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Relationship between liquidity index and stabilized strength of local subgrade materials in a tropical area

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ABSTRACT

This paper presents the effect of soil liquidity index and cement stabilizer on strength properties for the usage of low traffic volume subgrade roads. Three types of soil were used to represent a different soil based on liquid limit value. Standard proctor tests have been conducted to determine the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of stabilized soils with 0%, 7%, and 13% Ordinary Portland Cement (OPC). In order to study the effect of the soil Liquidity Index, various moisture contents are used based on the OMC value from the compaction test (0.9, 1.0, and 1.1 from OMC). The California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) tests were conducted to determine the strength of all soil samples at optimum moisture content after 7 days curing period. It has been observed that the CBR and UCS values increased by increasing the percentage of cement content. This study found that 7% of cement content was the optimum percentage of cement content to be added to all tested soils to achieve the minimum required strength of 0.8 MPa and 80% CBR for low traffic volume roads. The presented results could provide a guideline for engineers as regards the property changes of the local subgrade materials in a tropical area due to the addition of cement content.

1. Introduction

Based on the road constructor authorities of the Malaysia Public Work Department (PWD), a low volume road can be defined as having low Average Daily Traffic (ADT), which is below 250 vehicles per day [1]. It can also be described as having less than one million of Equivalent Standard Axle Load (ESAL) crossing over the design life of the road [1]. These specifications dictate both stabilized base materials and stabilized subgrade layer to have a minimum California Bearing Ratio (CBR) of 80% and Unconfined Compressive Strength (UCS) of 0.8 MPa [1]. Soil stabilization technique using Ordinary Portland Cement (OPC) is one of the most popular methods to enhance the strength of subgrade materials, on account of the fact it is the most universal stabilizing agent for use on different types of soil conditions [2–4]. Several researchers have used the OPC as a stabiliser agent including Bergado et al. [5], Porbaha et al. [6], Topolnicki [7], Chew et al. [8], Kitazume [4], Guyer [9], and Meei-Hoan et al. [10]. They concluded that a chemical reaction between the stabilising agent and clay produces a cemented composite material and increases the strength of the soil, thus providing enhanced bearing resistance and settlement performance. Several factors affect the physical properties of soil–cement material including soil type, moisture content, quantity of cement, degree of mixing, time of curing, and dry density of the compacted mixture [11,12].

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Various studies have previously established the relationship between stabilized strength and affecting parameters in the stabilization process such as curing period, moisture content, and percentage of cement [13–19,6,12,20]. However, no attempt has been made to study the relationship between stabilized soil strength and Liquidity Index (Li), which is obtained by dividing the difference of in situ water content and Plastic Limit by the difference of Liquid Limit and Plastic Limit. This relationship is important because water is an influencing factor in the stabilization process and the in situ water content keeps changing due to environmental effects in practice [21].

This paper presents the relationship between stabilized soil compressive strength and Li. This relationship can be used as a guideline for subgrade material by using minimum cement and moisture contents to achieve the minimum required strength (compressive strength) for low traffic volume roads. Different soils including Silty Clay, Silt, and Laterite were used as subgrade materials. In order to study the potential relationship between the strength of each stabilized soil and Li, a series of laboratory tests were conducted under 7 days curing period and different percentages of cement content for each soil type, which are reported in the paper.

2. Materials

Three types of soil consisting of Silty Clay, Silt, and Laterite were used in this study as suitable materials for subgrade construction with the Plasticity Index of less than 55% [1]. These soils were selected based on their suitable characteristics, accessibility, and availability as local subgrade materials in a tropical area. Light brown reddish Silty Clay soil was brought from the top surface of local soil strata in Permas Jaya district, Johor, Malaysia. Based on the Unified Soil Classification System (USCS), this soil is grouped as clay of high plasticity, CH. Silt soil was originated from the top surface of another local soil strata in Kluang district, Johor, Malaysia and is classified as silt of high plasticity, MH, according to USCS. Laterite soil was collected from a hilly area near Universiti Teknologi Malaysia, Johor, Malaysia. All samples were left for 7 days air drying before using in tests. The properties of different soils are stated in Table 1. In order to enhance the strength properties of subgrade materials, OPC was used as a stabilizer agent to be mixed with each soil type.

3. Preparation of samples

For compaction test, mixtures of 2 kg were prepared at 0%, 7%, and 13% cement of the weight of each soil type. This range of cement content was recommended by Walsh-Healey Public Contracts Act (PCA) [22] for Silty and Clayey soils. The soil and OPC were mixed thoroughly to a uniform colour and water was added to facilitate the mixing and compaction process. A test was conducted immediately since the delay will decrease the shear strength [23]. The Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of each mixture were determined by the Standard Proctor compaction test. This test was conducted based on BS 1377: Part 4: 1990 [24] by using light compaction of 2.5 kg rammer Standard Proctor with free drop of 310 mm.

All samples were prepared at OMC value prior to conducting CBR and UCS tests. Then, CBR and UCS tests were conducted immediately after the 7 days curing period. The preparation of samples and procedure of CBR test was based on BS 1377: Part 4: 1990. Cylindrical soil–cement samples of UCS test were prepared with diameter of 38 mm and height of 76 mm based on BS1377: Part 7: 1990 [25]. For this study, only unsoaked CBR tests were conducted in order to compare with the UCS results under OMC condition. Unsoaked CBR tests were employed due to the similarity of sample condition during the testing between the UCS and Unsoaked CBR tests. In addition, two extra cylindrical samples were prepared with moisture contents of 0.9 and 1.1 OMC to study the relationship between soil Liquidity Index and strength of the mixtures. The samples were prepared at only three different moisture content value based on the acceptable range between the MDD results from laboratory and field where 95% as the differences (Yoder and Witczak). On other hand, these moisture content values were used due to the easy technique on preparing and handling during the UCS testing. Otherwise, a broken sample will be gained if the moisture less than 0.9 and more than 1.1 OMC value. Simple notations are used in this paper to explain the conditions of 0.9 and 1.1 OMC as minimum and maximum, respectively. In total, nine samples were prepared for each soil type which was cured for 7 days before conducting the relevant tests.

4. Results analysis

4.1. Standard proctor compaction test

Fig. 1 shows the results of compaction tests for different mixtures of stabilized soil. The values of MDD and relevant OMC for each mixture of different soils and 0%, 7%, and 13% cement contents are determined respectively from sections a, b, and c of this figure. The MDD and OMC obtained for different soils mixed with different percentages of cement are stated in Table 2. Fig. 2 shows different trends

Table 1
Properties of different soil types.

Soil type	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	Specific gravity	Symbol
Silty Clay	83.0	37.4	45.6	2.73	CH
Silt	69.7	49.0	20.7	2.70	MH
Laterite	76.9	47.8	31.8	2.70	MH