International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 14 (2017) pp. 4687-4693
© Research India Publications. http://www.ripublication.com

# Study on Characteristic of Laterite Soil with Lime Stabilization as a Road Foundation

**Zubair Saing[1], Lawalenna Samang[2], Tri Harianto[3] and Johannes Patanduk[4]**

[1]*Doctoral Program of Civil Engineering, Hasanuddin University, Engineering Faculty, Poros Malino Street of Gowa, Indonesia.*
[2]*Professor of Civil Engineering, Hasanuddin University, Engineering Faculty, Poros Malino Street of Gowa, Indonesia.*
[3]*Associate Professor of Civil Engineering, Hasanuddin University, Engineering Faculty, Poros Malino Street of Gowa, Indonesia.*
[4]*Associate Professor of Civil Engineering, Hasanuddin University, Engineering Faculty, Poros Malino Street of Gowa, Indonesia.*

## Abstract

Regional growth and development led to an increase in infrastructure especially roads. Along with that, material requirements as the road foundation also increased. Meanwhile, the number of qualified materials in certain areas is limited, difficult to obtain and expensive. Therefore, efforts are required to exploit the potential of local soils as a qualified road foundation material. One of them is laterite soil which is only wasted from mining activities. This study aims to analyze and produce the characteristics of laterite soil with lime stabilization to be used as a road foundation. Physical and mechanical properties, mineral content, and chemical composition, obtained from laboratory testing. Meanwhile, to obtain soil bearing capacity, the physical model of the road foundation was examined. The addition of lime with compositions of 3, 5, 7, and 10% at maximum dry density from Proctor standard test, then cured to 3, 7, 14, and 28 days before testing. Subsequently, the soil mixture is fed into the test tub with length (L) = 8m, width (W) = 2m, and height (H) = 2.5m. The physical model of road foundation consists of a subgrade soil with 1.5 m thickness and above the subgrade is placed lime treated base with 0.1 m thickness. Dial gauge to read the magnitute of vertical deformation occurs when loading is placed on surface with 0.2 m distance. Furthermore, static loading test on each mixture of lime treated base. The results show that, stabilization of 10% lime for 28 days curing time yields the strength and bearing capacity of the soil three times higher than soil before stabilization. Subgrade modulus increased significantly with increasing of lime content and curing time. Comparing the relation of subgrade modulus and CBR values for common soil and sediment soil with cement stabilization, it was found that performance of laterite soil with lime stabilization is better than sediment soil with cement stabilization and approaching of common soil. It is concluded that laterite soil with lime stabilization has potential as a road foundation.

**Keywords:** Laterite soil, lime stabilization, road foundation.

## INTRODUCTION

Materials requirement for road foundation in certain areas is often a problem because it is difficult to obtain, expensive, and limited number of eligible. So the development should be done on subgrade soil conditions such as soft soil, swelling soil, soil from the sea, even unstable soil in case of earthquake/vibration. One method that can be used to overcome the problem is soil stabilization before used. The purpose is to improve soil performance or to improve the soil geotechnical properties chemically so that the soil meets certain technical requirements. In addition to stabilization methods, the efficiency of soil use as a road foundation can be developed in areas with limited material conditions. This is intended to reduce the type and thickness of the road foundation, which is generally done with two types of foundation layers, namely bottom foundation layer (LPB) and upper foundation layer (LPA).

One of the most important challenges in the design of structures on soil is the reaction of the soil when in contact with the structure. The mechanical behavior of the soil is very complex, since the soil is naturally non-linear, anisotropic, heterogeneous, and deformed depending on the load given. Thus, in engineering work to design structures, soil modeling is made with all its complexity, with a simple system called a subgrade reaction model [1]. The determination of soil strength to support the above structure is determined by the soil reaction coefficient (ks) and the soil elasticity modulus (Es). The soil stiffness assumption model as the ratio between pressure ($\Delta\sigma$) and vertical displacement ($\Delta\delta$) is linear, and is known as the soil reaction coefficient (MN/m$^3$). This theory simulates the soil behavior as an independent spring group, with a linear-elastic model. This theory is widely developed for the calculation of stresses on a flexible foundation [2]. The value of soil reaction modulus can be determined based on field testing, laboratory testing, empirical equations, and tabulation values. Field tests using plate loading test, laboratory test using consolidation test and triaxial test [3] and [13].

One of the soil that can be developed is potentially laterite soil in Sorowako, East Luwu Regency, South Sulawesi. This area is relatively difficult to obtain the soil type that meets the technical requirements as road foundation, even must be imported from other regions. Instead it is dominated by laterite soils with relatively high metal content, especially iron oxide ($Fe_2O_3$), which is simply wasted from nickel mining [12], [18-20].

Recent study on laterite soil and soil stabilization with various methods has been widely practiced, especially in countries with many of these soils types, such as Asia and Africa. Some previous studies include; the higher content of clay minerals in the laterite soil causes a decrease in soil strength [4], the addition of lime and cement is more efficient in 2% cement and 3% lime mixture [5], sediment soil with cement stabilization increases the soil strength up to three times more than strength of original soil [6], laterite soil with polymer solution (GKS) stabilization resulting in increased soil compressive strength as the increasing of the curing time after 7 days [7], laterite soil stabilization using a mixture of charcoal and cement resulted in the most effective stabilization conditions in addition 6% charcoal sugar cane and 5% cement addition [8], laterite soil stabilization with corn cob ash (CCA), resulted in maximum increase of maximum dry density at 1.5% CCA content and increase the CBR value at 1.5% CCA [9], laterite soil stabilization using liquid sodium silicate, resulting in the addition of 9% sodium silicate increased soil strength [10], an increase of soil hydraulic gradient if mixing with fed gasoline [11].

## MATERIAL AND METHOD

The material used in this research is laterite soil from Sorowako East Luwu Regency South Sulawesi with coordinates S 2°56'21,16" and E 121°36'26,54". Tests of physical and mechanical properties of the soil were conducted in laboratory according to American Standard for Testing and Materials (ASTM), as shown in Table 1. Soil stabilization using quick lime with CaO = 97,8% and silica oxide ($SiO_2$) = 2,2%. The addition of lime with compositions of 3, 5, 7, and 10% at maximum dry density from Proctor standard test. The physical model test is performed on a test tub with dimension; height (H) = 2.5 m, length (L) = 8 m, and width (W) = 2 m. The physical model of road foundation layer consists of 1.5 m thick of subgrade layer and 0.1 m thick of laterite soil with lime stabilization (lime treated base) layer. The process of soil compacting in the test tube was conducted accordance with standard Proctor compaction process in the laboratory to ensure the suitability of soil density. After each layer was compacted, then the dial gauge for reading the magnitude of vertical deformation that occurs when loading is placed on the surface with 0.2 m distance, the next stage is the static loading for each soil mixture composition. The test results was used to determine of soil subgrade modulus (k), which is the ratio of pressure change ($\Delta\sigma$) and vertical deformation change ($\Delta\delta$). The physical model test as shown in Fig. 1.

**Table I:** ASTM Standard for Soil Testing

| Type of Testing | ASTM Standard Number |
|---|---|
| Grain size analysis | C-136-06 |
| Liquid limit (LL) | D-423-66 |
| Plastic limit (PL) | D-424-74 |
| Plastic index (IP) | D-4318-10 |
| Spesific gravity (Gs) | D-162 |
| Water content (Wc) | D-2216-98 |
| Unconfined compression Test (qu) | D-633-1994 |
| Compaction test | D-698 |
| CBR laboratory test | D-1833 |
| Direct shear test | D-3080 |
| XRD test | D3906-03 (2013) |
| SEM test | E986-04 (2010) |
| EDS/EDAX | E1508-12a |

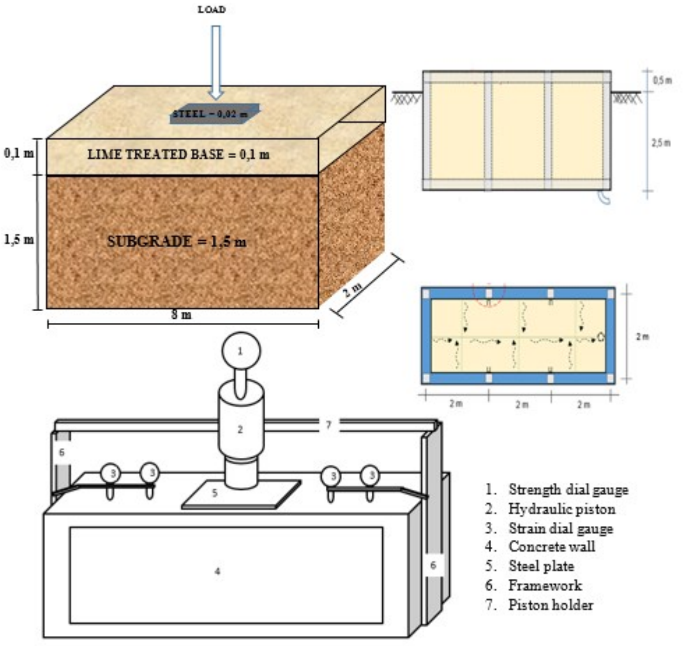

**Figure 1:** Physical model test of lime treated base as road foundation

## RESULT AND DISCUSSION

The results of physical and mechanical testing of alluvial soil and laterite soil are shown in Table 2, while mineral content and laterite soil chemical composition are shown in Tables 3 and 4.

**Table II:** Physical and Mechanical Properties of Alluvial and Laterite Soil

| No | Soil Characteristics | Unit | Alluvial Soil | Laterite Soil |
|---|---|---|---|---|
| 1 | Specific Gravity (Gs) | - | 2,65 | 2,62 |
| 2 | Water content (w) | % | 38,85 | 22,25 |
| 3 | Sieve analysis | | | |
| | a. gravel | % | - | - |
| | b. sand | % | 41,80 | 5,11 |
| | c. Silt/clay | % | 58,20 | 94,89 |
| 4 | Atterberg limits | | | |
| | a. Liquid limit (LL) | % | 65,46 | 68,73 |
| | b. Plastic limit (PL) | % | 33,90 | 37,96 |
| | c. Index plasticity (PI) | % | 31,56 | 30,77 |
| 5 | Standard Proctor compaction | | | |
| | a. Maximum dry density ($\gamma_{d\ maks}$) | kN/m$^3$ | 14,01 | 16,92 |
| | b. Optimum moisture content ($w_{opt}$) | % | 30,79 | 16,72 |
| 6 | Unconfined compression strength ($q_u$) | kN/m$^2$ | 48,85 | 128,88 |
| 7 | California Bearing Ratio (CBR) | | | |
| | a. CBR unsoaked | % | 7,33 | 22,99 |
| 8. | Direct shear test | | | |
| | a. Cohesion (C) | kN/m$^2$ | 12,19 | 16,3 |
| | b. Internal friction angle (θ) | ( $^0$ ) | 13 | 20 |
| 9. | Soil classification | | | |
| | a. USCS | | CH | CH |
| | b. AASTHO | | A-7-6 | A-7-6 |

**Table III:** Chemical Composition of Laterite Soil with 10% CaO Stabilization

| Chemical Compound (%) | Laterite Soil | Laterite Soil + 10% CaO | | | |
|---|---|---|---|---|---|
| | (%) | 3 days | 7 days | 14 days | 28 days |
| MgO | 0,83 | 2,61 | 1,98 | 0,07 | 3,21 |
| $Al_2O_3$ | 5,73 | 10,18 | 7,46 | 3,90 | 10,07 |
| $SiO_2$ | 2,28 | 6,75 | 5,35 | 3,41 | 8,92 |
| $K_2O$ | - | 0,32 | 0,29 | 0,00 | 0,00 |
| $TiO_2$ | - | 0,00 | 0,39 | 0,40 | 0,00 |
| FeO | 86,55 | 62,44 | 67,06 | 78,52 | 60,53 |
| NiO | 2,78 | 2,69 | 2,72 | 2,62 | 0,00 |
| $Cr_2O_3$ | - | 1,73 | 2,18 | 2,06 | 1,94 |
| $P_2O_5$ | - | 0,00 | 0,00 | 0,00 | 0,00 |
| $SO_3$ | 1.05 | 2,64 | 1,59 | 0,80 | 2.31 |
| $Na_2O$ | - | 3,47 | 1,70 | 0,00 | 2,51 |
| CaO | 0,25 | 6,84 | 9,25 | 8,22 | 10,51 |

Based on the results of Tables 2, it is known that alluvial soil and laterite soil grains are dominated by silt/clay material respectively 58.20% and 94.89%, with plasticity index of 31,56% and 30,77%. These results indicate that alluvial soil and laterite soils are included in clay classification with high plasticity (A-7-6 according to AASTHO and CH according to USCS). While based on mineral content on Table 3, showed that laterite soil was dominated by illite-montmorillonite minerals, and based on chemical composition showed on Table 4, laterite soils are dominated by iron oxide content up to 86.55%.

**Table IV:** Minerals content of laterite soil with 10% CaO stabilization

| Minerals Content (%) | Laterite Soil | Laterite Soil + 10% CaO | | | |
|---|---|---|---|---|---|
| | (%) | 7 days | 14 days | 21 days | 28 days |
| hematite HP, iron(III) oxide | 7 | 7 | 8 | 38 | 25 |
| Kaolinite | 8 | 6 | 11 | 9 | 5 |
| Illite-montmorillonite | 80 | 42 | 9 | 26 | 18 |

| | | | | | |
|---|---|---|---|---|---|
| (NR) | | | | | |
| Forsterite | 3 | - | 25 | 8 | 37 |
| Portlandite | - | 45 | 47 | 18 | 15 |

Subsequently, the strength test result of some variation CaO content and curing time is shown in Fig. 2.

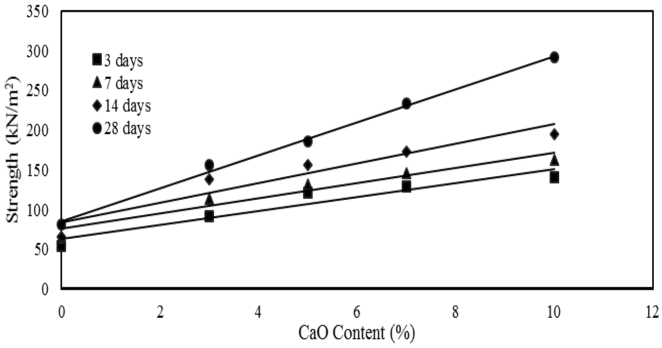

**Figure 2:** Relationship of laterite soil strength with lime content and curing time

The addition of lime causes the soil to become harder and stiff. An increase in compressive strength until it reaches the peak of strength indicates fragile collapse. Figure 2 shows the relationship of soil strength with lime content and curing time. It is seen that the increase in lime content and increase of curing time leads to increase the compressive strength of soil. In 10% lime content with 28 days cured, the compressive strength increased 300% (three times higher than untreated soil).

Increasing of soil compressive strength occurs due to clay particles have a high negative charge on the surface that can attract cations (positive charge ions) and water dipoles. Two reactions occur, that is cation exchange and flocculation-agglomeration, are rapid and direct result in increased strength due to decreased soil plasticity and increased soil capacity. The direct effects of CaO addition on the soil are obtained during curing and construction stage, related to cation exchange reactions and agglomeration flocculations. The effect of long-term stabilization occurs during and after curing, this is very important for soil strength. When this effect is produced to some extent due to cation exchange and agglomeration-flocculation, the resulting pozzolanic strength is predominantly generated. The addition of CaO to the soil directly undergoes a hydration process due to its chemical combination with water and heat release. The soil becomes dry because the water in the soil is reacted and evaporates. During stabilization and increasing the amount of CaO and $H_2O$ contents, pH of soil directly rises above 10.5 causing the clay particles to broken. Silica and alumina react with calcium from CaO in the form of calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH). This forms a matrix that contributes to producing strength layers of laterite soil with lime stabilization [14] and [15]. This condition leads to an increase of soil strength. The chemical reaction mechanism occurring in the stabilization of laterite soil with lime as shown in Fig. 3.

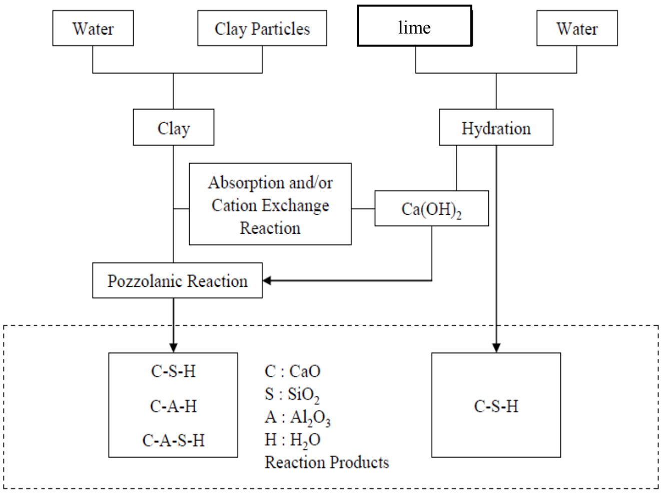

**Figure 3:** Chemical reaction of soil with lime stabilization (After Jaritngam, et. al., 2014)

According to Fig. 3, the chemical reactions occurring as a result of the addition of CaO and water ($H_2O$) to the laterite soil containing $SiO_2.Al_2O_3.Fe_2O_3$ are described as showed in Equation 1.

$$SiO_2.Al_2O_3.Fe_2O_3 + CaO + H_2O \rightarrow CaO.(SiO_2).H_2O + CaO.Al_2O_3.H_2O + CaO.\ 2Fe(OH)_3 \qquad (1)$$

Where, $SiO_2.Al_2O_3.Fe_2O_3$ is a laterite soil content, CaO is quick lime as a stabilizing agent and $H_2O$ is water. The resulting reaction consists of CaO. ($SiO_2$). $H_2O$ is Calcium Silicate Hydrate (CSH), $CaO.Al_2O_3.H_2O$ is Calcium Aluminate Hydrate (CAH), and $CaO.2Fe(OH)_3$ is Calcium Ferro Hydroxide (CFH).

In addition of soil compressive strength, the test of soil bearing capacity on some variation of CaO content and curing time was conducted. The change of CBR value showed in Fig. 4. Based on these figure, showed that increasing of CaO content to 10% and 28 days cured, causing the bearing capacity of the soil increased 300% (three times higher than untreated soil). Pozzolanic reaction causes pozzolanic strength which causes dry and dense soil due to CaO and water reaction, where calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH) form a cementation layer matrix causing the increase of soil strength. This resulted in bearing capacity of the soil also experienced significant increase. The dominance of clay minerals with high plasticity such as montmorillonite and illite with high iron oxide content and lime addition, will result in reaction forming CSH and CAH, which closes the micro pore of soil, so the soil becomes denser and causes the strength and bearing capacity increase as reaction in Equation 1. This condition is shown in Fig. 5.

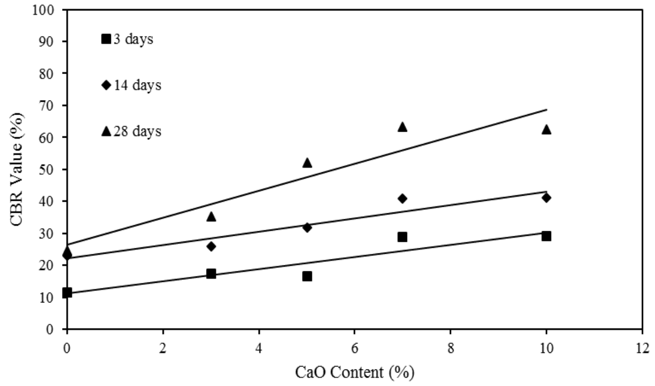

**Figure 4:** Relationship of laterite soil CBR value with CaO content and curing time

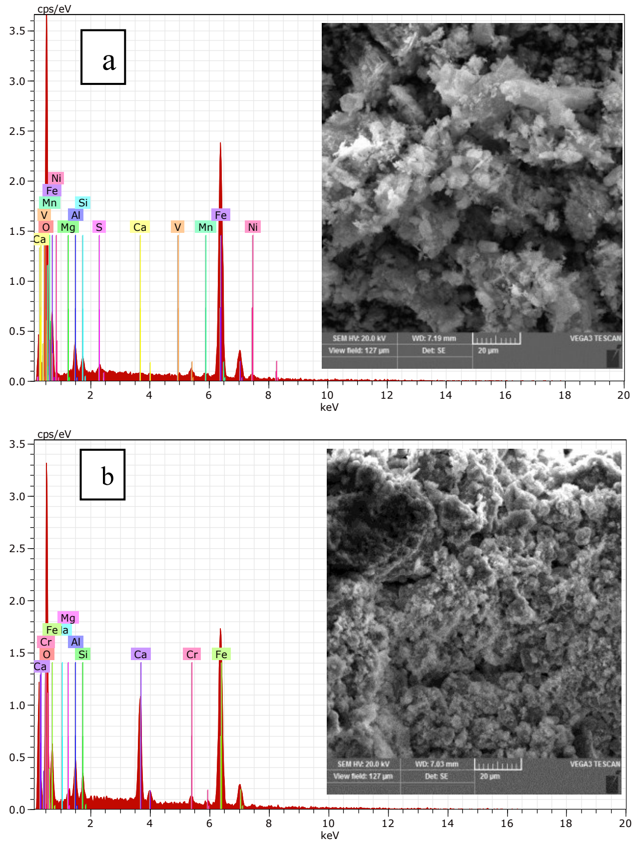

**Figure 5:** SEM Microphotograph of laterite soil; a) untreated soil; b) soil treated with 10% lime after 28 days cured

Based on Fig. 5, showed that, soil micro pores are relatively large and scattered before stabilized. The addition of CaO causes an ion exchange charge reaction in the soil. Release of negative ions on the surface and sides of the clay minerals as well as the exchange of negative and positive ions of hydrous oxide of iron and aluminium as reaction in Equation 1. This ion exchange reaction that causes the formation of cemented minerals that form the matrix and into the soil strength layers, as shown in Fig. 5b.

Utilization of laterite soil with lime stabilization as road foundation was conducted with physical model placed in a test tub with maximum dry density according to the laboratory results. Furthermore, the physical model is given static loading to find the bearing capacity and vertical deformation. The results test of road foundation physical model using laterite soil with lime stabilization are shown in Fig. 6. These figure shows the relation of pressure and vertical deformation that occurs due to loading applied in physical model of road foundation. An increased of addition lime content causes increased soil strength and decreases vertical deformation. This is in accordance with the results of soil capacity and soil microstructure characteristics. In addition, according to Fig. 6 can be determined the value of subgrade modulus, soil deformation, and the pressure for each percent of lime addition, as well as the pre-determined CBR field values, as shown in Table 5.

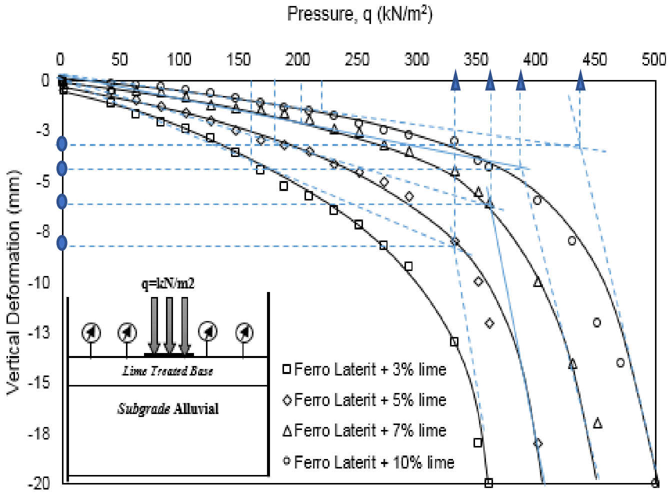

**Figure 6:** Relationship of pressure vs vertical deformation

**Table V:** Subgrade modulus and CBR value of laterite soil with lime stabilization

| CaO Content (%) | Pressure, q (kN/m$^2$) | Vertical deformation ($10^{-3}$m) | Subgrade modulus, k (kN/m$^2$ per mm) | CBR Value (%) |
|---|---|---|---|---|
| **3** | 330,0 | 8,2 | 40,2 | 12,00 |
| **5** | 362,5 | 6,0 | 60,4 | 31,92 |
| **7** | 387,5 | 4,5 | 86,1 | 40,91 |
| **10** | 437,5 | 3,3 | 132,6 | 45,00 |

Based on Table 5, relationship between the soil subgrade modulus and CBR value and compared with similar curves for general soil (PU. Bina Marga, 2003) and sediment soil with cement stabilization (Yusuf, H., et al, 2013) as shown in Fig. 7.

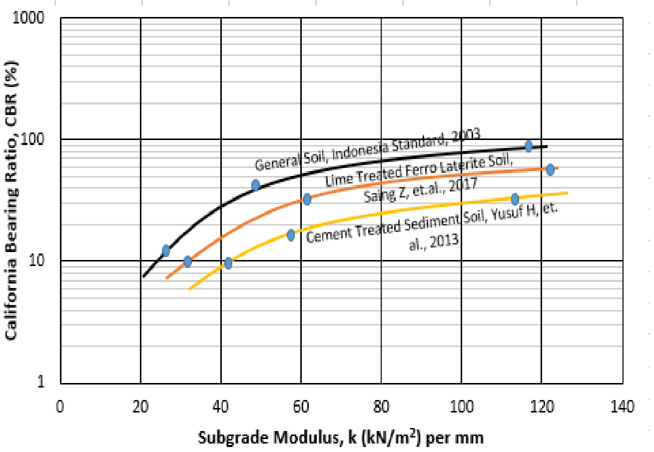

**Figure 7:** Relationship of subgrade modulus vs CBR

Based on Fig. 7, it is seen that the laterite soil with lime stabilization curve lies between the general soil curve and the sediment soil cement stabilization. The laterite soil with lime stabilization showed better performance than the sediment soil cement stabilization. These results indicate that laterite soil with lime stabilization is good for use as road foundation.

## CONCLUSIONS

The addition of CaO up to 10% with curing after 28 days showed significant improvement of soil strength and bearing capacity three times higher than untreated soil. The laterite soil reaction with CaO form the cementation matrix of calcium silicate hydrate (CSH), calcium alumina hydrate (CAH) as a coating that contributes to increased strength and soil bearing capacity. Subsequently, the addition of lime to 10% leads to increased soil strength and decreases vertical deformation. Comparing the relationship of subgrade modulus and the CBR values for common soil and sediment soil with cement stabilization, it was found that laterite soil with lime stabilization curves is in between common soil and sediment soil with cement stabilization. This condition indicated that performance of laterite soil with lime stabilization is better than sediment soil with cement stabilization and in accordance with common soil. It is concluded that laterite soil with lime stabilization has the potential of utilization as road foundation.

## ACKNOWLEDGMENT

We would like to thank Soil Mechanics Laboratory Hasanuddin University for permits to use material testing tools, and special thank to Indonesian Ministry of Research Technolgy and Higher Education for funding this research.

## REFERENCES

[1] Naeini S. A., Ziaie Moayed R., Allahyari F, 2014, “Subgrade Reaction Modulus (Ks) of Clayey Soils Based on Field Tests”, *Journal of Engineering Geology*, Vol.**8**, No.1, Springer.

[2] Daloglu A. T., Vallabhan C. V. G., 2000, “Values of k for Slab on Winkler Foundation”, *Journal of Geotechnical and Geoenviron-mental Engineering*, ASCE, pp. 463-471.

[3] Dutta S. C., Roy R. A., 2002, “Critical Review on Idealization and Modeling for Interaction among Soil Foundation-Structure System”, *Computers and Structures*, **80**, pp. 1579-1594.

[4] Sree Danya, Ajitha, A.R, Evangeline, Y. Sheela., 2010, “Study on Amended Soil Liner Using Lateritic Soil”, *Indian Geotechnical Conference*, GEO*trendz* IGS Mumbai Chapter & IIT Bombay, pp. 381-284.

[5] F.H.M. Portelinha, D.C. Lima, M.P.F. Fontes, C.A.B. Carvalho, 2012, “Modification of a Lateritic Soil with Lime and Cement: An Economical Alternative for Flexible Pavement Layers”, Soils and Rocks, São Paulo, **35**(1): pp. 51-63.

[6] Yusuf H, Pallu M.H , Samang L and Tjaronge M.W, “Characteristical Analysis of Unconfined Compressive Strength and CBR Laboratory on Dredging Sediment Stabilized With Portland Cement”, *International Journal of Civil & Environmental Engineering*, **12**(04), pp. 25-31.

[7] Marto A, Lativi N, Souhaei H, 2013, “Stabilization of Laterite Soil using GKS Soil Stabilizer”, *Engineering Journal of Geotechnical and Environmental*, **18**, pp. 521-532.

[8] Kiran S.P, A.N Ramakrishna, Shrinivas.H.R, 2014, “Stabilization of Lateritic Soil by using Sugarcane Straw Ash and Cement”, *Journal of Civil Engineering Technology and Research*, **2**(10), pp. 615-620.

[9] Yinusa A. Jimoh, O. Ahmed Apampa, 2014, “An Evaluation of the Influence of Corn Cob Ash on the Strength Parameters of Lateritic Soils”, *Civil and Environmental Research*, **6**(5).

[10] Nima Latifi, Amin Eisazadeh, Aminaton Marto, 2014, “Strength behavior and microstructural characteristics of tropical laterite soil treated with sodium silicate-based liquid stabilizer”, *Environmental Earth Science*, **72**, pp. 91–98, Springer-Verlag Berlin Heidelberg.

[11] Wisley Moreira Farias, Geraldo Resende Boaventura, Éder de Souza Martins, Fabrício Bueno da Fonseca Cardoso, José Camapum de Carvalho and Edi Mendes Guimarães., 2014, "Chemical and Hydraulic Behavior of a Tropical Soil Compacted Submitted to the Flow of Gasoline Hydrocarbons", *Environmental Risk Assessment of Soil Contamination, Intech*, pp. 638-655.

[12] Saing, Z., Samang, L., Haryanto, T. and Patanduk, J., 2014, "Microstructural and Mechanical Characteristic of Potential Ferro Laterite Soil as Sub-base Material", *International Journal of Innovative Research in Advance Engineering*, **3** (2), pp 42-48.

[13] Harianto, T., Hayashi, S., Du, Y.J., and Suetsugu, D., 2008, "Experimental investigation on strength and mechanical behavior of campacted soil-fiber mixtures", *In Geosynthetics in Civil and Environmental Engineering*, pp. 392-397, Springer Berlin Heidelberg.

[14] Ken O. C., and Okoafor F.O., 2012, "Geochemistry of Soil Stabilization", *Journal of Earth Science Asian Research Publishing Network*, **1**(1), pp. 32-35.

[15] Tanh D.T., Yu-Jun C., Anh Minh Tang, Martin A., Roger C., 2014, "Effect on lime treatment on the microstructure and hydraulic conductivity of Hericourt clay", *Journal of Rock Mechanics and Geotechnical Engineering*, Elsevier, **6**, pp. 399-404.

[16] Jaritngam S, O. Somchainuek, and P. Taneerananon, 2014, "Feasibility of Laterite-Cement Mixture as Pavement Base Course Aggregat", *International Journal of Science and Technology Transaction of Civil Engineering* Vol. **38**. No. C1+, pp. 275-284

[17] Pranshoo Solanki and Musharraf Zaman (2012). "Microstructural and Mineralogical Characterization of Clay Stabilized Using Calcium-Based Stabilizers", Scanning Electron Microscopy, Dr. Viacheslav Kazmiruk (Ed.), ISBN:978-953-51-0092-8, InTech.

[18] Zubair Saing, Lawalenna Samang, Tri Harianto and Johannes Patanduk, "Mechanical Characteristic of Ferro Laterite Soil with Cement Stabilizationas a Subgrade Material", *International Journal of Civil Engineering and Technology*, **8**(3), 2017, pp. 609–616.

[19] Zubair Saing, Vertical Deformation of Lime Treated Base (LTB) Model of Laterite Soil using Numerical Analysis. International Journal of Civil Engineering and Technology, **8**(5), 2017, pp. 758–764.

[20] Saing, Z., Samang, L., Harianto, T. and Patanduk, J., 2016, "Quick Lime Stabilization of Ferro Laterite Soil to Subgrade Material Implementation", *International Journal of Science and Research*, 5 (11), pp 582-586.