Int. J. of GEOMATE, June, 2015, Vol. 8, No. 2 (Sl. No. 16), pp. 1232-1238
Geotech., Const. Mat. and Env., ISSN:2186-2982(P), 2186-2990(O), Japan

PERFORMANCE OF LIME-TREATED MARINE CLAY ON STRENGTH AND COMPRESSIBILITY CHRACTERISTICS

Nor Zurairahetty Mohd Yunus[1], Aminaton Marto[2], Faizal Pakir[3], Khairulanam Kasran[4], Mohd Akmal Azri Jamal[5], Siti Norafida Jusoh[6] and Norliana Abdullah[6]

[1,2,3,6] Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310, Skudai, Johor, Malaysia
[4] Engineer, KBK Glokal, 83610 Muar, Johor, Malaysia
[5] Engineer, Asia Lab (M) Sdn. Bhd. 2400, Kemaman, Terengganu, Malaysia

ABSTRACT: The presence of marine clay in Iskandar Malaysia Region, Nusajaya has caused expensive solutions in the construction of structures and roads. Alternatively, soil treatment is suggested to increase the strength of the unsuitable material to meet the constructions requirement for foundation and also to achieve the specifications for development work. In this study, a series of laboratory test has been conducted to determine the potential of lime to stabilize marine clay to form the basis of a strong, reliable land for construction of roads and building. Testing program involves obtaining specimens of marine clays from various locations at Iskandar Malaysia Region, followed by laboratory tests to determine the physical and engineering properties with and without the addition of lime. The proportions of hydrated lime added are 3%, 6% and 9% to the untreated marine clay and tested at 7 and 28 days curing periods. Results show an increase in strength with increasing lime content. In addition, strength also increases significantly as early as 7 curing days and continues for 28 curing days. In agreement with the strength tests, compression characteristics improved with increasing lime content and as time prolonged. Hence, lime is successful and considered effective to improve the strength and compressibility behavior of Marine clay.

Keywords:Marine Clay; hydrated lime, Compressibility

1.0 INTRODUCTION

Marine clay is a type of clay found both in the coastal and in several offshore areas spread over many parts of the world. The properties of saturated marine clay differ significantly from moist soil and dry soil. Marine clay is microcrystalline in nature and clay minerals like chlorite, kaolinite and illite and non-clay minerals like quartz and feldspar are present in the soil. The soils have higher proportion of organic matters that acts as a cementing agent. Marine clay soils in particular can present great problems in pavement design due to uncertainty associated with their performance [1], [2], [3], [4], [5]. They are often unstable beneath a pavement and they are the most susceptible to problems due to changes in moisture.

Nusajaya (about 4% of the area of Iskandar Malaysia) is one of the main focuses of several recent developments within the Iskandar region. However, the weak behavior of clay deposit in various site of development needs to be replaced or be specifically improved. Various ground improvement methods have been introduced and tested, both in research and in practice. However their respective suitability are considered to be project-specific; being dependent on the existing soil's characteristics, cost and the stabilizers' potential impact or effectiveness for the proposed application. Chemical stabilization is one of the methods recommended to improve the properties of soil and lime stabilization is proven effective in most cases [6], [7], [8].

In order to develop a fundamental understanding of the engineering behavior of Malaysian marine clays, the influence of lime to improve the strength and compressibility behavior of Marine clay was investigated experimentally. Index testing such as Atterberg limit, specific gravity and compaction test were carried out initially on untreated specimen to determine the suitability of lime for lime-clay reactions. Meanwhile, strength and compressibility behavior were determined by unconfined compressive strength (UCS) test and oedometer test, respectively. In this study, the effectiveness of lime to stabilize Marine clay was investigated on the basis of lime content and at different curing periods.

2.0 MATERIALS & SPECIMEN PREPARATION

2.1 Marine clay

In this research, Marine clay was the soil used and it was obtained from Nusajaya, an area in Gelang Patah, Johor. It was dredged from the seabed offshore the southern coast of the Nusajaya where there is an under-construction harbour project. The soil was dumped on the other part of the area. It was dark grey and highly disturbed by dredging. It was then collected in oil tanks and transported to the laboratory. The properties of the collected Marine clays in Nusajaya are shown in Figure 1. The results of index testing and chemical composition carried out on untreated Marine clay in Table 1 and Table 2 respectively. In general, soil is considered as suitable to be stabilized by lime because the plasticity index (PI) is more than 10.

Table 1 Physical properties of Marine clay

Properties	Marine Clay
Liquid limit (%)	58
Plastic limit (%)	36
Plasticity index (%)	22
Specific gravity	2.62
OMC (%)	21
MDD (kg/m^3)	1600
Organic content (%)	4.2

Table 2 Chemical composition of Marine clay

Chemical formula	Concentration (%)
SiO2	36.8
Al2O3	13.3
Fe2O3	2.61
K2O	2.4
SO3	1.47
TiO2	0.66
MgO	0.35
Cl	0.32
Na2O	0.26
ZrO2	0.20

Table 3 summarizes the basic properties of Marine clay obtained in Malaysia, Thailand and India, and this data was compared to the properties of marine clay used in this study. Based on the comparison, Nusajaya marine clay shares the same properties as those from Kor Yo in Thailand, Eastern Cost of India and Kuala Muda Kedah in Malaysia

Table 3 Summary properties of Marine clays

Location	KorYo, thailand	Eastern coast of India	Kuala Muda, Kedah	Nusajaya Malaysia
Author	[3]	[4]	[5]	MohdYunus et. al (2014)
Gs	2.69	2.62	2.6	2.62
MDD (kg/m^3)	1655	1430	1500	1600
OMC (%)	21	32	22	21

2.2.1 XRD analysis

XRD analysis was carried out to determine the mineralogical of marine clay. The XRD pattern shows that the peaks at 19.8°, 24.9° and 34.9° confirm the presence of montmorillonite (Figure 1). The formula that matched of the monmorillonite peak was $NaO_3(AlMg)2Si_4O10OH_26H_2O$.

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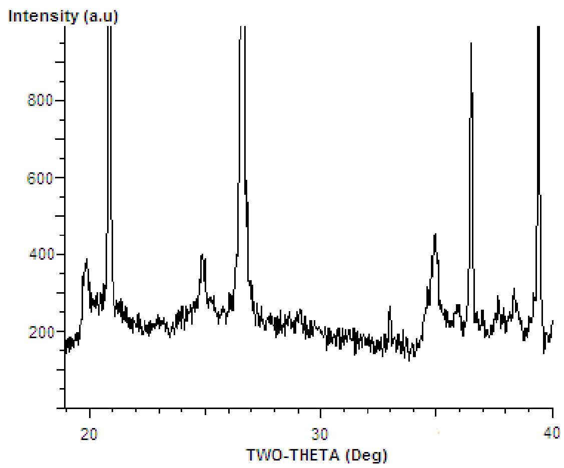

Figure 1 XRD pattern for the marine clay

2.2 Hydrated Lime

The hydrated lime used was supplied by Lime treat (M) Sdn Bhd, a company from Pasir Gudang, Johor. It was used as a chemical additive. The proportion of lime added to the soil was 3%, 6% and 9%.

2.3 Sample Preparation

Results obtained from the compaction tests played an important role in the preparation of treated specimen. All the treated specimens were prepared referring to the respective maximum dry densities (MDD) and optimum moisture contents (OMC) of untreated soil. The required dry mass of soil samples was calculated with the reference of the mould volume and the MDD. Predetermined quantities of lime were then measured based on the dry mass of soil sample and mixed until homogenous. The soil specimen was then mixed with water content corresponding to the OMC.

Mixing process was carried within a reasonable time (approximately five minutes) to ensure that lime was not exposed to the air for too long. The specimens were mixed thoroughly and compacted in three layers into the 38mm x 76mm cylindrical mould. The inner surface of the brass mould was layered with a thin, transparent sheet to minimize friction. After that, the specimens were extruded from the mould and wrapped with a cling film to preserve the water content and prevent from the carbon dioxide (CO_2) exposure. The weight of the specimens was measured and cured in a controlled temperature room at 20ºC and humidity greater than 90% for 7 and 28 days. Similarly, specimens of oedometer test were prepared based on OMD and MDD of untreated soil before being placed in the cylindrical metal ring with the dimensions of 75mm diameter and 20mm height.

3.0 TESTING PROGRAMME

Laboratory tests such as specific gravity test, Atterberg limit test and standard proctor test were carried out to determine physical properties of marine clay. The strength and compressibility of the lime stabilized soil was determined through UCS and oedometer test at 7 and 28 days of curing. Physical tests were carried out in the early stage as an initial step to indicate the suitability of soil for lime stabilization. In the second phase of experimental work, hydrated lime was added to stabilize the marine clay. This study was carried out to investigate the effectiveness of lime to stabilize clay with different amounts of lime contents. The effectiveness of lime stabilization process was investigated by monitoring the improvement of strength and compressibility behavior of lime-clay reaction over time.

4.0 RESULTS AND DISCUSSION

4.1 Shear Strength Behaviour

Unconfined compression test is carried out to determine the maximum compressive strength of marine clay soil when lime is added. The summary of the data from unconfined compressive test (UCT) at different curing periods at different lime content is shown in the Table 4. The detailed calculation of each specimen is tabulated in Appendix. Table 4 shows the summary of the strength result obtained from all of the samples of marine clay at different curing period which is 7 days and 28 days. From table 3, for untreated sample of marine clay the strength of the sample remains the same for both periods which are 21kPa.Besides that, strength at 7 days increasing from 21kPa of untreated marine clay to 138, 294, and 379 for lime treated marine clay 3% 6% and 9% respectively. In addition, it shows that the increase of strength gained from untreated to 3% of lime at 7 days is 85.5%. Increasing of strength gained 3% to 6% of lime and 6% to 9% of lime are 53% and 22%. It shows that by increasing the lime, the strength of marine clay is also increased. Furthermore, by increasing the curing period, the strength of marine clay is also reinforced [9], [10], [11]. This can be shown by comparing 9% of lime at 7 days and 9% of lime used at 28 days, the strength is 379kPa and 517kPa. The difference is 138kPa which is rather high.

The results of the unconfined compressive strength is obtained and plotted at different curing periods as shown in Figure 2, and Figure 3. Figure 2 shows the effect of lime content at 7 curing days, while Figure 3 shows the effect of lime content at 28 curing days. The shear strength of each specimen is determined based on the peak strength of stress versus strain curve. Based on Figure 2 and 3, the result for the untreated is the same and it remains constant after achieving a peak strength which is 21kPa. In Figure 2, it can be seen that the strength slightly increases at 7 days before decreases at 28 days of curing.

The sample also increased gradually during first 7 and 28 days of curing. After 7 days, the increase became more rapid with sample treated 9% of lime showing the most increment. The small increases of strength during early days of curing between 7 days and 14 days are because of the modification process within mixes. This is because of frictional component of shear strength. For nearly 28 days, there is an increase in strength but at a higher constant rate. This is due to the pozzolanic reactions between lime and soil [12], [13], [14].

Table 4 Summary of UCS data at different curing period

Sample	UCS (Kpa) 7 days	UCS (kPa) 28 days
Untreated	21	21
Marine clay + 3% of lime	138	144
Marine clay + 6% of lime	294	423
Marine clay + 9% of lime	379	517

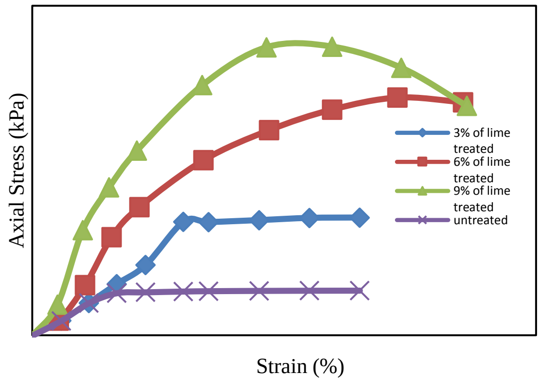

Figure 2 Axial stress versus Strain at 7 days

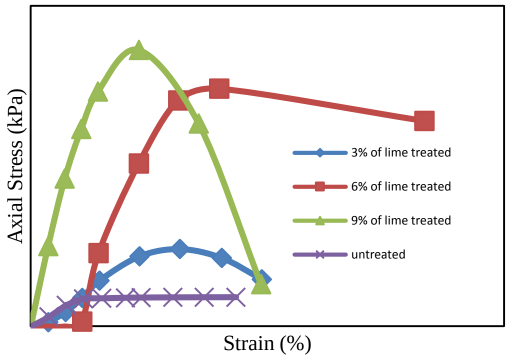

Figure 3 Axial stress versus Strain at 28 days

In general, the strength of marine clay with 9% lime at curing of 28 days is 517kPa which higher than the strength of marine clay with 3% and 6% lime. Comparing two result of 9% lime treated marine clay with different curing day, at 28 days the strength of marine clay is higher than 7 days. So, it is proven that curing process is a factor in determining the strength of the treated marine clay. The lowest strength is 138kPa when the sample is added only 3% of lime and the curing period is 7 days. However, the strength of the soil slightly increase at 144kPa when the curing period is longer at 28 days and the concentration of lime is the same at 3%. The strength gradually increases by adding more concentration of lime which is 6%. It has been proven that 3% increase in strength is less significant, which shows that addition of 3% lime is not really effective to stabilize marine clay. However with further addition if 6% and 9% of lime content, the strength gains more significantly. The percentage of strength gained recorded for marine clay treated of 6% and 9% of lime content between 7 to 28 days are 30% and 27%. Prior to analysis, the strength of marine clay could be stabilized with high increasing concentration of lime. Therefore, based on the study, it is proven that the strength of lime-treated marine clay will be reinforced if the curing time is longer.

4.2 Compressibility Behaviour

The odometer test was conducted on both untreated marine and treated marine clay. The untreated marine clay specimen was prepared and tested as a control specimen for comparison purpose with the treated specimens. Meanwhile, each duplicate sample was prepared for lime-treated marine clay at different curing period and lime contents, respectively. The proportions of lime added in this study were 3%, 6% and 9% and tested at curing period of 7 and 28 days. In this experiment, we use 12.5 kPa of sample as an initial load. The vertical compression under each load is observed at suitable intervals normally until up to 24 hours period. The load increment ratio (LIR=2) applied was 12.5kPa, 25.0kPa, 50.0kPa, 100kPa and lastly 200kPa while four decrement ratio were applied during reloading stage which were 50kPa and 12.5kPa. This section assesses the compressibility behaviour of lime-treated marine clay at different curing periods. The effect the lime-clay reactions is analysed in terms of changes in void ratio (e), compression index (c_c) and coefficient of consolidation (c_v) which defines a soil's compressibility.

Table 5 summarises the initial properties of lime-treated marine clay after 7 curing days. In this study, each specimen was prepared to an initial water content equal to their respective compaction test OMC obtained from compaction test. Figure 6 illustrates the range of initial void ratio (e_i) of the lime-treated marine clay. The $e_i$was calculated prior to applying the necessary loads. The compression index,c_c for untreated marine was 0.143, c_c was found to decrease to 0.040 with addition of 9% of lime.

Table 5 Summary of oedometer tests on lime-treated marine clay at 7 curing days.

Specimen	M0% L	M3% L	M6% L	M9% L
Diameter (mm)	50.0	50.0	50.0	50.0
Height (mm)	20.0	20.0	20.0	20.0
Initial void ratio, e_i	0.66	0.64	0.72	0.77
Compression index,Cc	0.143	0.066	0.050	0.040
Preconsolidation pressure, P_c (kPa)	19.0	21.0	22.0	41.0

Table 6 summarises the initial properties of lime-treated marine clay after 28 curing days. In this study, each specimen was prepared to an initial water content equal to their respective compaction test. Figure 7 shows the range of initial void ratio (e_i) of lime-treated marine clay. The $e_i$was calculated prior to applying the necessary loads. The effect of lime content on compressibility behaviour of lime-treated marine clay was further analysed at 28 days. Table 6 summarises the initial properties of lime-treated marine clay specimens at 28 curing days. The compression index,c_c for untreated marine is 0.143 and the value of compression is decrease to 0.028 for marine clay treated with 9% of lime.

Table 6 Summary of oedometer tests on lime-treated marine clay at 28 curing days.

Specimen	M0% L	M3% L	M6% L	M9% L
Diameter (mm)	50.0	50.0	50.0	50.0
Height (mm)	20.0	20.0	20.0	20.0

Initial void ratio, e_i	0.64	0.59	0.62	0.73
Compression index,Cc	0.143	0.047	0.040	0.028
Preconsolidation pressure, P_c (kPa)	19.0	34.0	37.0	50.0

From figure 4 we can see that about 7 days curing period, the difference of void ratio of untreated marine clay is 0.114 while for marine clay treated with 3% of lime is about 0.03. For marine clay treated with 9% of lime the difference of void ratio is 0.022. It shows that the void ratio of lime-treated marine clay decreases with increasing lime content.

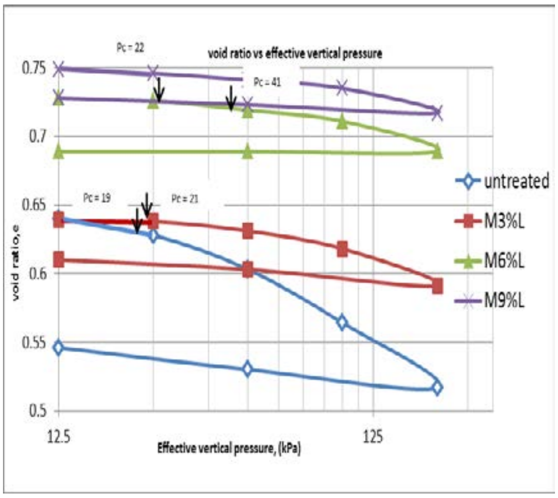

Figure 4 Effect of lime on compression curves of treated marine clay after 7 curing days

From figure 5 we can see that at 28 days curing period, the difference of void ratio of untreated marine clay is 0.114 while for marine clay treated with 6 % of lime is about 0.036. For marine clay treated with 9% of lime the difference of void ratio is 0.014. It shows that the void ratio of lime-treated marine clay decreases with increasing lime content.

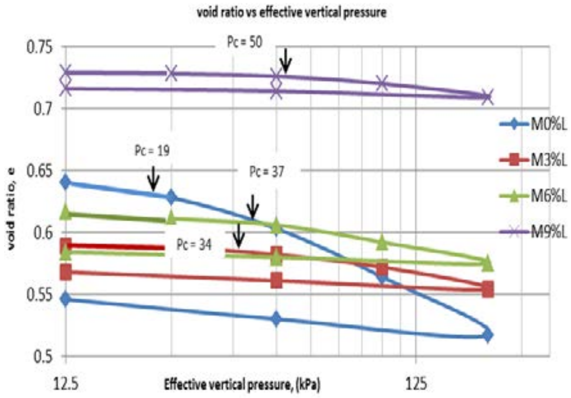

Figure 5 Effect of lime on compression curves of treated marine clay after 28 curing days

Figure 6 and figure 7 show the effect of lime-treated marine clay on coefficient of consolidation (c_v) at 7 and 28 days respectively. The rate of consolidation could be determined by measuring the coefficient of consolidation (c_v) obtained for each specimen at corresponding applied pressure. c_v was evaluated based on the Taylor method. Based on that figure, it can be seen c_v decrease with increasing lime content which indicates that specimens experienced less compressible behaviour. Consequently, a decrease in c_v values were observed on lime-treated marine clay with higher lime content[15], [16], [17], [18], [19]. From figure 8 we can see that, the coefficient of consolidation (c_v) for 7 days curing period for untreated marine clay is 8.3 m^2/years at 12.5 kPa than it increases to 8.61 m^2/years at 25 kPa and for 200 kPa coefficient of consolidation is 13.31 m^2/years. At 12.5kPa, marine clay treated with 9% of lime the coefficient of consolidation is decrease to 5.6 m^2/years compare to untreated marine clay which is 8.3 m^2/years.

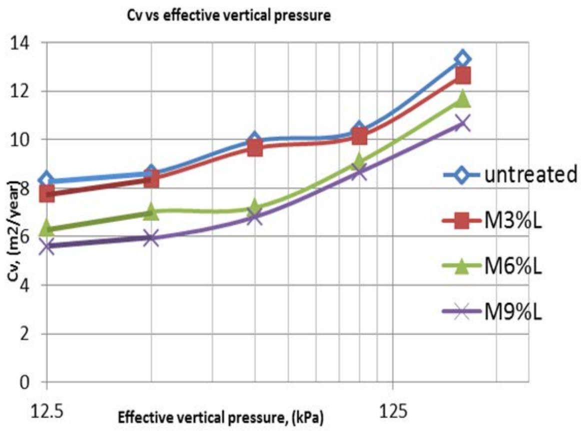

Figure 6 Effect of lime-treated marine clay on coefficient of consolidation (c_v) at 7 curing days.

From figure 7 we can see that, the coefficient of consolidation (c_v) for 28 days curing period for untreated marine clay is 8.3 m^2/years at 12.5 kPa than it increases to 8.61 m^2/years at 25 kPa and for 200 kPa coefficient of consolidation is 13.31 m^2/years. At 12.5 kPa, marine clay treated with 9% of lime the coefficient of consolidation decreases to 5.5 m^2/years, compared to untreated marine clay which is 8.3 m^2/years

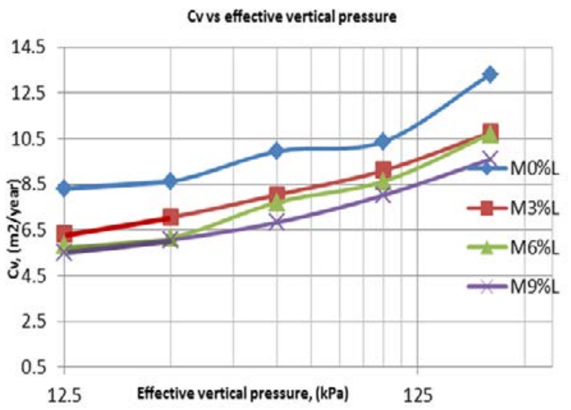

Figure 7 Effect of lime-treated marine clay on coefficient of consolidation (c_v) at 28 curing days

5.0 CONCLUSIONS

The physical properties of untreated and treated lime stabilized the marine clays were investigated and discussed in this study. Plasticity chart the marine clay can be classified as MH which is high silt. Since the value of Plastic Index (PI) is more than 10, the marine clay is suitable to be stabilized with lime. From the Standard Proctor Compaction Test, the maximum dry density (MDD) and optimum moisture content (OMC) is 1.55 Mg/m^3 and 21.20 % respectively while the specific gravity is 2.62. From the Unconfined Compression Test (UCT) test, it was illustrated that the strength development after 7 days is less significant. This is due to the process of modification. However, the strength treated soils increases rapidly at 28 days curing period. This phenomenon could be related to the process of stabilization. Overall, this study proves that when lime is added into soils, the reactions between lime and clay particles change the properties of soils and these would increase the compression strength and shear strength of soil, which makes marine clay more stable. The consolidation test concludes that the void ratio of the sample decreases as the percentage of lime content increases from 3% to 9%. Then, the coefficient of consolidation (c_v) of soil specimens with addition of lime decreases as the lime content increases compared to the untreated marine clay where specimen with 3% lime content increased about 18.4% from untreated marine clay at 7 curing period. Compression index (c_c) value signifies the compressibility of a soil, c_c value decreases as lime content increases.

Acknowledgement

The authors gratefully acknowledged the financial supports by the Research Management Centre (RMC) under the Potential Academic Staff Grant (Vot 00K65) and also the Universiti Teknologi Malaysia (UTM) in undertaking the research to publish the results. The support of the Construction Research Centre and Construction Research Alliance, UTM is also acknowledged.

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Int. J. of GEOMATE, June, 2015, Vol. 8, No. 2 (Sl. No. 16), pp. 1232-1238.
MS No. 4132 received on June 12, 2014 and reviewed under GEOMATE publication policies.

Pertinent discussion including authors’ closure, if any, will be published in June 2016 if the discussion is received by Dec. 2015.

Corresponding Author: Nor Z. Mohd Yunus