and harder. The laboratory and field specimens are presented in Fig. 2.



Figure 2. Laboratory and field specimens after unconfined compression test and drying in the oven. From the left: laboratory specimen S, heap specimen K1 and structure specimen K2.

3 UNCINFINED COMPRESSION STRENGTH UCS

3.1 Laboratory specimens

Three sets of parallel specimens were prepared for unconfined compression testing. The total number of specimens was 237 including normal (50 mm x 100 mm) and small (20 mm x 40 mm) size specimens, Table 3.

Table 3. Number of specimens

Size	Small	Large
L	72	15
S	84	42
K1	6	12
K2	-	6

For specimens S and L the development of strength with time is presented in Figs. 3 and 4 respectively. Figures show that the strength increases with time only if the cement amount is high enough. For both clays the strength increase starts at the cement amount $C_w = 15 \dots 20$ kg/m³ or $A_w = 2 \dots 2.5$ % and the directive requirement of UCS ≥ 100 kPa is obtained with $C_w = 30 \dots 40$ kg/m³ ($A_w = 4 \dots 5$ % for clay L and $A_w = 3 \dots 4$ % for clay S). Different values of A_w are due to different natural water contents.

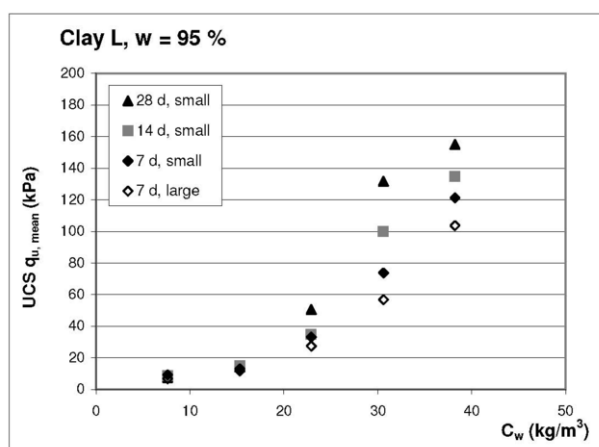


Figure 3. Development of UCS for specimens L with different amounts of binder.

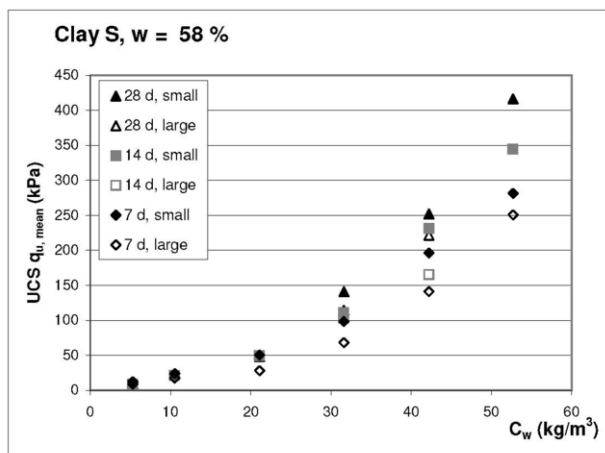


Figure 4. Development of UCS for specimens S with different amounts of binder.

3.2 Field specimens

In the field the clay was stabilised using a cement amount of $C_w = 30 \text{ kg/m}^3$. Comparison of the laboratory and field strengths is presented in Fig. 5. Heaped Clay K1 meets the UCS requirement already on the following day from stabilisation. Two of K2 results remain below the requirement.

Generally, the field specimens behave like the specimens stabilised in the laboratory. Strength increases with time and the strengths of the large size specimens are mainly lower than those of the small specimens, approximately 70 % of small specimens' UCS. The effect of the specimen size can partly be explained by the specimen preparation procedure which results in lower water contents in the small specimens. More air bubbles was observed in large size specimens.

The quality of the field specimens varies much and the scatter in the strengths of the parallel specimens is bigger than with the laboratory specimens. As it can be seen in Fig. 5 the scatter of results is biggest in the K2 specimens.

Surprising in Fig. 5 is that the K1 strength after 14 days are higher than those of 28 days. This can be explained by the structural difference of the specimens caused e.g. by compaction. In addition, mixing in the field inevitably causes differences in the cement content.

It is seen in Fig. 5 that the strengths of the specimens K1 taken from a stabilised pile are higher, approximately double the strengths obtained from in the laboratory mixed samples. Also the strengths of the specimens K2 taken from the structure are higher than those obtained from samples L and S, with an exception of the two low values. The higher strengths can be explained by lower water contents and higher densities of the field specimens.

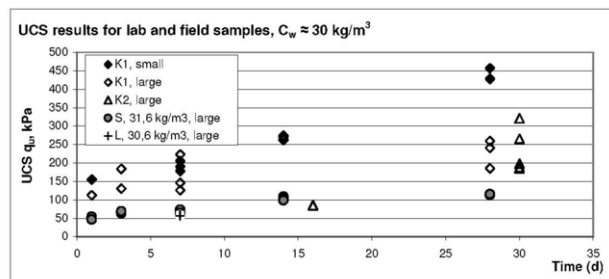


Figure 5. UCS against time for field specimens K1 (heaped and stabilised clay) and K2 (undisturbed sample from structure) and for in laboratory stabilised specimens S and L.

4 PERMEABILITY

4.1 Oedometer tests

Permeability was tested mainly using an oedometer equipped for falling head permeability, because tests with a flexible wall permeameter are much more time consuming. Most of the tests were run on sample S. Permeability was tested for natural clay specimens and for specimens stabilised with $C_w = 52.7, 42.2, 31.6$ and 21.1 kg/m^3 . Specimens L were tested as natural and with $C_w = 38.2$ and 30.6 kg/m^3 .

Timing of the oedometer tests was such that the results would be comparable with those of the flexible wall tests. The time effect was minimised by starting the oedometer tests 28 days after stabilisation. The effect of the specimen storage time was studied by measuring permeability of two specimens 7 and 28 days after stabilisation. The specimens were stored immersed in water at a room temperature. Tests were made at the end of the primary consolidation stage of each loading step.

Most of the oedometer tests were performed in the summer and autumn 2007 and some tests one year later (denoted by * in the following).

4.2 Flexible wall permeability tests

One permeability test with a back-pressured flexible wall permeameter takes three weeks and because only one permeability cell was available, the number of tests had to be limited to four for specimens S with $C_w = 52.7, 42.2, 31.6$ and 21.1 kg/m^3 and one for specimen K1 with $C_w \approx 30 \text{ kg/m}^3$.

The coefficient of permeability k was measured from the records of the last testing week after the flow through the specimen had become steady. At the last measurement stage the cell, front and back pressures were 210, 170 and 140 kPa respectively. The effective cell pressure was 55 kPa and the hydraulic gradient between 30 and 37 depending on the specimen height. The coefficient of permeability was determined as a mean value of the four last measurements.

4.3 Test results

The results of the permeability tests against dry density for specimens L are presented in Fig. 6, for specimens S in Fig. 7 and for field specimens K1 and K2 in Fig. 8. In Fig. 8 two additional oedometer test results of the stabilized Lempola site samples are presented. Sample "Wet, 1 d" was taken from a heap in which the stabilised clay seemed to have a relative high water content. Sample "Structure, 4 d" was collected from the uncompacted part of the stabilised clay structure. In the oedometer tests, for natural reasons, permeability decreases while the dry density increases during the consolidation process. Permeabilities of practically all specimens are within the order of magnitude $k = 10^{-10} \dots 10^{-9} \text{ m/s}$. The only exceptions are the specimen "K1, 28 d, F" and the specimen "K2 > 30 d". The former was prepared in the laboratory and tested with a flexible wall permeameter. The latter has a much higher density as taken from a compacted structure.

Related to the dry density, permeabilities obtained in the flexible wall permeameter are lower than those measured in the oedometer test. However, the dry densities measured from the flexible wall permeameter specimens were not as accurate as those from the oedometer.

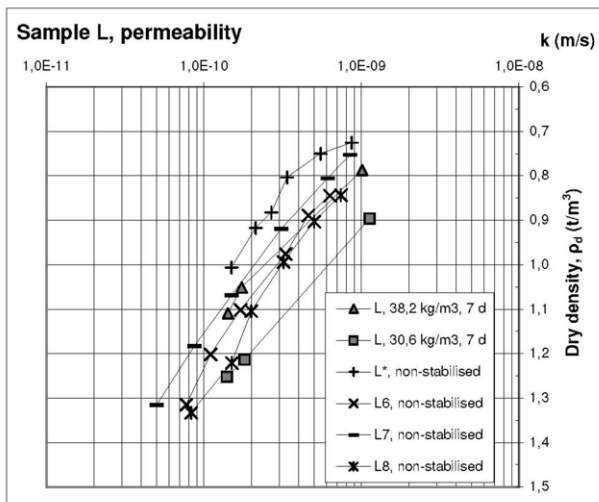


Figure 6. Permeability test results of the specimens L. * denotes a test performed a year after sampling. Samples L6, L7 and L8 were mixed together to form the sample L.

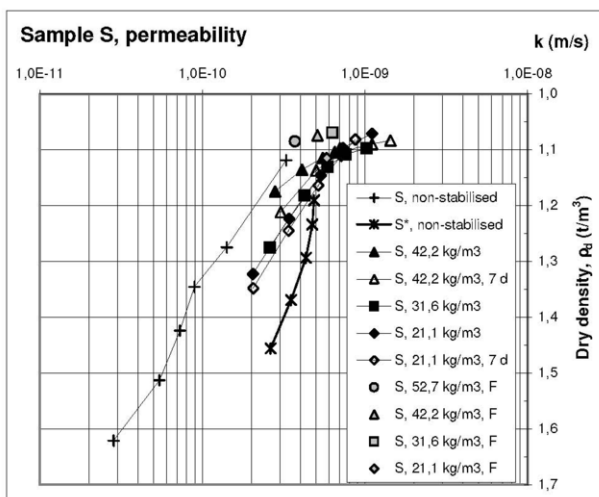


Figure 7. Permeability test results of the specimens S. F denotes a flexible wall permeameter test and * denotes a test performed a year after sampling.

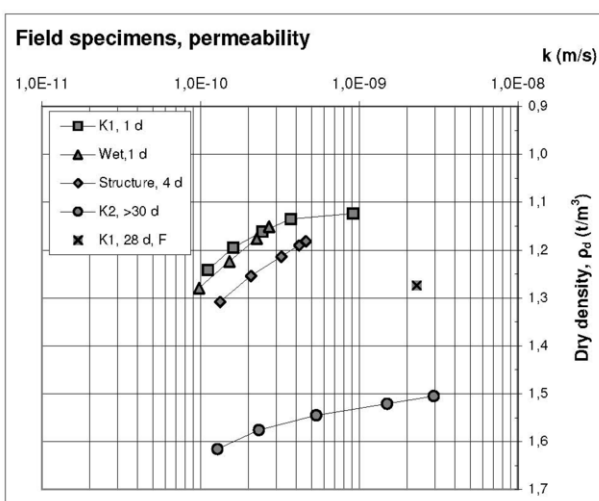


Figure 8. Permeability test results of field specimens.

5 CONCLUSIONS

As a result of the study the following conclusions can be made:

- the increase in strength with time is noticeable only if the cement amount exceeds $C_w = 15 \dots 20 \text{ kg/m}^3$
- the directive requirement of $\text{UCS} \geq 100 \text{ kPa}$ is achieved with the cement amount of $C_w = 30 \dots 40 \text{ kg/m}^3$
- effect of small cement amounts on permeability is small and stabilised laboratory specimens meet the requirement $k \leq 10^{-9} \text{ m/s}$ if the remoulded natural clay meets it.

ACKNOWLEDGEMENT

This paper was made with the aid of the research project "Use of soft clay in protection barriers" financed by the Academy of Finland.

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