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Linear Regression Equation for Subgrade Lateritic Soil

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Abstract: *The results of a study that considered the use of linear regression equations to have a correlation between index properties and California bearing ratio of some lateritic soil within Osogbo. South Western Nigeria have been presented. For an appreciable conclusion to be established, lateritic soil samples were collected from eight (8) different borrow pits within the town and various laboratory tests including Atterberg limit, Sieve analysis, California bearing ratio, Compaction and Specific gravity were performed on the soil samples. Various linear relationships between index properties and California bearing ratio (CBR) of the samples were investigated and predictive equations estimating (CBR) from the experimental index values were estimated. The findings indicate that good correlation exists between the two groups. Consequently, the values of the CBR computed from the models are only to be used for preliminary assessment in view of theoretical and economy and not acceptable alternatives to laboratory testing because of the anisotropic nature of lateritic soil and its heterogeneity.*
Keywords: *Borrow pits, Carlifornia bearing ratio, Lateritic soil, Linear regression equation, Models, Predictive equation*

I. Introduction

Index properties have wide applications in geotechnical engineering practice and a number of index properties are easily recognized in soil mechanics have been outlined by many authors (Lambe and Whitman, 1979; Holtz and Kovacs, 1981; Das, 1998). It is normal practice to try to predict the engineering behaviour of soils from their index properties. The properties form the basis for soil classification into groups where each group is said to have similar behaviour. Some authors (Lambe and Whitman, 1979; Holtz and Kovacs, 1981) have given reasons for the use of index properties in predicting soil behaviour. Accordingly, many research have made attempt at predicting some engineering properties of soil such as compaction parameters (Korfiatis and Manikopoulos, 1982; Al-khafaji, 1987; Howell et al., 1997; Boltz et al., 1998), permeability (Benson et a!.. 1994; Benson and Trast, 1995; Boadu, 2000; Osinubi and Amadi, 2006), swelling pressure (Komornik and David, 1969), consolidation parameters such as compression index (Azzouz et al., 1976; Al-khajaji and Andersland, 1992), California bearing ratio (Adegbola and Alajede, 2003) using index properties. However, soil composition affects index properties of soils. Most of these predictions often utilize atterberg limit values which are affected essentially by some soil compositional as well as environmental factors,

The strength of subgrade is the main factor in determining the thickness of the pavement. Subgrade strength is expressed in terms of its California Bearing Ratio (CBR) value. The CBR test is generally carried out in the Laboratory on remoulded samples of the subgrade, as described in BS 1377 of 1990. The sample must be compacted at the equilibrium moisture content to the dry density likely to apply after the road has been constructed. It is to be noted that CBR test is widely accepted internationally as a reliable method of pavement design and is also used in soil classification of base and sub-base (road base) materials for highway designs and construction, thus it becomes necessary to add to the existing knowledge by using linear regression to predict the range of CBR values for use where constraints as to the level of expertise and equipment arise (Adegbola and Alajede, 2003).

Laterites (or lateritic soils) as a soil group rather than well-designed materials are most commonly found in the leached soils of the humid tropics where they were first studied. According to wooltorton (1975) these soils are formed under weathering systems productive of the process of laterization, the most important characteristic of which is the decomposition of ferro-alumino silicate minerals and the permanent deposition of sesquioxides (i.e. oxides of iron and aluminium - Fe_2O_3 and Al_2O_3) within the profile to form the horizon of material known as laterite. Gidigasu and Kuma (1987) used the term "laterization" to describe the processes that produce lateritic soils. Lateritic soils are being used in the construction of roads, highways, airfields, and earth dams and as the foundation of structures (Gidigasu, 1976).

It should be noted that researchers have done a lot in using statistical parameters such as regression analysis in solving geotechnical problems. Adegbola and Alajede (2003) established a relationship between

CBR and index properties and concluded that a strong correlation exist between the two tests and suggests that the method of a approach is sufficient to predict the range of CBR values expected through mathematical analysis without actually performing CBR laboratory tests on soil samples within the locality. Adedimila and Usifo (1994) carried out a comparative study of CBR and Unconfined Compression Tests (UCT) in the area of characterizing cohesive soils for pavement design and analysis in view of theoretical development and economy,

Thus, Osun State government has embarked upon mass construction of roads within the state capital, Osogbo to ease the means of transportation within the stale capital and the surrounding towns. Most of these roads consisted mainly of transported materials. As a result of this, there is a need to replace them with good paving materials. Hence, eight borrow pits that have large quantities of good constructional materials for the pavement construction were identified after geotechnical investigation with respect to quality and quantity had been carried out. As a result of this, the study now considered the use of linear regression equation to have a correlation between index properties and California bearing ratio of lateritic soil within Osogbo, South western Nigeria.

II. Materials and Method

The study commenced with deskwork and reconnaissance survey of the project site. Then, sampling was carried out through trial pitting which permitted a close examination of the sites.

Preparation of specimens: Samples that have been collected via trial pitting were prepared in accordance with BS 1377, 1990 and Head, 1992. Prior to preparing the test specimens, the materials were air - dried and broken into smaller fragments, care being taken not to reduce the sizes of the individual particles.

Test Procedures: The following tests viz: Atterberg limits, Particle grain analysis, California bearing ratio, and Compaction test were carried out on each of the disturbed samples. The procedures of their tests are as follows:

Grain size analysis: Representative sample of approximately 500kg was used for the test after washing and oven-dried. The sieving was done by mechanical method using an automatic shakers and a set of sieves.

Liquid limit determination: Soil sample passing through 425um sieve, weighing 200g was mixed with water to form a thick homogeneous paste. The paste was collected inside the Casangrade's apparatus cup with a grove created and the number of blows to close it was recorded.

Plastic limit determination: soil sample weighing 200g was taken from the
material passing the 425um test sieve and then mixed with water till it become homogenous and plastic to be shaped to ball. The ball of soil was rolled on u glass plate until the thread cracked at approximately 3mm diameter.

California Bearing Ratio (CBR): Fresh sets of 3kg air-dried soil were mixed with suitable amount of water of about 5% of Its weight of water. The sample was completed following the standard procedure (BS1377, 1990). The sample was put in CBR mould in 3 layers with each layer compacted with 55 blows using 2.5kg hammer at a drop of 50mm (standard proctor test). The compacted soil and the mould were weighed and placed under CBR machine following the standard procedure. Load was recorded at penetration of 0.625, 1.9, 2.25, 6.25, 7.5,10 and 12.5mm.

Compaction test: Samples that were crushed to pass through 4.76mm (BS No.4) sieve aperture as outlined by head (1992) of about 3kg was used. The sample was mixed with suitable amount of water of 5% at the initial stage and later increased to 7%, 9%, 10 % and 13% on subsequent tests. The soil was compacted using BS mould of 105m diameter and 115.5mm height. The compaction was done in 5 layers. Each layer was compacted with 4.5kg rammer at 10 blows from a dropping height 300mm. This method is known as West Africa Standard (WAS). Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) were determined from the graph of dry density against moisture content. (Bowles, 1988 and BS 1377, 1990)

III. Results and Discussion

Sieve Analysis: The percentage of the lateritic soil samples passing BS Sieves 2mm, 425µm and 5µm are shown in Table l. The percentage passing through No. 200(75µm) BS sieve ranges between 10.5% and 24.7% showing that the soil samples arc coarse materials according to Unified Soil Classification System (USCS). The soil samples can be basically suitable for sub-grade construction as their percentage by weight finer than No.

200 BS sieve is less than 35%, according to Federal Ministry of Works and Housing (1972) specification. The lateritic soil samples also belong to A-2-6 sub-grade according to AASHTO method of classification as shown on Table 1.

Atterberg Limit: The liquid limits of the soil sarnples range between 28.6% and 45% and plastic limits between 18.8% and 25% while plasticity index is between 14.2% and 20.7% as shown in table 1. Soils with liquid limit less than 30% are considered to be of low plasticity, those with liquid limit between 30% and 50% exhibit medium plasticity and those with liquid limit greater than 50% exhibit medium plasticity and those with liquid limit greater than 50% exhibit high plasticity. All samples exhibit medium plasticity except sample T5 which exhibit low plasticity. This type of liquid limit can be expected for silty soils which usually have typical values of 25% to 50% (BS 1377. 1990). Also, a liquid limit of 50 (maximum) and a plasticity index of 15 (maximum) have been recommended, thus samples T2, T3 and T5 have fallen out of the recommendation.

Specific Gravity: The values of the specific gravity for the samples ranged between 2.66 and 2.77 as shown in Table 1. The specific gravity values are within the range recommended in BS 1377 of (1990). Thus, lower specific gravity value indicates a coarse soil, while higher values indicate a fine grained soil.
Compaction: British standard light compactive effort was used. The Maximum Dry Density (MDD) ranges between 1.98Mg/m^3 and 2.21Mg/m^3 while the optimum moisture content ranges between 10.81% and 12.52% as depicted in Table 2,

California bearing ratio: The values of CBR have been shown in Table 3. lt has unsoakcd CBR ranges between 64 and 85% which that of its corresponding soaked samples range between 26 and 33%. The percentage decreases from unsoaked CBR to soaked CBR. This implies that as water is absorbed into compacted specimen, the resistance to penetration becomes drastically reduced. It has been recommended by Federal Ministry of Works and Housing (1972) that the values of CBR for road base, sub-base and subgrade should not be less than 80%, 30% and 10% respectively under soaked condition. It can be seen that samples Tl and T5 do not satisfy the condition for both road base and sub-base.

Table 1: Summary of Grain size analysis, Atterberg limit and Specific gravity

Sample No	Grading % passing BS sieve 2mm 425^m 75|im	Atterberg limit LL (%)PL(%)PI (%)	Specific gravity	AASHTO Classification
Tl	68.9 51.7 21.5	33,0 18.8 14.2	2.68	A-2-6
T2	83.1 65.6 24.7	36.7 19.1 17.6	2.70	A-2-6
T3	88.2 50.0 18.6	38.0 20.6 17.4	2.66	A-2-6 .
T4	69.4 33.4 13.1	45.0 24.3 20.7	2.74	A-2-6
T5	54.8 32,2 10.5	28.6 17.4 11.2	2.77	A-2-6
T6	84.8 53.8 23.7	36.0 18.9 17.1	2.67	A-2-6
T7	77.6 42.4 20.3	36.0 18.0 16.0	2.66	A-2-6
T8	80.4 52.7 21.8	40.0 25.0 15.0	2.71	A-2-6

Table 2: Summary of California bearing value and Compaction

Sample No	CBR (Unsoaked%)CBR (Soaked %) '		MDD (Mg/m^3)	OMC (%)
Tl	66.7	29	2,13	11.58
T2	79.3	33	2.09	11.98
T3	78	30	2.18	U.15
T4	85	32	2.20	10.90
T5	64 '	26	1.98	12.52
T6	73	31	2.16	11.23
T7	77	34	2.04	12.34
T8	84	33	2.21	10.81

Computational analysis of linear regression equations: Table 3 presents the summary of the computation of linear regression equations for different categories of tests results while table 4 presents the summary of the experimental and calculated values of the California bearing ratio, compaction and other index values. Attempts were made to establish correlations between California bearing ratio values and index properties of the soil samples using linear regression analysis (Loveday, 1989),

Table 3: Linear regression equation for different categories of test

Description	Linear regression

CBR (unsoaked) vs. Liquid limit CBR	CBR = 0.031 LL + 83.19
CBR (unsoaked) vs. Plastic limit	CBR = 0.8 P.L +65.31
CB-R (unsoaked) vs. Specific gravity	CBR=10.43 S.G +56.19
CBR (unsoaked) vs. MDD	CBR = 8.66 MDD+ 65.88
CBR (soaked) vs. Liquid limit	CBR. = 0.22 L.L + 28.87
CBR (soaked) vs. Plastic limit	CBR = 1.04 P.L + 13.56
CBR (soaked) vs. Specific gravity	CBR = 9.42 S.G+10.91
CBR (soaked) vs. MDD	CBR=50.28MDD-70.22

Table 4: Summary table for experimental and calculated values

Sample No.	Tl	T2	T3	T4	T5	T6	T7	T8
Liquid limit	**33**	**36.7**	**38**	**45**	**28.6**	**36**	**36**	**40**
Experimental value of CBR (unsoaked)	66.7	79.3	78	85	64	73	77	84
Calculated value of CBR	84.19	84.3	84.37	84.6	84.1	84.3	84.3	84.4
Plastic limit	**18.8**	**19.1**	**20.6**	**24.3**	**17.4**	**18.9**	**18.0**	**25**
Experimental value of CBR (unsoaked)	66.7	79.3	78	85	64	73	77	84
Calculated value of CBR	80.4	80.6	81.8	84.8	79.23	80.4	79.7	85.3
Specific gravity	**2.68**	**2.7**	**2.66**	**2.74**	**2.77**	**2.67**	**2.66**	**2.71**
Experimental value of CBR (unsoaked)	66.7	79.3	78	85	64	73	77	84
Calculated value of CBR	84.14	84.4	83.3	84.77	85.08	84.04	83.93	84.46
Maximum dry density	**2.13**	**2.09**	**2.18**	**2.20**	**1.98**	**2,16**	**2.04**	**2.21**
Experimental value of CBR (unsoaked)	66.7	79.3	78	85	64	73	77	84
Calculated value of CBR	84.32	83.98	84.76	84.93	83.03	84.59	83.55	8^.02
Liquid limit	**33**	**36.7**	**38**	**45**	**28.6**	**36**	**36**	**40**
Experimental value of CBR (soaked)	29	33	30	32	26	31	34	33
Calculated value of CBR	36.13	36.9	37.2	38.8	35.16	36.8	36.8	37.67
Plastic limit	**18.8**	**19.1**	**20.6**	**24.3**	**17.4**	**18.9**	**18.0**	**25**
Experimental value of CBR (soaked)	29	33	30	32	26	31	34	33
Calculated value of CBR	33.1	33.4	34.98	38.8	31.66	33.2	32.28	39.56
Specific gravity	**2.68**	**2.7**	**2.66**	**2.74**	**2.77**	**2.67**	**2.66**	**2.71**
Experimental value of CBR (soaked) "	29	33	30	32 •	26	31	34	33
Calculated value of CBR	36.19	36.34	35.97	36.72	37.0	36.06	35.97	36.44
Maximum dry density	**2.13**	**2.09**	**2.18**	**2.20**	**1.98**	**2.16**	**2.04**	**2.21**
Experimental value of CBR (soaked)	29	33	30	32	26	31	34	33
Calculated value of CBR	36.88	33.8	39.39	40.4	29.33	38.38	32.5	40.9

IV. Conclusion

The construction of highway pavement requires to meet regulatory minimum CBR which should not be less than 80%, 30% and 10% for base, sub-base and sub-grade materials thus requires careful selection of materials. The suh presented an empirical approach for calculating or predicting California bearing ratio which serves as the most important factor during road pavement construction.

The results of the experimental analysis show that California bearing ratio for the unsoaked samples ranges between 66.7% and 85% while that of the calculated value ranges between 79.2% and 85.3%. In the same vein, the results of the experimental value for the soaked California bearing ratio shows that the values range between 26% and 34% while that of the calculated value ranged between 29.3% and 40.9%. Thus, the results of the analysis indicate that there is a relationship between California bearing ratio compaction and index properties. The results of the experimental values show that sample Tl and T5 do not satisfy the requirement for both road base and base materials can only be used for sub-grade material. In the other way, when looking at angle of the calculated value there is slight contradiction because the values satisfy the conditions for the base and sub-base materials. Also, for the soaked California bearing ratio, samples Tl and T5 have values that are less than 30% from the experimental point of view but greater than 30% from the calculated value.

It can thus be safely concluded that linear regression analysis provides a sound background for predicting California bearing ratio of samples for preliminary assessment and not an acceptable alternative to laboratory testing. It is recommended for future research that regression based motels such as two ways ANOVA and computer based reliability analysis be carried out on a wider variety of soil samples so as to specify the range of applicability of the derived model viz-a-viz the input variable.

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