27 Years' investigation on property of in-situ quicklime treated clay

27 ans de recherches sur les propriétés de l'argile traitée à la chaux vive

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ABSTRACT
Deep Mixing Method was developed in Japan and Scandinavian countries in 1970s. After then, a lot of research efforts have been carried out on the strength characteristics of treated soil, interaction of treated soil and surrounding soils, developments of new binder, development new execution machine and technique, establishment of design procedure, and so on. However, long term property of treated soil has not been throughout investigated. Authors have kept two columns of in-situ quicklime treated soil underground more than 27 years. Laboratory tests were carried out on one of them at 11 and 27 years' curing periods. In this article, unconfined compressive strength, wet density, water content and calcium content on 11 and 27 years' specimen are presented to reveal that the treated soil cured for 27 years has gain threefold strength of original treated soil.

RÉSUMÉ
La méthode de réalisation de colonne traitées par malaxage en place ont été développées au Japon et en Scandinavie dans les années 70. Pour en améliorer les performances, beaucoup de recherches ont été réalisées sur la résistance des sols traités, les interactions entre le sol traité et le sol environnant, le développement de nouveaux liants, le développement de nouveaux procédés et de nouvelles machines de traitement en place, l'établissement de procédures de dimensionnement, etc. Cependant les propriétés à long terme des sols traités ne sont pas encore complètement connues. Les auteurs ont gardé deux colonnes de sol traité en place pendant plus de 27 ans. Des essais de laboratoire ont été réalisés sur l'une d'elle à 11 et à 27 ans de cure. Cette communication présente la résistance en compression non confinés, la densité humide, la teneur en eau et la teneur en calcium d'échantillons agés de 27 ans : la résistance apparaît trois fois supérieure à la résistance initiale du sol traité.

Keywords : quicklime treated soil, durability, unconfined compressive strength, wet density, water content, calcium content

1 THE FIRST HEADING

Deep Mixing Method, a kind of in-situ admixture stabilization technique using lime, cement or their mixture as a stabilizing binder, was developed in Japan and Scandinavian countries in 1970s (CDIT, 2002). After then, a lot of research efforts have been performed on the characteristics of treated soil, interaction of treated soil and surrounding soil, developments of new binder and new execution machine and technique, establishment of design procedure, and so on. The long term property of cement treated soil has been investigated by Terashi *et al*. (1983) in which treated soil manufactured and cured in a laboratory were investigated. Kitazume *et al*. (2003) and Nakamura and Kitazume (2006) measured the long term strength of laboratory mixed treated soil. On in-situ treated soil, Hayashi *et al*. (2003), Ichiba *et al*. (2002) and Ohishi *et al*. (2002) investigated the field treated soils cured more than 26 years. These research efforts were summarized, in which the treated soil far from the boundary continuously increased in strength but the soil close to the boundary decreased in strength.

However, a number of investigations on the long term strength of quicklime treated soil is limited. Authors have kept two columns of in-situ quicklime treated soil underground more than 27 years in order to investigate the change in their long term property. In the series of the investigation, laboratory tests were carried out on one of two treated column at 11 and 27 years' curing periods. In the tests, unconfined compressive strength, needle penetration strength, wet density, water content and calcium content were measured on the core samples. A part of the investigation was presented by Terashi and Kitazume (1992), in which unconfined compressive strength, wet density, water content and calcium content of 11 years' cured soil were reported. In this article, the construction of the treated soil and the laboratory tests are briefly described to discuss the durability of the quicklime treated soil cured more than 27 years.

2 SPECIMEN TO BE INVESTIGATED

2.1 *Construction of Treated Soil*

The quicklime treated soil investigated was constructed in Fukuyama Prefecture, Japan, in 1979 as a part of field execution test for developing mixing machinery. The site was a reclaimed land, where a sandy and gravel soil layer with 2.3m thickness and a clay layer with 5m thickness were stratified. The clay layer, which had clay particle content of 60%, sand particle content of 1%, w_L of 90%, w_P of 21%, I_p of 69 and natural water content of 80%, was improved with massive lump of quicklime. A mixing machine used had two mixing shafts and three stacks of mixing blades, as shown in Fig. 1. In the execution, dry massive lump of quicklime was injected and mixed with the clay during withdrawal stage.

During the execution, the withdrawal speed, the rotation speed of mixing blades and the surface level of quicklime in the casing pipe were measured, as shown in Fig. 2. The binder content, a_w, defined as a ratio of dry weights of quicklime and soil, was calculated and plotted in the figure. According to the execution record, the binder content of the soil block investigated was estimated as 12.5%.

After two months' curing in the field, a part of the treated soil of the depth of 0 to -1m was excavated and divided into two

Proceedings of the 17[th] International Conference on Soil Mechanics and Geotechnical Engineering
M. Hamza et al. (Eds.)

doi:10.3233/978-1-60750-031-5-2358

blocks for ease of carry. The blocks were carried to the PARI and buried underground below the water level in the concrete tank whose diameter and depth were 7m and 2m respectively.

Fig. 1. Mixing shafts and blades

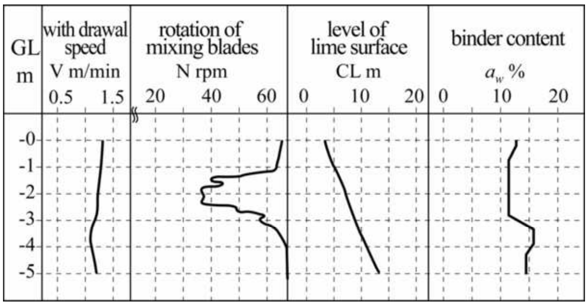


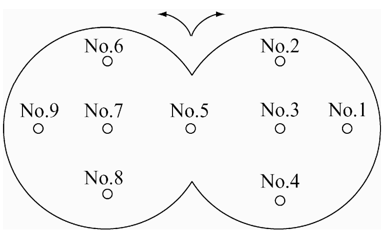
Fig. 2. Execution record

2.2 *Strength of Treated Soil*

At 64 days after the execution, core sampling was carried out on the treated soil just beneath the excavated block to investigate the properties of the in-situ treated soil. The measured properties, water content, w, dry density, ρ_d, and unconfined compressive strength, q_u, are tabulated in Table 1 together with the sampling location in the columns. Although there is a scatter in the data, negligible difference in the property is found in the treated soils block A and B. The average water content, wet density and unconfined compressive strength are 57.3%, 1.536 g/cm^3 and 1020 kN/m^2.

Table 1. Soil strength at 64 days

Block	No.	w (%)	ρ_d (g/cm^3)	q_u (kN/m^2)
A	1	57.7	1.547	1,190
	2	55.5	1.595	781
	3	51.2	1.550	948
	4	61.7	1.481	920
	5	51.9	1.507	1,120
B	6	50.8	1.588	1,220
	7	55.9	1.538	1,380
	8	60.2	1.531	899
	9	60.7	1.490	741
Ave.		57.3	1.536	1,020
COV		7.0%	2.43%	20.0%



3 LONG TERM PROPERTY TESTS

3.1 *Location of Core Sampling*

The core sampling was carried out on the soil block B by a rotary type boring machine in 1991 and 2007 to investigate the long term soil property. The position of core sampling is illustrated in Fig. 3: the samplings at V1 to V8 were carried out in 1991 and V9 to V12 and H1 to H3 were carried out in 2007. The horizontal samplings at H1 to H3 were carried out to the existing core holes V6 to V4 respectively. After each sampling, the treated soil block was overlaid by the soil and cured again for future test.

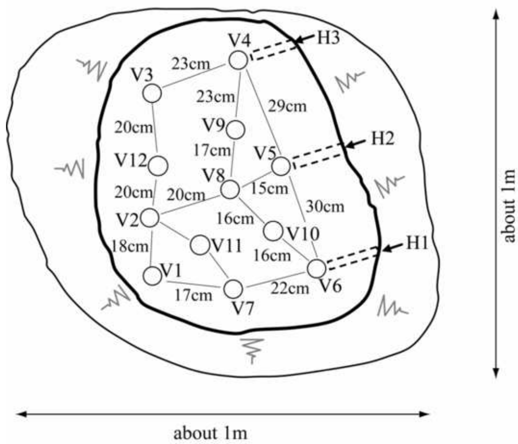


Fig. 3. Location of core sampling for block B

3.2 *Laboratory Tests*

The unconfined compression tests, wet density, water content and calcium content tests were carried out on the core specimen. The measured data at 64 days, 11 and 27 years are summarized along the depth in Fig. 4 and their summary is tabulated in Table 2.

4 DISCUSSION

4.1 *Wet Density*

Although there is a scatter in the measured data, the wet density was slightly decreased with the depth, as shown in Fig. 4. Figure 5 shows the wet density change with elapsed time. The density was slightly decreased from 1.536 g/ cm^3 to 1.527 g/cm^3 during the early 11 years but increased to 1.537 g/cm^3 after then. It can be concluded that negligible change in the wet density took place during 27 years by taking into account the scatter of the measured data.

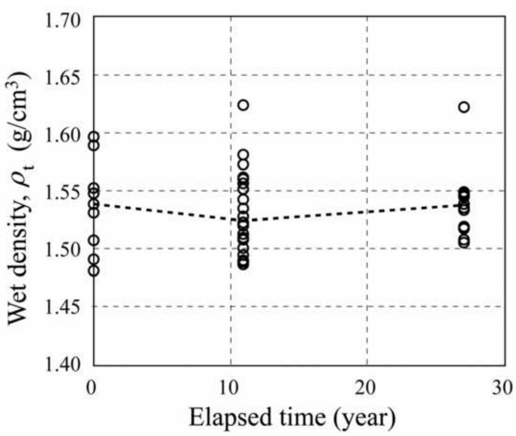


Fig. 5. Wet density with elapsed time

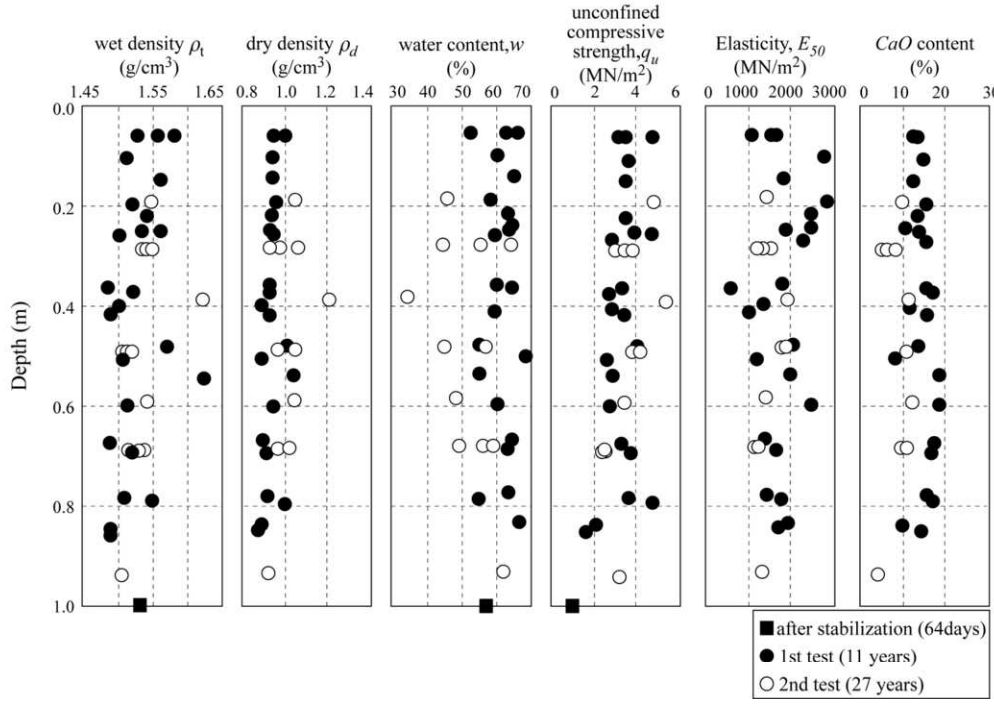


Fig. 4. Soil property profile along depth

Table 2. Summary of soil property

Property		No. of specimen	Max.	Min.	Ave.	COV
wet density, ρ_w (g/cm^3)	64 d	9	1.595	1.481	1.536	2.43%
	11 y	24	1.623	1.486	1.527	2.29%
	27 y	12	1.622	1.505	1.537	1.90%
dry density, ρ_d (g/cm^3)	11 y	24	1.045	0.872	0.945	4.18%
	27 y	12	1.206	0.928	1.018	7.00%
water content (%)	64 d	9	61.9	50.8	57.3	7.01%
	11 y	24	70.8	52.2	61.9	7.50%
	27 y	12	64.1	34.5	51.5	16.05%
unconfined compressive strength, q_u (kN/m^2)	64 d	9	726	1352	1000	20.0%
	11 y	24	4814	1784	3424	21.73%
	27 y	12	5326	2507	3538	23.76%
elastic modules (MN/m^2)	11 y	24	2774	623	1772	30.62%
	27 y	12	1921	1132	1416	18.04%
CaO content (%)	11 y	24	18.55	8.42	14.37	18.79%
	27 y	12	12.00	4.30	9.13	25.56%

4.2 *Unconfined Compressive Strength*

The height, *H*, and diameter ratio, *D*, of specimen for unconfined compression test is standardized as *H/D* =2 by the Japanese Geotechnical Association (JGS, 1998). However, due to the several cracks in the 11 years' core samples which took place during the coring stage, some of the unconfined compression tests had to be carried out on the specimen with the height and diameter ratio, *H/D*, being less than 2. The measured strength on the specimen with *H/D* less than 1.8 was modified by following equation and shown in Fig. 4 and Table 2.

$$q_u^* = \frac{0.889 \cdot q_u}{0.778 + 0.222 \cdot D/H} \quad (1)$$

where
D : diameter of specimen (cm)
H : height of specimen (cm)
q_u : measured unconfined compressive strength (kN/m^2)
q_u^* : modified unconfined compressive strength (kN/m^2).

The measured data is plotted along the elapsed time in Fig. 6. Although there is a lot of scatter in the measured data, the treated soil strength was increased to threefold in the early 11 years' curing but became almost constant for further 15 years' curing, as shown in Fig. 6.

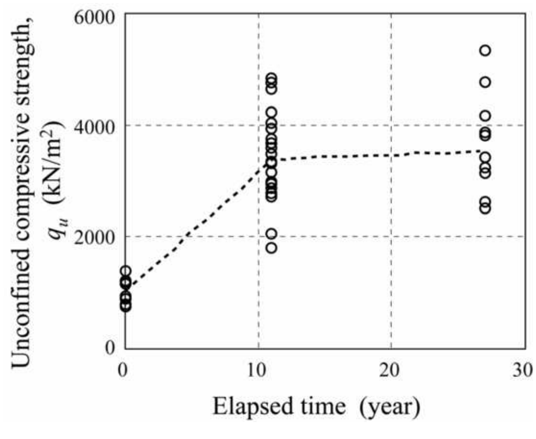


Fig. 6. Unconfined compressive strength with elapsed time

4.3 *Elastic Modulus*

Figure 7 shows the relationship between the elastic modulus, E_{50}, and unconfined compressive strength, q_u. As mentioned before, the measured data of the first test are plotted separately according to the *H/D* ratio of specimen. The E_{50} has a linear relationship to the q_u, but it is highly dependent upon the *H/D* ratio and the curing period. In the first test (11 years' curing), unique relationship, $E_{50} = 700\ q_u$ for $H/D > 1.8$ and $E_{50} = 400\ q_u$ for $H/D < 1.8$, is found according to the *H/D*. In the second test (27 years' curing), however, $E_{50} = 400\ q_u$ is found even the $H/D = 2$. Further research will be necessary to investigate the reason of this discrepancy.

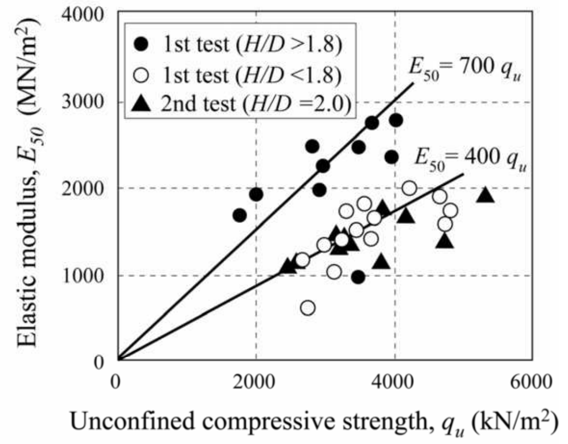


Fig. 7. Elastic modulus and unconfined compressive strength relationship with elapsed time

4.4 *Calcium Content*

The calcium content of the treated soil was measured by the 'F-18 method' proposed by Japan Cement Association (1967). The measured calcium content is almost constant along the depth in the first and second tests, as shown in Fig. 4. The calcium content is plotted along the curing period in Fig. 8. As shown in the figure, the calcium content was decreased from 14.37% to 9.13% from 11 years to 26 years. Some of previous researches mentioned the relationship between the calcium content and the soil strength. In the tests, the soil strength was almost constant during the period, as shown in Fig. 6, and no clear relationship is found between the calcium content and the q_u value. Although the detail cause is not clarified yet, the difference in the preparation method for the calcium content test can be one of the causes.

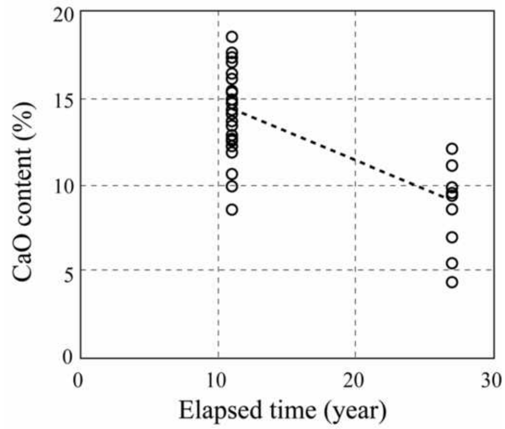


Fig. 8. Calcium content with elapsed time

5 CONCLUSIONS

In the present test, more than 27 years' long term property of the field quicklime treated soil was briefly described. The major conclusions derived are summarized as below:

1) The wet density of the treated soil has been almost constant during 27 years' curing.
2) The treated soil strength was increased about threefold during the early 11 years, but became almost constant after then.
3) The elastic modulus decreased about 20% in the recent 15 years.
4) The calcium content of the treated soil was decreased about 5% during the recent 15 years.

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