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# Compaction characteristics of lime-treated tropical soil

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**Abstract.** Like soils of other regions in the world, some tropical soils are also associated with problems of low strength. To improve engineering characteristics of soils, several methods have been employed worldwide which are categorized as mechanical, chemical, thermal and electrical. The aim of this research is to compare the compaction characteristics of untreated and lime-treated soils. Soil samples obtained from three different points within a project site in Klang, Selangor were utilized in this study. Each sample was subjected to Eades and Grimm's test in accordance with ASTM D6276-99a to determine the appropriate lime dosage for soil stabilization. The required lime dosage was found between 1.3% and 3.4%. Then each untreated soil and soil sample mixed with 5% lime, higher than that obtained from Eades and Grimm's tests were compacted in accordance with BS 1377:1990. Generally, each soil sample achieved lower values of maximum dry density after treated with 5% lime than those of the untreated soils. Such observations were in good agreement with those obtained by previous researchers working on lime-treated soils. Nonetheless, the optimum moisture content of the lime-treated sample from Points 1 was slightly higher than that of the untreated sample. This finding was different from those obtained by previous researchers. Such contradicting observation might be due to the type and quantity of mineralogical contents of the soils studied.

Keywords: lime, compaction, tropical soil

## 1. Introduction

Poor engineering properties of soil may lead to bearing capacity failures and intolerable settlements upon placement of loads. Hence, effective remediation programs need to be undertaken so that structures to be built on this type of soil will not be exposed to devastating failures in terms of safety and cost. Several methods have been employed worldwide to improve the engineering characteristics of soils. Such methods can be categorised into different classes of stabilisation, which are mechanical, chemical, thermal and electrical. Stabilisation at shallow depths may involve chemical treatment and compaction, whereas deep stabilisation may include piling, vibrocompaction, stone columns, lime piles, etc. The methods employed are normally chosen based on site conditions, soil characteristics, location, available technology and more importantly the cost.

With regard to chemical stabilisation, the general objectives of mixing chemical additives with soils are to improve or control volume stability, strength and stress-strain properties, hydraulic conductivity and durability [1]. Volume stability against swelling and shrinkage can be improved by replacement of



high hydration cations such as sodium with low hydration cations such as calcium, magnesium, aluminium or iron. Several types of additives have been proven to successfully improve the engineering characteristics of clayey soils worldwide. Among the chemicals that have been utilised to improve engineering properties of soils in the forms of either solution or powder include cement, fly ash, calcium chloride, sodium chloride, gypsum, bitumen and sodium silicate [2, 3, 4, 5, 6]. In addition, chemicals normally used in grouting can also be applied to improve the engineering characteristics of the soil, but their costs are considered as prohibitive [1].

Several techniques of soil improvement have been proven applicable for both temperate and tropical soils. Nonetheless, special attention has to be emphasised on improving tropical soil since most of the established methods were studied and developed particularly for temperate soils. Hence, the adoption of such techniques to tropical soils has to be done with great precautions. Thus, the aim of this research is to establish the compaction characteristics of the untreated and lime-treated soils.

## 2. Literature Review

All aspects of soil stability such as bearing capacity, slope stability, the supporting capacity of deep foundations and penetration resistance depend on soil strength. In general, resistance to shearing stress is developed in soils by particle interlocking, meshing of irregularities on particle surfaces, adhesion, cohesion and cementation by secondary minerals such as iron oxides and carbonates, which are deposited interstitially. Clay minerals are also playing an important role in establishing shear resistance of soils. Cohesion, under the influence of physico-chemical properties, has a direct impact on the strength of a soil. Several sources of cohesion have been proposed, which include cementation, electrostatic and electromagnetic attractions, primary valence bonding and adhesion. Three possible causes for the development of bonds according to [7] are i) cementation through the deposition of carbonates, hydroxides, organic matter, ii) solution and re-precipitation of cementing agents, such as silicates and iii) growth of bonds during the chemical alteration of minerals.

The stabilisation of soil using chemical additives involves chemical reactions between the additives and the soils, which are controlled largely by the surface-chemical properties of the earth material. Accordingly, the development and maintenance of high strength and stiffness are achieved by elimination of large pores, by bonding particles and aggregates together, by the maintenance of flocculent particle arrangements and by preventing swelling. Shallow stabilisation is normally performed by adding stabiliser, where soil and additive are mixed thoroughly, compacted and allowed to cure. The most commonly used additives for soil improvement are Portland cement, lime and bitumen. In terms of quantity of additives to be used, lime treatment levels of 3% to 8% by weight of dry soil are typical for improvement of plastic and expansive fine-grained soils [8].

Garzón et al. (2016) performed laboratory investigation on a Spanish phyllite clay treated with 3, 5 and 7 % lime [9]. It was found from the study that the addition of 3 wt.% lime was sufficient to reach the index of capacity amble specified in the Sheet of Technical General Prescriptions for Works of Roads and Bridges PG-3, significantly reducing the [plasticity](#) index value, with the compacted mixture undergoing no swelling under soakage [10]. In another study on Algerian clay soils, showed that both the cohesion and internal friction angle in lime added samples increased with time [11].

Lime-clay reactions can be categorised into two distinctive time dependent phenomena, namely short-term reactions and long-term reactions. Short-term reactions or termed as a modification in most cases is more or less instantaneous, whereas the modification takes place within approximately 24 to 72 hours of mixing lime and clay together [12, 13]. The most probable hypothesis for the immediate actions of lime is that of a linkage process between the clay minerals [14]. It was found that the reactions caused the clay particles to undergo flocculation to form aggregates resulting in a permanent chemical change, which produced a new material that has a needle-like interlocking molecular structure compared to the plate-like structure of natural clays [13].

Long-term reactions (stabilisation) between lime and siliceous clay components occur more slowly, and these reactions can continue for years. The established high pH environment (12.4) causes the silica and alumina to dissolve from the clay particles (Mitchell, 1981 and Glendinning and Rogers, 1996). The

chemical reactions between lime and these pozzolanic components form gels of calcium silicate and calcium aluminate, which bind the soil particles together (Glendinning and Rogers, 1996). With time, these gels gradually crystallise into calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH).

With regard to strength enhancement, the previous study found that strength increases of 10 to 20 times the untreated value are perhaps typical [8]. In a related study, showed that there is a linear relationship between the unconfined compressive strength and the lime content, whereby the strength of the tested soil continued to increase with the increase in lime percentage with the anticipation that a maximum will occur at the lime content larger than the 8% used in the study [15].

In addition to soil improvement or strengthening especially those involving clayey soils, attempts have been made to use lime to stabilise contaminated soils. Such attempts were accomplished by mixing lime and the contaminated soil at the site using mechanical means [16, 17]. This type of stabilisation can be categorised as stabilisation and solidification, where the contaminants are immobilised due to increase in pH whilst the reactions between the clayey soil and the lime produce cementitious materials, solidify the soil-lime mixture and entrap the contaminants. In order to evaluate the effectiveness of this method of stabilisation, tests have to be performed which among others include leaching, hydraulic conductivity as well as shear strength before and after leaching.

Laboratory experiments on lime stabilised contaminated soils were also conducted by several researchers. In overall, the authors believe that this stabilisation technique is able to produce a stabilised material that is capable of retaining their long-term integrity in terms of strength and low hydraulic conductivity [18, 19, 20]. The concentrations of contaminants mainly heavy metals are reduced significantly in the effluents of the leaching tests. It is also learnt from the study that cementitious materials are continuously developed during the leaching process.

### **3. Materials and Laboratory Tests**

Soil samples were collected from three different points within a proposed project in Klang, Selangor. Adequate quantities of soils were picked from each sample for pH determinations. Then the remaining soil samples were oven dried for 24 hours after which lumps present in the samples were broken using rubber pestles. Sieve and hydrometer analyses were performed on the three samples. Eades and Grimm's test was carried out to determine the appropriate lime dosage for soil stabilization [21]. The Standard Proctor compaction tests on the soil samples were performed as specified in the BS1377:1990 to establish a compaction curve for each soil sample to be used as reference [22]. Compaction on lime treated soil samples was also conducted to establish compaction curves of lime treated soils. The mixture of lime treated specimens was kept for 24 hours prior compaction test to ensure the uniformity of the specimens. The hydrated lime used in this study was supplied by Lhoist (M) Sdn. Bhd and the pH is monitored regularly to ensure its alkaline condition.

### **4. Results and Discussion**

Results from the sieve and hydrometer analyses are as shown in Figure 1. In terms of grain size, the soil samples obtained from Points 1 and 2 are categorized as silt with sand and gravel, whilst soil from point 3 is categorized as sand with fine and gravel. The pH values are 6.81, 6.43 and 6.48 for soil samples Points 1, 2 and 3, respectively. Even though soils from Points 1 and 2 showed similar particle size gradation, the difference in pH might be due to the difference in terms of the types and quantity of mineralogical content.

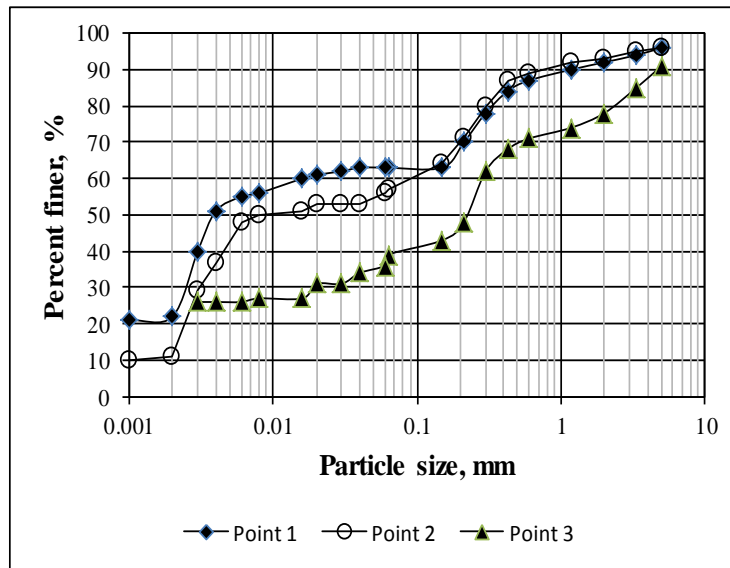


Figure 1. Particle size distribution of soils from points 1, 2 and 3.

Note that the minimum required lime content for soil stabilization is when the pH of soil-lime mix equals to 12.4. Results from the Eades and Grimm’s tests on the soil samples as shown by Figs. 2 – 4 yielded 1.4%, 3.4% and 1.3% lime required for stabilization of soils from Points 1, 2 and 3, respectively. As in the case of pH of the soils, the difference in terms of lime requirement might be due to the difference in the types and amount of mineralogical contents of the soil samples. It can be summarized that soil from Point 2 was the most acidic and required a higher amount of lime for stabilization than those from Points 1 and 3. Addition of 5% lime to soil samples for compaction tests on the lime-treated soils was chosen to cover the range of lime dosages obtained from the Eades and Grimm’s tests. Furthermore, the extra dosage was considered as a precaution to achieve uniformity of soil-lime mixes.

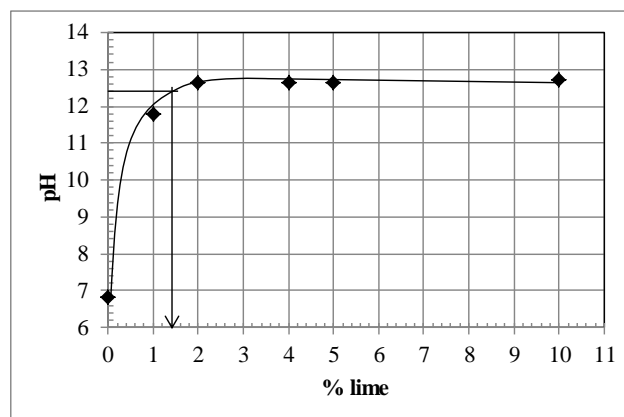


Figure 2. Results of Eades and Grimm’s test on soil Point 1.

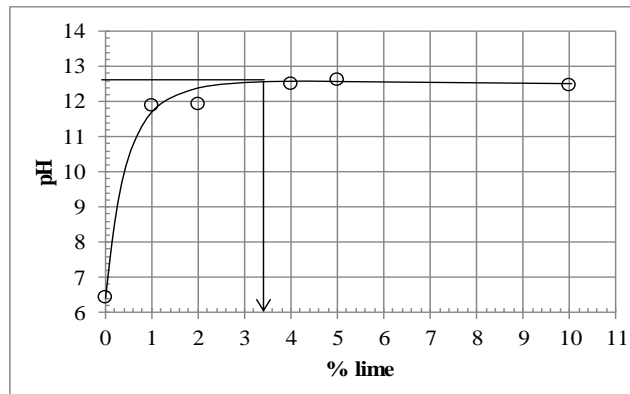


Figure 3. Results of Eades and Grimm’s test on soil Point 2.

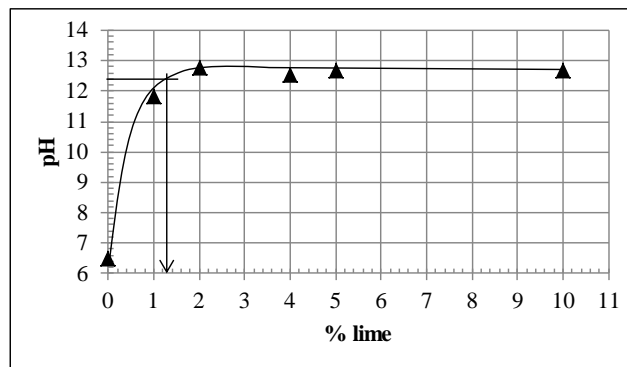


Figure 4. Results of Eades and Grimm’s test on soil Point 3.

The results of compaction tests performed on the untreated and soil-lime mixes are illustrated in Fig. 5 – 7. As shown in Fig. 5, the maximum dry density of soil from Point 1 is 1.67 Mg/m<sup>3</sup> after the addition of 5% lime, lower than that of the untreated soil which is 1.76 Mg/m<sup>3</sup>. The optimum moisture contents to achieve the maximum dry densities are 13.3% and 15% for the untreated, and the lime-treated samples, respectively.

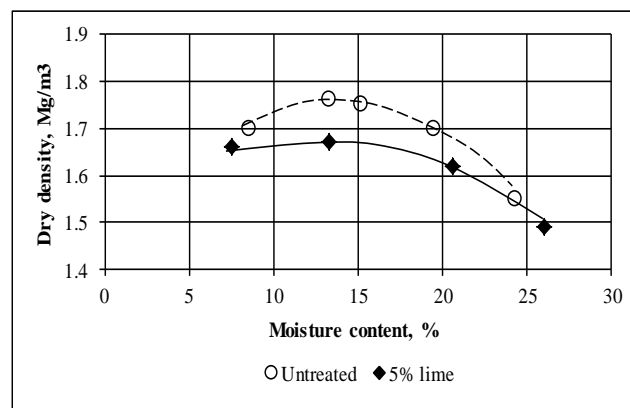
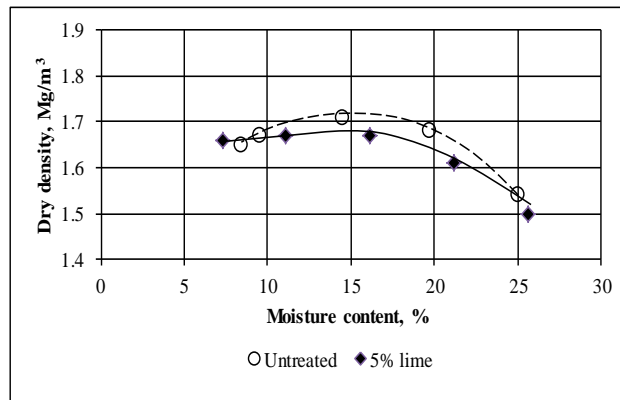


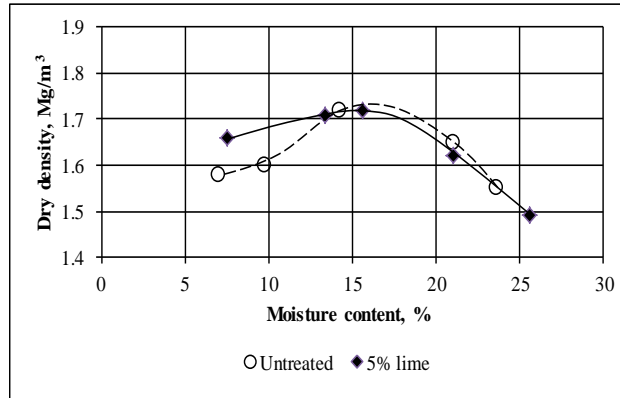
Figure 5. Compaction curves of soil Point 1.

In the case of soil from Point 2 shown in Fig. 6, adding 5% lime produced a maximum dry density of 1.67 Mg/m<sup>3</sup>, which is lower than that of the untreated sample 1.71 Mg/m<sup>3</sup>. Both the untreated and the lime-treated samples achieved their maximum values of dry density with similar optimum moisture content 16%.



**Figure 6.** Compaction curves of soil Point 2.

Fig. 7 illustrates the results of compaction tests performed on soil from Point 3. The maximum dry density of soil from Point 3 is 1.72 Mg/m<sup>3</sup> after the addition of 5% lime, lower than that of the untreated soil which is 1.73 Mg/m<sup>3</sup>. The optimum moisture contents to achieve the maximum dry densities are 16.5% and 15.5% for the untreated, and the lime-treated samples, respectively.



**Figure 7.** Compaction curves of soil Point 3

Chemical reactions in soils, due to their nature are complicated processes where at times difficult to predict and to reproduce. Mixing lime with clay in the presence of water resulted in ion exchanges, causing a reduction in thickness of the double layer and changes in consistencies of the clay [12, 23, 24, 25, 26]. Adding lime to soil containing clay minerals with the present of water would result in the formation of calcium aluminate silicate hydrate (CASH) gel. Due to the different amount of clay minerals in the soils as suspected, the quantity of CASH might be different leading to different characteristics of the compacted soil-lime mixes as observed from the obtained results. These gels might facilitate lubrication between soil particles thus resulting in good packing and high maximum dry unit weight. On the other hand, a high amount of lime might be detrimental leading to increase in frictional forces between soil particles that inhibited good packing which resulted in low maximum dry unit weight. With time, these gels gradually crystallise into calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH). Nonetheless, all the untreated and soil-lime mixes showed a similar trend

where the values of dry density increased with moisture content up to the optimum moisture content beyond which the values of dry density decreased.

## 5. Conclusions

Series of laboratory tests involving particle size distribution, Eades and Grimm's and compaction were conducted on soil samples obtained from three different points within a proposed project site in Klang, Selangor. The three samples in overall contain fine, sand and little gravel, with samples from Points 1 and 2 are almost similar in terms of particle size gradation. Generally, each soil sample achieved lower values of maximum dry density after treated with 5% lime. Such observations were in good agreement with those obtained by previous researchers working on lime-treated soils. In addition, the optimum moisture content of the lime-treated sample from Points 1 was higher than that of the untreated sample. This finding was different from those obtained by previous researchers. Such contradicting observation might be due to the type and quantity of mineralogical contents of the soils studied.

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