REDUCING COST OF QUALITY CONTROL FOR SOIL STABILIZATION

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Abstract
A quality control procedure developed for soil-cement stabilization to reduce the cost of quality control in the field is proposed. Its application can make for the completion of constructional works well within schedule. It involves the use of graphical and regression model relationship between soaked and unsoaked unconfined compressive strength (UCS) values measured in accordance with the Nigerian General Specifications for Roads and Bridges. The linear regression approach was used I estimating the regression models with suitable transformation made to extend the functional forms tested to some non-linear forms, in order to obtain a high level of accuracy, strict supervision is recommended for constructional works and testing of materials.

Introduction

Usually, it is required or specified to base design as well as field quality control of constructional works of stabilized materials e.g. road base and base, on the results of CBR and UCS tests. While some specifications specify values for both CBR and UCS, others like that of Nigerian General Specifications for Road and Bridge works (1) specify values only for the CBR, the values are measured for both soaked and unsoaked specimens, while only soaked and Unsoaked specimens are used for the CBR tests. This document will herein after be referred to as "the General Specification". However, in order to save on costs of tests, it may be necessary to perform only one of the other if a model that relates the two variables to each other is available. Since the soaked condition is worse than the unsoaked condition and since this latter condition requires longer period of curing as enshrined in the General specifications, a model that has the Unsoaked UCS as the dependent variable and the soaked UCS as the independent variable is desirable. This present work, therefore, has as its goals the description of how to develop appropriate regression models and how such models can be used for quality control to save costs in the quality control process.

The Quality Control Process of the General Specifications

The relevant clauses of the general specifications are presented below (CLAUSE 6229: PROCEDURE FOR ESTIMATION OF CEMENT CONTENT)

a) Classify the soil according to US Public Road Administration system

b) The estimated range of cement content is determined using the A.A.S.H.O. soil group (shown in Table VI-6)
c) Material requiring high content should be rejected as unsuitable
d) Perform B.S compaction on the material to establish MDD and OMC using the middle cement content e.g. (4.5%) cement for A-2 as shown in Table VI-6 etc. The CBR and UCS specimens shall be moulded to this density and moisture content.
e) Establish the relationship between cement content vs. CBR and UCS (unconfined compression shear) for soaked and unsoaked specimens.

i. Moulding 3 CBR specimens and 6 UCS at each cement contents e.g. for A-2-3%, 4.5% and 6%
ii. Wax and cure all specimens for 6 days (except 3 UCS specimens at each cement content which should be cured for 7 days and tested without soaking)
iii. Testing all CBR specimen and the 3 UCS specimens at each cement content after 24hours soaking by complete immersion in water and allowed to drain for 15minutes
iv. Plot graphs of cement contents vs. CBR (soaked) and cement contents vs. UCS (soaked and unsoaked). Establish the required cement content at 180% CBR for site mix or 160% for plant mix and the corresponding UCS values soaked and unsoaked for quality control in the field.

Table VI-6 is not reproduced in this report.

The clause is translated as in Table 1 and Figure 1

TABLE 1: Representation of clause 6229 e (i) and (ii)

Cement content (%)	Required no of specimens		No of specimens cured for			
			6 days		7 days	
	CBR	UCS	CBR	UCS	CBR	UCS
Cc1	3	6	3	3	0	3
Cc2	3	6	3	3	0	3
Cc3	3	6	3	3	0	3

Specimens cured for 6 days are soaked for 24 hours before testing. Those cured for 7 days are not soaked

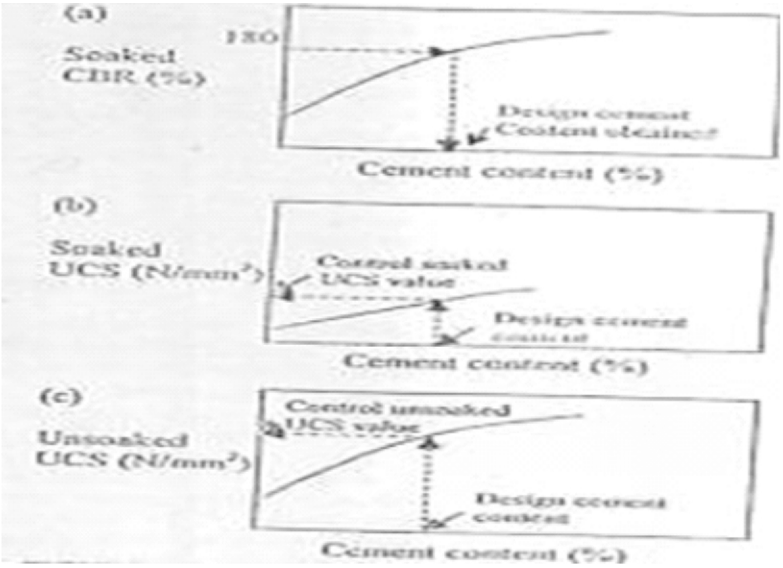

Figure 1: Graphical translation of Clause 6229

The hatched arrow lines in Figure 1 indicate the procedure; (1) obtaining the required (design) cement content (i.e. corresponding to 180% or 160% for mix-in-place and plant mix as the case maybe) for Figure 1(a), (2) using the design cement content as in (1) for obtaining the soaked UCS value for field control for Figure 1(b)n and (3) using the design cement content as in (1) for obtaining the soaked UCS value for filed control for Figure1(c).

Using Relationships Developed for Quality Control

After the determination of the cement content for a project concerned as described above and obtaining the values of the soaked and unsoaked UCS corresponding to this cement content as control values, it will now be necessary to set the platforms for field quality control. The platform that is being presented in this work is a relationship between the soaked UCS values and the unsoaked UCS values. The idea is to save time and cost by performing the test for just one of the values and estimating the other value from the known value. As mentioned earlier in the introduction, since the soaked condition is a worse condition than the unsoaked one (and in fact a short duration of durability test), it will be this that will be the independent variable and unsoaked UCS the dependent variable. Money cost is saved if it will no longer be necessary to prepare and perform tests on unsoaked UCS specimens. Time cost is also saved if all UCS tests for quality control are performed after 6days of curing and no longer extended to 7 days.

The particular platform envisaged here could be in the form of a graphical or regression model relationship between the soaked and unsoaked UCS values. These are described in the following subsections.

Graphical Relationship

The graphical relationship proposed is one in which the unsoaked UCS as the dependent variable is the ordinate while the soaked UCS as the independent variable is the abscissa (Figure 2). The points or coordinates on the graph are obtained by plotting soaked and unsoaked UCS values corresponding to the same cement contents used in the required cement content determination exercise according to the General Specifications. This kind of plot is not mentioned in the specification, neither has the present author ever come across it in literature. This is not to say it does not exist or has never existed.

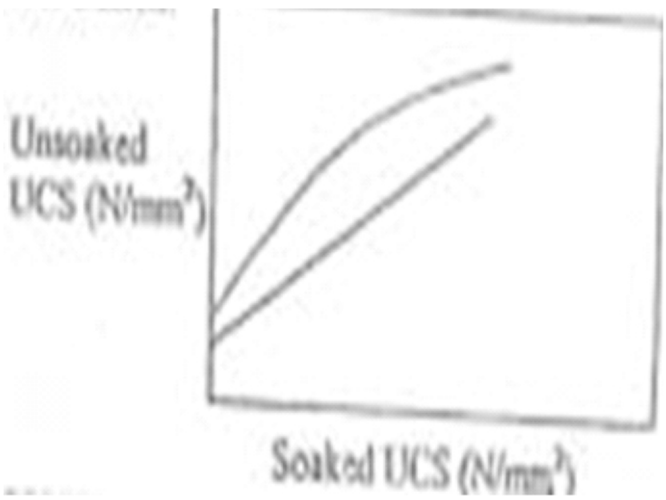

Figure 2: Expected typical UCS relationships

This graphical plot may or may not be linear depending on the nature of the soil with respect to the clay mineralogy of the soil or any other factor. To use this plot for quality control all that needs to be measured for the field soil-cement mix is the soaked UCS value. This value is used to obtain the corresponding unsoaked UCS value by scaling it off on the graphical plot as in Figure 3.

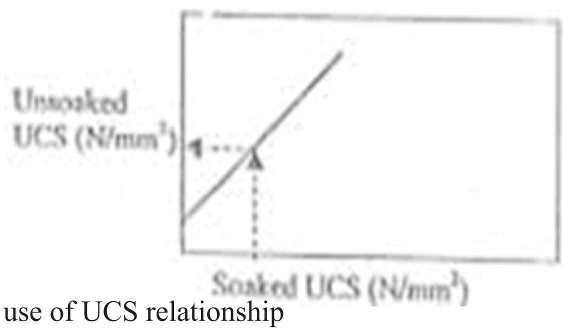

Figure 3: Quality control use of UCS relationship

Regression Model Relationships and Framework

Review of Models Involving UCS

While many relationships abound for CBR and some other soil characterization parameters (Emesiobi, 2005) provides a good review of some of these relationships), very few are to be found containing UCS related to other parameters. Still there seems as yet none that relates soaked and unsoaked UCS values. Further, existing models appear in different functional forms, with the linear ones have been estimated on the basis of a maintained hypothesis i.e. modelling with only the linear functional form in mind and not allowing the dataset to determine its own functional form (Hensher and Johnson, 1979).

In addition to the primary objective if evolving a procedure for saving costs in quality control for cement stabilization in Nigeria, this present work will also describe a procedure for the development of appropriate functional forms for models to be used in quality control.

However, the original Box-Cox method (Box and Cox, 1964) has over the years been extended to the transformation of the independent variable, allowing for the transformation of both variables in one regression modelling exercise (Zarembka, 1968; 1974). For sample uses of the Box-Cox method, the interested is referred to (Wang et al, 1981) and only recently (Osula, 2004).

However, the Box-Cox method (Box and Cox, 1964) is tedious and may not be readily applied and may not be readily applied in the field unless with a computer package. Its major advantage is in allowing the regression developing process to take an entirely empirical approach. Because of the rigours in its application in its place, it may suffice to use a selective transformation which at the end of the day yields results similar to those expected from using the Box-Cox method with careful and empirical selection.

The selective transformation approach involves testing some common functional forms to select which one model best models the data relationship. The functional forms that the present author considers will mimic the UCS (soaked)-UCS (unsoaked) relationships are:

Model 1 $\quad Y = a + bX \quad (1)$

Model 2 $\quad Y = a + b\log X \quad (2)$

Model 3 $\quad \log Y = a + bX \quad (3)$

Model 4 $\quad \log Y = a + b\log X \quad (4)$

Models (3) and (4) are linearized of the non-linear models represented, respectively as;

$$Y' = a'e^{bX} \quad (5)$$

And

$$Y' = a'X'^{b} \quad (6)$$

It is to be advised that models other than (1) will not be tested if the graphical relationship between the variables concerned do not shift or differ seriously from a linear one (i.e. a straight line relationship).

To use the relationship that eventually evolves, with a known value of UCS (soaked), the UCS (unsoaked) is obtained by substituting the UCS (soaked) into model. This resulting UCS (unsoaked) is compared with the control UCS (unsoaked) just as described in the previous section for graphical relationship. The idea of developing the models presupposes the hypothesis that a functional relationship is definable between the variables. This hypothesis is considered proven in this work in the event that a model is found significant in terms of the parameters of the model, the regression coefficient of determination and the analysis of variance results (t-test, R^2, and F-ratio respectively). The selection of the best model is done by comparing the model's overall statistical significance and the statistical significance of the model's parameters at the 5% level (i.e. the 95% level of confidence) as well as the value of the error sum of squares of the residuals.

The 95% level of confidence is here being recommended because it is the level usually considered the middle-of-the-road in research. At this level, there is only a 5% chance that a conclusion drawn from the researcher is 95% confident of the inferences made.

On a final note, it is needless to advise that strict supervision of constructional works and testing of materials is imperative to render this approach to quality control effective.

Sample Regression Model Estimation and Discussion

Actual data have not been available for use but surrogate data have been sourced from (Osula and Adebisi, 2001). The data used (see Table 2) for both the dependent and independent variables are not necessarily unsoaked and soaked UCS values, but unsoaked UCS and CBR values. They have been used purely to describe the extent to which analysis should go in selecting the appropriate regression model.

Table 2: Data used in regression modelling exercise

Cement content	UCS (N/mm^2)	CBR (%)
4	0.48	9
6	1.16	50
8	1.65	95
12	2.42	130

The results of the regression modelling exercise are presented in Table 3. The models estimated are written as;

Model 1 $UCS = 0.336 + 0.154CBR$

Model 2 $UCS = -1.052 + 0.639\log CBR$

Model 3 $UCS = 0.495e^{0.13CBR}$

Model 4 $UCS = 0.132CBR^{0.573}$

Table 3: Results of regression modelling

Model no	Const (t-test) (α)	Coeff (t-test) (α)	F-test (α)	R^2 (SEM)
1	0.336 (2.878) (0.102)	1.538E-02 (11.128) (0.073)	128.830 (0.008)	0.984 (0.1262)
2	-1.052 (-1.470) (0.0570)	0.639 (4.585) (0.026)	12.852 (0.070)	0.865 (0.3673)
3	-0.702 (-4.002) (0.057)	1.271E-02 (6.113) (0.028)	37.374 (0.020)	0.949 (0.1899)
4	-2.023 (-9.231) (0.012)	0.573 (10.495) (0.009)	110.148 (0.009)	0.982 (0.1125)

LEGEND: Const. Constant; Coeff. Coefficient; SEM Error sum of squares

A thorough study of the information in the Table shows that of the four models, only model 2 is not significant in the overall at the 5% level. Finally, this model has the smallest error sum of squares of residuals at 0.1125. It is therefore the one that is adopted where the data set used actual UCS (soaked) and UCS (unsoaked).

For the logarithmic transformation, the $\log_e$ performs slightly better than the $\log_{10.}$ For this reason it is the log that was used in this example and is what is recommended for use if the proposal in this work is judged acceptable for field quality control in cement stabilization in Nigeria. The proposal has not been made to take the place of the quality control process in the General Specifications but to facilitate completing the constructional works well within schedule through the reduction of time and money costs in the quality control process. This being the case, it is expected that its use on any job will be at the request of the contractor but after the approval of the Engineer or Engineer's Representative for the project. The proposal could be recommended by the Engineer or Engineer's Representative to the contractor, if he is satisfied with the level of workmanship of the contractor, again so that constructional works are completed well within schedule. Both parties should work towards early completion of the project.

Finally, should the proposal in this report be accepted for use in Nigeria, it is recommended that it be incorporated in the General Specifications. Better still, a complete revision of the General Specifications is recommended to bring the document and other highway-related design and constructional works documents in line with advances in research and development.

Conclusion

This report has been on a proposal for reducing the time and money costs of quality control in soil-cement stabilization. The proposed method involves the use of graphical and regression model relationships between soaked and unsoaked UCS values gotten from the cement content estimation exercise carried out in accordance with the Nigerian General Specifications for roads and bridges. In order to obtain a high level of accuracy in using the proposal for quality control, strict supervision of constructional works and testing of materials is recommended.

Finally it is recommended not only to incorporate the proposal in the General Specifications but to also embark on a complete revision of the General Specifications to bring the document and other highway-related design and constructional works documents in line with advances in research and developments.

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