An application of lime stabilization to marine clay

L'application de la stabilisation de la chaux vive à l'argile marine

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ABSTRACT: The engineering properties of marine clay and lime as an improvement agent were investigated through the comprehensive laboratory experiments. Two different methods of clay improvement with the quick lime locally available were evaluated in this study. One is the lime mixing method, and the other is the lime pile method, respectively. In the lime mixing method, the compressive strength and compressibility of the lime treated clay at different mixing ratio and curing time were examined and these results then were compared with those from the untreated one. In case the lime pile method, model test using the cylindrical container was carried out. The characteristics of the excess pore pressure dissipation at varying radial distances along the model lime pile were monitored and then these data were compared with the theoretical predictions. In addition some valuable design parameters emerged from the model test were presented.

RESUME: La propriété technologique de l'argile marine et l'argile marine comme un sujet de l'amélioration a été examiné par l'éxperimentation laboratoire comprehensible. Deux méthodes differentes de l'amélioration de l'argile avec la chaux vive a été évalué en cette étude. L'un est la méthode du mélange de la chaux vive et l'autre est celle du piquet de la chaux vive. En la méthode du mélange de la chaux vive, la puissance comprimée et la compressibilité de l'argile traitée avec la chaux vive dans la proportion differente de la mélange et le temps qui fait le prise ont été examiné et après ces resultats ont été comparé avec ceux de l'argile intraitée. En la méthode du piquet de la chaux vive, le modèle test en usant le conteneur circulaire a été exécuté. Le caractère de l'excès pore pression dissipation en variant la distance radiale près du modèle de la chaux vive a été surveillé et après ces resultats ont été comparé avec les prédictions théoriques. D'ailleurs, quelques paramètres de plan obtenus par le modèle test a été presenté.

1 INTRODUTION

The development of suitable ground improvement technique is being focused as a rapid growth of the either on or off shore projects in Korea. To meet this demand, the engineering properties of marine clay improved by the quick lime action were studied. The material properties of the locally available lime were evaluated and how much these charateristics influence the clay properties were throughly investigated by performing the two different improvement techniques. Namely, one is the lime mixing method and the other is lime pile method.

2 THE ENGINEERING PROPERTIES OF THE LIME TREATED CLAY

2.1. *The properties of lime*

The lime used in this study was produced in Danyang located at the south-east of Seoul in Korea. Its specific gravity was 3.06 and was found that this value is closed to the lower limit of typical lime ranging from 3.01 to 3.30. The lime was well-graded as shown in Fig. 1, and its chemical composition is presented in Table 1.

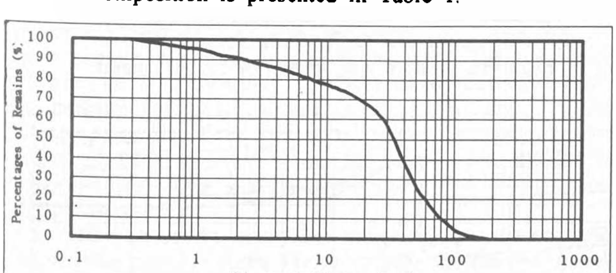


Fig. 1 Gradation Curve of lime used

Table 1. Chemical composition of lime used.

Components	Content (%)
SiO_2	1.8
AL_2O_3	0.5
Fe_2O_3	0.3
CaO	93.2
MgO	1.8
Na_2O	0.01
K_2O	0.04
Ig-Loss	2.30
SUM	100

2.2 *The properties of clay*

The clay used in this study was collected from the Gadug new harbor area located in the South Coast of Korea. The index properties of the marine clay are as shown in Table 2. The test results clearly indicated that this marine clay has low plasticity and highly compressibility.

Table 2. Index properties of marine clay

Properties	Values
Moisture Contents	64% ~ 72%
Liquid Limit	28% ~ 32%
Plastic Limit	12% ~ 17%
Specific Gravity(G_s)	2.65 ~ 2.69
Optimum Water Content	13% ~ 17%
Maximum Dry Density	17.2kN/m^3
NaCL	0.40%
Organic Matter	5.18%
pH	7.99

2.3 *The unconfined compressive strength of lime treated clay*

Several unconfined compressive strength tests were performed at different water contents and lime contents. The mixing percentages of water and clay(W/MC) by weight are 60, 70, 80. The weights of lime per unit weight of

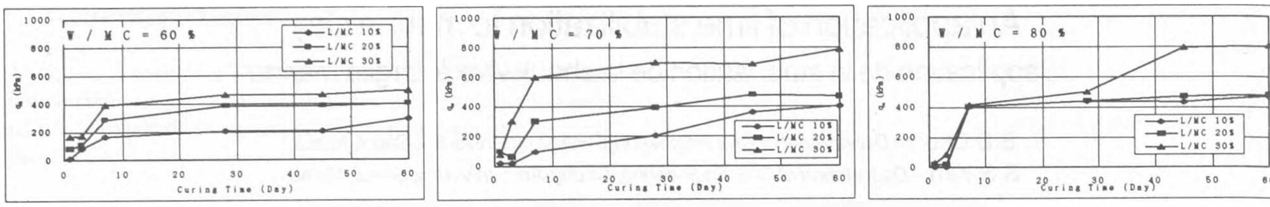


Fig. 2 Unconfined compressive strength of marine clay with curing times

clay(L/MC) for each case are 10, 20 and 30, respectively. The curing temperature was maintained 25±5 °C in the humidity control chamber. The unconfined compressive strength obtained from the treated clay at curing days of 1, 3, 7, 28, 45 and 60 are demonstrated in Fig. 2.

Fig. 2 shows that the strength of the lime treated clay is increased as curing times and L/MC values are increased. It is quite interesting to note that the strength increment is rapid at the early stages of curing. These trends, however, have not been observed after the curing time longer than 10 days.

2.4 *The compaction characteristics of lime treated clay*

Two samples of lime/clay mixture at percentages of 20 and 30 having the same water/clay ratio of 0.7 were compacted. These samples were also cured under the same conditions as those for strength tests described in Section 2.3. The relationships between the maximum dry density and the optimum moisture content are shown in Table 4. The compaction curves are also illustrated in Fig. 3. It is seen from Fig. 3 that the maximum dry density, the optimum moisture content of lime treated clay are less than those of the untreated one. The effect of curing time is not seen clearly.

Table 3. Relationship between γ_{dmax} and w_{opt} (W/MC=0.7)

Curing Times (Days)	L/MC (%)	γ_{dmax} (kN/m^3)	w_{opt} (%)
Initial		17.15	17.1
1	20	13.80	26.7
	30	12.35	28.4
3	20	14.55	29.3
	30	14.51	24.3
7	20	13.54	32.2
	30	13.53	28.1
28	20	12.02	34.5
	30	12.61	34.4
45	20	14.31	25.1
	30	13.72	25.9

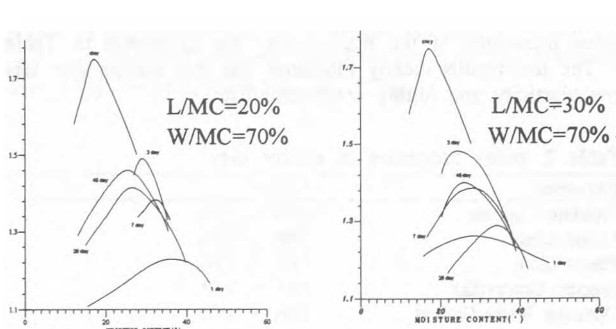


Fig. 3 Compaction curves of lime treated clay

2.5 *The trend of water content redution*

The moisture content ratio of sample was decreased due to initial hydration. The decrement of moisture content is closely ralated with inital compressive strength of lime treated clay. Fig. 4 illustrated the change of moisture content ratio with the curing days of lime treated marine clay.

3 THE PORE PRESSURE AROUND LIME PILE BY ITS EXPANSION

3.1. *The expansion of lime pile*

To investigate the radial expansion ability of quick lime pile within the ground, the following one-dimensional expansion test (upward unconfined, bottom and radial direction confined) was carried out using consolidometer. It is aimed to find the lime expansion properties indirectly by vertical loading. The test was performed by using lime mixture with distilled water as well as salt water(3%) to the lime of dry density 13.1kN/m^3. Test results show that the amount of expansion decreased as vertical stress increased.(see Fig.5) However, the strains under the stress more than 98kPa are more or less the same.

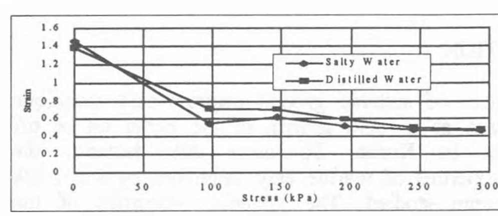


Fig. 5 Variation of vertical expansion (distilled water, 3% salty water)

3.2. *Expansion pressure of lime*

Six centimeters in diameter and ten centimeters long mold was made for the measurement of lime expansion pressure. The dry density of lime was varied at different levels; 10.8, 12.7, 14.7kN/m^3 using distilled water and salty water(3%), respectively. For the case of distilled water, the expansion pressures with times are shown in Fig. 6.

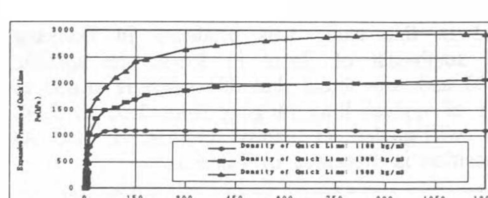


Fig. 6 Expansion pressure with times (3% of salt content)

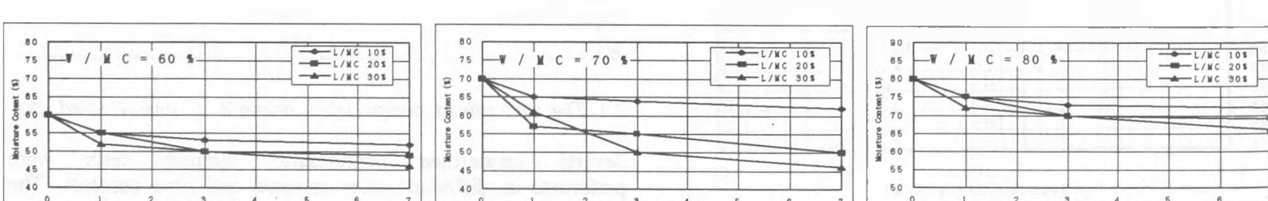
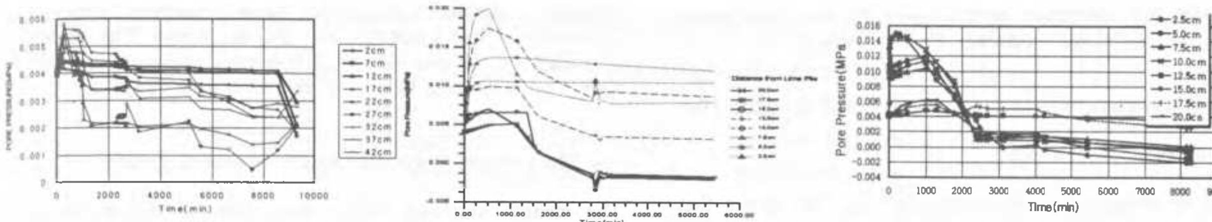


Fig. 4 Decrement of moisture contents of lime treated clay with curing days



(a) 1st test (b) 2nd test (c) 3rd test

Fig. 7 Pore pressure to radial distance with times

It was found that the maximum expansion pressure of lime was 2930kPa in the distilled water and 2577kPa in salt water respectively. These results are the values suggested by Kuroda(1980). The expansion pressure is increased as the density is increased.

3.3 *The compression ratio of the slaked lime to the quick lime*

The compression ratio of the slaked lime to the quick lime, C_5 denoted by Holyman & Mitchell(1983) in their formula is 0.2 irrespective of the density of lime. In this study, the observed ratio ranged from 0.2 to 0.5 when the stress of ground around lime pile was varying 0 to 147kPa.

3.4 *Compression ratio of lime to stress increment*

The consolidation mold tests were carried out by changing dry density from 10.8kN/m^3 to 14.7kN/m^3 and stress from 0 to 0.35MPa. The compression ratio of lime to stress increment(C_3) tends to decrease as dry density of lime increases. However, it tends to decrease as the stress increases. Eventually these values converged to 0.3～1.2MPa^{-1} when the increment of stress is over 0.3MPa. And those are slightly less than the value reported by Holyman(1983) and Kuroda(1980).

3.5 *The consolidation test on the tested clay*

The average initial void ratio of sample was 1.514. As stress increased, void ratio varied from 0.544 to 1.452, and the coefficient of permeability and consolidation(C_v) were computed to $1.21\times10^{-8}\sim2.16\times10^{-5}$m/s and $1.08\times10^{-6}\sim5.88\times10^{-6}$m^2/s, respectively.

3.6 *Porepressure and expansion pressure around lime pile*

The diameter and height of test container used in the test are 50cm and 100cm, respectively. The eight stand pipes (the diameter and height are 5mm and 3m) were installed to monitor the changes of porepressure, which connected with steel pipes differed from the radial distances by 2.5cm, respectively. Fig. 7(a), (b), (c) show the pore pressure distribution along the radial distance in the condition of the same density and diameter of lime pile.

The results shown in Fig. 7 demonstrates the pore pressure distrubutions to times were similar each other. The development of the pore pressure due to the expansion of lime is completed before about 1000 minutes. The maximum pore pressure was measured 0.02MPa. The maximum peak pore pressure difference shown in Fig. 7(a) and 7(b) is attributed to errors of the initial test process.

Holyman(1983) reported that the maximum expansion pressure around lime was about 0.5MPa and the reaction time is 2days.

Chen(1993) reported that the maximum excessive pore pressure was about 0.1MPa on the condition that the initial pore pressure was 0.02MPa.

The measured maximum pore pressure were 0.057MPa～0.02MPa, and these values are much lower than those obtained by previous reserchers. The farther the distance from the pile the faster the dissipation of the pore pressure.

3.7 *The pore pressure predictions around lime pile by theories*

3.7.1 *Holyman & Michell's theory*

Fig. 8 shows the pore pressure distribution around lime pile calculated by Holyman & Michell.

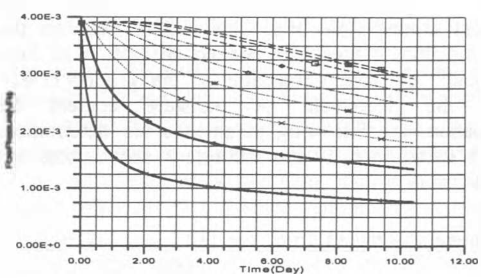


Fig. 8 can be explained as follows;

- The stiffness coefficient(K_1) calculated was different from the test results. (∵ The result of calculation was negative)
- The increment of pore pressure by the expansion of the pile was not considered, showed only the dissipation processing, and the reaction time was different from real action.
- The increment of pore pressure(Δu) to radial distance was calculated with the constant value to radial distance at the same time.

3.7.2 *The analysis of the pore pressure distribution by Chen & Law's theory*

The Pore pressure distribution on the ground around the lime pile was obtained by Chen & Law's equation(1993). Its properties were inclined to be similar with the case of test container.(Fig. 9) However, there were some differences that theoretical reaction time was far longer than real time and it spent so long time on pore pressure dissipation. Theoretical maximum pore pressure was about 0.35MPa, but the actual value by test was 0.02MPa, otherwise, the test value by Chen or Holyman were similar with that actual value. It was

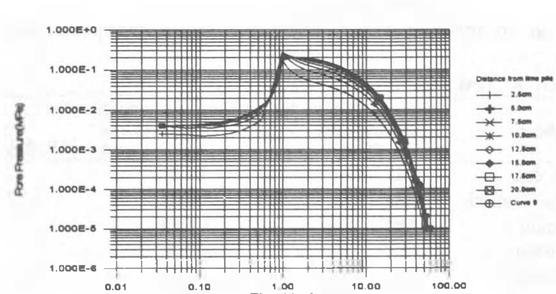


Fig. 9 Pore pressure to radial distance and times by Chen & Law's theory

analized that the dissipation time of pore pressure was longer than the case of the test container by 10~20days.

4 THE ENGINEERING PROPERTIES OF SOIL AROUND LIME PILE

4.1 *The strength of lime pile*

The strength of lime pile was evaluated. Fig. 10 shows that the cohesion of the lime pile largely depends on the density and it tends to increase as density of lime increases.

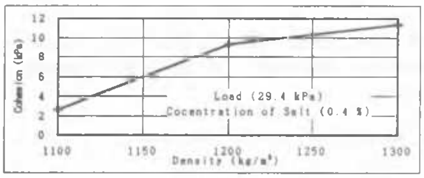


Fig. 10 Variation of cohesion with the density

4.2 *Parameters for the calculations*

ISHIDA(1977) suggested prediction method using the moisture content around lime pile. This method requires the decrement of moisture content by slaked absorption of lime pile ($\triangle W_h$), and by void absorption of the ground($\triangle W_s$). To calculate the decrement of moisture content by theoretical equation, the following parameters are determined. The parameters determined by the laboratory experiments are summarized in Table 5.

Table 5. Parameters obtained from the test

Parameter	Value
G_o(Specific Gravity of Slaked Lime)	2.24
h	0.27
γ_o	12.4 kN/m^3
n'	0.63
ε_v	0.5
S_r'	86

In the case of the area ratio, which represents the area proportion between lime pile and soil to be improved, 5:1, the theoretical predictions and the test results are nearly the same. However, the differences are being greater as the area ratio decreased to 10:1.

Table 6. Comparisons of the test results with theoretical predictions

Area Ratio	Initial w(%)	w(%) at 28 curing days	
		Theoretical Prediction	Test data
5:1 (20%)	58.4	37.4	34.5
10:1 (10%)	58.4	48.4	40.2

4.3 *The calculation of strength*

The strengths were calculated using the existing equations about strength increment rate (m). In Table 7, they were compared with the test data.

The strengths predicted by Mohr-Coulomb, Bjerrum were similar to the test result, while the others overpredicted the strengths. These differences were resulted from the difference of soil properties and the test errors. The deviation estimated by Mohr-Coulomb's, Bjerrum's equation was about 13% and these also belong to the acceptable range.

Table 7. Test results (Area ratio 5:1)

Methods	Shear strength before improvement C_{u0} (kPa)	Shear strength after improvement $C_{u1} = C_{u0} + m \cdot \Delta P$ (kPa)
Test data	8.82	62.72
Mohr-Coulomb	8.82	54.88
Bjerrum	8.82	54.88
Karlsson	8.82	49.00
Skempton	8.82	45.08
Mayne	8.82	81.34
Wreth	8.82	76.44
Kang Byung-Hee	8.82	72.52

4.4 *The strength properties of the improved ground*

The stength variation to the area ratio of the ground and lime, in case of 5:1, resulted in three times greater than that of 10:1 (at the standard of 28 curing days). The strength of the ground was increased to the value of 62.7kPa from the initial value of 9.8kPa.

5 CONCLUDING REMARKS

An applicability of lime treatment to marine clay was studied and the followings are drawn from this study.

1) The lime produced in Korea has been proved as a suitable improvement agent of soft ground.

2) The unconfined compressive stength of marine-lime treated soil(L/MC=30%, W/MC=70% and L/MC=30%, W/MC=80%) is increased, much compared with that of untreated clay, and the more the lime mixing ratio the higher the strength.

3) The prediction of pore pressure development around the lime pile by Chen & Law's equation was similar to the test result. However the test data is slightly larger than those of predicted.

4) The higher the density of lime and the concentration of salty water, the lower the strength. It is found that the density of lime considerably affect the construction of lime pile.

5) In the case of area ratio 5 : 1, the shear strength of soil around the lime pile was increased as much 6 times, while the area ratio 10 : 1increased the strength 2 times.

6) It is proved that Karlsson's, Bjerrum's and Mohr-Coulumb's equation can be used as an design tool.

REFERENCES

Chew, H.H. T. Takeda, Kichikawa 1993. Chemico Lime Pile Soil Improvement Used for Soft Clay Ground, Eleventh Southeast Asian Geotechnical Conference. 4-8 May:319-324. Singapore.

Chun, B.S. 1987. The Method for Ground Improvement: 145-148:Kunseulyoungusa.

GADA 1983. The Stabilization Methods by Use of Lime: 12-38:Gashima Publication Co.

Holyman, A. & J.K. Mitchell 1983. Assessment of Quicklime Pile Behavior, Improvement of Ground. Vol 2: 897-902.

Ingles, O.G. & J.B. Metcalf 1972. Soil Stabilization:127-143. Australia:Butterworths.

Institute of Construction Technology, Samsung Heavy Industries Co. Ltd. 1996. Proceedings on New Technology Development for Seacoast-Reclamation and Improvement of Soft Ground: 6.1-6.81.

ISHIDA 1977. About the Derement of Moisture Contents by Lime Pile. JSGE 12th Conference. No.321:1265-1268. Japan.

ISHIDA 1974. The Improvement of Clay Loam by Use of Quick Lime. Soils and Foundations. Vol.22. No.5:37-42.

Korean Geotechnical Society 1995. Soft Ground:65-147.

JSL 1970. The Stabilization Methods by Use of Lime:6-9. Japan:Sangaidou.

Lee, Y.S. 1992. Study on the Shear Properties of Korean West and South Coast Alluvial Clay. Chungang Contruction Graduate.

Law, K.T. & P.A. Chen 1993. Pore Pressure Change In Soft Soils Improved By Lime-Fly Ash Piles. Eleventh Southeast Asian Geotechnical Conference. 4-8 May:363-367. Singapore.