Effects of Cement on the Compaction Properties of Lateritic Soil

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Abstract. Lateritic soils at Universiti Teknologi Malaysia (UTM) Skudai, Malaysia was investigated subjected to their geotechnical properties and their suitability to be used as construction materials. The soil samples were collected and tested for various basic soil properties tests such as Atterberg Limit, Specific Gravity (SG), Sieve Analysis, and Compaction test. Atterberg's consistency limit test shows that the liquid limit (LL) is 70.3%, the plastic limit (PL) is 42.0%, and the plasticity index (PI) is 28.3%. The specific gravity (SG) value for laterite is 2.74. For the compaction test, the optimum moisture content (OMC) and maximum dry density (MDD) obtained are 28% and 1.39 g/cm³. A laboratory study was performed to compare and evaluate the stabilization efficiency of different percentages (3%, 6%, 9%, 12%) of Ordinary Portland Cement (OPC) when applied to the available laterite soil; a major soil group in the tropical areas. Analysis of laboratory data is assessed from a soil compaction test through the standard proctor method by using the automatic compactor. The soil mixtures were compacted at optimum moisture content in accordance with the British Standard (BS) of BS 1377-4:1990. From the preceding results, it was found that the OMC increase from 28% to 34% while the MDD increase from 1.39 g/cm³ to 1.47 g/cm³ with the rise in the percentage of cement.

1. Introduction
It has been estimated that road lengths in Malaysia are around 216,837 kilometres which are comprised of federal and state roads [1]. Mainly, the roads are categorized under low volume road type enclosed by rural development as it promotes access to people for generating their income. But due to the rapid population growth, Malaysia is facing an insufficiency of desirable road infrastructure. Therefore, the soil stabilization method may be used in the process of low-volume road enhancement in Malaysia to achieve a self-sustaining nation.

Lateritic soils are soil groups rich in iron where they are formed in hot and wet tropical regions. Generally, all lateritic soils are developing by intensive and severe weathering of the parent rock, and mostly they are in reddish-brown because of the high iron oxides content. Laterite soils comprise about one-third of the earth's continental land sections [2]. Besides, lateritic soils are shaped from the leaching of parent sedimentary rocks (clays, limestones, sandstones), volcanic rocks, and mineralized rocks, which permit the more enigmatic irons, mostly iron and aluminium [3].

Normally, laterite soils have been used as subgrade layers for low-volume road pavement because they are easy to operate on the road surface and naturally have grading stability [4]. Besides, they also have a certain proportion of clayey materials, which act as binders in pavement layers. Therefore, to
attain a sustainable road, the process of soil stabilization shall be implemented as stated by various researchers such as [5], [6], [7], and [8].

Soil stabilization is extensively known as soil treatment which allows the soils in advancing their strength and durability such that they will be beyond their original properties in construction purposes. Soil stabilization techniques may include the blending or mixing of soils with the available additives or agents that may alter the texture, gradation, or plasticity of soil [6]. Soil stabilization can be conducted through various techniques. All these techniques fall into two major groups, which are chemical and mechanical stabilization. Chemical stabilization is an alteration of soil geotechnical properties through a chemical reaction between chemical additives (lime and cement) and soil minerals (pozzolanic material) [9]. Mechanical stabilization is not the focus of this study; therefore, it will not be further discussed.

Cementitious stabilization is a type of chemical stabilization, which has been used widely and broadly in Malaysia. For instance, cement-stabilized soil was used as a road base instead of mine gravel at Labuk and North Roads in Sabah [10]. A model of cement-stabilized soil also was constructed by [11] to study the effect of weathering, soil-cement had been applied instead of using crushed aggregate in a road development at Labuan and Sandakan, Sabah [12], and cement stabilization of high fines in Melaka can achieve the compressive strength of 2.8 MPa through the fines content modification with river sand [13].

Soils are deemed as unique materials which they do not always show the desired properties for constructions. Hence, soil modification is necessary at the site, to enhance their engineering properties. Due to its cost-effectiveness, soil compaction is the widely used method to achieve soil properties enhancement. By compacting the earth fills, the subsequent soil settlement may be reduced, the soil permeability may be decreased, and the shear strength of the soil also can increase. Compaction is essential in many geotechnical applications such as railway subgrades, road pavements, and earth retaining structures. However, laboratory compacted soil is mostly used for pavement design.

Therefore, the main objective of this research is to compare the compaction characteristics of untreated and cement-treated lateritic soil. Besides, the author also intends to investigate the impact of cement percentage on the compaction behavior of soil.

2. Materials and Method
For the study, the disturbed samples were collected from a borrow pit nearest to Block P16, Faculty of Electrical Engineering at Universiti Teknologi Malaysia Skudai, where 40 kilograms of laterite soils were excavated using a backhoe, quickly placed in an airtight container, and brought to the laboratory for further laboratory analysis which includes: Natural Moisture Content, Atterberg Limit, SG, Sieve Analysis and Compaction test. Lateritic soils at Universiti Teknologi Malaysia (UTM) Skudai, Malaysia was investigated subjected to their geotechnical properties.

While cement that is used in this research is from the Holcim brand of OPC (CEM I 42.5N) which is manufactured by YTL Cement Sdn. Bhd. From the literature, it is deemed that cement acts to be a useful additive material. Therefore, this laboratory method is based on the formulation of the mixture between different cement percentages with poor material (lateritic soil) to produce a better quality product. The constituents of the OPC are described in Table 1, which took from the provided cement test certificate by YTL Cement Sdn. Bhd.
Table 1. Cement specifications from the test certificate of the Holcim OPC.

| Specification Items                  | MS EN 197-1:2014 (CEM I 42.5N) SPECIFICATIONS | Test Results |
|--------------------------------------|-----------------------------------------------|--------------|
| Initial setting time (minutes)       | MS EN 196-3:2007 Clause 6                    | 140          |
| Soundness : Expansion (mm)           | MS EN 196-3:2007 Clause 7                    | 1            |
| Compressive strength (N/mm^2) – 2 days | MS EN 196-1:2007                            | 25.8         |
| Compressive strength (N/mm^2) – 28 days | MS EN 196-1:2007                            | 52.4         |
| Loss on ignition, LOI (%)            | MS EN 196-2:2007 Clause 7                    | 0.97         |
| Insoluble residue, IR (%)            | MS EN 196-2:2007 Clause 9                    | 1.24         |
| Chloride, Cl (%)                     | MS EN 196-2:2007 Clause 14                   | 0.03         |
| Sulphate, SO_3 (%)                   | In house test method                         | 3.09         |

All the laboratory testing procedure starts with three days of air-dried process of the soil samples at the provided place, with a temperature of 26°C. After that, the procedure continues by drying the samples in the oven for three days at 60°C. The reason for this low-temperature drying technique is to avoid the desiccations of organic material and oxidation of the mineral elements in the lateritic soils, as well as mentioned by [14] in their research.

The grain size distribution is performed by a combination of wet sieving and particle analyzer method according to the [15] as well as the Atterberg limit and SG tests. While for the test that comprising moisture-density relationship is conducted on both untreated and treated lateritic soil according to the [16]. In the compaction test, the cement addition (3%, 6%, 9%, and 12% by dry weight of soil) was blended into the soil-water mixture with thoroughly mixing until a homogeneous wet cemented soil mixture was achieved.

After that, the soil is compacted into a 1000 cm³ volume of proctor mould by using an automatic compactor machine. The compaction effort performed throughout the laboratory test is the modified proctor method where the energy derived from 4.5 kg rammer falling through onto three layers which each is receiving 25 blows. Next, the samples are extracted by using the modified extruder. However, it is essential to note that, due to the utilization of the automatic mechanical compactor, the result dispersions do not subject to the compaction energy applied.

\[ \rho_b = \frac{W}{V} \]  
(1)

Where \( \rho_b \) is the bulk density, \( W \) is the weight of compacted soil and \( V \) is the volume of the mould. After that, from Equation 1, dry density is obtained.

\[ \rho_d = \frac{\rho_b \times (1 + \frac{MC}{100})}{1 + \frac{MC}{100}} \]  
(2)

Where \( \rho_d \) is the dry density and MC is the moisture content.

By compacting the soil through the modified proctor method, subsequent settlement may be reduced under working loads as well as decreasing the void gaps between soil particles because it creates difficulties for water to freely move and flow through the compacted soil.

3. Results and Interpretations
The engineering properties of lateritic soil have been obtained, as shown in Table 2. From the obtained particle size results, the soil tends to be clay and also considered as high plastic because the
PI value is more than 17 [17]. Besides, it shows that the specimen is sandy elastic silt following the USCS (Unified Soil Classification System) based on the grading curve results. The SG values of soil are quite high, which indicating that the soil is tropical iron-rich laterite. Compaction results for untreated soil are shown in Figure 1, where the OMC is 28%, and MDD is $1.39\, \text{g/cm}^3$.

**Figure 2** displays the compaction curves of laterite and cemented laterite specimens with 3%, 6%, 9%, and 12% of cement addition. The cemented soil exhibited greater values of MDD than the untreated one while the OMC fluctuates a little (**Figure 3**). This expresses a universal indication of soil enhancement. For instance, the MDD is increased from $1.39\, \text{g/cm}^3$ (natural laterite) to $1.41\, \text{g/cm}^3$ (3% soil-cement) and keep increased until $1.47\, \text{g/cm}^3$ (12% soil-cement).

It is deduced that the significant increment in MDD is because of the cement addition since the cement tends to loosen the silt particles in the presence of water, which causing denser packing during the compaction process. Hence, the increment of MDD in soil-cement mixtures is due to cement particles that performed cations exchange with the soil elements, thus occupying the voids and compactly packing the soil particles together. Besides, the fine cement particles tend to fill up the void spaces between the soil particles, which developing a denser soil matrix.

While for the OMC, it is increased from 28% to 30%, then it reduced to 28% and increased again until 33%. A similar trend has also been reported by [18], [19], [20], and [21] in their research. These patterns explained that an increase in OMC of soil-cement mixtures is because of the cementitious binder increment in the soil, facilitating the movement of ions in the pozzolanic reaction. However, the slight decrease in OMC at 9% soil-cement (from 30% to 28%) may be due to the self-degradation of the water used during the cement hydration process.

The zero air void line (ZAVL) present in the graph (**Figure 2**), acts as the baseline for the compaction results. ZAVL is well-known as a line which plots from the dry unit weight of soil versus moisture content at 100% degree of saturation. Therefore, if ZAVL overlaps the compaction line, that probably indicates the unreliability results; this is because, during the proctor test, air voids cannot be removed completely. Hence, the compaction curve can’t cross the ZAVL as ZAVL is the plotted line without any air voids in the soil.

### Table 2. Properties of lateritic soil.

| Property                        | Value                  |
|---------------------------------|------------------------|
| Natural Moisture Content (%)    | 40.34                  |
| Liquid Limit (%)                | 70.3                   |
| Plastic Limit (%)               | 42.0                   |
| Plasticity Index (%)            | 28.3                   |
| Gravel (%)                      | 13                     |
| Sand (%)                        | 18                     |
| Silt and Clay (%)               | 69                     |
| $C_u$                           | 8.96 (well-graded)     |
| $C_c$                           | 0.98 (well-graded)     |
| USCS                            | MH (Sandy Elastic Silt)|
| Specific Gravity                | 2.74                   |
| OMC (%)                         | 28                     |
| MDD (g/cm³)                     | 1.39                   |
Figure 1. MDD vs OMC graph for untreated lateritic soil.

Figure 2. MDD vs OMC graph for untreated and treated lateritic soil.
4. Conclusion
This paper investigated the influence of cement on the compaction characteristics of lateritic soil (OMC and MDD). Based on the obtained results, the following conclusions can be drawn:

1. The maximum dry density (MDD) increased with cement content, indicating that the addition of cement causes the specimen to denser.
2. The optimum moisture content (OMC) increased with cement content, implying that the more cement added, the more water is necessary.
3. The zero air void line (ZAVL) did not cross the compaction curves, indicating the correctness and reliability of the compaction results.

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