An Empirical Model to Predict the Strength of Cement Stabilized Lateritic Soil

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ABSTRACT: Lateritic soils when stabilized with cement to create Cement Stabilized Lateritic Soil (CSLS) can be used in place of crushed rock as base course. CSLS use, however, requires a mix design. In order to reduce the time and effort required for the design, a mathematical model may be used to facilitate the initial prediction of cement content (CC) and strength. This study seeks to develop empirical equations to predict the UCS at any CC for any curing age. To develop the equations, samples of a lateritic soil for CSLS were airdried and characterized. Then CSLS at different CC ranging from 2% to 8% were prepared. For each CC, CSLS samples were prepared at the respective optimum moisture contents and cured for 4, 11, 18 and 32 days after which the UCS was determined. The results were analyzed to develop empirical equations to compute the UCS for given CC and AGE.

1 INTRODUCTION

Laterites and lateritic soils abound in the tropics and are frequently used as road pavement layers. However, for the construction of pavements for heavy traffic, natural lateritic soils have been found to be unsuitable as a base layer. Consequently, for the construction of the base layer of medium to heavily trafficked roads, crushed rock is used. This, however usually involve long haulage distances thus making the use of crushed rock increasingly uneconomical.

As an alternative, cement stabilized lateritic soil (CSLS) meeting certain specifications is used. However, economically achieving the specifications in situ comes with its own challenges which arise mainly because of the difficulty of creating homogeneous mixes. To achieve the specification requires several laboratory mix trials which is both time consuming and expensive. There is therefore an urgent need to find ways to reduce the testing and simplify the mix design procedure.

Laterites and lateritic soils, due to their low silica-sesquioxide ratios, are readily stabilized by cement as a binder as confirmed in studies by Felt (1955), Moh et al. (1967) and De-Graft Johnson & Bhatia (1967). The concept of using the clay water-to-cement content ratio as a key parameter to examine the engineering behaviour of cement-stabilized soils, appears to be well established for high water content clay admixtures as shown by the extensive studies on the subject including studies by Tatsuoka & Kobayashi (1983), Consoli et al. (2000) and Miura et al (2001). However, for coarse grained material used for the construction of pavement layers which require relatively low cement contents of the order of less than 10%, apart from the work of Horpibulsuk et al (2006), this concept does not appear to have been applied.

This study is part of a larger study to develop an empirical model for predicting the strength of CSLS in the laboratory, as part of the effort to provide a simple procedure for CSLS design. Samples of a coarse-grained lateritic subbase material was stabilized with rapid hardening Portland cement at water-to-cement ratios ranging from 0.72 to 3.11 and cured for 4 days to 32 days. The unconfined compressive strength (UCS) was determined and the results were analyzed to develop empirical equations to predict the UCS of CSLS for given cement content and age. The ultimate objective is to be able to extend these equations to predict the field strength of CSLS.

2 METHODOLOGY

2.1 *Determining the Index Properties of Lateritic Soil*

Samples of lateritic soil from a borrow pit were obtained and air dried. The index properties were determined in accordance with BS1377 and the compaction properties were determined using the BS Heavy Compaction Standard (BS1377 Part 4). The cement used was the super strong Rapid Hardening Portland Cement (RHPC) 42.5R commercially available locally.

2.2 *Preparation and Measurement of Strength of Cement-Stabilized Lateritic Soil Mixtures*

A sample of air-dried lateritic soil sieved through the 20mm sieve was thoroughly mixed with rapid hardening Portland cement in proportions increasing from 2% to 8% at intervals of 2% by dry weight to obtain the CSLS. Each mix was subjected to the BS Heavy Compaction to determine the compaction characteristics, the maximum dry density (MDD) and the optimum water content (OMC).

Then for each cement content (CC), samples of CSLS were thoroughly mixed with water at the OMC and compacted using the BS Heavy Compaction Standard. The compacted CSLS was then sealed in a polythene bag to prevent moisture loss and stored in a constant moisture cabinet at 25^{o}C to undergo moist curing for specified durations of 1hr, 7days, 14 days and 28 days each followed by 4 days wet curing to give total curing durations of 4 days, 11 days, 18 days and 32 days. After the specified curing, the sample was subjected to UCS test according to BS 1377.

3 DISCUSSION OF RESULTS

3.1 *Component material Properties*

The CSLS was made from a lateritic soil and rapid hardening Portland Cement. The grading characteristics of the lateritic soil is shown in Figure 1. The index and compaction properties of the natural lateritic soil are summarized alongside those of the stabilized soil in Table 1. From the index properties, the lateritic soil may be classified as a well-graded gravel (GW) in the Unified Soil Classification System or A-2-4 in the AASHTO Classification System. With a silica-to-sesquioxide ratio of 1.42, the soil may be described as a true laterite. The cement was RHPC- 42.5R with a Silica and Calcium Oxide contents of 20.7 and 63.0% respectively.

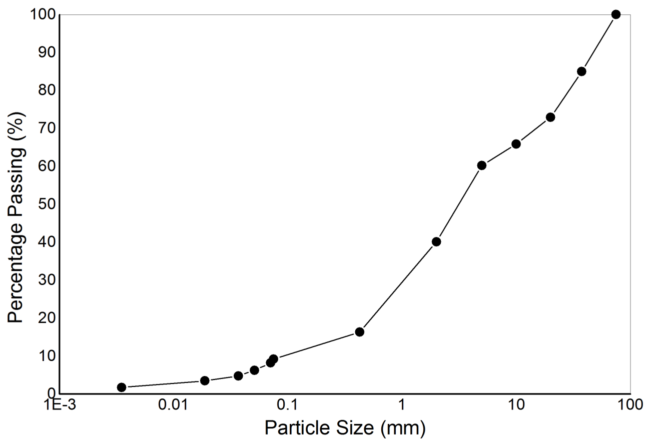

Fig. 1 Grading Characteristics of lateritic gravel

3.2 *Properties of Cement Stabilized Lateritic Soil*

The index properties including the LL and PI as well as the compaction properties of CSLS with different cement contents are summarized in Table 1. It should be noted that the zero-cement content refers to the natural lateritic soil. The compaction characteristics of the CSLS at different cement contents are plotted in Fig. 2 while a summary of the MDDs and the OMCs are plotted in Fig. 3. The figure shows that the MDDs increase from 2.243 for 0% CC to 2.271 for 8% CC while correspondingly, the OMC drops from 6.43% to 5.73%. The relatively small changes in both MDD and OMC with increasing cement content is due to the low fines content of the laterite. Similarly, the addition of 8% CC did not drastically change either the LL or PI values. The specific gravity (Gs) values increase with increasing CC from 2.61 to 2.76. Ampadu & Arthur 2021 have noted that the of lateritic soils measured in the laboratory Gs values obtained from using the standard procedure are lower than those predicted using other methods.

Table 1 Summary of Properties of Lateritic Soil and Cement Stabilized lateritic Soil

Cement Content (%)	0	2	4	6	8
LL	24.8	25.7	22.7	24.7	26.8
PI	10.2	9.2	4.3	7.7	7.6
MDD (Mg/m^3)	2.243	2.256	2.261	2.265	2.271
OMC (%)	6.43	6.2	6.13	5.94	5.73
Gs	2.61	2.63	2.66	2.71	2.76

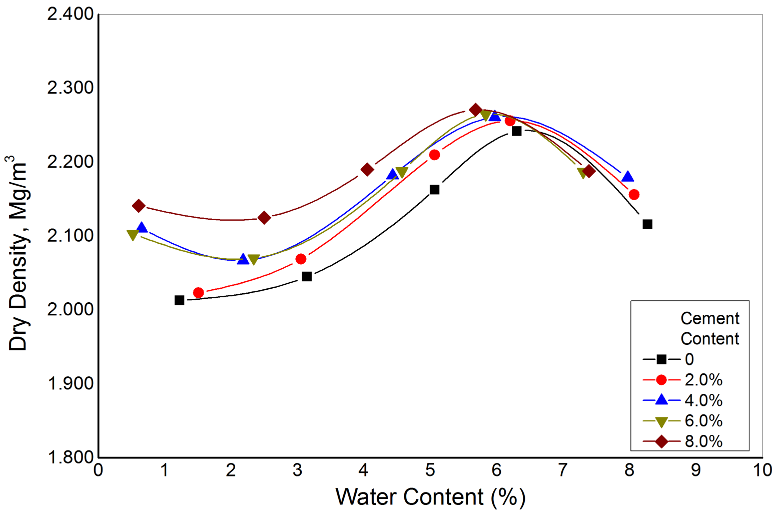

Fig. 2 Compaction characteristics of Cement Stabilized Lateritic Soil

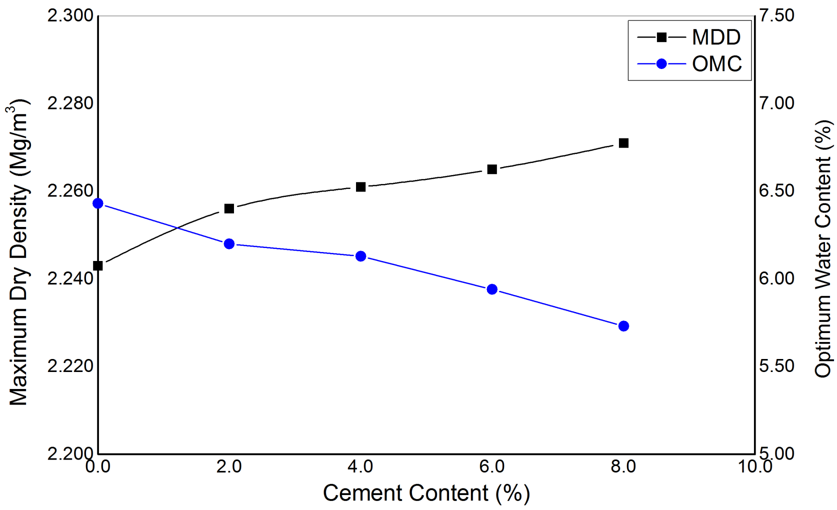

Fig. 3 Variation of MDD and OMC with Cement Content for Cement Stabilized Lateritic Soil

3.3 *The Compressive Strength of Cement Stabilized Lateritic Soil*

Table 2 is a summary of the results of the increase in UCS of the CSLS prepared at the OMC and cured under the specified conditions for 4 to 32 days. It must be noted that the levels of compaction (LC) achieved were from 97.5% to 99.4% indicating very high levels of compaction.

Table 2 Summary of Strength increase of Cement Stabilized Lateritic Soil

Cement Content (%)	Age (days)	Water Content (%)	Level of compaction (%)	UCS (N/mm^2)	W/C Ratio
2	4	6.25	98.68	1.39	3.13
	11	6.19	98.84	2.11	3.10
	18	6.20	99.27	2.70	3.10
	32	6.21	99.18	2.97	3.11
4	4	6.19	99.42	2.29	1.55
	11	6.13	98.52	3.33	1.53
	18	6.15	98.54	4.18	1.54
	32	6.22	98.90	4.65	1.56
6	4	6.01	99.26	3.13	1.00
	11	5.89	98.09	4.23	0.98
	18	5.91	98.46	5.25	0.99
	32	5.79	99.30	5.84	0.97
8	4	5.79	99.25	4.66	0.72
	11	5.65	97.47	5.78	0.71
	18	5.69	98.62	6.47	0.71
	32	5.74	98.11	7.14	0.72

3.4 *The Empirical Equation*

3.4.1 *Concrete Technology*

In concrete technology, the water-to-cement ratio (w/c) and the level of compaction (LC) are the two key factors that determine the strength of concrete at a given age and cured under given temperature. For fully compacted concrete (for which the air voids do not exceed about 1%), Abram (Abrams 1919) proposed Equation 1 which is the form of the well-known "Abrams law" relating the strength of concrete (f_c) to the w/c as given in Neville (1981), where K_1 and K_2 are empirical constants.

$$f_c = \frac{K_1}{{K_2}^{W/C}} \quad (1)$$

3.4.2 *The Strength Development Mechanism in CSLS*

In the case of CSLS, when the soil and cement in the dry state are thoroughly mixed at a water content around the OMC and compacted, as the level of compaction increases, air is removed from the mixture, thus increasing the degree of saturation and arranging the soil particles into a densely packed state. Under such a state the soil-cement interaction is physico-chemical in nature. The subsequent chemical cementation bonds "weld" the soil particles together with a bond strength controlled by the water-cement ratio. Horpibulsuk et al. (2006), proposed Equation 2 as the relationship between the UCS and the w/c.

$$UCS = \frac{A}{({}^{W}/_{C})^{B}} \quad (2)$$

3.5 *Determining the Parameters of the Equation*

In this study, the variation in w/c was achieved by increasing the cement content for the given OMC values which increased with increasing cement content. The data in Table 2 was fitted to Equation (2). In order to determine the parameters of Equation (2), the UCS data was plotted against the W/C values in Fig. 3 for the different curing periods and the data fitted to Equation 2.

For each curing period the corresponding values of A and B were determined. The results suggests that B may be a constant and its value was assumed to be equal to the average of the B values which was determined to be 0.69.

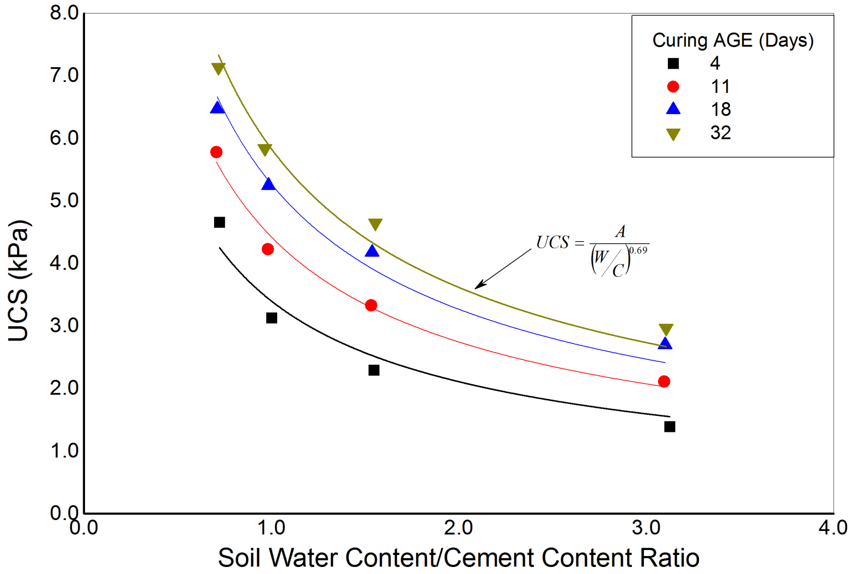

Fig. 3 Fitting Equations to the UCS-W/C data

When the average value of B of 0.69 is assumed, the resulting fitted equations for the various ages are shown in Table 3. The values of the coefficient of regression vary from 0.946 to 0.987 which indicates very good fit

Table 3 Parameters for fitting equation based on B=0.69

AGE (days)	Parameter A	Parameter B	Coefficient of Regression R2
4	3.402	0.69	0.9456
11	4.426	0.69	0.9867
18	5.270	0.69	0.9746
32	5.836	0.69	0.9715

With the value of B known, the next step is to find a fitting function for the variation of Parameter A with Age. Different fitting functions may be used but perhaps a log function is more common. When the A-parameter is plotted against the log (AGE), a linear relationship is obtained.

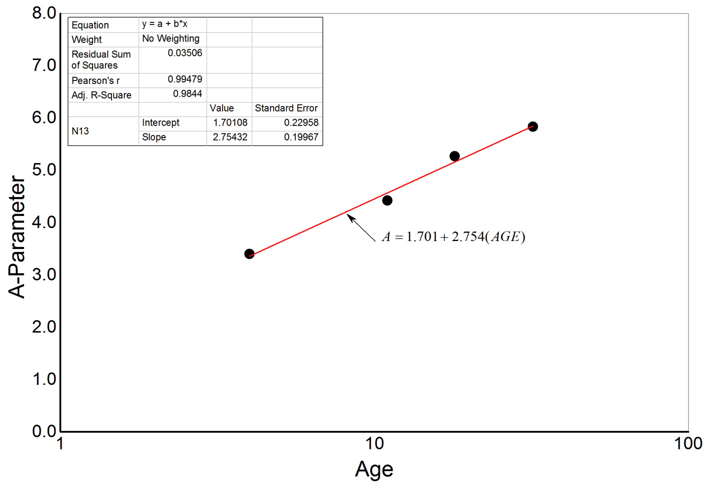

Fig. 4 Variation of parameter A with Age

By substituting the values of A and B into Equation (2), the final equation relating UCS to CC and AGE is obtained as Equation (3).

$$UCS = \frac{1.701 + 2.754 \log AGE}{(W/C)^{0.69}} \tag{3}$$

3.6 *The Prediction Equation*

Equation (3) may be used to estimate the UCS expected at any given AGE for a given W/C ratio to facilitate mix design of CSLS. However, most of the time once a mix design has been achieved, the next step is to predict the strength expected at a given age. To expedite this process, the 4-day cured strength may be used as a reference strength from which all other strengths may be predicted as shown in Equation (4). Using this equation it may be predicted, for example, that the ratio of the 28-day strength to the 4 -day strength is 1.693.

$$\frac{UCS_{AGE}}{UCS_4} = 0.506 + 0.82 \log AGE \tag{4}$$

4 CONCLUSIONS AND RECOMMENDATIONS

Based on the results of CSLS at RHPC- 42.5R contents from 2% to 8% in a lateritic soil at water-to-cement ratios varying between 0.71 and 3.11, the following conclusions may be made concerning the UCS strength:

1. There is an inverse relationship between the UCS and water-to-cement ratio of coarse-grained laterite which for a given cement type appear to depend only on the age of CSLS
2. For a given lateritic soil and mix i.e. water-to-cement ratio, the relationship between the ratio of the UCS strengths at any two ages is a linear function of the logarithm of the age.

The studies are on-going and further studies will be extended to cover other lateritic soils and other types of cements available on the local market.

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