Laboratory Investigation on the Effect of Lime on Compressibility of Soil

Saeid. Amiralian, Amin. Chegenizadeh, and Hamid. Nikraz

***Abstract*—** Settlement and heave of soils is known as critical problems in civil engineering projects. In order to control this problem, were indicated several technique. Soil stabilization with a binder such as lime is one of the most regular methods. This paper presents a series of laboratory test for investigation and evaluation of lime effect on the compressibility and swelling properties of soil. In this study, the compression index, swelling index, coefficient of consolidation and initial void ratio of one un-stabilized sample and six stabilized samples with variation of lime additives were investigated. Generally, the results of this study indicate that lime stabilization could improve consolidation and swelling behaviour of soil, which could reduce the coefficient of consolidation, initial void ratio of soil by adding additives. It was also observed the divers result that was shown the different rate of stabilization effectivity on consolidation and swelling properties of soil.

***Keywords*—** Consolidation, Lime, Stabilization.

I. Introduction

PROPERTIES of soil, economic and environmental view is the main elements, which is considered by engineers for constructing a geotechnical building such as embankments, structures and roadwork.

For this reason, sufficient engineering characteristics of soil play a main role in geotechnical engineering projects. On the other hand, on reality cannot expect that the entire engineering projects be built on a soil with sufficient properties. In some cases, engineers had to find a solution to solve the mechanical and chemical problems of local soil. Due to overcome this predictable problem in geotechnical construction, the diversity of methods were performed. Displacement, replacement, reinforcement, and stabilization are some techniques that are applied for improving the properties of poor soil [1],[2].

Soil stabilization as a cost-effective and environmental method was performed to adjust the mechanical and chemical characteristics of soils through the pozzolanic reaction, which leads to progress the engineering properties of soil [1]-[3]. In some cases, chemical stabilization is useful for building the soil systems like dams, canals and river levees[1]-[3], nevertheless, the research about the consequences and efficiency of lime treatment on consolidation behaviour of soil is extremely limited.

One of the most important properties of soil in engineering construction is compressibility. This factor is demanded in the large number of geotechnical application such as dams projects, foundation and embankment systems. The compressibility of soil is defined by consolidation process. Consolidation is a method that water particles and void are extruded by implementation of loads in a specific time. The time rate of consolidation associated with the volume of air and the permeability of the soil.

If the soil is not saturated completely, a part of consolidation will happen almost immediately because of expulsion of air or water that remains among the soil particles. The deformation of soil particles led to the settlement of soil mass that evaluated the volume variation behaviour of a soil. The compressibility is measured by compression index (C_c) parameter, which is the slope of the line achieved through the void ratio versus the effective vertical stress curve [4]-[6].

The numerous researches are established about soil stabilization effect on compressibility of soil, however, it seems that the obtained result are limited and need to be more consider.

Therefore, with regard to the significance of the consolidation behaviour of soil composite to evaluation of final settlement and limited research about the effect of chemical stabilization on soil compressibility, this study was carried out to evaluate the effect of lime on the consolidation properties of soil.

II. Background

Compressibility property of soil known as a pivotal part in the building of roads and airport, structure's foundation and embankments is. In order to minimize settlement in the geotechnical structure such as embankment, structural backfill material, and roadway, the compressibility properties of soil should be controlled.

In this filed, the Leaning Tower of Pisa is the classic instance of differential settlement. The tower had been tilted after finishing two-third of the construction and then has been settling differentially [1].

Through implementing load over the pre-consolidation stress on the in situ soil, soil structure (i.e., Soil particles, pore and other materials) are reorganized into a new situation for

Saeid. Amiralian is Master candidate in Department of Civil Engineering, Curtin University (e-mail: saeid.amiralian@postgrad.curtin.edu.au).

Amin. Chegenizadeh, is Lecturer in Department of Civil Engineering, Curtin University (e-mail: Amin.Chegenizadeh@curtin.edu.au).

Hamid. Nikraz is Professor and Head of Department of Civil Engineering, Curtin University (e-mail: H.Nikraz@curtin.edu.au).

increasing the stability of soil structure [2],[3]. The numerous numbers of studies were investigated for finding a relationship between the value of compression index of soil with the natural moisture content, the initial void ratio, etc. [2],[3]. In this field, some researches achieved a correlation among void ratio, liquid limit and vertical stress to estimate the compression index [1]-[3].

On the other hand, lack of availability of soil with efficient properties for construction cause to use of alternative material to soil treatment [1]. In this field, due to the lower cost and availability lime, lime stabilization is progressed. Study on lime show that, develop the soil resistance was known as one of the most remarkable advantage of soil treatment with lime. Regarding to reaction between lime and water of the soil, calcium cation (Ca_2^+) and hydroxylanions (OH^-) are released. Due to the cations exchange, flocculation agglomeration, lime carbonation and pozzolanic reaction soil particles stick to each other and make larger particles [1]-[3].

III. Laboratory Investigation

A. Material Characteristic

Regarding to widespread availability of sand in Western of Australia the demonstrative soil samples in this study were Baldivis Yellow Concrete Sand. The local sand used in this study has been collected from the Baldivis, 50_{km} south of Perth (Western of Australia), and known as quartz sand. Baldivis sand is extensively applied as a suitable material for mixing, footings, making concrete and mortar in geotechnical construction of Western of Australia. Due to, unacceptably of utilization consolidation test for sand settlement "kaolin clay" was applied for mixing with sand.

Kaolin an industrialized mineral with a chemical formal $Al_2Si_2O_5(OH)_4$ is known as mineral clay. Kaolin clay that was applied for this research is simply discrete in water and is ideal for bulging to slurries. It is typically consisted of; $_{\%}46.1$ Silicon Dioxide (Sio_2), $_{\%}36.5$ Aluminium Oxide (Al_2O_3) and other martials such as, Iron Oxide, Calcium Oxide, Potassium Oxide, and etc.

The lime utilized in this study was an industrial hydrated lime, which, appropriate for engineering applications such as neutralising agent in water and sewage treatment, a binder in mortars, soil stabilisation and maintaining alkaline conditions for mineral processing. More than $_{\%}95$ of particle size of hydrated lime is less than 75 micrometers. The lime composition is between $_{\%}80$-95 Calcium hydroxide, $_{\%}0$-6 magnesium hydroxide, $_{\%}0$-8 silicon dioxide, $_{\%}0$-1 aluminium oxide and $_{\%}$ 0-.05iron III oxide.

B. Sample Preparation

In sample preparation step, for removing the natural moister of Baldivis Yellow Concrete Sand that was dried in the oven temperature (100±1 ^{o}c) for 24 hours and was passed through US Number 4 sieve (4.76_{mm} aperture). The applied optimum moisture content and maximum dry density, for adding to sample was achieved by standard proctor compaction test specifically for each sample. The mixture was compacted in the consolidometer ring, which had a diameter 63.5_{mm} and height 25.4_{mm} for the essential dry unit weight. In this research, use 50-percent kaolin clay and 50-percent sand for non-stabilized specimen and, other six samples were combined by different percentages of the lime (i.e., $_{\%}1$-$_{\%}3$) combination based on dry weight of non-stabilized specimen. Samples were prepared and saved on the laboratory room with 22.5 ^{o}c for one hour curing time.

C. One-Dimensional Consolidation Test

A series of one-dimensional consolidation test is performed in order to investigation on lime composite settlement. Consolidation test given in the *AS1289.6.6.1* is applied on the saturated and partially saturated subsamples. This test will be performed in order to the determine magnitude and rate of volume decrease of soil that is laterally limited endures the different vertical pressures. The results will be analysed based on the "void ratio-effective stress curves" and "settlement- log time curves". In order to achieve a reliable result, the automatic consolidation device was applied and data (i.e., Load, displacement, elapsed time) were recorded at each second by the program. Samples were positioned between two porous stone and filter paper, which are set on top and bottom of sample. Specimens are located under an initial seating load of $50_{kpa,}$ and the next incremental load was doubled until 400_{kpa}. The period of each loading was taken between minimum (i.e., 3 hours) and maximum (i.e., 24 hours) depend on the initial data and software calculation. The program was calculated minimum require time that the displacement would be fixed in each loading, and then was computed 100 % primary consolidation. Furthermore, the researches about consolidation tests with different duration of load increments on soil with lime indicate that, primary consolidation of lime samples was completed faster than evaluated time for each load increment [1].

IV. Result And Discussion

Consolidation characteristics of soil based on the rate and amount of consolidation settlement, coefficient of consolidation, settlement and void ratio of the samples were studied in this paper. Moreover, the swelling behaviour of samples was investigated, for evaluating the effect of lime on swelling properties of soil.

Fig 1-7 contain the graphs that achieved by the void ratio and effective vertical stress in log scale (e_σ′p) for sand and lime composites with a various amount of lime as $_{\%}0.5$, $_{\%}1$, $_{\%}1.5$, $_{\%}2$, $_{\%}2.5$ and $_{\%}3$. The results are indicated the effect of lime treatment on the compressibility of non-stabilizer sample through improvement in the consolidation properties and swelling behaviour of soil. The compression index (C_c) and swell index (C_s) express the compressibility of soil that are presented in TABLE I.

TABLE I
COMPRESSION INDEX AND SWELLING INDEX DATA

SAMPLE	C_C	C_S
% 0 LIME	$4.65*10E^{-2}$	$1.66*10E^{-2}$
% 0.5 LIME	$2.65*10E^{-2}$	$1.49*10E^{-2}$
% 1 LIME	$2.10*10E^{-2}$	$1.32*10E^{-2}$
% 1.5 LIME	$1.77*10E^{-2}$	$1.16*10E^{-2}$
% 2 LIME	$1.55*10E^{-2}$	$9.13*10E^{-3}$
% 2.5 LIME	$1.21*10E^{-2}$	$7.47*10E^{-3}$
% 3 LIME	$9.96*10E^{-3}$	$5.81*10E^{-3}$

Fig 1 illustrates the compression curve of sample without adding lime. The initial void ratio in zero percentage of lime sample is around 0.520, compression index is $4.65*10e^{-2,}$ and swell index is $1.66*10e^{-2}$. The range and quality of lime stabilization on sand will estimate by comparison between results of lime combinations and sand sample.

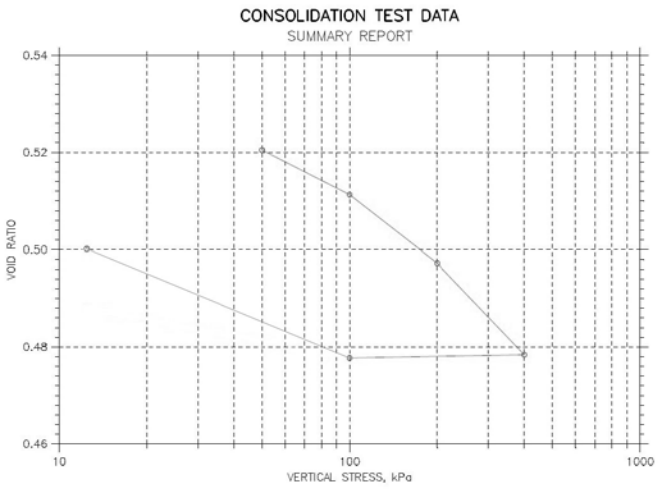

Fig. 1 Consolidation curve of %0 lime

A. Characteristics of Compression and Swelling Curves

Compression curve and swelling curve of soil treated samples with additive are indicated that soil properties of stabilized specimens had a different behaviour in each combination of additives (Fig2-7). In overall, through lime stabilization the amount of compression index was reduced in lime treated samples. This lessening has a continuous tendency, which was reduced C_c in each combination in compared with, the previous sample. The slope of compression curve of stabilized sample illustrates that a moderate reduction in comparison with untreated sample that had an extreme decrease in the slope of compression curves slope.

TABLE I illustrates that adding 0.5percent lime to non-stabilized sample led to a remarkable decrease in the compression index of soil. The compression index of untreated sample was $4.65*10e^{-2}$, then by adding 0.5 percentage of lime was dropped to $2.65*10e^{-2}$.

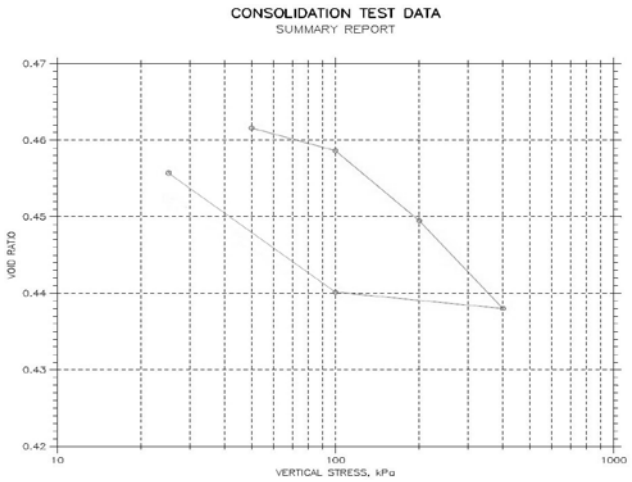

Fig. 2 Consolidation curve of %0.5 lime

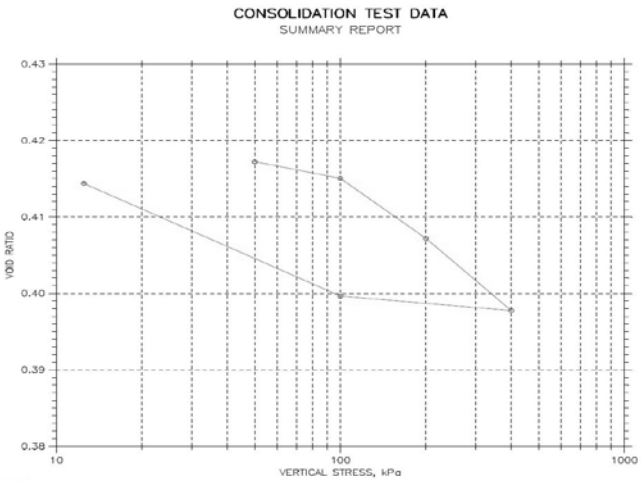

Fig. 3 Consolidation curve of %1 lime

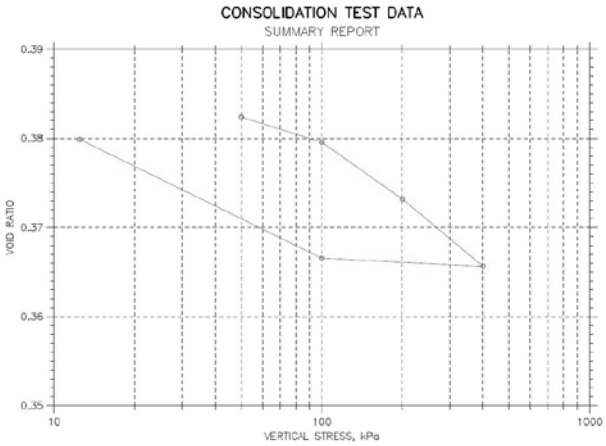

Fig. 4 Consolidation curve of %1.5 lime

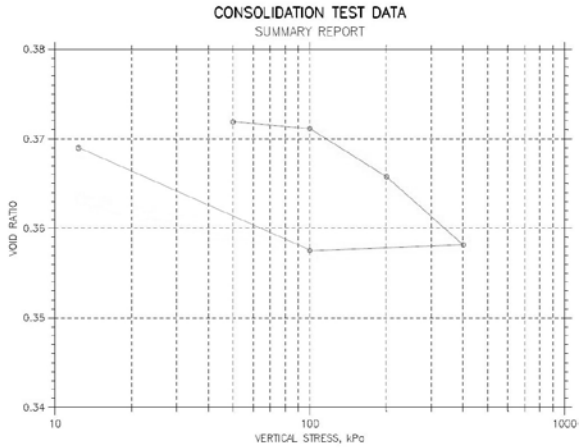

Fig. 5 Consolidation curve of %2 lime

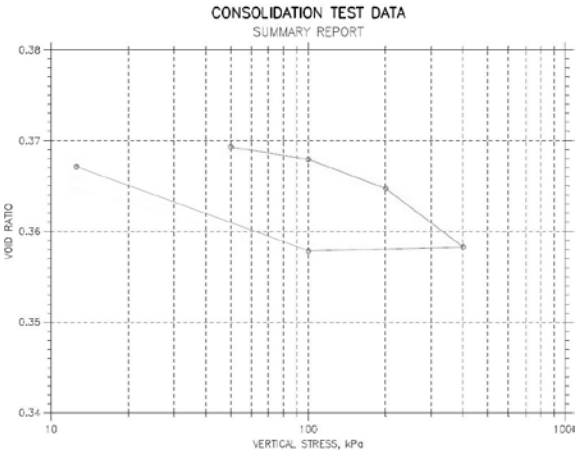

Fig. 6 Consolidation curve of %2.5 lime

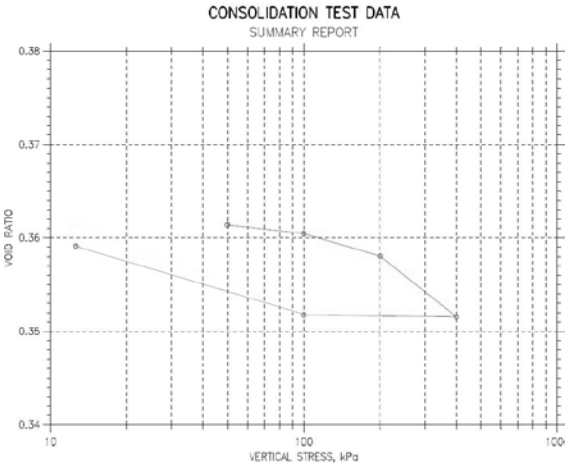

Fig. 7 Consolidation curve of %3 lime

The Fig 7 is indicated that the lowest settlement related to stabilized sample with 3 percentage of lime. It can be seen from the TABLE I the compression index in the sample with 3 percentage of lime $9.96*10e^{-3,}$ whilst the reduction of settlement was notable compared with stabilization with 2.5 percentage of lime.

Furthermore, it can clearly be seen from the TABLE II, the correlation between initial void ratio and coefficient of consolidation are confirmed the relationship between the amount of additive with e_0 and C_v. Adding more amount of additives in to combinations led to reduction in the coefficient of consolidation. As is represented by TABLE II, the sample with 3 percentage of lime had the minimum amount of initial void ratio as well as lowest coefficient of consolidation in contrast with non-stabilized sample that had the maximum C_v and most e_0 among the other samples.

TABLEI I

INITIAL VOID RATIO AND COEFFICIENT OF CONSOLIDATION DATA

SAMPLE	E_0	$C_{V\ (CM^2)\ /\ SEC}$
% 0 LIME	0.520	$8.27 * 10E^{-5}$
% 0.5 LIME	0.462	$8.14 * 10E^{-5}$
% 1 LIME	0.417	$8.02 * 10E^{-5}$
% 1.5 LIME	0.382	$7.56 * 10E^{-5}$
% 2 LIME	0.372	$7.455 * 10E^{-5}$
% 2.5 LIME	0.369	$7.450 * 10E^{-5}$
% 3 LIME	0.361	$7.35 * 10E^{-5}$

On the other hand, in the field of swell properties of sand the given results about swelling behaviour of lime treatment samples were indicated that lime had a constant and regular effect on the swelling index of sand. As is shown by TABLE I C_s in sand specimen is $1.66*10e^{-2}$ that is more than the amount of swelling index in sand treatment with lime. The results of swell index for stabilized specimens were revealed that lime could decrease the C_s of lime combinations. Moreover, sand stabilization with more than 1.5 percentage of lime lead to a remarkable reduction in swelling index. This notable trend was started on lime treatment with 2 percentage of lime by $9.13*10e^{-3}$, and was continued by adding more lime to specimen combination. The significance effect related to stabilization with 3 percentage of lime.

Although some factors such as curing time, duration and amount of loading and unloading pressure that were applied in this test, can be the effect on compressibility and swelling properties of soil, the achieved results were suggested the necessity of more investigation in this field. Thus, it can be seen that utilization of lime as an additive led to decrease the amount of compression index and swelling index of samples.

V.CONCLUSION

Regarding to utilization of stabilization method in improvement of characteristic of poor soils, this study was conducted in order to study the effect of lime additions on compressibility and swelling behaviour of sand. Based on experimental research on seven specimens, which are divided to un-stabilized sample and lime stabilized sample (i.e., %0.5, %1, %1.5, %2, %2.5, and %3) this study represents the laboratory investigation results of consolidation and swelling properties of sand.

The results indicate that, the compressibility of stabilized specimens was improved in contrast with pure sand. In all stabilized specimens were monitored the effective role of lime addition for reducing the compression index of samples due to

pozzolanic reaction between lime and soil particles. The achieved result illustrates the compression index between $4.65*10e^{-2}$ _$9.96*10e^{-3}$ for samples.

In the field of relationship between the amount of lime and compression index, it seems that, use of more dosage of lime lead to mutual reaction in reduction of initial void ratio. The reduction of C_c had a continuous reduction in all specimens.

Investigations on the swelling properties of lime treated samples were revealed the wide variation results for swelling index characteristic of sand treatment with lime. The obtained swelling index was in the range of $1.16*10e^{-2}$_$4.98*10e^{-3}$. Increase in the amount of additive related with reduction in swelling index. The results illustrate that adding 0.5percent lime into pure specimen, lead to reduction in the swelling index of non-stabilized sample. Furthermore, stabilization with more than 2percent of lime had a remarkable effect on C_s. The lowest amount related to sample with 3percent lime.

The initial void ratio of each combination was reduced with increased in the amount of lime percentage. In this field, the soil treatment with 3percent lime had the minimum initial void between the other mixtures.

Lime stabilization was effective in reducing the coefficient of consolidation of pure soil. It was observed that C_v of lime tarted samples different in the range of $8.27*10e^{-5}$_ $7.35*10e^{-5}$ $_{(cm^2) / sec}$. It was also observed that reduction in the coefficient of consolidation related with increment the amount of additive. The minimum coefficient of consolidation related to sample stabilization with 3percent lime.

Overall, the results suggest that utilization of lime could be effective on improvement the compressibility and swelling properties of soil. The optimum results are achieved by adding 3 percentage of lime. Nevertheless, regarding with continually trend of the coefficient of consolidation results, and decreasing tendency in compression index and swelling index of lime-stabilized samples, it is essential to organize more investigation by more and different dosage of lime in this field.

REFERENCES

[1] Harichane, K., M. Ghrici, and H. Missoum, *Influence of natural pozzolana and lime additives on* the *temporal variation of soil compaction and shear strength.* Frontiers of Earth Science, 2011. 5(2): p. 162-169.

[2] Saeid. Amiralian, Amin. Chegenizadeh, and H. Nikraz, *Investigation on the Effect of Lime and Fly Ash on Hydraulic Conductivity of Soil.* International Journal of Biological, Ecological and Environmental Sciences (IJBEES), 2012. Vol. 1(3): p. 120-123.

[3] Cuisinier, O., et al., *Microstructure and hydraulic conductivity of a compacted lime-treated soil.* Engineering geology, 2011. 123(3): p. 187-193.

[4] Nalbantoglu, Z., *Compressibility and hydraulic conductivity of a chemically treated expansive clay.* Canadian Geotechnical Journal, 2001. 38(1): p. 154.

[5] National Research Council . Transportation Research, B., *Soil stabilization, 1991*. 1991, Washington, D.C.: Transportation Research Board, National Research Council.

[6] Tiwari, B. and B. Ajmera, *Consolidation and swelling behavior of major clay minerals and their mixtures.* Applied Clay Science, 2011. 54(3–4): p. 264-273.

[7] Horpibulsuk, S., et al., *Consolidation behavior of soil–cement column improved ground.* Computers and Geotechnics, 2012. 43(0): p. 37-50.

[8] Cetin, H., *Soil-particle and pore orientations during consolidation of cohesive soils.* Engineering geology, 2004. 73(1–2): p. 1-11.

[9] Budhu, M., *Soil Mechanics and Foundations (3rd Edition)*. 2011.

[10] Moghal, A.A.B., VPuvvadi, and Sivapullaiah, *Effect of pozzolanic reactivity on compressibility characteristics of stabilised low lime fly ashes.* Geotechnical and geological engineering, 2011. 29(5): p. 665.

[11] Saeid. Amiralian, Amin. Chegenizadeh, and H. Nikraz, *A Review on The Lime and Fly ash Application in Soil Stabilization.* International Journal of Biological, Ecological and Environmental Sciences (IJBEES), 2012. vol .1(3): p. 124-126.

[12] [1]Harichane H ,M. Ghrici , S. Kenai , K. Grine., *Use of Natural Pozzolana and Lime for Stabilization of Cohesive Soils.* Geotechnical and geological engineering, 2011. 29(5): p. 759.