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Shear strength and compressibility behaviour of lime-treated organic clay

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ABSTRACT: Apart from strength characteristics, a review of studies on the compressibility of lime-treated soils is equally important that influenced the stability of soil structures. Due to the fact that no study has been carried out, an investigation on the effects of humic acid on strength and compressibility behaviour of lime-stabilised organic clay is presented in this paper. Unconfined Compressive Strength (UCS) and oedometer tests were carried out at different curing periods of 7, 28 and 90 days. Consolidation data was analysed in terms of changes in void ratio (e), volumetric strain (ε_1), compression index (Cc), and coefficient of consolidation (c_v) which defines a soil's compressibility. The results showed a similar behaviour when compared to both tests. It can be conclude that the cementation bonding was associated with the fabric arrangement of soil structures.

Keywords: Geotechnical engineering, strength, compressibility, humic acid and lime stabilisation

1. Introduction

Lime is used as a stabiliser mainly due to the considerable improvement it affords to the engineering behaviour of weak soils, especially clay (Davidson et al. 1965; Choquette et al. 1987; Bell, 1996; Rajasekaran & Rao, 1997; James et al. 2008; Consoli et al. 2009 & 2011). Furthermore, lime is also considered as a low cost material, making it a popular choice amongst many other effective stabilisers. The immediate reaction of a clay soil to the introduction of lime is that it becomes friable due to the hygroscopic properties of the lime causing moisture loss (Onitsuka et al. 2001; Mallela et al. 2004; Koslanant et al. 2006). As a result the soil structure becomes more aggregated and this in turn improves the workability of the mixture. Permanent and maximum structural stabilisation of clay treated with lime is attainable in the longer term, when a pozzolanic reaction takes place (Choquette et al. 1987; Rajasekaran & Rao 1997; Petry & Glazier, 2002; James at al. 2008; Liu et al. 2012).

However, there is some evidence in the literature that the presence of high concentrations of organic matter in clay soil can lessen the chemical reaction between lime and clay minerals and have detrimental effects on engineering properties of soil. In particular, humic acid is a well known constituent of organic matter with the potential to disrupt the soil stabilisation process. In fact, it has been reported that, more than 1% humic acid content in clay may render lime stabilisation process ineffective (Huat et al. 2005; Koslanant et al. 2006; Harris et al. 2009; Zhu et al. 2009; Mohd Yunus et al. 2011). Mechanisms on lime-treated organic clay are thought to be affected by factors such as water content and insufficient dissolution of clay minerals during pozzolanic reaction. Organic matters have high water holding capacity which limits the water available for the hydration process (Chen & Wang, 2006). In addition, high water content may induce more spacing between aggregations, hence reducing a required cementation bonding.

Apart from strength, compressibility parameters have also shown an improvement when organic clay was treated with lime. Sakr et al. (2009) investigated the changes in the consolidation behaviour in terms of compression index, Cc, initial void ratio, e_o, and pre consolidation pressure, Pc on untreated and 1% lime treated organic clay. He found that the initial void ratio of treated soils decreased after 7 days of curing. It was due to the bonded structure of the lime stabilised specimens provide by cementation gels. In this paper an experimental study on the behaviour of lime-treated organic clay on strength and compressibility behaviour was determined with respect to three main factors: lime content, humic acid content, and curing

period. The relationship between level of cementation bond and its effect of soil fabric was compared from results given by engineering testing.

2. MATERIALS

Artificial organic clay used in this study was prepared by mixing commercial kaolin with commercial humic acid contents of 0%, 0.5%, 1.5% and 3.0% according to the dry mass of kaolin. The chemical elements present in each soil mixture are given in Table 1.

Table 1. Chemical elements in the tested soils.

	Wt%			
Element	0HA	0.5HA	1.5HA	3.0HA
C	2.12	2.8	2.74	20.16
O	47.91	50.45	54.54	48.97
Na	0.2	0.36	0.41	0.81
Mg	0.64	0.65	0.64	0.56
Al	19.43	16.94	18.47	12.8
Si	26.71	24.74	21.52	14.07
P	0.09	0.18	0.28	0.16
S	0.02	0.05	0.12	0.42
Cl	0	0	0.01	0.19
K	2.65	3.42	0.79	0.59
Ca	0.02	0.02	0.04	0.33
Ti	0	0	0.02	0.18
V	0	0	0.01	0.01
Fe	0.21	0.39	0.4	0.74

The molecule and organic structure is shown in Fig. 1. In general, the effect of humic acid on the chemical elements can be detected from the increase in carbon and oxide ions. As a result, the increase in amounts of carbon and oxide ions and the decrease in silica and alumina contents can be observed with increasing humic acid content, as shown in Table 1. The results of index testing carried out on inorganic and organic clays are summarized in Table 2. All of the tested soils were suitable to be stabilized by lime as the plasticity index (PI) is more than 10.

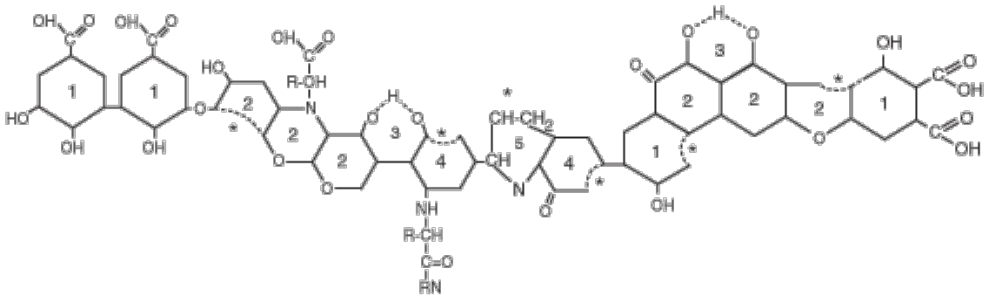


Fig. 1. The organic structure of humic acid

Table 2. Physical properties of clay with different humic acid contents.

Property	Humic acid content (%)			
	0	0.5	1.5	3
Liquid limit (%)	65.4	64.4	63.6	61.0
Plastic limit (%)	30.4	33.0	33.8	34.5
Plasticity index (%)	35	31.4	29.5	26.5
Specific gravity	2.61	2.53	2.51	2.47
pH	5.52	5.34	5.16	5.07
OMC (%)	30.6	30.9	30.6	33.4
MDD (kg/m^3)	1440	1429	1425	1404

3. SPECIMEN PREPARATION

This section discusses the laboratory preparation of specimens to study the effects of humic acid on engineering properties (strength and compressive behaviour) of lime-treated clay. As recommended by ASTM D 5102-96 (ASTM, 2004), soil for mixture preparation was oven-dried at 60°C overnight or until constant dry weight was obtained. Results obtained from the compaction tests were the key for preparation of the specimens for the subsequent strength testing. All of the treated specimens were prepared according to their respective maximum dry densities (MDD) and optimum moisture contents (OMC), as determined by compaction tests in an untreated state. The required dry mass of samples could be calculated, with knowledge of the mould volume and the MDD. Predetermined quantities of each additive (i.e. lime and salts) were then derived based on the dry mass of soil solid and mixed until homogenous. This material was then mixed with water content equal to OMC. Clay with different amounts of humic acid was prepared by mixing relevant amounts of dry kaolin with 0.5%, 1.5%, and 3% of humic acid by dry mass of kaolin. Mixing of dry materials was continued until a uniform appearance of the kaolin-humic acid mixture was obtained. Distilled water was then added and further mixing was performed until a homogeneous appearance of the soil paste was achieved. This paste was then used for plasticity and compaction tests. The specimens (76 mm in height and 38 mm in diameter) for UCS test were compacted into the mould, extruded from it and wrapped in cling film to preserve the water content and to minimise the exposure of carbon dioxide (CO_2) with specimens. The specimens were then cured in a desiccator at 20°C and with humidity of more than 90% for 7, 28, and 90 days, respectively. Meanwhile, the oedometer specimen preparation procedure was adopted by Burland (1990). The soil paste was cured for 7 and 28 days in a desiccator at 20°C and a humidity of more than 90% before being placed in the cylindrical metal ring with the dimensions of 75mm diameter and 20mm height. Slightly different from the strength test, the requisite quantity of lime was mixed thoroughly with organic clay at respective liquid limit. This is in consideration of deep soil stabilisation where soil may be below ground water table. Specimens were prepared based on liquid limit as it represents the maximum water content beyond which soil begin to flow under its own weight. The oedometer specimens were sealed in air-tight plastic bag and cured for 7 and 28 days in desiccators at 20°C to minimize moisture loss during the curing period.

4. RESULTS AND DISCUSSION

4.1 Strength behaviour

The results of a short term strength assessment of lime-treated clay with different humic acid contents (0%, 0.5%, 1.5%, 3%) and lime contents (5%, 8%, 10%, 15%) are shown in Fig. 2.

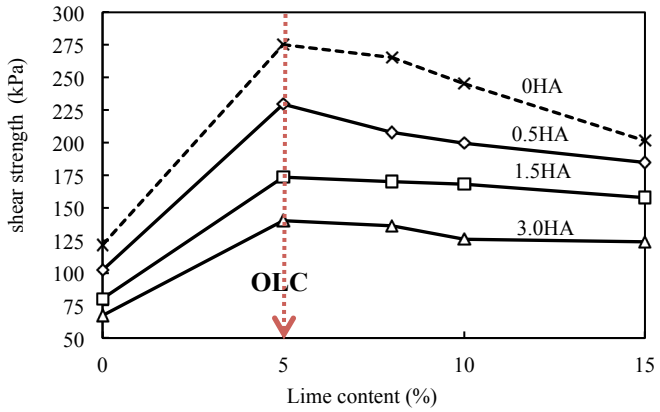


Fig. 2. Effect of lime content on the shear strength of clay with different humic acid contents after 7 days curing.

All the specimens were cured for 7 days. A slight reduction in the strength of the sample can be seen in the addition of 5% to 8% lime content regardless of the humic acid content in the clay. In addition, the shear strength of the specimens with 5% lime content increases significantly compared to the strength of untreated clay (i.e. 0% lime). It gives the impression that the optimum lime content (OLC) in this study may be in the range of 3% to 4% of lime. However, as there is no data is available in the range of 3% to 6% of lime content, 5% was taken as the optimum lime content (OLC) for each type of organic clay within the scope of this study. It is therefore prudent and imperative to consider a lower lime content range to clarify the OLC values for further prospective study. Fig. 2 also shows that the shear strength of organic clay decreases with increasing humic acid content, which proves that the presence of humic acid in organic clay diminishes its shear strength. In a further assessment of the effect of humic acid on lime stabilisation, samples were tested at 0, 7, 28, and 90 days to ascertain the duration of the stabilisation process. Since the OLC of each specimen was identical, investigation of the development of the lime-clay reaction with time was conducted only at 5% lime content. Fig. 3 illustrates the development of the shear strength of the lime-treated specimens at 0, 7, 28 and 90 days. It appears that with the exception of the inorganic clay (0% humic acid) the shear strength of the lime-treated clays comprising 0.5%, 1.5% and 3.0% humic acid decreased over the 90 day curing period. A slight loss in the strength is observed for organic clay with 0.5% humic acid, while substantial loss in strength is evident where the humic acid content is equal to or greater than 1.5% (Mohd Yunus et al. 2011). The results demonstrate that lime stabilisation of organic clay with high humic acid content is not very efficient in the long term. Similar observations were reported by other researchers (Huat et al. 2005; Koslanant et al. 2006; Harris et al. 2009; Zhu et al. 2011). It should be noted that despite exhibiting a loss in strength in the long term, the undrained strengths of lime-treated samples at 90 days were still higher than those of untreated specimens (see Fig. 2 for 0% lime). However, for practical purposes, it is not reasonable to consider lime stabilisation as successful when long term strength is uncertain.

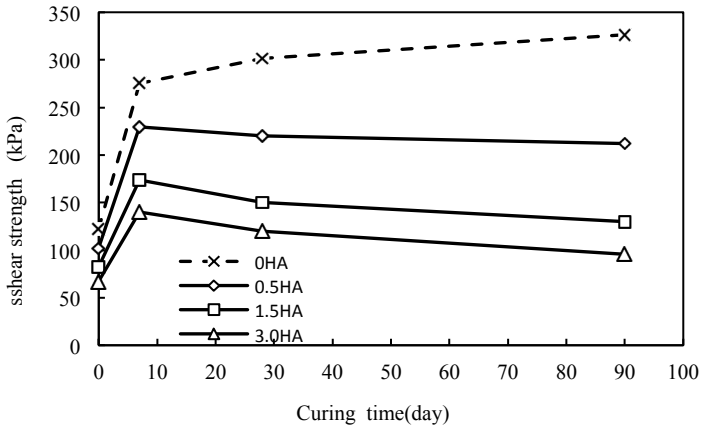


Fig. 3. Effect of curing period on the shear strength of lime-treated clay.

The interference in the formation and development of cementitious products with increasing humic acid content over longer curing periods may be due to various reasons. It was believed that the reduction in pH value at longer curing periods may be one of the reasons that decreased the shear strength value (Mohd Yunus et al. 2012). This is associated with the dissolution of clay minerals when react with lime which highly dependent on pH value. It is thought that the presence of a certain amount of humic acid made it difficult for the solution to recover from its acidified condition. The humic acid may have coated the clay particles, thereby preventing the lime from coming into contact with clay minerals during the pozzolanic reaction. Consequently, the dissolution of clay minerals becomes insufficient, thus limiting the production of cementitious materials. The findings obtained from the experiments on lime-treated organic clay revealed that lime may not be suitable for stabilising organic clay with more than 1.5% humic acid content (Kazemian et al. 2011).

4.2 Compressibility behaviour

This section assesses the compressibility behaviour of lime-treated organic clay with varying humic acid contents at different curing periods. The effect of humic acid on the lime-clay reactions is analysed in terms of changes in void ratio (e), volumetric strain (ε_1), and compression index (Cc) which defines a soil's compressibility. Table 3 summarises the initial properties of lime-treated clay with various humic acid content tested after 7 curing days. All of the specimens were treated with 5% lime which corresponds to the optimum lime content (OLC) given by the strength tests. In this study, each specimen was prepared to an initial water content equal to their respective liquid limits, For this study these were of 65%, 64%, 63% and 61% for 0%, 0.5%, 1.5% and 3.0% humic acid contents, respectively, primarily because the liquid limit is the extreme limiting water content above which the soil begins to flow. Besides, in oedometer test the most concern part is to study the effect of humic acid on the soil structure which much more related to the water content.

Table 3. Summary of oedometer tests on lime-treated clay with various humic acid contents at 7 curing days.

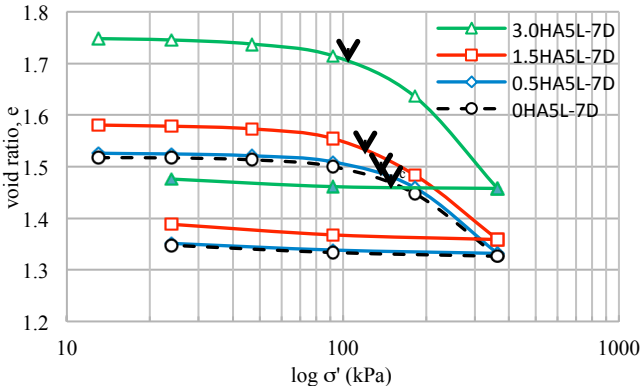
Property	Humic acid (%)			
	0	0.5	1.5	3
Height (mm)	19.2	19.2	19.2	19.2
Initial water content, w_i (%)	58.2	60.5	63.3	60.9
Initial void ratio, e_i	1.52	1.53	1.5	1.76
Compression index, C_c	0.29	0.3	0.33	0.43
Preconsolidation pressure, P_c (kPa)	160	145	115	100
Overconsolidation ratio (P_o=50 kPa)	3.2	2.9	2.3	2
Overconsolidation ratio (P_o=100 kPa)	1.6	1.45	1.15	1

** P_0 = Present consolidation stress*

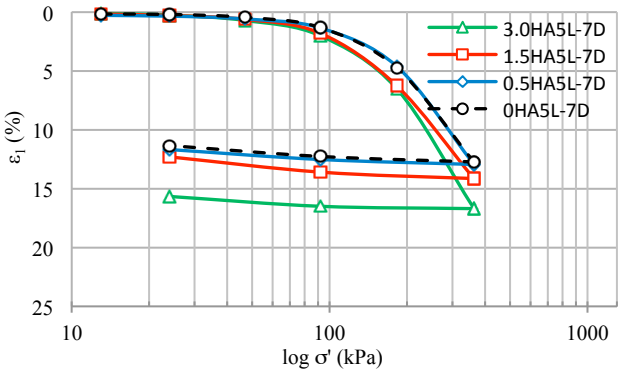
As can be seen from Table 3, that the range of initial void ratio (ei) of lime-treated organic clays varies from 1.52 to 1.75. The ei was calculated prior to applying the necessary loads. This ei was altered due to addition of lime and effect of humic acid. The addition of lime was believed could reduce the initial water content of specimen due to hydration process. Such behaviour (hydration process) was thought to be affected to the specimen at low humic acid content (i.e. 0.5%) and those without humic acid after 7 days curing. In contrast, at higher humic acid content, the effect of lime was interfered by the presence of humic acid. This is because, humic acid has a high water holding capacity which makes less water available for the hydration process (Chen & Wang, 2006). Fig. 4 compares the effects of humic acid content on compression curves for lime-treated clay after 7 days curing. It appears from Fig. 4(a) that the void ratio of lime-treated clay increases with increasing humic acid content. This indicates that the presence of organic matter, specified as humic acid in clay impart higher void ratio to the clay, which result in higher compressibility. These findings were in agreement with study done by Tremblay et al. (2000) who also found that the presence of organic matter increased the void ratio of lime-treated organic clay.

The compression curve for the 0.5% humic acid mixture is shown to exhibit similar behaviour to that of the inorganic clay. In contrast, the ei started to increase significantly beyond 1.5% humic acid even under a small stress of 13 kPa. A further increase in void ratio was observed at 3.0% humic acid content. The abovementioned results contradict those reported by Tremblay et al. (2000 & 2002), who found that e_i only started to increase with the presence of 8% organic matter content in lime-treated clay specimen. Furthermore at 3% organic matter content, their specimens continued to behave like inorganic clay. However they made no reference to the types of organic matter used in their research to enable comparison with the findings of this study. Comparisons cannot be made as it is assumed that humic acid may modify soil properties to a greater extent than other types of organic matter. Furthermore, in Fig. 4(a), changes in preconsolidation pressure (Pc) are indicated by an arrow positioned at the point where the maximum vertical overburden stress that specimens can sustained in the past. The Pc was estimated based on the Casagrande's method. It can be seen that the lower the void ratio, the higher Pc was obtained. This suggests that reduction in void ratio greatly improves the interparticle bonds governed by Pc (Onitsuka, 2001). Based on these findings, it can be assumed that the cementation bonding within the soil structure can be associated with the fabric arrangement. In order to eliminate the effect of variation in ei, ε_1-log σ' curves were presented in such a way that the relationship can be clearly seen as shown in Fig. 4(b). It can be seen from Figure 4(b) that the specimens with higher humic

acid content (i.e. 3%) undergo more compression than those with lower amount (i.e. 0.5%). This can also be observed by comparing Cc value from Table 3, where Cc increases with increasing humic acid content.



(a)



(b)

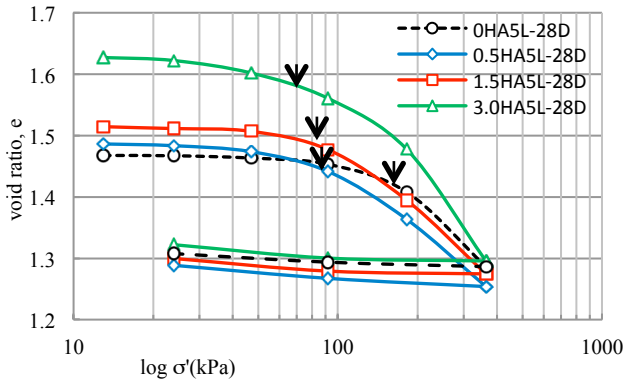
Fig. 4. Effect of humic acid on compression curves of lime-treated clay after 7 curing days, (a) e vs. log σ', (b) ε_1 vs. log σ'.

The effect of humic acid content on compressibility behaviour of lime-treated clay was further analysed at 28 days. Table 4 summarises the initial properties of lime-treated clay specimens subjected to various humic acid content tested at 28 curing days. It can be seen that the initial void ratio of lime-treated clay with different humic acid contents was reduced from 7 to 28 days. This is due to the effect of lime content rather than humic acid interference. The presence of lime was beneficial to improve interparticle bonds between aggregates.

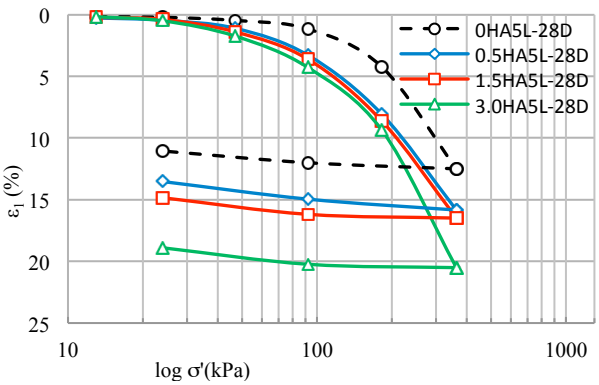
Table 4. Summary of oedometer tests on lime-treated clay with various humic acid contents at 28 curing days.

Property	Humic acid (%)			
	0	0.5	1.5	3
Height (mm)	19.2	19.2	19.2	19.2
Initial water content, w_i (%)	56.3	62.1	63	60.8
Initial void ratio, e_i	1.47	1.49	1.52	1.63
Compression index,C_c	0.28	0.31	0.34	0.44
Preconsolidation pressure, Pc (kPa)	175	86	80	70
Overconsolidation ratio (P_o=50 kPa)	3.5	1.72	1.6	1.4
Overconsolidation ratio (P_o=100 kPa)	1.75	0.86	0.8	0.7

Fig. 5(a) and (b) show the variation in void ratio and volumetric strain of lime-treated clay for different humic acid contents after 28 curing days. From Fig. 5(a), it can be observed that, the void ratio obtained upon every load increment, increases with increasing humic acid content. Furthermore, in Figure 5(a), changes in preconsolidation pressure (Pc) have been related to the observed changes in void ratio. In agreement with findings after 7 days, the observed reduction in void ratio after 28 days showed that the interparticle bonds governed by Pc had been greatly enhanced. Conversely, the only significant improvement in Pc was observed for the lime-treated inorganic clay (i.e. containing 0% humic acid). The behaviour of the lime-treated organic clay is also described using ε_1-log σ' plots as shown by Fig. 5(b). ε_1-log σ' plots are consistent with the e-log σ' curves, in that specimens having comparatively lower humic acid content undergo compression more quickly, and reach the end of their primary consolidation much earlier. It was proved by the coefficient of consolidation, c_v as obtained from previous study (Mohd Yunus et al. 2013). This suggests that the higher the humic acid content, the more compressible the specimens became.



(a)



(b)

Fig. 5. Effect of humic acid on compression curves of lime-treated clay after 28 curing days, (a) e vs. log σ', (b) ε_1 vs. log σ'.

In order to undertake a comparison of the compressibility behaviour at different curing periods, the compression index, Cc was determined to predict the soil compressibility. Fig. 6 compares the Cc of specimens between 7 and 28 curing days. Based on Fig. 6, it can be seen that the resistance of lime-treated organic clays to compression was improved considerably at 7 curing days. The increase in magnitudes of Cc for specimens with 0.5%, 1.5% and 3.0% humic acid contents, from 7 to 28 days was 0.30, 0.33 and 0.43 to 0.31, 0.34 and 0.44, respectively. The results given by Cc indicates that the specimens tested after longer curing periods undergo more compression than those cured at 7 days. In contrast, compression decreases from 7 to 28 days for lime-treated inorganic clays (i.e. 0% humic acid) which in agreement with study done by Kassim & Huey, 2000.

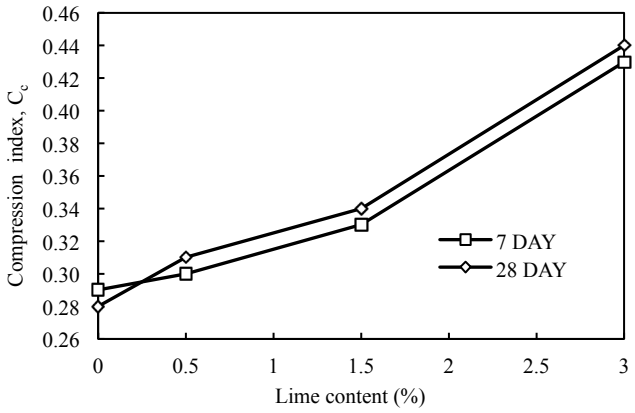


Fig. 6. Effect of compression index (Cc) of lime-treated clay with various humic acid content at 7 and 28 days.

5. CONCLUSIONS

In this paper, the effectiveness of lime stabilisation of organic clay was investigated based on their strength and compressibility characteristics. Based on the experimental results obtained in the study, the following conclusions can be made.

1. The shear strength of lime-treated organic clay reduces when the lime content exceeds 5%. Thus, 5% of lime is identified as the optimum lime content (OLC) for the organic clay tested in this study.
2. The shear strength of the lime-treated organic clay reduces at longer curing periods. A slight loss in strength is observed for organic clay with 0.5% humic acid, while a substantial loss in strength is evident where the humic acid content is

equal to or greater than 1.5%. These results show that the presence of more than 1.5% humic acid in the organic clay tested in this study reduces significantly the efficiency of the lime stabilisation process.

3. The oedometer test results revealed that the compressibility behaviour of lime-treated inorganic clay (i.e. 0% humic acid) was slightly improved at longer curing periods (i.e. 28 days). However, for the lime-treated organic clays, specimens cured for 7 days underwent compression more quickly, and reached the end of the primary consolidation stage much earlier compared to specimens cured for 28 days. Therefore, the compressibility of lime-treated organic clays increased at longer curing periods.
4. In addition, the compression index, Cc increased from 7 to 28 curing days. The increase in magnitudes of Cc for specimens with 0.5%, 1.5% and 3.0% humic acid contents, from 7 to 28 days was 0.30, 0.33 and 0.43 to 0.31, 0.34 and 0.44, respectively. The results given by Cc proved that the specimens tested after longer curing periods undergo more compression than those cured at 7 days. In contrast, the compressibility decreased from 7 to 28 days for lime-treated inorganic clays (i.e. 0% humic acid).

Overall, the effectiveness of lime as chemical stabilizer to improve the engineering properties of clay is disrupted by the presence humic acid contents as time prolonged. In light of the above mentioned, it may be necessary to consider other admixtures to mitigate the drawback of lime-treated organic clay.

6. REFERENCES

Annual Book of ASTM Standards (2004). Section 4, Volume 04.08, Soil and Rock (I): D 420 - D 5611.

Bell, F.G. (1996). "Lime stabilization of clay minerals and soils." Engineering Geology 42(4): 223-237.

Burland, J.B. (1990). "On the compressibility and shear strength of natural clays." Geotechnique 40(3): 329-378.

Chen, H. and Wang, Q. (2006). "The behaviour of organic matter in the process of soft soil stabilization using cement." Bulletin of Engineering Geology and the Environment 65(4): 445-448.

Choquette, M., Andre Bérubé, M. and Locat, J. (1987). "Mineralogical and microtextural changes associated with lime stabilization of marine clays from Eastern Canada." Applied Clay Science 2(3): 215-232.

Consoli, N.C., da Silva Lopes, Jr. L. and Heineck, K.S. (2009). "Key parameters for the strength control of lime stabilized soils." Journal of Materials in Civil Engineering 21(5): 210-216.

Consoli, N.C., da Silva Lopes, Jr.L., Prietto, P.D.M., Festugato, L. and Cruz, R.C. (2011). "Variables Controlling Stiffness and Strength of Lime Stabilized Soils." Journal of Geotechnical and Geoenvironmental Engineering 137(6): 628-632.

Davidson, L.K., Demeril, T. and Handy, R.L. (1965). "Soil pulverization and lime migration in soil lime stabilization." HRB Record 92, Highway Research Board, National Research Council, Washington, D.C., pp: 103-126.

Harris, P., Harvey, O., Sebesta, S., Chikyala, S.R., Puppala, A. and Saride, S. (2009). "Mitigating the effects of organics in stabilized soil." Technical Report No. 0-5540-1,Texas Transportation Institute, USA.

Huat, B.B., Maail, K.S. and Ahmed Mohamed, T. (2005). "Effect of chemical admixtures on the engineering properties of tropical peat soils." American J. of Applied Sciences 2(7): 1113-1120.

James, R., Kamruzzaman, A.H.M., Haque, A. and Wilkinson, A. (2008). "Behaviour of lime-slag-treated clay." Proc. the ICE, Ground Improvement 161(4): 207-216.

Kassim, K.A. and Huey, C.S. (2000). "Consolidation characteristics of lime stabilised soil." Journal of Civil Engineering 12(1): 31-42.

Kazemian, S., Huat, B.B.K. and Barghchi, M. (2011). "Effect of calcium chloride and kaolinite on shear strength and shrinkage of cement grout." International Journal of the Physical Sciences 6(4): 707-713.

Konsonant, S., Onitsuka, K. and Negami, T. (2006). "Influence of salt additive in lime stabilization on organic clay." Geotechnical Engineering 39: 95-101.

Liu, M.D., Indraratna, B., Horpibulsuk, S. and Suebsuk, J. (2012). "Variations in strength of lime-treated soft clays. "Journal of Ground Improvement 165(14): 217-223.

Mallela, J., Harold Von Quintus, P.E. and Smith, K.L. (2004). "Consideration of lime-stabilized layers in mechanistic-empirical pavement design." The National Lime Association, Arlington, Virgginia.

Mohd Yunus, N.Z., Wanatowski, D., and Stace, L.R., (2011) "Effect of humic acid on physical and engineering properties of lime-treated organic clay," Proceedings World Academy of Science Engineering and Technology, Issue 59, Part XV, pp 1820-1825.

Mohd Yunus, N.Z., Wanatowski, D. and Stace, L.R. (2011). "Effect of humic acid and salt additives on the behavior of lime-stabilised organic clay." Second International Conference on Geotechnique, Construction Materials and Environment, Kuala Lumpur, Malaysia, Nov. 14-16, 2012, ISBN: 978-4-9905958-1-4 C3051: 253-256.

Mohd Yunus, N.Z., Wanatowski, D. and Stace, L.R. (2012). "Effect of humic acid and chloride salts on the behaviour of lime-treated organic clay." PhD thesis, University of Nottingham, United Kingdom.

Mohd Yunus, N.Z., Wanatowski, D. and Stace, L.R. (2013). "The Influence of Chloride Salts on Compressibility Behaviour of Lime-Treated Organic Clay." Int. J. of Geomate, Sept., 2013, Vol. 5, No. 1 (Sl. No. 9), pp. 640-646, Geotec., Const. Mat. & Env., ISSN:2186-2982(P), 2186-2990(O), Japan.

Onitsuka, K., Modmoltin, C. and Kouno, M. (2001). "Investigation on microstructure and strength of lime and cement stabilized Ariake clay." Reports of the Faculty of Science and Engineering, Saga 30(1): 49-63.

Petry, T.M. and Glazier, E.J. (2004). "The effect of organic content on lime treatment of highly expansive clay." Project Report.

Rajasekaran, G. and Rao, N. (1997). "The microstructure of lime-stabilized marine clay." Ocean Engineering 24(9): 867-875.

Sakr, M.A. and Shahin, M.A. (2009). "Utilization of Lime for Stabilizing Soft Clay Soil of High Organic Content." Geotechnical and Geological Engineering 27: 105-113.

Tremblay, H., Locat, L. and Leroueil, S. (2000). "Effect of organic matter on the compressibility of a soil treated with cement." International symposium on coastal geotechnical engineering in Practice, Sep 20-22 Yokohama : 733-738.

Tremblay, H., Duchesne, J., Locat, L. and Leroueil, S. (2002). "Influence of the nature of organic compounds on fine soil stabilization with cement." Canadian Geotechnical Journal 39: 535-546.

Zhu, W., Chiu, C.F., Zhang, C.L. and Zeng, K. (2009). "Effect of humic acid on the behaviour of solidified dredged material." Canadian Geotechnical Journal 46: 1093-1099.