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Performance of Laterite Soil Stabilized with Lime and Cement as a Road Foundation

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Abstract

As many areas in west Papua region are covered by the laterite soil and noticeable shortage of stones and sand, further study and development are required on the work of using lime and cement for soil mechanical properties improvement. Laboratory and field testing programs were conducted to evaluated lime-cement treated laterite soil for application in the evaluation procedures of pavement structures. The laboratory program consisted of performing unconfined compression test on lime-cement treated laterite soil. The field testing program included conducting in-situ tests of Light Weight Deflectometer (LWD), and field CBR. Based on the performance of the treated laterite soil observed in the present study it can be suggested that the treated laterite soil with lime and cement content of 12% and 5%, respectively, can be employed as a pavement foundation layer to bear the vehicle loads.

Keywords: Lime, cement, laterite soil, unconfined compression, LWD value, field CBR value

INTRODUCTION

In particular many areas at West Papua in Indonesia are covered with the laterite soil. At dry condition, the hardened laterite soil can be compacted to produce the hardened layer but in wet or rainy condition the hardened laterite soil becomes a loose layer due to the vehicle load, therefore it is not suitable as a subbase layer or foundation for road pavements construction. It is important to improve the mechanical properties of the less competent soil due to the existence of conventional good quality materials such as sand, stone and gravel are limited in those areas.

Based on many investigations lime and cement have been regarded as the effective materials to improve the soil properties and their stabilization mechanisms being relatively well understood (e.g., Portelinha 2012; Praticò and Puppala 2012). When cement is blended with soils, the stabilization mechanisms arise from the hydration and pozzolanic reactions. In lime stabilized soils, the soil particles become closer and the soil is stabilized through flocculation and pozzolanic reactions.

Many investigations in the literature address the quality assessment of the stabilized soil using the laboratory unconfined compression test (e.g., Zhang and Tao 2008; Dash and Hussain 2012; N. Yoobanpot et al. 2017; Horpibulsuk et al. 2005)).

One of the empirical or experimental methods to assess pavement materials used by road engineers as a field method for characterising the bearing capacity of soils and unbound granular materials is the Californian Bearing Ratio (CBR) test (e.g., Al-Amoudi et al. 2002; Seman and Shoop 2007).

In recent times, lightweight falling deflectometer (LWD) device has been introduced and employed to investigate directly the stiffness of compacted layers of pavement structure, instead of testing the quality of those layers in term of field density. A number of existing investigations have provided detailed descriptions of LWD for evaluating soil compaction in the field (e.g., Meehan et al. 2012; Tehrani and Meehan 2010; Rao et al. 2015; Umashankar, et al. 2015; Ebrahimi and Edil. 2015; Shaban and Cosentino 2016).

Liming and cement stabilized were employed to improve the mechanical properties of laterite soil in this study. In order to assess the suitability of the stabilized laterite soil as a subbase layer or foundation of road construction, this study conducted several laboratory and field investigations as the devise criteria to which stabilized laterite soil must comply in order to qualify for a use in a road pavement structure.

MATERIAL AND EXPERIMENTAL METHODS

Laterite Soil

Laterite soil obtained from Merauke district, West Papua region. Table 1 shows laterite soil properties. The general properties of laterite soil can be classified into the A-7-5 group according to ASTM D-427. Table 2 shows chemical characteristics of laterite soil.

Table 1. Laterite soil properties

No.	Physical properties	Value
1	Specific gravity	2.58
2	Sieve analysis	>30% (passing sieve) no.200
3	Atterberg limits	
	a. Liquid limit (LL)	46.10%
	b. Plastic limit (PL)	24.31%
	c. Plasticy index (PI)	21.79%
4	Soil classification	A-7-5
	Mechanical characteristics	
1	Compaction	
	a. ɤdry	1.60 gr/cm^3
	b. W_{opt}	21.64%

Table 2. Chemical characteristics of laterite soil

Component	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MgO	ZrO_2	K_2O	SO_3	Cl
Content (%)	73.74	17.49	5.61	1.82	0.7	0.23	0.14	0.10	0.05

Portland composite cement (PCC)

In this research Portland composite cement (PCC) was used for the laterite soil and hydrated lime blended. This cement is produced by a national cement factory and complies with ASTM blended cement Type IP (Portland-pozzolan cement). Table 3 shows the physical properties of PCC. A study conducted by M. W. Tjaronge et al (2014), stated that the self compacting concrete containing PCC underwent the hydration process and created the tobermorite ($_3CaOSiO_2H_2O$) to develop the compressive strength of the hardened concrete with the elapse time.

Table 3. Physical properties of Portland composite cement (PCC)

Material characteristics	SNI 15-7064-2004 Standard	Value
Water content (%)	12 max.	11.5
Smoothness	280 min.	382
Expansion, % (max.)	0.8 max.	-

Compressive strength			
a.	3 days (kg/cm^2)	125 min.	185
b.	7 days (kg/cm^2)	200 min.	163
c.	28 days (kg/cm^2)	250 min.	410
Time hardening (Vicat test)			
a.	Initial hardening, minute	45 min.	132.5
b.	Final hardening, minute	375 min.	198
False bond time		50 min	-
Hydration temperature 7 days, cal/gr			65
Normal consistency (%)			25.15
Specific gravity			3.13

Unconfined Compression Stress (UCS) Test

The lime used in this study was calcium hydroxide (traditionally called slaked lime), $Ca(OH)_2$. The lime content was optimized at a content of 12% based on the preliminary test results by the authors, and the corresponding mixture was used for subsequent lime-cement laterite soil stabilization experiments. Cement content of 3, 4 and 5% was used to determine the optimal content of lime and cement as stabilizer for the treated soil. UCS test was conducted according to SNI 03-6887-2002. Figure 1 shows the UCS test in laboratory. The soil samples for UCS test were prepared using cylindrical molds, which have an inner diameter of 5 mm and a height/diameter ratio of 2.0 for reducing the end effects during UCS testing. Three replicates of each sample set were prepared to assure reproducibility.

Figure 1. Equipment of UCS test in laboratory

Field Test Site

The field investigation was conducted on a selected mixture based on the unconfined compression test result. The field study described in this paper was performed at borrow pit in Merauke district, West Papua province. The field preparation can briefly be described as follows:

A 15 -m-long x 3-m wide x 0.25-m deep pavement sub base layer was laid and constructed on the uncompacted layer of the laterite soil ground. Caterpillar RM 01 rotary machine was used to create a loose layer of laterite soil with thickness of approximately 0.25 m. The Caterpillar RM 01 rotary machine was equipped with a computerized system, which proved beneficial for establishing a relatively uniform and consistent

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loose layer thickness. After spreading the hydrated lime on the loose soil layer, a Caterpillar RM 01 rotary machine was used to spread water and to blend the loose soil with the hydrated lime. Upon completion of blending, the mixture of the laterite soil and hydrated lime was compacted in one lift using a Caterpillar CS56 vibratory smooth drum roller. Upon completion of compacting, the blended soil layer was covered by a layer of plastic and cured for 24 hour to reduce the PI index. After cured, the hardened layer of the mixture of the laterite soil and the hydrated lime was blended again using a Caterpillar RM 01 rotary machine to create a loose layer with thickness of approximately 0.25 m. After spreading the PCC on the loose layer of the mixture of the laterite soil and the hydrated lime, a Caterpillar RM 01 rotary machine was used to spread water and to blend the loose layer of the mixture of the laterite soil and the hydrated lime with the PCC. Upon completion of blending, the blended soil layer was compacted in one lift using a Caterpillar CS56 vibratory smooth drum roller. Compaction of the treated soil layer involved thirteen passes to achieve a relative compaction of 90%. Upon completion of compacting, the blended soil layer was cured until testing day. Figure 2 shows mixing and compaction process on the field.

Figure 2. Mixing and compaction process on the field

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Light Weight Deflectometer (LWD) Test

The Ministry of Public Works and Public Housing's Institute of Road Engineering, Agency for Research and Development (Pusjatan) has developed LWD device that used in this present study. The LWD measures the deflection of the test layer produced from a given drop weight, drop height, and load according to the Indonesian National Standard (Pd–03-2016-B, SE PUPR Minister No/19/SE/M/2016), "Standard Test Method for Measuring Deflections with a Light Weight Deflectometer.". Furthermore the deflection value obtained from LWD is used to determine the elasticity moduli of E_{LWD}. Table 4 shows properties of various light weight deflectometer devices. Figure 4 shows LWD test to measure the deflection at the prepared field.

Table 4. Properties of Various Lightweight Deflectometer Devices

Properties	Zorn	Prima	TFT	Dynatest	LWD Used in This Research
Plate style	Solid	Annulus	Annulus	Solid	Solid
Plate diameter (mm)	150, 200, 300	100, 200, 300	100, 150, 200, 300	100, 150, 200, 300	300
Drop mass (kg)	10	10, 15, 20	10, 15, 20	10, 15, 20	20
Drop height (m)	0.72	Variable	Variable	Variable	1.20
Damper	Steel spring	Rubber	Rubber	Urethane	Rubber

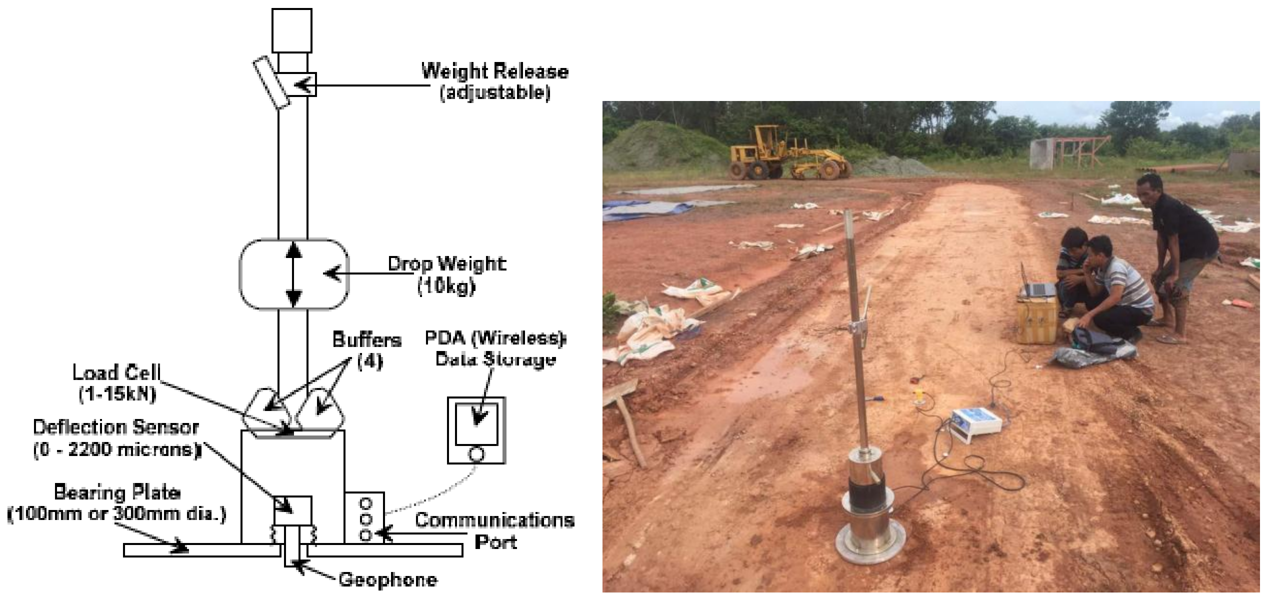

Figure 4. LWD test for measuring the deflection at the field

Field CBR Test

Figure 3 shows the field CBR equipments. CBR test was conducted in general standard practice accordance with SNI 1738:2011 (Standard Test Method for CBR (California Bearing Ratio) of Soils in Place).

Figure 3. Field CBR testing equipments

Correlation between field CBR and E_{LWD} Value

The field CBR value can be determined as a function of E_{LWD} value using an equation that established by Nazal (2003) in Nageshwar Rao, et al., (2008) as following expression:

$$CBR = 14.0 + 0.66\,(E_{LWD}) \quad \ldots\ldots (1)$$

RESULTS AND DISCUSSION

Influence of Lime and Cement Addition on Unconfined Compression Stress

Fig. 5 depicts the effects of lime-cement content on the stress-strain behavior curves of the treated laterite soil in the UCS test at 7 days curing. All mixtures illustrate that the compression stress of treated soil increased with an increase in axial strain up to a certain peak. After reaching the peak strength, the unconfined compression stress was stable while the axial strain increase and strain softening occurred prior to fracture. It is evident that treated soil with lime and cement has ductile behavior in compression. As shown in Fig. 7, the treated soil with cement content of 3, 4 and 5 % attained the fracture strain of 4, 4 and 5.2%, respectively. This result revealed that at lime content of 12%, the improvement of ductility in compression for treated soil by cement increment is significant.

The maximum unconfined compressive stress with referred to the unconfined compression strength increased as cement content rose. The treated soil with constant lime content of 12% and varied cement content of 3, 4 and 5% corresponded with the unconfined compression strength of 2.2, 2.5 and 3.5 MPa, respectively, and occurred at axial strain of 2, 2 and 3.5 %, respectively. Accordingly, from the test results the optimum amount of cement content is reasonably selected at 5%.

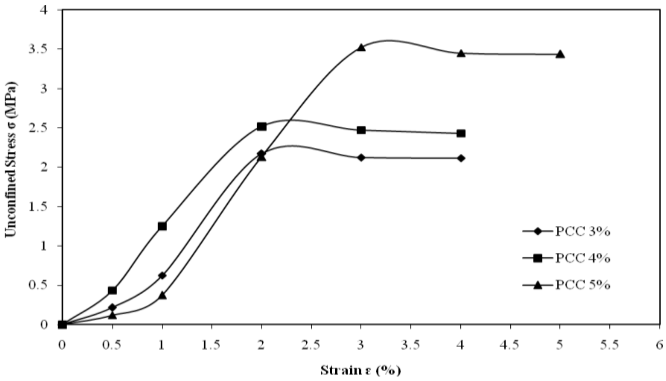

Figure 5. Stress- Strain curves of the treated laterite soil

E_{LWD} value and Field CBR value

The field investigation was performed on a selected mixture with lime and cement content of 12% and 5%, respectively, upon completion the blending, compaction and curing process. Table 5 shows the E_{LWD} values, corresponding standard deviation and coefficient of variation (CV) values. There were total of twelve test point were conducted for treated soil layer

The value of the deflection (ώ) and the E_{LWD} value were found to similar along the pad length, owing to consistent in the compaction energy imparted of the compactor passes that corresponds to the similar density of the each testing point at the treated laterite soil as shown in Figure 6 and Figure 7. The deflection of treated layer was found to range from approximately 0.122 to 0.163 mm and it was represented by an average value of 0.14 mm as shown in Table 5 and Figure 6. The CoV in deflection from test location on treated soil was found to be 8% as shown in Table 5.

The E_{LWD} value of the treated soil layer was found to range from 207 to 252 MPa with an average value of 232.75 MPa as shown in Table 6 and Figure 7. The E_{LWD} modulus was found uniform with the coefficient of variation (CoV) of 6%. This means that the treated laterite soil with lime and cement content of 12% and 5% provided a stable layer.

The E_{LWD} value of the treated soil layer obtained in the present study was then compared to the E_{LWD} value obtained by other related investigations. Rao, et al (2015) reported the E_{LWD} value of the lateritic subgrades of Dakshina Kannada, in India found to range from 5 to 175 MPa as reported in a figure of correlation between PFWD and CBR observations. This result is in good agreement with the E_{LWD} measurements on the treated soil conducted on the test pad considered in the present study. Furthermore, the E_{LWD} value of the asphalt surface layer, constructed using dense-graded bituminous macadam was found to range from 105 to 120 MPa as reported by Umashankar, et al (2015). In this regard, the E_{LWD} value obtained in the present study showed that the treated laterite soil layer can be used together with other layer pavement as subbase layer or foundation to bear the vehicle loads.

Table 6 shows the compaction rate and field CBR value of the treated soil were 86.2% and 112.44%, respectively. The results would be reflective of the improvement in the soil's mechanical properties by using lime 12% and cement 5%. The correlation between the estimated E_{LWD} value and the CBR value as shown in Equation 1 is adopted in this study to verify the result of E_{LWD} value obtained by LWD device. The purpose of Table 7 is to describe the comparison between the CBR value obtained by in situ device and the CBR value estimated by Equation 1. Through this comparison, it can be observed that the CBR value (112.44%) of the treated soil layer obtained by in situ device had a similar value with the CBR value (129.76%) of the treated soil layer estimated by the E_{LWD} value using Equation 1.

Table 5. LWD test results at 7 days curing

Test Point	STA	ώ	E_{LWD} (MPa)
1	0.01	0.141	226.00
2	0.011	0.138	244.00
3	0.013	0.137	224.00
4	0.017	0.163	226.00
5	0.018	0.138	235.00
6	0.019	0.128	252.00
7	0.02	0.122	241.00
8	0.021	0.133	244.00
9	0.022	0.127	233.00
10	0.023	0.130	246.00
11	0.024	0.143	207.00
12	0.025	0.139	215.00

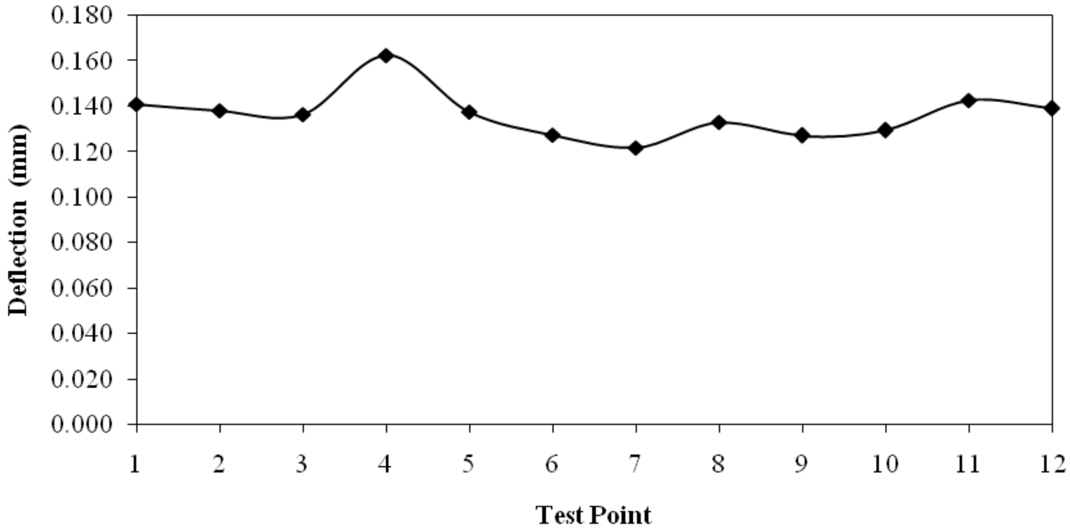

Figure 6. Deflection -Test point curves of the LWD test result

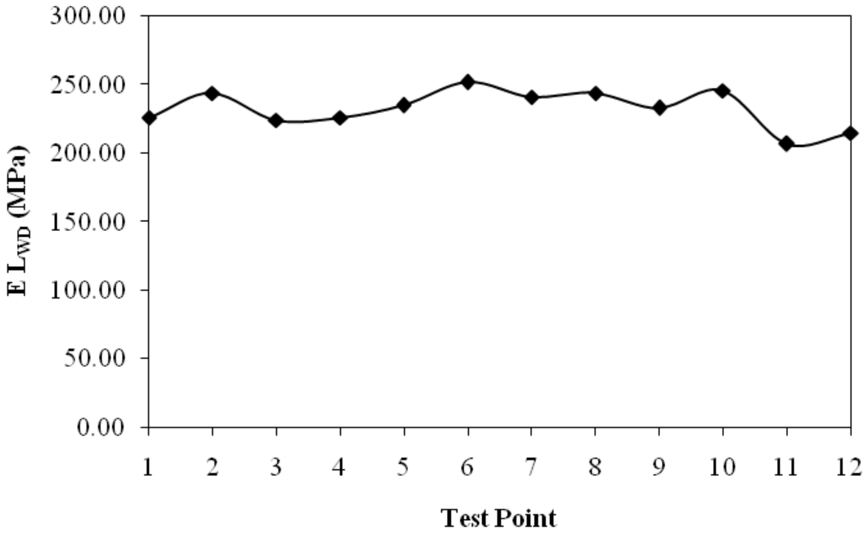

Figure 7. ELWD-Test point curves of the LWD test result

Table 6. Recapitulation of LWD Test Results

Statistical properties	**Deflection (ώ)**	**E_{LWD}**
Mean	0.15 (mm)	232.75 (MPa)
Standard deviation, σ	0.02 (mm)	26.63 (MPa)
Coefficient of variation, CoV (%)	8	6

Table 7. Comparison between the in situ CBR value the estimated CBR value

Field Density	**CBR value (in situ)**	**CBR value (estimated by Equation 1)**
86.2 (%)	112.44 (%)	129.76 (%)

CONCLUSIONS

1. According to the results of this study, the optimum value of strength was found at PCC 5% with lime content 12% where the compaction rate and field CBR value of the treated soil were 86.2% and 112.44%, respectively.
2. Field CBR, deflection and E_{LWD} values obtained in the present study show that the treated laterite soil had capacity to bear vehicle loads and can be used as a subbase layer or foundation of pavement structure.

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