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THE INFLUENCE OF CHLORIDE SALTS ON COMPRESSIBILITY BEHAVIOUR OF LIME-TREATED ORGANIC CLAY

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ABSTRACT: Previous studies have shown that the compressibility behaviour of lime-treated organic clay with varying humic acid contents were not effective as time prolonged. Therefore, chloride salts in the amounts of 0.5%, 2.0% and 5.0% were introduced in conjunction with lime-treated organic containing 1.5% humic acid content to assess the influence of salts on the improvement of compressibility behaviour of lime-treated organic clay. The compressibility behaviour of lime-treated organic clay with varying amounts of chloride salts was studied at different curing periods. The influence of the chloride salts on the lime-clay reactions was analysed in terms of changes in void ratio (e), volumetric strain (ε1), compression index (Cc), and coefficient of consolidation (cv) which defines a soil's compressibility. The addition of chloride salts to the lime-treated organic clay shows less compressible behaviour in the long term as evidenced by the oedometer tests. The results confirm the effectiveness of salt in lime-treated organic clay.

Keywords: Compressibility, Chloride Salts, Humic Aci ,Lime Stabilisation.

1. INTRODUCTION

A review of studies on the compressibility of lime stabilised soils is equally essential as strength assessment. It is essential to have a better view of improvement to the soil structure using lime. The permanent bonding between clay particles and lime is believed to create an increased resistance to compression. In addition, strength and permeability characteristics in stabilised soils to a large extent can be linked with their compressibility behaviour by examining changes in void ratio [1], [2], [3], [4].

Apart from strength, compressibility parameters have also shown an improvement when organic clay was treated with lime. Sakr & Shahin, 2009 [5] investigated the changes in the consolidation behaviour in terms of compression index, Cc, initial void ratio, eo, and pre consolidation pressure, Pc on untreated and 1% lime treated organic clay. It also 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 provided 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 on soil fabric was compared based on the results given by engineering testing.

In addition, an increase in permeability can occur in the initial (modification) stage when the clay undergoes flocculation. On the other hand a decrease in permeability can be caused by the addition of lime beyond ICL value after 28 days at which point cementitious products would have already occupied within the existing soil pores. Using this explanation, it can be concluded that a decrease in permeability could be linked to a decrease in void ratio. They could be observed by visualising the soil structures of stabilised material in microscopic scale. Cementitious products gradually filling up the space between the soil's particles and aggregates indirectly reduce the soil's void ratio and increase in its strength.

To date, no known attempt has been made to study the compressibility behaviour of lime treated organic clay with salts by oedometer test. The effects of salt in lime-treated organic clay were only investigated in terms of shear strength determination [6], [7], [8]. Study done by Onitsuka et al. 2009, [6] proved that the unconfined compressive strength of clay with 10% and 20% quicklime at a curing period of 28 days was relatively low compared to strengths of those stabilised in conjunction with salts. Its results indicated a 10 fold strength gain upon the addition of 10% of salt. Furthermore, it reported that the addition of salts to the organic clay coagulates the soil, thereby causing the clay particles to expose themselves to the lime for pozzolanic reactions to occur. [6] further elucidated that salts can reduce pore space between soil particles as a result of cementing material. Consequently by these two actions (of coagulation and pore space reduction), lime-salt mixtures can yield higher strengths. As reported by [9] the salt concentration plays an important role to mitigate the adverse effect of humic acid due to the effect of cementation bond and fabric. Results given from strength test is a function of the level of cementation bonding, meanwhile the result given from oedometer will directly affected the fabric of soil (represent pore spacing between aggregation) which beneficial to identify the flocculation process. Thus, in this paper, the influence of chloride salts to mitigate the adverse effect humic acid has on lime-treated clay will be examined using oedometer test.

2. MATERIALS

Artificial organic clay used in this study was prepared by mixing commercial kaolin with commercial humic acid contents of 1.5% according to the dry mass of kaolin. A commercial hydrated lime used was supplied by John A. Stephen Ltd. The percentage of lime used was 5% based on the optimum lime content (reference). In this study, calcium chloride ($CaCl_2$) and sodium chloride (NaCl) were introduced to help lime improve the disadvantage of lime-treated organic clay. Both salts were provided by Fisher Scientific UK Limited.

3. SPECIMEN PREPARATION

Specimens tested in this study were prepared using procedures described in the [10]. Initially, the specimens were oven-dried at 60°C until the constant weight was obtained. Clay with 1.5% humic acid content was prepared by dry mass of kaolin. The requisite quantity of lime (5%) 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. Mixing of dry materials was continued until a uniform appearance was obtained. Distilled water was then added and further mixing was performed until a homogeneous appearance of the soil paste was achieved. The oedometer specimen preparation procedure was adopted by [11]. 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. Specimens were tested after 7 and 28 curing days.

4. RESULTS AND DISCUSSIONS

The compressibility behaviour of lime-treated organic clay with varying amounts of chloride salts was studied at different curing periods. The influence of the chloride salts on the lime-clay reactions 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. All of the specimens were prepared with 1.5% humic acid and 5% lime content. Furthermore, each specimen had an initial water content of 63%, corresponding to the liquid limit of lime-treated clay containing 1.5% humic acid.

Fig. and Fig show the compression curves of lime-treated specimens containing $CaCl_2$ and NaCl respectively, after 7 curing days.Effect of adding various amounts of salt on the compressibility of lime-treated organic clay was illustrated further in the compression curves (ε_1-log σ') shown in Fig. and Fig. It can be seen from both figures that the ε_1 decreases much less with addition of 0.5% and 2.0% chloride salts when compared to those without salts.

However, the figures show the lime-treated specimens treated with 5% chloride salts have undergone more compression than those without salt despite having reduced void ratios.Such behaviour indicates that the properties of salts-treated specimen at 7 curing days improved with the addition of up to 2% chloride salts.The abovementioned improvement in the soils' structures supports the results of previously reported strength tests conducted on identically prepared specimens for the same curing period [7], [8]. It is therefore expected that the reduction in ε_1 of the salts-treated specimens was caused by the formation of cementitious products (i.e. CSH and CAH), which subsequently occupied the voids within the soils' structures. This inferred consequence results an increase in specimen strength and provides less compressibility. The effect of adding chloride salts can be further examined by estimating the preconsolidation pressure based on Casagrande's method. The P_c was noted as having slightly higher for the lime-treated specimens comprising 0.5% and 2.0% chloride salts for which similar values of 125 kPa and 120 kPa were recorded.In contrast, the estimated values of P_c reduced from 115 kPa for 0% NaCl and $CaCl_2$ specimens to 85 kPa and 80 kPa respectively when 5.0% of either salt was introduced.

The effect of adding chloride salts to lime-treated clay containing 1.5% humic acid can be explained further by comparing the compression indices, C_c necessary to predict the amount of primary consolidation settlement.Fig. shows the effect of chloride salts on the C_c of lime-treated organic clay after 7 curing days. It can be seen that C_c decreased substantially when the salt content ($CaCl_2$ and NaCl) increased from 0% to 0.5%, which explains the resistance of lime-treated organic clays to compression improved considerably.For instance, C_c decreases from 0.33 for lime-treated organic clay without salt content to 0.23 and 0.24 for lime-treated organic clay with 0.5% $CaCl_2$ and 0.5% NaCl, respectively.

In addition, the magnitudes of C_c for 0.5% and 2.0% chloride salts, increased from about 0.23 to 0.31 (for $CaCl_2$) and 0.24 to 0.31 (for NaCl). Further increase in C_c was reported at higher salts content (i.e. 5.0%), for which the magnitude of C_c was higher than specimens without salts. From the findings it is evident that after 7 curing days, only the specimens containing 0.5% and 2.0% chloride salts improved the compressibility behaviour of the organic lime-treated clay consisting of 1.5% humic acid. In addition, a comparison of C_c for the two salt types present in specimens treated with lime revealed that adding $CaCl_2$ salt to organic lime-treated mixtures lead to less compressible than specimens containing NaCl.

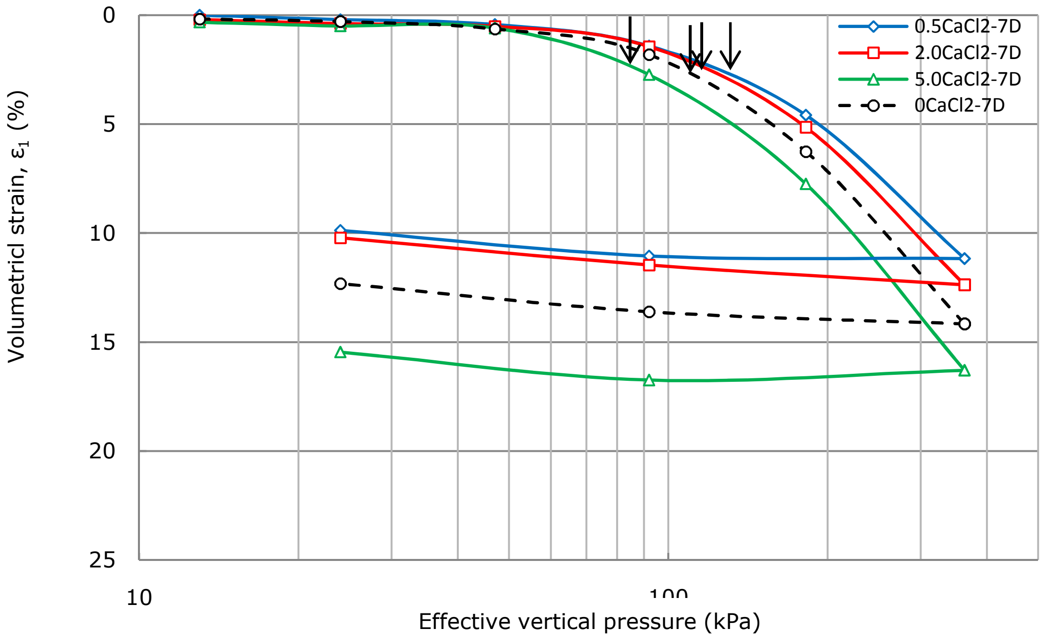


Fig.1 Effect of $CaCl_2$ on compression curves of lime-treated organic clay after 7 curing days.

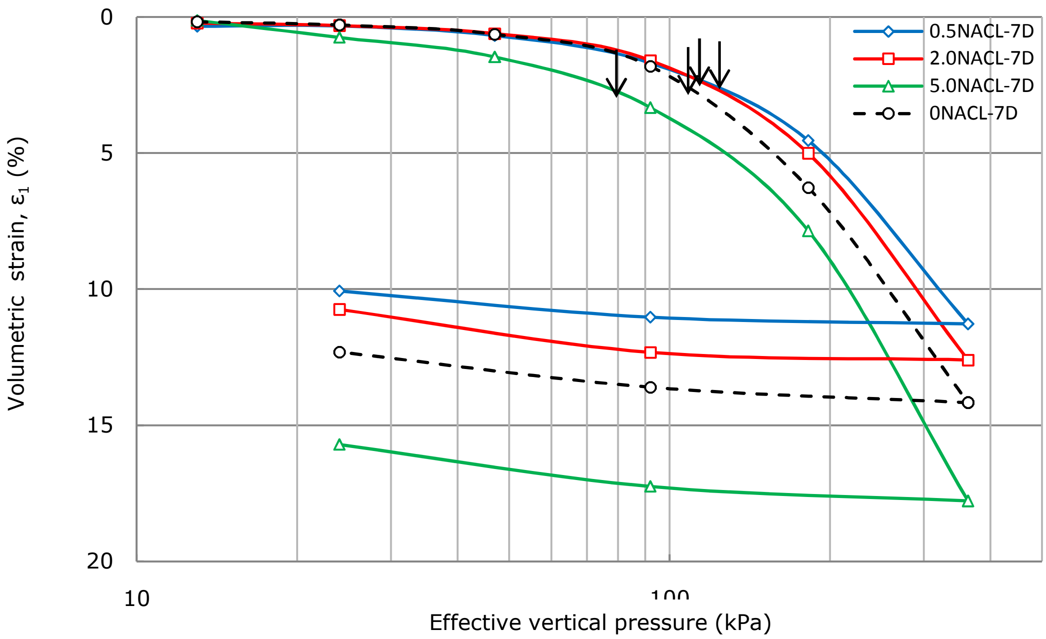


Fig. 2 Effect of NaCl on compression curves of lime-treated organic clay after 7 curing days.

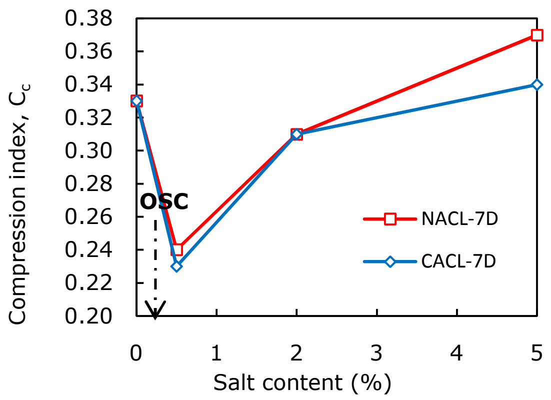


Fig.3 Effect of salt contents on the compression index (C_c) of lime-treated clay after 7 curing days.

The influence of salt content on the compressibility behaviour of lime-treated organic clay was further evaluated in longer period. The specimens were tested at 28 days to assess their long-term behaviour. Similar to earlier tests conducted at 7 days, changes in volumetric strain (ε_1) and compression index (C_c) which defines a soil's compressibility were the primary concerns.

Fig. andFig.show the compression curves of lime-treated specimens containing $CaCl_2$ and NaCl at 28 curing days. The ε_1-log σ' curves for lime-treated specimens with varying amounts of chloride salts are shown in Fig. and Fig.. Both figures show that the addition of chloride salts to the lime-treated organic clay specimens considerably improves the resistance of all the specimens to compression which is in contrast to previous results which showed the compressibility behaviour of samples cured for 7 daysto only improve when the chloride salts were at 2.0%. However, it must be noted that the total compression of lime-treated organic clay was higher over the longer curing period than during the 7 day cure period. It can therefore be conclude that the compressibility behaviour of lime treated clays containing chloride salts improves in the long term.The preconsolidation pressure, (P_c) estimated from compression curves is consistent with the results displayed in the compression curves plots. P_c was found to improve from 80 kPa for lime-treated organic clay specimen to 180 kPa, 142 kPa and 130 kPa for lime-treated organic clay specimens containing 0.5%, 2.0% and 5.0% $CaCl_2$.

A similar outcome was obtained for the lime-treated organic clays containing 0.5%, 2.0% and 5.0% NaCl for which P_c increased to 140 kPa, 130 kPa and 121 kPa, respectively. The effect of adding chloride salts to the lime-treated organic clay had on the compression indices, C_c after 28 curing daysis shown in Fig.. It can be clearly seen that C_c decreases substantially for the specimens containing 0.5% $CaCl_2$ and NaCl. Beyond the 0.5% salts content, further increases in C_c were evident for 2.0% and 5.0% salts contents. With the highest C_c being recorded for the specimen without salts the test results confirm that the compressive resistance of lime-treated organic clays is considerably improved upon the addition of chloride salts. Furthermore a comparison of C_c values between the two types of salts, introduced in amounts of 2.0% and 5.0% indicate that $CaCl_2$ specimens provides better resistance to compression than NaCl specimens.

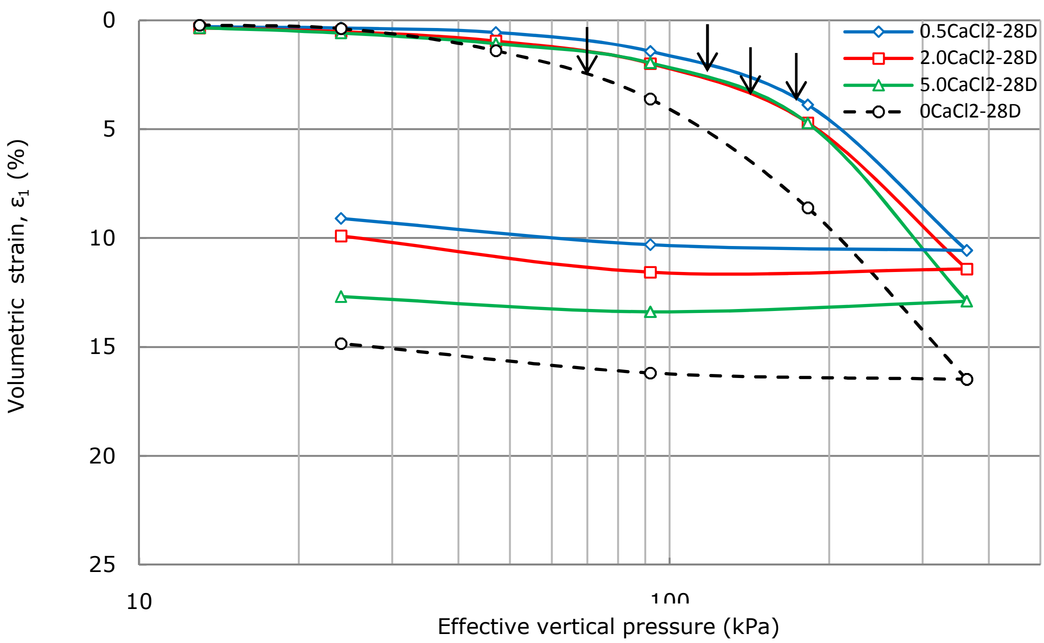


Fig.4 Effect of $CaCl_2$ on lime-treated organic clay at 28 curing days.

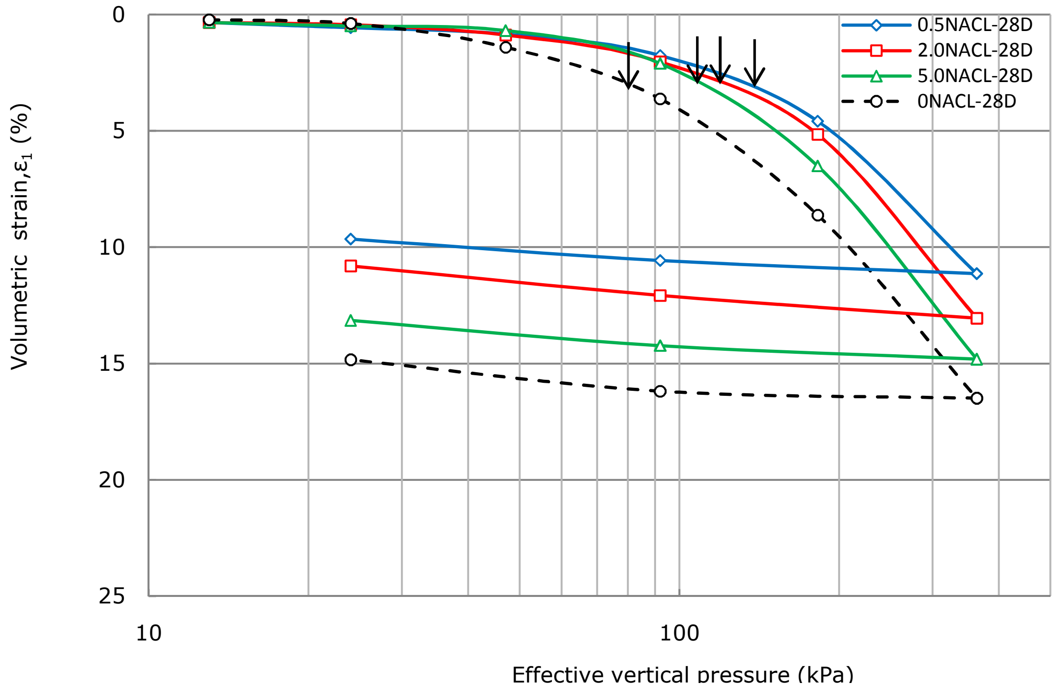


Fig.5 Effect of NaCl on lime-treated organic clay at 28 curing days.

Fig. and Fig. compare the effect of curing period on lime-treated organic clay specimens containing 0.5% $CaCl_2$ and 0.5% NaCl. The specimens containing 0.5% chloride salts were chosen for the purpose of comparison as they improved the lime-treated organic clay specimens the most during the initial stage. As discussed previously, lime-treated organic clay specimens undergo more compression when cured for longer periods. The effect of adding 0.5% chloride salts to lime-treated samples on void ratio is compared in Fig.(a) and Fig.(a) for specimens cured for 7 days and 28 days. For both types of chloride salts, a similar trend is observed, in that the void ratios decreased for the longer curing period. It is believed that the passage of 7 curing days allowed flocculation, wherein the soil particles attract each other, thereby resulting in aggregations to occur. This flocculation is also thought to have caused an increase in inter-particle voids. Although specimens at this stage would normally experience an increase in strength, the formation of cementing materials (i.e. CSH and CAH) may not as much as expected after 28 days. According to the formation of cementitious structure, the decrease in void ratio at 28 days was related to the decrease in the pore spaces [2], [5], [12].The observed reductions in void ratio at 28 days as shown in Fig.(a) and Fig.(a) is thought to have been caused by the presence of large amounts of cementing material occupying the voids between the aggregations. Consequently, from the results it confirms that the specimens cured for 28 days were less compressible than those cured 7 days.Fig.(b) and Fig.(b) give better insight to the effect of curing using ε_l-log σ' curves. In addition to e-log σ' curves, the effect of 0.5% chloride salts on ε_l at 7 and 28 days were insignificant. However, the specimens cured at 28 days were less insignificant than those cured at 7 days.

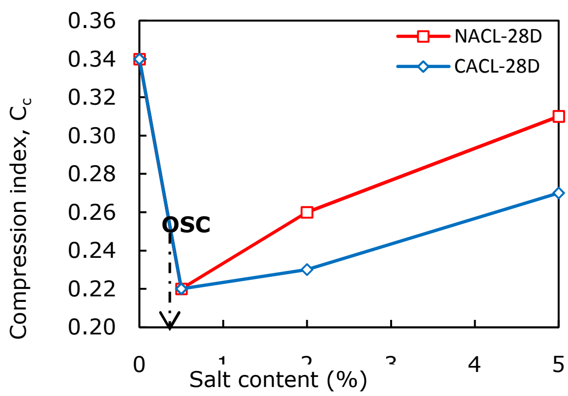
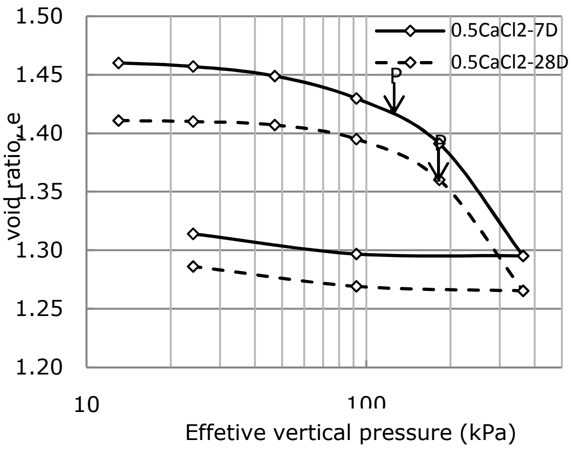
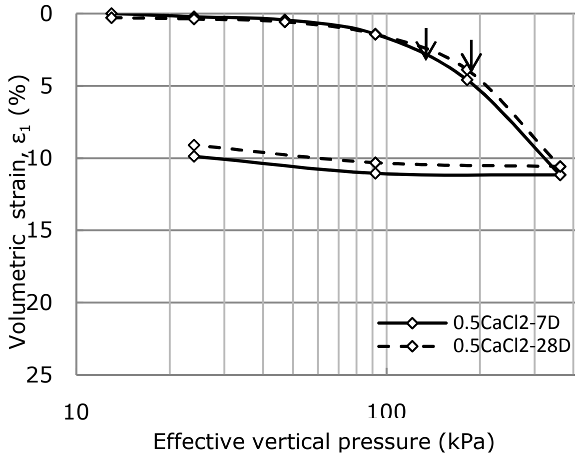


Fig.6 Effect of salt contents on the compression index (C_c) of lime-treated clay after 28 curing days.

The effect of curing period on the coefficient of consolidation (c_v) of lime-treated organic clay specimens containing 0.5% $CaCl_2$ and 0.5% NaCl is shown in Fig and Fig respectively. c_v values were calculated based on Casagrande's method. It was proved that the rate of consolidation decreases when measured at the end of a longer curing period for the specimens containing 0.5% chloride salts.

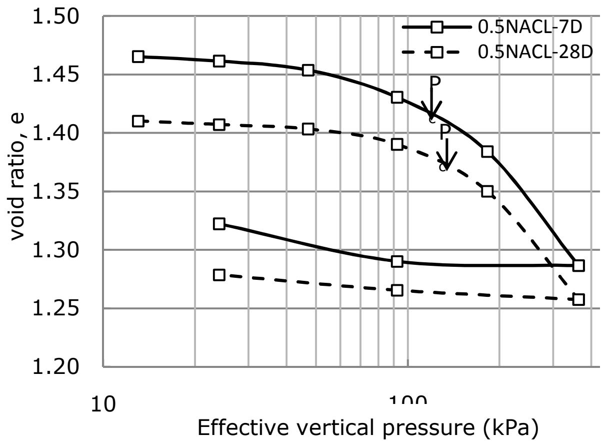


(a)



(b)

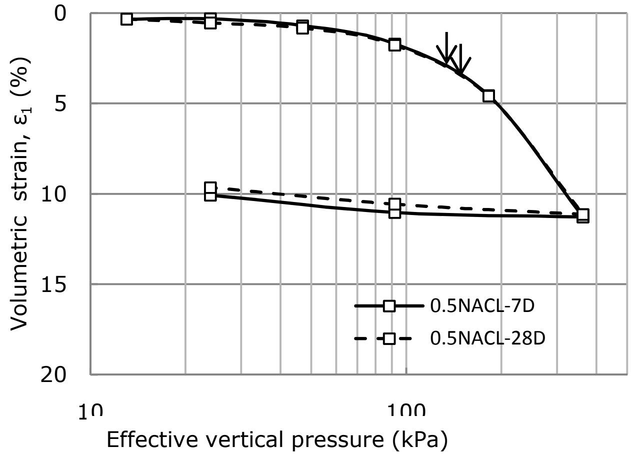
Fig.7 Comparison of compression curves for lime-treated organic clay with 0.5% $CaCl_2$ at 7 and 28 curing days (a) e vs. log σ', (b) ε_1 vs. log σ'.



(a)

Fig. 8a Comparison of compression curves for lime-treated organic clay with 0.5% NaCl at 7 and 28 curing days (e vs. log σ',)

This, once again confirmed the effectiveness of chloride salts, specifically at 0.5% in the modification of the compressibility behaviour of lime-treated organic clay.



(b)

Fig.8b Comparison of compression curves for lime-treated organic clay with 0.5% NaCl at 7 and 28 curing days (ε_1 vs. log σ').

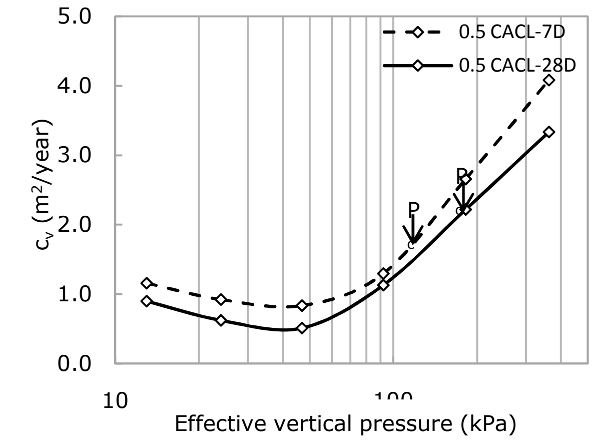


Fig. 9 Effect of curing periods on coefficient of consolidation (c_v) for specimen with 0.5% $CaCl_2$.

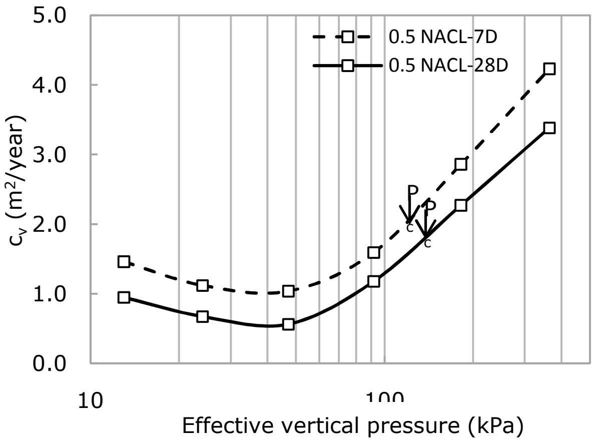


Fig. 10 Effect of curing periods on coefficient of consolidation (c_v) for specimen with 0.5% NaCl.

5. CONCLUSION

In this paper, the effectiveness of lime stabilisation of organic clay with addition of chloride salts was investigated based on their compressibility characteristics. Based on the experimental results obtained in the study, the following conclusions are made:

1. Based on each test carried out, it was found that the effectiveness of the behaviour of lime-treated organic clay reduced with salt content. A less compressible behaviour was observed at 0.5% chloride salts. Therefore, an optimum salt content (OSC) of 0.5% was deduced from each test conducted for the two salt types. This is because the excessive salt contents cause an imbalance in the positive charges surrounding clay surface, leading to the deflocculated of the soil's structure.
2. It was found that the addition of chloride salts to the lime-treated organic clay shows less compressible behaviour in the long term as evidenced by the oedometer tests. At 28 days, the lime-treated clay comprising 1.5% humic acid showed substantial increases in Pc values i.e. from 80 kPa to 180 kPa and 140 kPa with the addition of 0.5% CaCl2 and 0.5% NaCl, respectively.
3. Besides, the reduction in the Cc values for a lime-treated clay specimen with 1.5% humic acid to which 0.5% chloride salts had been added, from 0.34 to 0.22 with addition of both chloride salts (i.e. 0.5%) confirm the effectiveness of salt in lime-treated organic clay.
4. In addition, based on c_v values, it was proved that the rate of consolidation decreases when measured at the end of a longer curing period for the specimens containing 0.5% chloride salts. This, once again confirmed the effectiveness of chloride salts, specifically at 0.5% in the modification of the compressibility behaviour of lime-treated organic clay.

6.REFERENCES

[1] Tremblay H, Locat L, and Leroueil S, "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, 2000, pp. 733-738.

[2] Rajasekaran G and Rao N,"The microstructure of lime-stabilized marine clay." Ocean Engineering, 1997,vol. 24, no. 9, pp. 867-875.

[3] Ahnberg H, "Measured permeabilities in stabilised Swedish soils." Proceedings of ICE, 3rd International Conference on Grouting and Ground Treatment, New Orleans, 2004, pp. 622-633.

[4] Cassia de Brito Galvão T and Elsharief A. Gustavo FS, "Effects of lime on permeability and compressibility of two tropical residual soils." Journal of Environmental Engineering, 2004, vol. 130, no. 8, pp. 881-885.

[5] Sakr MA and Shahin MA, "Utilization of Lime for Stabilizing Soft Clay Soil of High Organic Content." Geotechnical and Geological Engineering, 2009, vol. 27, pp. 105-113.

[6] Koslanant S, Onitsuka K and Negami T, "Influence of salt additive in lime stabilization on organic clay." Geotechnical Engineering, 2006, vol. 39, pp. 95-101.

[7] Mohd Yunus NZ, Wanatowski D and Stace, "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, 2011, ISBN: 978-4-9905958-1-4 C3051, pp. 253-256.

[8] Mohd Yunus NZ, "Effect of humic acid and chloride salts on the behaviour of lime-treated organic clay." PhD thesis, 2012, University of Nottingham, United Kingdom.

[9] Onitsuka K, Modmoltin C and Kouno M, "Investigation on microstructure and strength of lime and cement stabilized Ariake clay." Reports of the Faculty of Science and Engineering, Saga, 2001, vol. 30, no. 1, pp. 49-63.

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

[11] Burland JB, "On the compressibility and shear strength of natural clays. "Geotechnique, 1990, vol. 40, no. 3, pp. 329-378.

[12] Kassim KA and Huey CS, "Consolidation characteristics of lime stabilised soil." Journal of Civil Engineering, 2000, vol. 12, no. 1, pp. 31-42.

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