Empirical Correlations Between CBR and Index Properties for Sri Lankan Soils

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ABSTRACT : The California Bearing Ratio (CBR) is an important parameter used in pavements designs. However; as it is difficult to obtain a representative CBR value, many correlations had been proposed by various researchers since 1960s, using soil index properties. The published correlations were analyzed with soil data obtained from several Sri Lankan project sites. However, the existing correlations are not in good agreement with local soils. A study was carried out to find out correlations between CBR with soil index properties those best suit for local soils. Atterberg Limits and grain size distribution data together with compaction parameters were used, as these tests are economical and faster than conducting a CBR test. The correlations were developed in the form of equations using the method of Microsoft Excel Regression analysis. Finally, several laboratory tests were conducted to compare with the results of regression equations for compiled data, in order to validate the developed correlations.

1 INTRODUCTION

Civil engineers always encounter difficulties in obtaining representative CBR value to evaluate the mechanical strength of sub-grades and base-courses for design of road pavement; due to the high cost and time consumption and also due to the requirement of large quantities of samples. Over the years, many correlations have been proposed by various researchers in order to predict the CBR based on soil index properties. Though various attempts have been made to predict the CBR value by different researchers from samples of their locality, adopting those developed methods without any adjustment to suit with the local conditions lead towards misinterpretation of soil behavior.

The aim of the present study is to generate correlations which could describe the relationships among Soil Index Properties, Compaction Parameters and the CBR of Sri Lankan soils which could be utilized as sub-base and sub-grade layers in pavement systems, as an attempt to reduce the amount of CBR testing done in the industry.

Therefore, this study will assist engineers to predict the CBR value of soil based on known physical properties and to choose the best suited material for the relevant projects in order to enhance the quality of the highway and pavement structures**.**

2 LITERATURE REVIEW

Literature review was done to understand the CBR and index properties of soil that related to the study; together with soil compaction and soil classification.

Further, literature study was carried out to study the published correlations that relate the CBR values with index properties. Although number of correlations found in literature has defined the relationships with CBR and several soil parameters, only the relationships with the parameters obtained from typical index tests (i.e. Atterberg Limits carried out according to BS 1377:Part 2 and Grain Size Analysis excluding the Hydrometer Analysis carried out according to ASTM D 422) were considered in this study, which were developed by Agarawal et al (2011), Ayodele et al (2009), Datta and Chottopadhyay (2011), Dharamveer et al (2011), Magdi (2012), National Cooperative Highway Research Program (2001) and The Highway Agency (1994).

However, in most of the correlations found in literature, the original sources are unclear and also not available and unobtainable at the time of this research. Some of such correlations were cited from other research papers/thesis in their literature study such as Breytenbach (2009).

3 METHODOLOGY

This study covers only the Sri Lankan soils compacted to Maximum Dry density (MDD) and Optimum Moisture Content (OMC) obtained according to ASTM D 698 using standard effort in predicting CBR values that could be obtained according to ASTM D 1883.

The data on CBR value and its physical properties of soil were collected from number of local projects to compare with the published correlations and to develop new regression based models.

A total numbers of 165 data were considered for this study. From the collected data, several parameters of CBR(%), MDD(g/cm^3), OMC(%), % Liquid Limit (LL), % Plastic Limit (PL), % Plasticity Index (PI), % of gravel, % of sand, % passing 75μm, 425μm, 2360μm (screens referred as P075, P425 and P2360) and diameters (in mm) corresponding to 60%, 50%, 30% and 10% finer in the grain size distribution respectively denoted as D_{60}, D_{50}, D_{30} and D_{10} were included into the database.

Primarily, the variations of the CBR values were plotted in a bar graph. Then omitting the outliers, filtered data of CBR below 30% was considered for further analysis.

As the initial step, materials were basically categorized into the different groups of fine-grained and coarse-grained soils based on Unified Soil Classification System (USCS) according to ASTM D 2487. Each group of soils was not considered in detailed analysis due to lack of availability of data. The detailed analysis and comparisons were done only for the two group of soil categories identified as;

- Fine grained plastic soils (having the soil symbols of CH, CL, MH, ML according to USCS); and
- Coarse grained plastic and non-plastic soils which contain fines content greater than 12%, (having the soil symbols of SM, SC, SM-SC, GM, GC, GM-GC according to USCS).

The consideration was first given for the determination of relationships between CBR and individual soil parameters; which was done by Microsoft Excel graphical representation method using scatter plots. The regression types for each and every plot were determined according to the trendline option which gives the maximum coefficient of determination, R^2.

Thereafter, several analyses were done to evaluate the applicability of existing published correlations using local soil data by single and multiple linear regression analysis. The evaluation was differentiated based on the broad groups of soils, i.e. coarse-grained and fine-grained. However, due to limitation in the availability of data some of the published correlations have been omitted in evaluation within this study.

Finally, multiple regression analysis was done using Microsoft Excel Regression method according to Miles and Shevlin (2001), assuming that CBR has a linear relationship with soil index properties; and analysis was done for plastic and non-plastic soils separately.

By the Linear Regression, the coefficients of the linear equation were estimated with one or more independent variables that best predict the value of the dependent variable. Regression analysis was done to obtain different equations by correlating CBR values with different groups of soil properties.

At the end of analysis, new correlations were proposed in order to meet the final research objectives. Finally, laboratory test were carried out to validate the new correlations generated with the compiled data for verification purpose.

4 RESULTS & DISCUSSION

According to the scatter plots, individual soil parameters have no strong relationship with CBR since the R^2 values obtained was comparatively very low. Further, existing correlations have no strong relationship with local soil data as they also resulted with a low R^2 values and poorly fits the model.

In case of linear estimation for multiple parameter regression, initial analysis for the non-plastic coarse grained soils was done with 14 nos of data which consisted only with Silty Sand, with the Unified Soil symbol of 'SM'. The summary output of regression analysis is as follows.

The regression statistics included of Multiple R of 0.95869, R^2 of 0.91908, adjusted R^2 of 0.58961 and standard error of 3.01543. This was given with 8 no. of parameters and an intercept, while 75% of them had P-value greater than 0.1. Further, Analysis Of Variance (ANOVA) of the regression was given 7.0987 of F-factor together with 0.0374 of Significance-F.

By omitting the parameters with highest P value which is used to interpret the t-stat until the P-value of all the parameters were reduced below 0.1, the F-factor which shows the quality of the entire model has increased, Significance-F has reduced and Standard Error of the model was then reduced.

Finally, Adjusted R^2 has increased up to 0.83. Therefore, the model was statistically significant, and the new correlation was developed to predict

CBR value of Non Plastic coarse grained soils as given in Eq. (1) below;

CBR = 304.8 - 75.63(MDD) - 4.57(OMC) - 1.39(P075) + 0.28(P425) -0.63(P2360) - 15.43(D50) (1)

CBR value is well predicted by the above correlation with six no. of variables using two sets of test information (i.e sieve analysis and Proctor compaction).

The graph of actual CBR vs. predicted CBR was plotted based on Equation (1) as given in Fig.1 below.

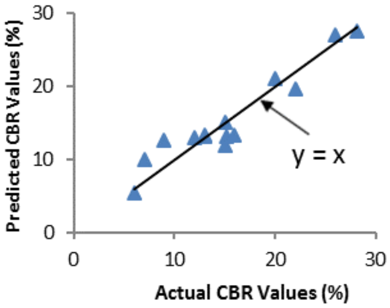

Fig.1. Comparison of Eq. (1) for non-plastic coarse grained soils

In the similar way, several other correlations were developed for plastic soils as well; with applying constraints in some cases. Of these, only the correlations developed with considerably higher correlation coefficients are summarized below.

For plastic fine grained soils of CBR below 20% considering 22 nos. data has given Eq. (2) with R^2 0.78124 and Adjusted R^2 0.72977.

CBR =28.79-0.61(OMC) + 0.44(PL) + 0.48(PI) - 0.82(%Sand) (2)

For plastic coarse grained soils in the group of SC with CBR below 25% considering 17 nos. data has given Eq. (3) with R^2 0.933751 and Adjusted R^2 0.882224.

CBR = -14.3 +37.6(MDD)- 0.68(LL) + 0.7(PL) - 1.1(%Sand) - 1.5(P425) + 1.3(P2360) + 2.1(D60) (3)

For plastic coarse grained soils in the group of SM with CBR below 25% considering 59 nos. data has given Eq. (4) with R^2 0.80079 and Adjusted R^2 0.771745.

CBR=11.969(MDD)-0.1807(OMC)+0.1274(P075) - 0.2048(P425) (4)

CBR value is well predicted by the above correlations with several variables using simple index test information (i.e sieve analysis, Atterberg limits and Proctor compaction) which are more economical, faster and easier to perform than CBR test. Several other correlations were also developed for other soil groups, however with lower R^2 values. Therefore, these categories were not considered for further analysis.

Finally, laboratory tests were carried out for validation of the developed correlations by compacting soil in to MDD and OMC using standard effort together with Atterberg Limit tests and sieve analysis. Altogether 24 nos. test data were collected for model verification, as 17 nos. for plastic soils and 7 nos. for non-plastic soils.

In case of plastic soils, only 13 nos. data can be used for model verifications; of which 10 nos. data were available for the category of 'SC' and only 3 nos. data were available for the category of 'SM'.

The rest of the data obtained from test results belongs to the other soil groups where no reliable equation generated to predict the CBR due to poor correlation coefficients. Therefore, they were not further considered in the validation.

Consequently, there were no data obtained for plastic fine grained soils in the category of 'MH' and 'ML'. Therefore, the model Eq. (2) was not considered for verification during this study.

The correlation generated to predict CBR of non-plastic soils of 'SM' group as given in Eq. (1) was validated with 7 nos. soil data. This has resulted a predicted CBR with the tolerance of around +/- 5 as shown in Fig.2.

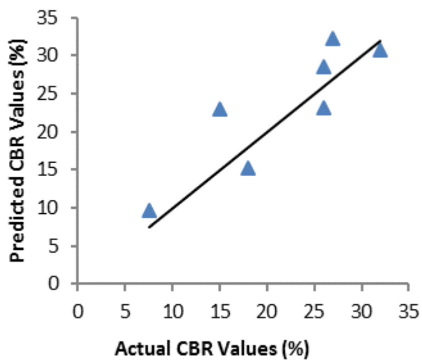

Fig. 2 Verification of developed new correlation – Eq. (1).

Then, Eq. (3) was validated using available 3 nos. data for plastic coarse grained soils in the category of 'SM' as shown in Fig. 3.

Finally, verification was done for the Eq. (4) developed for soil category of 'SC'. This has resulted a predicted CBR with the tolerance of around +/- 5 as shown in Fig. 4.

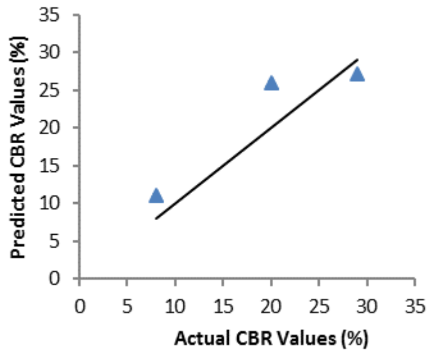

Fig.3 Verification of developed new correlation– Eq. (3)

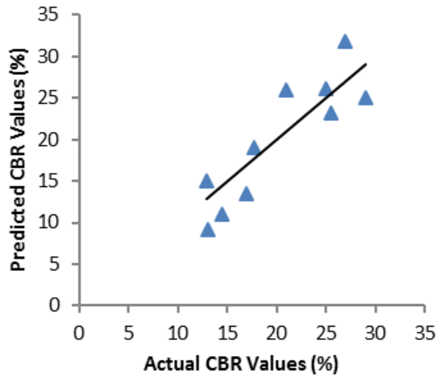

Fig. 4: Verification of developed new correlation – Eq. (4)

5 CONCLUSIONS

Based on the analyses carried out, the conclusions of this study were summarized as follows;

- Typical range of CBR values found in Sri Lanka is around 30% to 35% for soils compacted using standard effort.
- Individual soil index parameters do not provide a good correlation with CBR.
- The multiple parameter relationships are better than the individual parameter relationships. This was evidenced by the value of R^2.
- Published correlation proposed by other researchers are not reliable in estimating the CBR values of local soils under study, as the (R^2) value is lower than 0.5 and it is even very low as below 0.3 in most of the cases.
- Non plastic coarse grained soils have a good correlation with CBR as depicted in Eq. (1).
- Eq. (2) is reliable in predicting CBR values below 20%, for fine grained plastic soils.
- Eq. (3) and Eq. (4) are reliable in predicting CBR values of 'Clayey Sand' which gives USCS classification of 'SC' and 'Silty Sand' which gives USCS classification of 'SM' respectively which have CBR less than 25%. Although, considering Eq. (4), it is overestimated the CBR below 5% and underestimated the CBR above 20% by around ±10% in some cases.

Based on the new correlations developed in this study assuming linear relationship only, CBR has significant compatibility with soil index properties with limited index test parameters. However, in some cases CBR was predicted with the tolerance up to around ±10% using the developed relationships.

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