Vol. 10, No. 3, September 2010
Halaman 202 - 300

ISSN 1411-8904
Terakreditasi BAN DIKTI No: 110/DIKTI/Kep/2009

Dinamika TEKNIK SIPIL

Majalah Ilmiah Teknik Sipil

Dinamika
TEKNIK SIPIL
Hal: 202 - 300

E-mail:
dinamikats@yahoo.com

Website:
http://publikasiilmiah.ums.ac.id

Majalah Ilmiah Teknik Sipil
TERAKREDITASI
BAN DIKTI No : 110/DIKTI/KEP/2009

Vol. 10, No. 3, September 2010 **ISSN 1411- 8904**
Halaman 202 - 300 Terakreditasi BAN DIKTI No : 110/DIKTI/Kep/2009

Dinamika TEKNIK SIPIL
Majalah Ilmiah Teknik Sipil

***Dinamika* TEKNIK SIPIL - Jurnal Teknik Sipil**
Diterbitkan oleh
Jurusan Teknik Sipil Universitas Muhammadiyah Surakarta (UMS)

Alamat Redaksi :
Jurusan Teknik Sipil
Fakultas Teknik Universitas Muhammadiyah Surakarta
Gedung J Lantai 1, Kampus II , Universitas Muhammadiyah Surakarta
Jl. A. Yani No. 1 Tromol Pos 1, Pabelan Kartasura Surakarta 57102
Telepon (0271) 717417 Psw 221
e-mail : dinamikats@yahoo.com
http://publikasiilmiah.ums.ac.id

Vol. 10, No. 3, September 2010
Halaman 202 - 300

ISSN 1411- 8904
Terakreditasi BAN DIKTI No : 110/DIKTI/Kep/2009

Dinamika TEKNIK SIPIL
Majalah Ilmiah Teknik Sipil

SUSUNAN DEWAN REDAKSI

Vol. 10, No. 3, September 2010 ISSN 1411- 8904
Halaman 202 - 300 Terakreditasi BAN DIKTI No : 110/DIKTI/Kep/2009

Dinamika TEKNIK SIPIL
Majalah Ilmiah Teknik Sipil

TERBIT, AKREDITASI DAN FOKUS BIDANG

Periode Terbit	: 3 kali setahun (Januari, Mei dan September)
Terbit Pertamakali	: Januari 2001
Akreditasi BAN DIKTI	: No: 110/DIKTI/Kep/2009, tanggal Akreditasi: 5 Desember 2009
Masa Berlaku Akreditasi	: Desember 2009 s/d Desember 2012

Dinamika TEKNIK SIPIL merupakan Jurnal Ilmiah Teknik Sipil yang diterbitkan oleh Jurusan Teknik Sipil Fakultas Teknik Universitas Muhammadiyah Surakarta. Sesuai dengan namanya, jurnal ini menyajikan artikel-artikel yang menunjukkan dinamika perkembangan ilmu Teknik Sipil, yang meliputi hasil-hasil penelitian bidang Teknik Sipil dan kajian pustaka yang ditambah pemikiran penerapannya pada kasus tertentu.

Dinamika TEKNIK SIPIL terakreditasi pertamakali dengan **peringkat B** berdasarkan surat keputusan Dirjen DIKTI **No: 55a/Dikti/Kep/2006.** Kemudian terakreditasi ulang dengan **peringkat B** pula berdasarkan surat keputusan Dirjen DIKTI **No: 110/DIKTI/kep/2009.**

A Laboratory Test on The Strength and Load-Settlement Characteristic of Improved Soft Soil Using Lime-Column

Uji Model Kuat Dukung dan Karakteristik Beban-Penurunan Tanah Lunak Dengan Perkuatan Kolom Kapur di Laboratorium

Agus Setyo Muntohar
Department of Civil Engineering, Universitas Muhammadiyah Yogyakarta
Jl. Lingkar Selatan Tamantirto, Bantul – Yogyakarta. 55183
Email: muntohar@umy.ac.id

ABSTRACT

This paper presents the application of lime-column technique on soft clay soil. The research studied the strength distribution surround the installed lime-column and the load-settlement characteristic in laboratory. The lime-column was designed as single column with 50 mm in diameter (D), and the depth was 200 mm. The laboratory tests carried out were unconfined compression strength test, cone penetration test, and small plate loading test. The soil and lime-column was prepared in a steel box sized of 1.2 m width x 1.2 m length x 1 m height. The test results show that the lime-column contributes to enhance the soil strength in radial and vertical direction up to 3xD from the center of lime-column. It was also observed that soil strength tends to increase with time. The bearing capacity of the soft soil increased from 0.23 kN to 5.2 kN after the lime-column was installed. For designing the lime-column grid, it was recommended that the spacing between lime-column was 4 times the column diameter.
Keywords: strength, settlement, soft soil, lime-column, expansive clay

ABSTRAKSI

Naskah ini menyajikan hasil uji aplikasi teknik kolom-kapur (lime-colimn) untuk perkuatan tanah lunak. Tujuan utama penelitian adalah untuk mengkaji sebaran kuat dukung tanah di sekitar kolom-kapur dan karakteristik hubungan beban dan penurunannya. Kolom-kapur dirancang sebagai kolom tunggal berdiameter (D) 50 mm dengan kedalaman 200 mm. Uji laboratorium yang dilakukan meliputi uji kuat tekan bebas, uji sondir, dan uji beban langsung. Tanah dan kolom-kapur diletakan di dalam kotak baja berukuran 1,2 m x 1,2 m dan tinggi 1 m. Hasil uji menyatakan bahwa pemasangan kolom-kapur meningkatkan kekuata stanah di sekitarnya baik pada arah radial maupun vertikal hingga mencapai jarak 3xD dari pusat kolom-kapur. Kekuatan tanah cenderung meningkat dengan bertambanya kada kapur. Kuat dukung tanah meningkat dari 0.23 kN menjadi 5.2 kN setelah diperkuat dengan kolom-kapur. Untuk keperluan aplikasinya, sebaiknya jarak antar kolom disusun denga ukuran 4 kali diameter kolom.
Kata-kata kunci: kuat dukung, penurunan, tanah lunak, kolom-kapur, tanah mengembang

INTRODUCTION

The Deep Mixing Method (DMM) is a common technique for an in situ soil treatment technology whereby the soil is blended with cementitious and/or other materials. These materials are widely referred to as "binders" and can be introduced in dry or slurry form. They are injected through hollow, rotated mixing shafts tipped with some type of cutting tool (Terashi, 1997). Other variant of the DMM was lime-column method (LC). The lime-column method was formed by injecting the dry or wet lime under preferable pressure into soil in-situ (Rogers and Glendinning, 1997). This lime-column technique has been applied successfully in recent years to improve the physical and mechanical properties of the soils. This technique would increase soil bearing capacity and reduces soil settlement owing to improving of soil strength and stiffness. Hence, this technique was preferable for soft soil improvement (Broms and Boman, 1975). A study carried by Baker (2000) on full-scale model showed that the stiffness of the improved soil using lime-column increased more significantly than that of lime-cement column. Several researchers (e.g. Shen et al., 2003; Tonoz et al., 2003; Budi, 2003) studied separately the strength of the soil surrounding the lime-column. They reported that the soil strength increased near the column to a distance up to 2 to 3 times of the column diameter in radial direction. But, the effect of strength change beneath the bottom of lime-column was not studied.

It is reasonable to assume that the lime will flow easily downward into soil in vertical direction and the soil strength may also increase with the availability of lime. This research studied the strength distribution surrounding the installed lime-column in both radial and vertical direction from the center of the lime-column. The research also investigated the settlement characteristics of the soil before and after the lime-column was installed.

EXPERIMENTAL DESIGN

Soils

The disturbed soil and undisturbed samples were taken from the field in Kasihan, Bantul. The specific gravity of the soil was about 2.64. The particle size distribution of the soil sample is shown in Figure 1a. The soil consisted of about ten percent coarse and 90% fine particles. The fine particle was dominantly silt size fraction (60%) and the rest, clay size particles. The liquid limit and plasticity index of the soil were 73% and 36% respectively. According to the Unified Soil Classification System (ASTM D2487-04), the soil used is classified as clayey soil (ML/OH, Figure 1b). The unconfined compressive strength of the soil at its liqud limit state was examined about 5.8 kPa. Consolidation test for undisturbed soil sample was found that the preconsolidation pressure was about 3.26 kPa, and the specimen can be categorized as overconsolidated clay since the overconsolidatio ratio (OCR) was about 1.89.

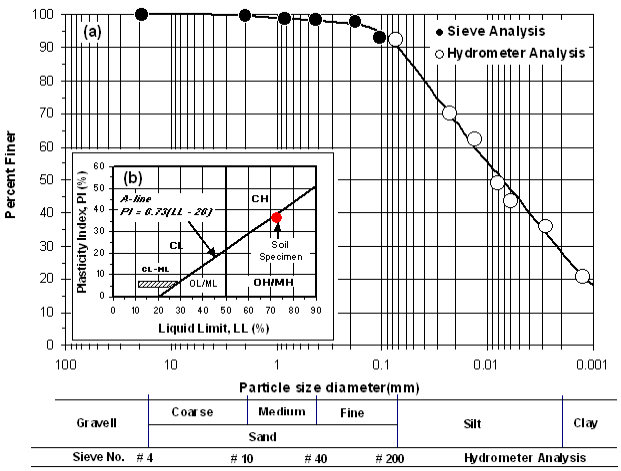

Figure 1. (a) Particle size distribution of the soil used in this study, (b) Plasticity chart

Laboratory Test

Lime columns of 50 mm in diameter and 200 mm in length were installed in the container of 120 x 120 x 100 cm in dimension (Figure 2). The clay prepared in the tank was saturated by controlling the water level at the ground surface for 1 – 2 months. Preloading was also performed to obtain a uniform thickness. The preloading was equivalent with surcharge pressure about 3.26 kPa. It results in a degree of saturation about 90%-98%. Soil sample was taken from the container for consolidation testing. The test results confirmed that the OCR value was about 1.85. Hence, the soil is overconsolidated clay. The compressibility coefficient (Cc) and swelling index (Cs) are about 0.5 to 0.6 and 0.07 to 0.085 respectively.

In the field application, a hollow tube is pushed into the soil to the required depth and quicklime powder is then forced into the pile or column by air pressure as the tube is withdrawn. In the laboratory, the field application was simulated by filling the column hole with the quicklime powder in four successive layers, each layer was compacted gently to form lime-column.

Laboratory tests conducted were unconfined compressive strength test (UCS) and cone penetration test (CPT). The UCS test procedure was according to the ASTM D2165. The UCS test was performed at varying distance from the installed LC that are 50 mm, 100 mm, 150 mm and 200 mm in radial direction (Figure 2c). To avoid much disturbance and sampling difficulties, the UCS samples were taken at depth of 100 mm (one-half of lime-column length) by using PVC tubes. The CPT was performed also at radial direction. The test method refers to ASTM D3441 for mechanical CPT. The cone resistance (q_c) was recorded every 200 mm of depth. So, in this study, the CPT will result cone resistance value at radial and vertical direction. Loading test was performed in thi study to investigate settlement characteristic. A steel plate with 25 mm thickness and 150 mm in diameter was placed on the soil surface. This foundation was then loaded until failure. The loading rate was arranged about 1 mm/minute. The settlement and load was recorded from the dial gauge on the foundation and in proving ring respectively (Figure 3).

RESULTS AND DISCUSSION

Unconfined Compression Test

Figure 4 and 5 show the development of unconfined compressive strength of soil surrounding the lime-column at different ages after installation. The effect of lime on the strength of soil depends on numerous factors such as type of soil and lime, curing period, moisture content, temperature, etc (Sakr et al., 2009). In this study, the unconfined compressive strength of the soil treated with the lime column has also been determined in order to compare the variation in unconfined compressive strength with the distance from the lime column. Figure 4 shows changes in unconfined compressive strength with aging time.

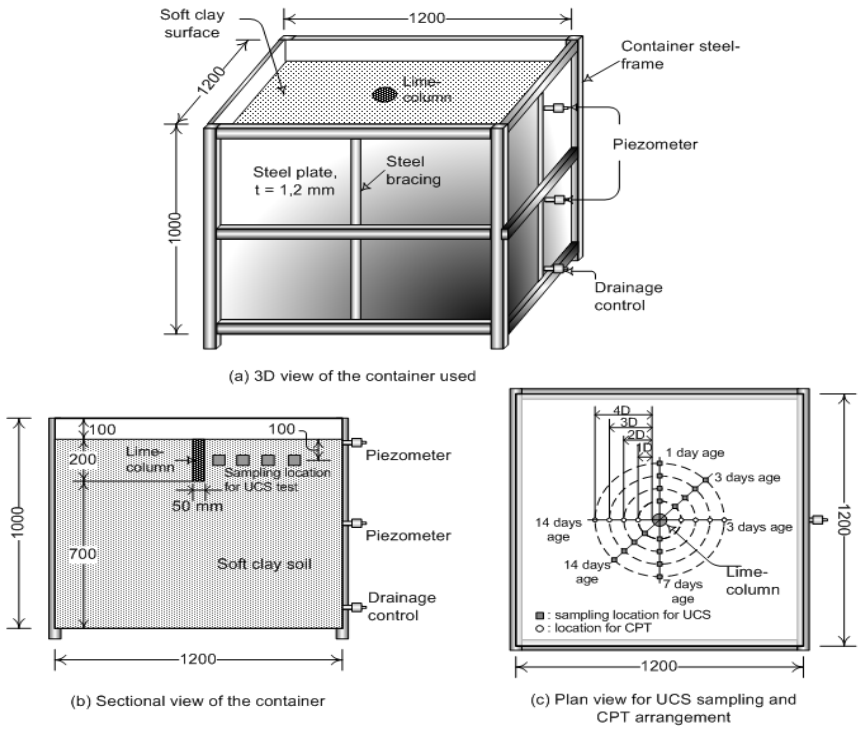

Figure 2. Scheme of the container used in this study (Note: All dimensions are in mm)

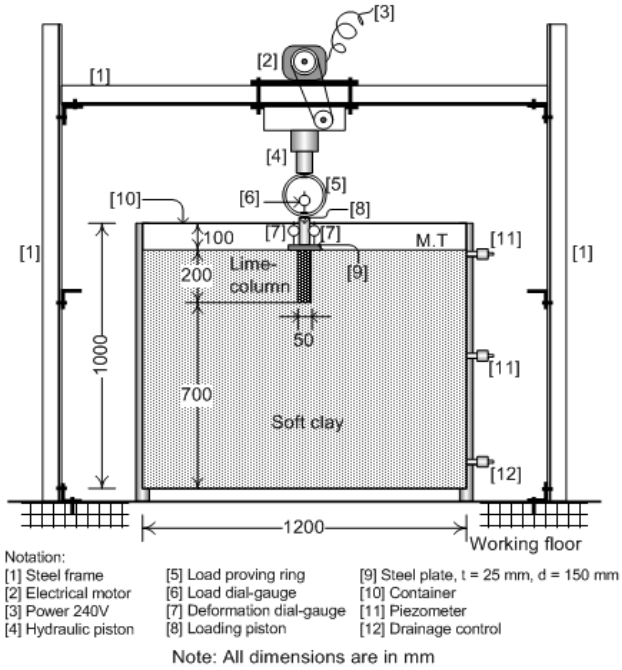

Figure 3. Schematic setup of loading test

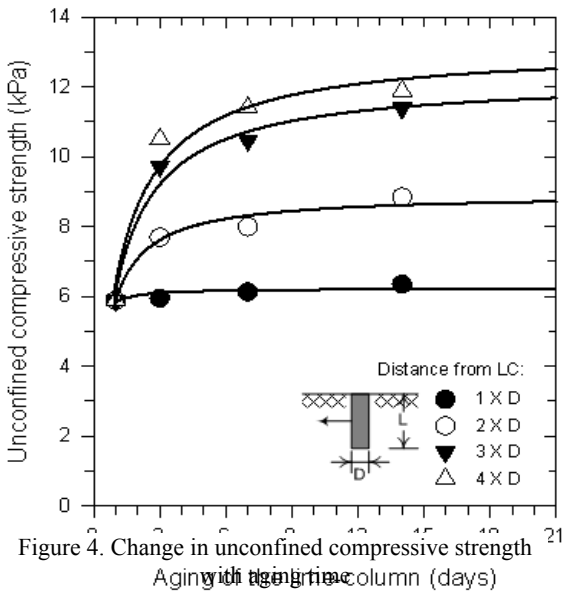

Figure 4. Change in unconfined compressive strength with aging time

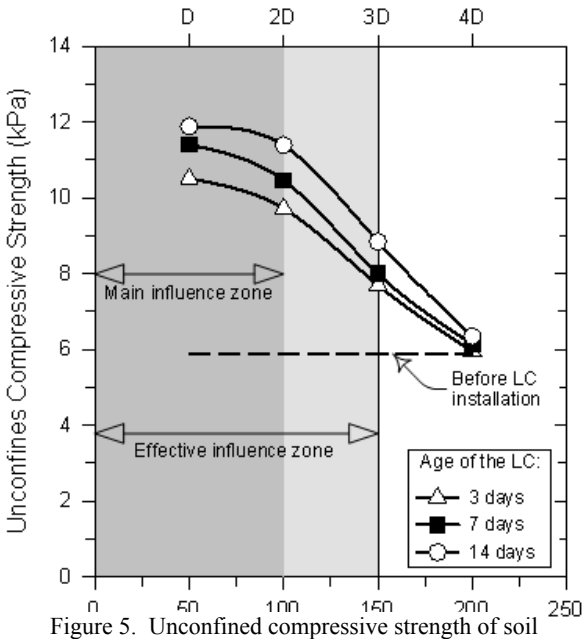

Figure 5. Unconfined compressive strength of soil surrounding LC

The figure illustrates that the the strength of the soil surrounding the lime-column does not increase very much after seven days of installation. After three days of installation, the soil strength near 1xD distance from the lime-column increase about 94%, and 57%, 35%, 7% respectively at 2xD, 3xD, 4xD from lime-column. Rao and Rajasekaran (1996) wrote that the lime migration takes place in seven to 15 days after installation to penetrate into soil up to 5xD in radial direction. Based on the result, it can be said that the effective time for lime-column installation is three days. Thus, after the period, the other construction activity may be allowed to be performed. This characteristic explained that after lime-column has been installed, the lime or calcium ions migrate into soil surrounding the lime-column. The soil properties around lime-column will change due to consolidation, densification, and hardening resulted by the chemical reaction between lime and soil. In chemical reaction, calcium and hydroxyl ions migrated through the clay. The hydroxyl ions cause highly alkalinic conditions in clay soil. This condition give rise to the slow solution of alumino-silicates which are then precipitated as hydrated cementitious reaction products. These reaction products contribute to flocculation by bonding adjacent soil particles together and when curing is allowed the clay soil is strengthened.

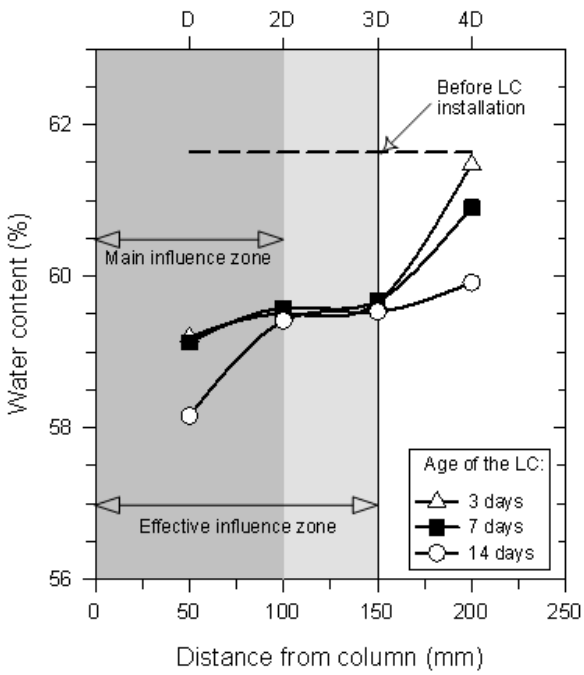

Figure 6. Variation of water contents from the lime-column

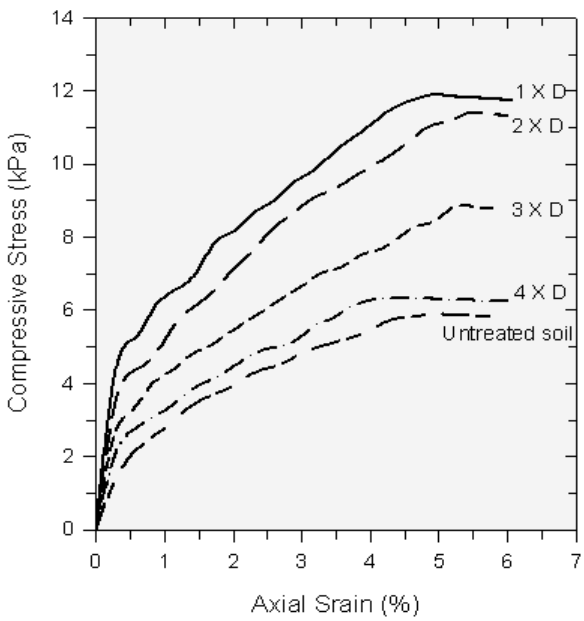

Figure 7. Stress and strain relationship from UCS test after 14 days

This mechanism will control the strength of the soil surround the lime-column (Rao and Rajeskaran, 1996; Bell, 1996). Fourteen days after installation, the soil strength around lime-column is higher than that of three and seven days after in-stallation. It implies that ageing factor has effect on the soil strength surround lime-column. This characteristic was in agreement with reaction mechanism by Bell (1996) and Sivapullaiah et al. (2000).

The lime – soil reaction takes place within one to three days after installation of the lime-column and resulted modification in soil strength (Figure 4). Since the pozzolanic reactions are time dependent, then the soil strength would increased with time. After that, the soil undergoes a permanent change in mechanical properties and the strength developed gradually over a long period. The soil strength around the lime-column varies with the distance from the center of the lime-column both in radial and vertical direction. It was observed that the soil strength was likely to the same with untreated soil if the distance from lime-column is greater than 200 mm or 4xD. The soil strength will increase if the distance is closed to lime-column. Most of the strength increase concentrates at the soil adjacent side surface of the lime-column, up to 50 mm or 1xD in radial direction from the column. The maximum soil strength increase about 2 times from 5.8 kPa to 11.9 kPa at 1xD radial direction. The soil strength in the distance of twice of the diameter (2xD) does not decrease very much (between five to seven percent, Figure 5). This influenced distance may be noted as main influenced zone. However it is noted that the lime migrates effectively to a radial distance of 3 times of the column diameter (3 x D), which is indicated by the higher soil strength than that before improvement. This zone may be called as effective influence zone within which the strength decreased in the range of 24%-28%. After a distance of 4xD (200 mm), the soil strength is approximately same as the soil strength before lime-column improvement. The migration distances are small in clayey soils because the soil has low to very low permeability. The coefficient of hydraulic conductivity of the clay soil used in this study ranges in between 2.6 x 10^{-8} to 8 x 10^{-10} m/sec.

In the field, lime-column was usually installed in a group of column instead of single column. Spacing between columns can be designed based on reduction of the soil strength associated with distance from lime-column. This study proposed that the spacing between lime-column was 4 times the diameter of lime-column to yield considerable improvement. The proposed spacing reflects to the main influence zone of the UCS surrounding lime-column (Figure 5). Bergado et al. (1994) noted that to reduce differential settlement between column and soil surrounding lime-column, then, the column spacing can be designed 3 to 4 times the diameter.

During migration, the lime reacts with the surrounding soil. As an exothermic reaction, this reaction consumes some amount of water and produces reaction product as cementation compound materials. A similar characterstic was also mentioned in Horpibulsuk et al. (2003) which studied cement admixture in high water content clay. In the case of soft clays, water is already present (or increases owing to the admixture): it is not free, but it is able to interact with the clay and develop strength cement admixed soft clays. As hydration process, the water content would decreases due to the lime reaction with water especially in the influenced zone (Figure 6). As a result, the soil strength nearby the lime-column increases with decreasing of water content.

It was interesting to understand the stress-strain behaviour after installation of the lime-column. As shown in Figure 7, no clear peak is observed at the stress–strain curves for the untreated samples. In comparison, the stress–strain curves of the lime-treated samples shown in Figure 7 have slight peaks due to cementation of soil particles resulted by the pozzolanic compounds from lime reactions. It indicates that soil becomes stiffer and behaves in a slightly brittle manner after lime treatment.

Static Cone Penetration Test (CPT)

Cone penetration test is commonly used to determine the soil strength. The cone-tip resistance (q_c) vary with soil layer and soil properties. Figure 8 shows variation of the CPT results after installation of lime-column. It is shown that the lime column not only improves the soil strength in radial direction but also in vertical direction beneath the column. This characteristic was consitent with the UCS results. The CPT results confirm that the q_c reaches higher value near the lime-column and decreases with distance from column.

In vertical direction, higher qc value is obtained near the base of column and decreases gradually to a depth of 40 cm to 60

cm underneath column. In other words, the lime can penetrate into soil about 8 to 12 times of column diameter beneath the column. It indicates that the length of the lime-column need not be installed fully in soft soil thickness. The influenced zone in vertical direction is wider than in radial direction. The lime migration in vertical direction was possible driven by the gravity force and due to the compaction during the installation to be able to migrate more rapidly and wider. It was found in this investigation that the main migration zone can reach up to 4 times of column diameter beneath the column tip (Figure 8). However, it should be noted that due to the variability of in-situ soil is relative high in vertical direction; the range of lime migration in the field may be different from the laboratory results.

Settlement Characteristic

Figure 9 shows the load–settlement curves for the constant rate loading test carried out using 150 mm circular plates directly on soft soil surface. When loading is applied, it is assumed that the column and soil nearby the column deform as a unit. Hence, the settlement will depend on the ratio between area of lime-column and the loaded or influencing area. The ratio is known as area replacement ratio (Bergado et al., 1994; Kempfert, 2003). The area replacement ratio (a_c) of the soil-column was 0.33 that is a ratio between diameter of lime-column (50 mm) and foundation (150 mm). Comparing the load–settlement curves, it was clearly observed that installation of the lime-column improved the bearing capacity of the soft soil. This behavior is consistent with the UCS test and CPT results as described in previous section.

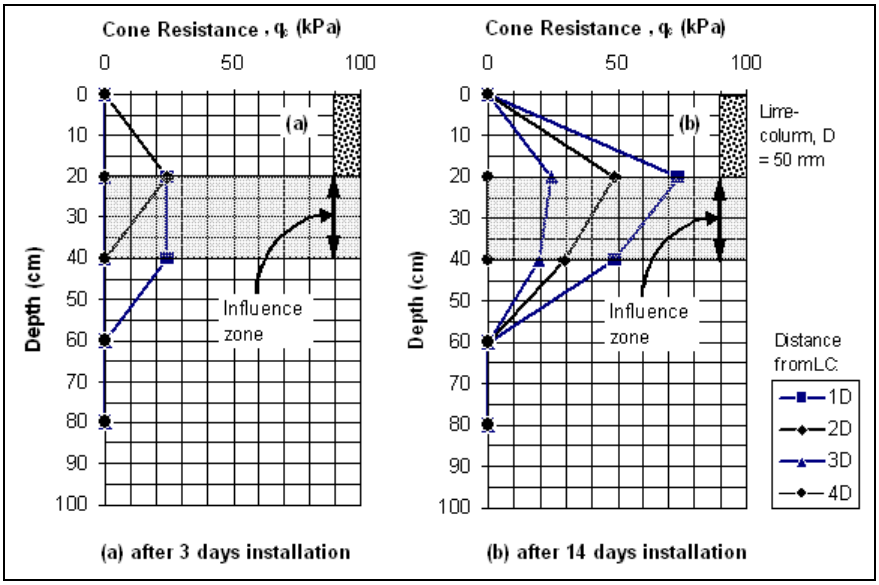

Figure 8. Variation of CPT results

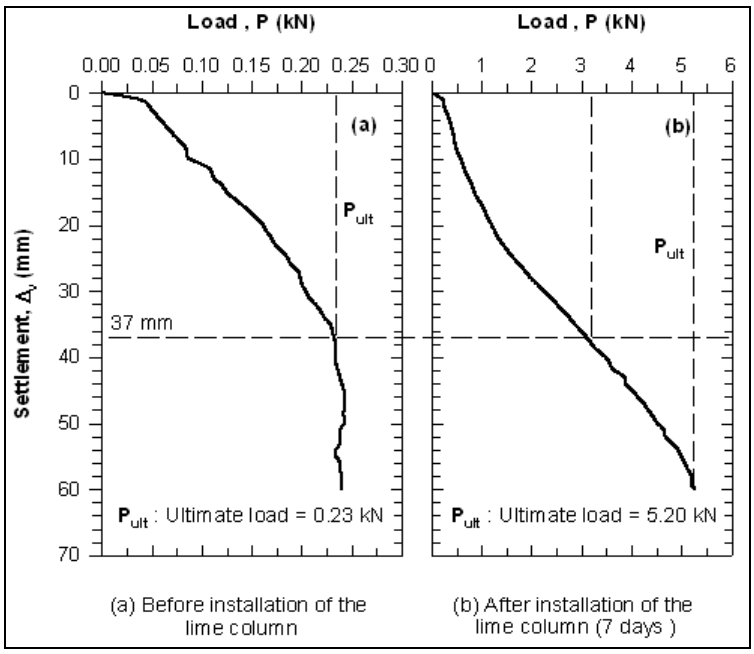

Figure 9. Load – settlement curve for constant rate

Before installation of the lime-column, based on the load-settlement curve, the mode of failure was likely defined as general shear failure (Craig, 2004). The soil experienced failure at 0.23 kN loading. Coincidently, the plate undergoes larger settlement up to 37 mm (Figure 9a). On contrary for the lime-column improved soft soil, the strength of improved soft soil increased continuously even at large deformations (Figure 9b). Failure would be attained after reaching 60 mm vertical deformation. The ultimate load was approaching 5.2 kN. It means that the bearing capacity increases 23 times approximately after the lime-column was intalled. But, if the load was measured at 37 mm vertical deformation, the bearing capacity increases 13 times from 0.23 kN to 3 kN.

Kempfert (2003) mentioned that the effect of a soil improvement is usually expressed by an improvement factor β:

$$\beta = \frac{\text{Settlement of the unimproved soil}}{\text{Settlement of the improved soil}} \quad (1)$$

Larger improvement factor indicates larger reduction in soil settlement. Comparing the settlement at P_{ult} = 0.23 kN, the settlement of the unimproved soil is about 37 mm while settlement of the improvent soil is about 2 mm. Hence, the improvement factor β is 18.5.

CONCLUSIONS

The following conclusions can be drawn from the above research findings.

1. The installation of lime-column in the soil can improve the strength of the soil surrounding the column in both vertical and radial directions. Higher strength attained near the column and decreased gradually with the distance from the column.
2. The increased soil strength is a result of the lime migration into and reaction with soil. The lime can penetrate into soil up to 3xD in radial direction and 8xD in vertical direction. But, the main influenced zone is within 2x in radial direction and 4xD beneath column in vertical direction. For designing the lime-column grid, it was recommended that the spacing between lime-column was 4 times the column diameter.
3. The water content of surrounding soil decrease after installation of the lime-column owing to the imbibing of water for chemical reaction between lime and soil. The amount of water content decrease reduces with the distance from the column edge.
4. The effective aging time of the lime-column is three days after installation.
5. The bearing capacity of the soft soil increased 23 times from 0.23 kN to 5.2 kN after the lime-column was installed. The improvement factor β, for are replacement ratio a_c = 0.33, was about 18.5.

ACKNOWLEDGEMENT

The author is thankful for the funding provided by the Directorate General of Higher Education, Ministry of National Education Republic of Indonesia through the research grant No. 129/SPPP/PP/DP3M/IV/2005, and counterpart funding from Universitas Muhammadiyah Yogyakarta No. 193/Rek.-LP3/II/2005.

REFERENCES

ASTM D2165-04. (2005). *Standard Test Method for Unconfined Compressive Strength of Cogesive Soil.* ASTM International, West Conshohocken, PA.

ASTM D2487-04. (2005). *Standard Classfication of Soils for Practical and Engineering Purposes.* ASTM International, West Conshohocken, PA.

ASTM D3441-04. (2005). *Standard Test Method for Mechanical Cone Penetration Test of Soil.* ASTM International, West Conshohocken, PA.

Baker, S. (2000). "Deformation Behavior of Lime/Cement Stabilized Clay." Ph.D Theses, Departement of Geotechnical Engineering, Chalmers University of Technology, Goterberg, Sweden.

Bell, F.G. (1996). "Lime Stabilization of Clay Minerals and Soils." *Engineering Geology*, Vol. 42, pp. 223–237.

Bergado, D.T., Chai, J.C., Alfaro, M.C., and Balasubramaniam, A.S. (1994). *Improvement Techniques of Soft Ground in Subsiding and Lowland Enviroment*, A.A. Balkema, Rotterdam, Netherland.

Broms, B.B. and P. Boman. (1975). "Lime Stabilized Column." *Proceedings 5th Asian Regional Conference on Soil Mechanic and Foundation Engineering*, Vol. 1, pp. 227-234.

Budi, G.S. (2003). "Penyebaran Kekuatan Dari Kolom Yang Terbuat Dari Limbah Karbit dan Kapur." *Dimensi Teknik Sipil*, Vol. 5 No. 2, pp. 99-102.

Craig, R.F. (2004). *Soil Mechanics*, 7th Edition, Spon Press, New York, USA.

Horpibulsuk, S., Miura, N., and Nagaraj, T.S. (2003). "Assessment of Strength Development in Cement-Admixed High Water Content Clays with Abrams' Law as A Basis." *Géotechnique*, Vol. 53 (4), pp. 439–444.

Kempfert, H.G. (2003). "Ground Improvement Methods with Special Emphasis on Column-Type Techniques." *Proceeding International Workshop on Geotechnics of Soft Soils -Theory and Practice*. Vermeer, Schweiger, Karstunen & Cudny (eds.), Netherlands, Glückauf, Verlag, pp 101 – 112.

Rao, S.N., and Rajasekaran, G. (1996). "Reaction Products Formed in Lime-Stabilized Marine Clays." *Journal of Geotechnical Engineering, ASCE*, Vol. 122 (5), pp. 329-336

Rogers, C.D.F., and Glendinning, S. (1997). "Improvement of Clay Soils In-situ Using Lime Piles." in UK. *Engineering Geology*, Vol. 47, pp. 243-257.

Sakr, M.A., Shanin, M.A., and Metwally, Y.M. (2009). "Utilization of Lime for Stabilizing Soft Clay Soil of High Organic Content." *Geotechnical and Geological Engineering*, Vol. 29 (1), pp. 105 – 113.

Shen, S.L., Miura, N., and Koga, H. (2003). "Interaction Mechanism Between Deep Mixing Column Surrounding Clay During Installation." *Canadian Geotechnical Journal*, Vol. 40, pp. 293-307.

Sivapullaiah, P.V., Sridharan, A., and Ramesh, H.N. (2000). "Strength Behavior of Lime-Treated Soils in The Presence of Sulphate." *Canadian Geotechnical Journal*, Vol. 37, 2000, pp. 1358–1367

Terashi, M. (1997). "Deep Mixing Method - Brief State of the Art." *Proceeding the 17th International Conference on Soil Mechanics and Foundation Engineering*, Hamburg, Germany, 1997, pp. 69-96.

Tonoz, M.C., Gokceoglu, G., and Ulusay, R. (2003). "A Laboratory-Scale Experimental Investigation on The Performance of Lime in Expansive Ankara (Turkey) Clay." *Bulletin Engineering Geology and Environmental*, Vol. 62, pp. 91-106.