Experimental Study on the Effects of Some Index Properties on California Bearing Ratio of Selected Soils

M. O. Abdulazeez, G. O. Adunoye, A. A. Adekola

Abstract— California bearing ratio (CBR) is a property of soil which is very vital in the design and construction of roads. This study was undertaken to determine the effect of some index properties on the CBR of selected soils. This was with a view to developing models for timely and less cumbersome estimation of CBR of soils. To achieve this aim, soil samples were collected from active borrow pits within Ile-Ife, Osun State, Nigeria. The following laboratory tests were conducted on the soil samples: natural moisture content; particle size analysis; Atterberg limit; compaction test; California bearing ratio (CBR) – unsoaked and soaked.. Data from the laboratory tests were then analysed and used to develop relationships between index properties and CBR, using Microsoft Excel and Xuru's regression tools. The maximum dry density of the soil samples ranged between 1.48 g/cm and 1.95 g/cm, while the optimum moisture content ranged between 13.03 % and 25.98 %. The unsoaked CBR values ranged between 9.44 % and 2.34 %, while soaked CBR values ranged between 4.91 % and 1.3 %. Combination of plasticity index (PI) and uniformity coefficient gave the best model for unsoaked CBR, while PI and coefficient of gradation gave the best model for soaked CBR. The study concluded that useful relationships exist between the selected index properties and CBR. The developed models could therefore be employed in the determination of the CBR of tested soils for preliminary analysis/assessment.

Index Terms— California bearing ratio, coefficient of gradation, index properties, regression, uniformity coefficient

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1 INTRODUCTION

THE importance of soils in road construction has necessitated the interest of highway engineers in the basic engineering properties of soil. One important engineering property of soil which is very vital in road construction is California bearing ratio (CBR). The bearing capacity of the soil beneath highways, airfield runways and other pavement systems is of great importance to the integrity of the pavement. The CBR test is an empirical method of design of flexible pavement. In other words, the CBR is utilised to design the thickness of pavement layer to be laid on the top of the sub-grade by highway engineers. The thickness of sub-grade depends on CBR value. Sub-grade that has lower CBR value will have thicker pavement compared with the sub grade that has higher CBR value and vice versa [1], [2].

The suitability and stability of soil is usually evaluated before its use in construction. Proper analysis is necessary to ensure that civil engineering infrastructures such as roads, buildings, rails, dams, etc. remain safe and free to withstand settlement and collapse. Geographical variability in soil conditions from one location to another makes it difficult to predict the properties of soil. It has therefore become necessary to investigate soil conditions for proper design [3].

As important as CBR is, it takes about four days to obtain the soaked CBR value of a soil, which makes CBR test cumbersome, costly and time-consuming. Thus, only a limited range of CBR test can be performed on the projected road to be constructed per kilometer. Such restricted range of CBR results might generally not reveal the variation within the CBR values over the whole length of the road to ensure economic, rational and safe construction [4]. The situation may also result in delay in the progress of the project and lead to escalation of the project cost. To overcome these difficulties, it is imperative to predict CBR values of sub-grade soils with easily determinable parameters. Since CBR test is time-consuming, a good prediction of CBR values from index tests (which are less cumbersome to perform) would be beneficial. To this end, attempts have been made to relate some geotechnical properties to CBR values, most of them with little or moderate success.

[5] studied the results of over 1000 soaked CBR tests obtained from road and airport works throughout central and southern Africa and prepared a chart giving a nest of straight lines that related CBR to plasticity index (PI) and grading modulus [4]. [2] established relationships between CBR and different soil properties. They concluded that liquid limit is considered as higher priority for predicting soaked CBR value followed by optimum moisture content (OMC), maximum dry density (MDD) and plasticity index (PI), based on assessment factor R^2 values. The developed equation is: $CBRs=-0.275LL+0.118PL+0.033F+5.106G$ with $R^2=0.961$. [6] performed regression analyses of index properties of soils as strength determinant for CBR. They developed linear and multiple regressions between CBR and selected index properties and concluded that the index properties of soils can be used to accurately determine the CBR values, for preliminary characterization of soils.

It has been observed that there is no available record of any study on the effects of index properties on CBR of soils in the study area. The observation has thus made this study very important. The study aimed to study the effects of selected index properties on the CBR of soils in Ile-Ife, Osun state, Southwestern Nigeria. This was with a view to finding a faster and less laborious means of predicting the CBR

1.1 Location and Geology of the Study Area

The study area is Ile-Ife. Ile-Ife is located within Latitude 7°26'N and 7°32'N and Longitude 4°29'E and 4°35'E, covering an area of about 1,894 km² in Osun State, Southwestern Nigeria. The study area falls within Ife Central and Ife East Local Government Areas, and has a population of about 501,952 [7], [8] (Figure 1). The study area falls within the basement complex of Southwestern Nigeria (Figure 2). It forms part of the African crystalline shield which consists predominantly of migmatised and undifferentiated gneisses and quartzite [9], [10], [11], [12], [13].

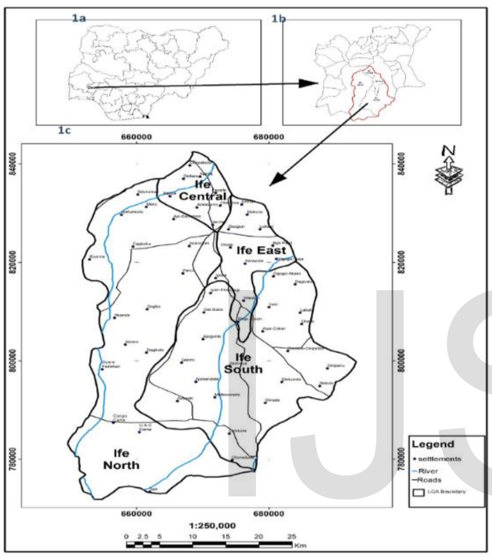

Fig. 1. Map of the study area: (a) Map of Nigeria showing Osun State; (b) Map of Osun State showing Ile-Ife; (c) Map of Ile-Ife (Adapted from [8])

2 MATERIALS AND METHODS

2.1 Materials and Equipment

The main material used was lateritic soil samples obtained from ten (10) identified locations (borrow pits) within the study area. Table 1 presents a description of the sampling points, while the list of equipment used for the various analyses/tests are contained in Table 2. All the equipment were available in the Geotechnical Engineering Laboratory of Department of Civil Engineering, Obafemi Awolowo University (OAU), Ile-Ife..

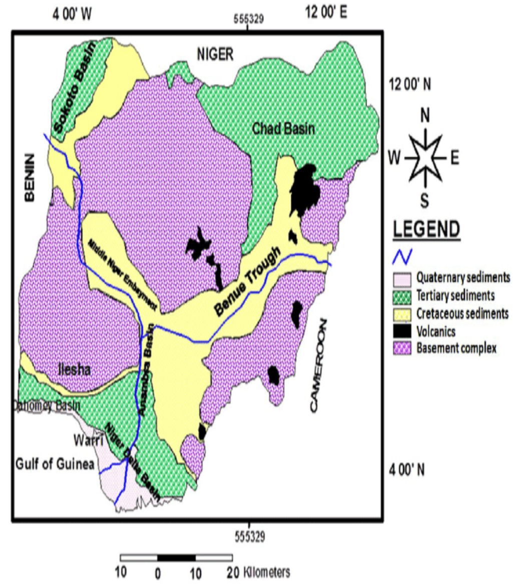

Fig. 2: Map of the Major Geological Formations of Nigeria [12]

TABLE 1
DESCRIPTION OF SAMPLE LOCATIONS

Sample ID	Latitude	Longitude
1	N7°29′52.5012″	E4°26′57.0876″
2	N7°29′31.0848″	E4°29′10.3164″
3	N7°30′10.5696″	E4°35′43.5768″
4	N7°28′46.2108″	E4°34′44.886″
5	N7°31′10.8084″	E4°32′5.9208″
6	N7°31′8.31″	E4°30′45.3096″
7	N7°29′42.8382″	E4°31′44.6772″
8	N7°30′30.5″	E4°30′09.9″
9	N7°33′06.5″	E4°35′14.3″
10	N7°33′16.9392″	E4°35′27.264″

2.2 Sample Collection and Preparation

In each of the identified sampling points, test pits were dug and excavated with the aid of digger and shovel. The depth of sample collection was 0.5 m – 1 m [14], [15]. 20 - 25 kg of each sample was collected into a polythene bag, sealed and immediately taken to the Geotechnical Laboratory of the Department of Civil Engineering, OAU, Ile-Ife, for analyses. After determining the initial moisture content, the samples were prepared for subsequent laboratory analyses by air-drying and grinding to pass 2 mm sieve [13].

2.3 Preliminary and Engineering Tests on Soil Samples

The following tests were conducted on the soil samples, using standard procedures as outlined in [16]: natural moisture content determination; particle size analysis; specific gravity; plastic limit; liquid limit; compaction and CBR - both unsoaked and soaked. From the results of the sieve analyses, uniformity coefficient (C_u) and coefficient of gradation (C_c) were determined using Equations 1 and 2. Also, from the results of Atterberg limit tests, plasticity index (PI) was determined using Equation 3.

$$C_u = \frac{D_{60}}{D_{10}} \tag{1}$$

$$C_C = \frac{D_{30}^2}{D_{60} \times D_{10}} \quad (2)$$

$$PI = LL - PL \quad (3)$$

Where D_{10} =Grain size for which 10% of the sample is finer
D_{30} =Grain size for which 30% of the sample is finer
D_{60} =Grain size for which 60% of the sample is finer
PL = Plastic limit
LL = Liquid limit

TABLE 2
LIST OF EQUIPMENT

Equipment	Purpose
Set of Sieves (4.5mm to 0.06mm)	Particle size analysis (coarse grain)
Sieve Shaker	Shaking of soil sieves
Hydrometer Bulb	Particle size analysis (fine grain)
Specific Gravity Bottle	Specific gravity determination
Atterberg Apparatus	Plastic and liquid limits determination
Electric Oven (Temp 105^{o}C to 110^{o}C)	Drying of moist soil sample
Weighing balance	Weighing of soil
Measuring Cans	Measurement
Compaction Moulds and Rammers	Compaction test
CBR Machine	Determination of soil CBR

2.4 Development of Relationships between CBR and the Index Properties of Soil

In studying the relationship between CBR and index properties, CBR was used as the dependent variable, while the index properties were independent variables. The validity of each developed relationship (model) was verified using the coefficient of determination (R^2). If R^2 is 1, there is a perfect correlation between the variables; if it is close to 1, there is a strong relationship between the estimated values and the actual values. CBR values were correlated with the values of each index property, using linear regression on Microsoft Excel tool. The index properties used were: natural moisture content, specific gravity, Atterberg limits (liquid limit, plastic limit, plasticity index) and particle size coefficients. Index properties with the stronger or higher correlations with the CBR were then identified; and using Xuru's regression tool [17], multiple regressions were then developed between CBR and the selected index properties.

3 RESULTS AND DISUSSION

3.1 Results of Preliminary and Engineering Tests on Soil Samples

The summary of the results obtained from preliminary tests conducted on the soil samples are presented in Table 3. The values of natural moisture content were determined under the prevailing weather condition at the time of sample collection. The samples with higher moisture contents were collected during wet season with a rise in water table. The specific gravity values fall within the acceptable range for lateritic soil [18], [19]. The particle size distribution aided in the classification of the soils (see Table 3). According to AASHTO classification, the soil samples could be described as granular materials; while the soil samples could be said to be coarse grained (sandy), according to USCS classification [20]. The values of Atterberg limits show that the soil samples are suitable for subgrade and base courses in road construction.

Table 4 presents the results of the compaction and CBR tests. The values of MDD of the soil samples ranged between 1.48 g/cm^3 and 1.95 g/cm^3, while the values of OMC ranged between 13.03 % and 25.98 %. Sample 10 has the highest MDD value of 1.95 g/cm^3 and lowest OMC value of 13.03 %; while sample 9 has the minimum MDD value of 1.48 g/cm^3 with OMC value of 23.21 %. In other words, if the soil samples are subjected to the same compaction method on the field, sample 10 will have the highest dry density while sample 9 will have the lowest dry density. Also, sample 9 has the highest unsoaked CBR value of 9.44 % and sample 1 has the lowest unsoaked CBR value of 2.34 %. Samples 6 and 7 have the highest soaked CBR value of 4.91 % each, while sample 10 has the lowest soaked CBR value of 1.3 %. The percentage decrease from unsoaked CBR to soaked CBR indicates, as expected, that, as water is absorbed into the compacted sample, the resistance to penetration becomes drastically reduced. Generally speaking, the values of the unsoaked and soaked CBR indicate that the soil samples are only suitable for sub-grade fill in road construction [21].

3.2 Correlations between CBR and Selected Index Properties

Results of correlations between CBR (unsoaked and soaked) and index properties are presented in Tables 5 and 6. For unsoaked CBR, PI and C_u have better correlations with CBR; while for soaked CBR, PI and C_c showed fairer correlation with CBR. The results of multiple regression between CBR (unsoaked

ISSN 2229-5518

and soaked) and the selected index properties above are shown in Tables 7 and 8. Figure 3 presents a pictorial relationship between experimental and model CBR (for unsoaked CBR), while Figure 4 presents a pictorial relationship between experimental and model CBR (for soaked CBR). From the results, it is clear that unsoaked CBR has a strong correlation with the selected index properties, while the soaked CBR could be said to have a moderate correlation with the selected index properties.

TABLE 3
RESULTS OF PRELIMINARY ANALYSIS ON SOIL SAMPLES

Sample ID	Gs	LL(%)	PL(%)	PI(%)	C_u	C_c	AASHTO Classification	USCS Classification
1	2.49	54.92	52.95	1.97	8.50	1.44	A-1-a	SP-SM
2	2.21	47.16	35.44	11.72	6.00	2.04	A-2-7	SP
3	2.54	32.52	19.26	13.26	8.75	1.61	A-2-6	SW-SC
4	2.56	44.41	29.68	14.73	9.50	1.68	A-2-7	SP
5	2.68	31.36	18.57	12.79	5.00	0.45	A-2-6	SC
6	2.67	40.12	22.71	17.41	10.00	0.90	A-2-6	SC
7	2.7	47.11	46.56	0.55	8.75	0.58	A-1-a	SC
8	2.76	31.08	21.71	9.37	10.00	2.50	A-2-4	SW-SC
9	2.45	45.56	21.36	24.2	20.00	2.45	A-2-7	SC
10	2.75	24.66	13.28	11.38	14.00	0.64	A-2-6	SC

TABLE 4
RESULTS OF ENGINEERING TESTS ON SOIL SAMPLES

Sample ID	MDD (g/cm^3)	OMC (%)	CBR (%)	
			Unsoaked	Soaked
1	1.5	25.98	2.34	2.81
2	1.71	21.22	4.23	2.34
3	1.72	17.83	3.02	3.01
4	1.5	25.82	6.12	3.02
5	1.76	15.68	3.51	3.36
6	1.71	15.69	5.36	4.91
7	1.62	19.04	4.23	3.55
8	1.83	16.05	4.53	4.91
9	1.48	23.21	9.44	3.56
10	1.95	13.03	6.12	1,3

TABLE 5
CORRELATION OF INDEX PROPERTIES WITH UNSOAKED CBR

Index Property	Correlation Equation	R^2
nm (%)	y = -0.117x + 7.495	0.12
Gs	y = -0.381x + 5.874	0.001
LL	y = -0.008x + 5.203	0,0014
PL	y = -0.064x + 6.70	0.173
PI	y = 0.215x + 2.371	0,533
C_u	y = 0.408x + 0.79	0.734
C_c	y = 0.857x + 3.665	0,104

y = unsoaked CBR; x = index property

TABLE 6
CORRELATION OF INDEX PROPERTIES WITH SOAKED CBR

Index Property	Correlation Equation	R^2
nm (%)	y = -0.055x + 4.477	0.081
Gs	y = 1.993x - 1.867	0.096
LL	y = 0.007x + 2.988	0.004
PL	y = -0.003x + 3.353	0.001
PI	y = 0.024x + 3.000	0.022
C_u	y = -0.0057 x + 3.334	0.0005
C_c	y = 0.330x + 2.805	0.537

y = soaked CBR; x = index property

4 CONCLUSION

In a bid to achieve the aim of this study, the index and enngineering properties (including CBR) of selected soil samples were determined. The effects of the index properties on CBR were studied by correlating the properties with both the unsoaked and soaked CBR values. The obtained CBR values gave an indication that all the soil samples, in their natural state, could only be used for subgrade filling in road construction work. It was also observed that

PI and C_u have the highest and very strong correlation with unsoaked CBR, while PI and C_c, have a fair correlation with soaked CBR. Therefore, the identified index properties could be used in predating the CBR values of the selected soil samples for preliminary assessment. The obtained results are valid for the study area. Further work is also recommended, especially on the prediction of the soaked CBR. Effects of index properties on CBR of soils from different locations should also be studied.

TABLE 7

MULTIPLE REGRESSION RESULTS BETWEEN SELECTED INDEX PROPERTIES AND UNSOAKED CBR

Metrics	Value/Description
Equation	$y = 0.013x_1^2 – 0.04x_1\ x_2 + 0.028x_2^2 + 0.233x_1 + 0.252x_2 – 0.727$
RSS	5.548
R2	0.85

y = unsoaked CBR; x_1 = PI, $x_2 = C_u$

TABLE 8

MULTIPLE REGRESSION RESULTS BETWEEN SELECTED INDEX PROPERTIES AND SOAKED CBR

Metrics	Value/Description
Equation	$y = 1.047x_1^2 – 0.234\ x_1x_2 + 0.018x_2^2 – 0.045x_1 – 0.062x_2 + 2.376$
RSS	5.999
R2	$0.436·10^{-1}$

y = soaked CBR; $x_1 = C_c$, x_2 = PI

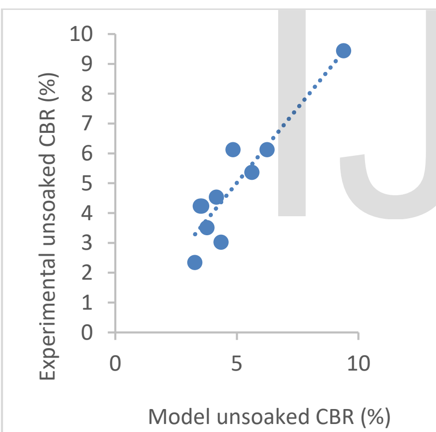

Fig 3: Experimental CBR vs Model CBR (unsoaked)

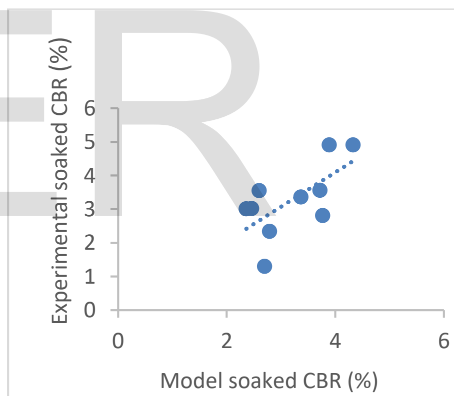

Figure 4: Experimental CBR vs model CBR (soaked)

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