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Model for the Prediction of California Bearing Ratio Using the Geotechnical Properties for Subgrade Soil

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Abstract **Original Research Article**

The subgrade soil is an important component of the pavement structure because it can affect the performance and durability of the road during the service life. One of the essential properties of the subgrade soil to evaluate the strength is the California bearing ratio (CBR). It is necessary to predict the CBR of any soil to determine its suitability as subgrade soil before use. Therefore this study was to develop multiple regression model for prediction of CBR using the geotechnical properties of the soils. The tests carried out in the study were consistency limis, particle size analysis, compaction and CBR tests. It was found that the soils were characterized to range from very poor to excellent for subgrade purposes. The coefficient of correlation, coefficient of determination and standard error of the model were found to be 0.834744, 0,696797 and 10.28991 respectively. Also, all the dependent variables were very significant in predicting the California bearing ratio.

Keywords: Multiple Regression Model, Geotechnical Properties, Subgrade Soil.

1.0 INTRODUCTION

Subgrade soil is a very important component of a road work because it forms the main foundation on which the pavement structure is being laid. It is usually made up of natural soil or slightly treated with other materials especially when it is deficient of some geotechnical properties. Soils in natural and treated conditions had been used as subgrade soils (Okonkwo, 2018; Ikeagwuani *et al.*, 2019; Kennedy and Okonkwo, 2023; Enyinnia *et al*., 2024). Soils from the tropics in the treated condition had also been utilized for various civil engineering works such as pavement structure (Sani *et al*,. 2020; Ukpai and Okonkwo, 2025), waste containment (Okonkwo *et al.,* 2018; Osinubi *et al*., 2020; Etim *et al*., 2022) and cement blocks (Mimboe *et al.,* 2020; Akinyemi *et al.*, 2020; Ibedu *et al.,* 2023).

The performance of a road pavement layer during its service life is highly influenced by the strength and stiffness of the subgrade soil (Ghanizadeh *et al.,* 2024). The stiffness of a subgrade soil refers to the degree of resistance it could offer when it is being loaded which fundamentally is dependent on the soil characteristics, conditions of stress being subjected and the history of stress on the soil (Yong *et al.*, 2019). Consequently, the properties of the subgrade relating to its strength and stiffness are very important considerations to resist deformation or any form of deterioration of the pavement structure.

One critical problem facing the geotechnical engineers in the tropics and subtropics is the level at which the soils encountered for construction works are not amenable to test and pretest conditions of the conventional testing standards (Okonkwo, 2024). This is as a result of their structural peculiarities such that two soils can never be the same in all geotechnical point of view. In other words, when soils are similar in consistency indices, they would differ in some other geotechnical characteristics such as particle size grading which would definitely affect their behaviours. These variabilities that exist between tropical soils had been exhaustively explained by Gidigasu (1976) from their pedogenesis.

Based on the foregoing, conducting the number of tests required for the prediction of the geotechnical properties of soils in the subtropics and tropics would be laborious. One of the ways that could be used to overcome this daunting task is by the use of mathematical models. Models had been used for predictions of soil factors of a plantation (Wen *et al.*, 2021), Calories of fuel derivatives from refuse (Luqman *et al.,* 2023) and compaction delay in stabilized soil for pavement structures (Okonkwo *et al.,* 2023). Most efforts in using models for predicting strength characteristics of soils had never considered consistency limits and grading of the soils simultaneously in the same model. Therefore, this study focused on the developing of multiple regression model for the prediction of California bearing ratio using the geotechnical characteristics for subgrade soil purposes.

2.0 MATERIALS AND METHODS

The soil samples were collected with disturbed sampling method from 20 soil deposit sites in Awka South local government area of Anambra State, Nigeria which lies on approximate range of latitudes 6.33^0 to 6.55^0 and Longitudes 7.00^0E to 7.25^0E. The soil samples were tested for consistency indices and particle size analysis using ASTM D4318-17 (2018) and ASTM D6913-04 (2017) respectively. The soil samples were further classified in the AASHTO (2011) rating. The compaction test and the California bearing ratio test were carried out in accordance to BS 1377-1 (2016). The energy from the British Standard Light in which three layers were given 27 blows to each layer. The optimum moisture content obtained from the moisture-density relationships were used to conduct the California bearing ratio tests. For all the tests conducted on the soil samples, three sets of samples were tested from each soil deposit and the mean value of the results were taken. The multiple regression was developed using Microsoft excel software to make the computation less rigorous.

3.0 RESULTS AND DISCUSSION

3.1 Results of the Soil Tests

The results of the consistency limits and the particle sizes are shown in Table 1. The linear shrinkage, liquid limit, plastic limit, plasticity index and percentage passing sieve number 200 (75µm) ranges were 2.4-13.6, 14.2-89.67, 7.2-26.55, 5.1-63.5, 0.04-33.38 respectively. The AASHTO (2011) classifications were also shown and the ratings fell between A-2-4 and A-2-7 with the group index (GI) ranging from 0-1.9. The values of the consistency limits and particle sizes were useful in rating the soils in the AASHTO (2011). Judging by the classification rating of the soils, the A-2 soil group are found almost at the left side of the AASHTO Table (2011) and also low values of group index showed the soils as suitable for road construction works (Okonkwo and Uwanuakwa, 2021; Ekeoma *et al.*, 2023). Most soils in the A-2 group are also virtually non-swelling which is a very good attribute required for soils to be suitable for construction works.

Table 1: Results of Consistency Limits, Particle Sizes and Soil Classifications of the Subgrade Soils

Sample Code	Moisture Content (%)	Linear shrinkage value	Liquid limit, WL (%)	Plastic limit, Wp (%)	Plasticity index, PI (%)	% of Soil Passing 2.36mm sieve	% of Soil Passing 425µm sieve	% of Soil Passing 75µm sieve	Group index, GI	AASHTO Classification
S_1	11.9	2.4	18.21	13.1	5.1	97.16	70.28	33.63	0.0	A-2-4
S_2	12.2	13.6	89.67	26.15	63.5	81.91	51.80	25.58	1.4	A-2-7
S_3	12.6	5.1	32.38	21.55	10.8	95.62	73.53	23.42	0.0	A-2-6
S_4	11.85	4.2	25.2	16.2	9.0	100.00	71.13	21.25	0.0	A-2-4
S_5	13.35	8.1	43.61	26.4	17.2	99.69	56.83	27.08	0.0	A-2-7
S_6	12.6	4.8	27.24	17.05	10.2	100.00	63.79	21.32	0.0	A-2-6
S_7	13.05	8.4	44.47	26.55	17.9	100.00	55.01	27.14	0.0	A-2-7
S_8	12.4	5.5	37.24	25.5	11.7	98.52	87.88	26.27	0.0	A-2-6
S_9	12.15	3.4	33.35	26.05	7.3	96.23	62.39	24.49	0.0	A-2-4
S_10	11.9	3.3	14.2	7.2	7.0	98.01	52.98	0.04	0.0	A-2-4
S_11	12.2	8.6	40.47	22.2	18.3	99.07	55.16	0.07	0.0	A-2-7
S_12	12.6	8.2	32.9	15.5	17.4	97.75	52.90	0.36	0.0	A-2-6
S_13	11.85	3.4	19.44	12.3	7.1	97.53	74.00	6.94	0.0	A-2-4
S_14	13.35	4.5	23.95	14.4	9.5	95.64	71.84	4.21	0.0	A-2-4
S_15	12.6	2.7	19.4	13.75	5.7	91.18	59.68	3.32	0.0	A-2-4
S_16	13.05	3.9	23.43	15.1	8.3	94.08	82.66	18.57	0.0	A-2-4
S_17	12.4	7.5	30.6	14.55	16.1	98.22	89.82	38.38	1.9	A-2-6
S_18	12.15	3.7	25.15	17.2	8.0	99.32	70.79	21.45	0.0	A-2-4
S_19	11.5	4.1	23.43	14.7	8.7	100.00	81.89	22.02	0.0	A-2-4
S_20	18.25	4.0	23.43	14.9	8.5	99.88	58.73	18.19	0.0	A-2-4

Table 2 presents the results of compaction and strength characteristics of the soils. The range of optimum moisture content, maximum dry density and California bearing ratio for the soils were 8.2-30.1%, 1558- 2255 Kg/m^3, 3-54% respectively. From the point-of-view of strength property (California bearing ratio), the soils were seen to be from poor to excellent. In spite of the AASHTO (2011) rating of the soils, the California bearing ratio is an important consideration for subgrade soils.

Table 2: Results of Compaction and Strength Characteristics of the Subgrade Soil

Sample code	Optimum moisture content (%)	Maximum dry density (Mg/m3)	Soaked CBR(%)	General Rating	Use
S_1	8.2	1.975	21	Excellent	S5 Subgrade
S_2	10.2	2.046	11	Fair to good	S5 Subgrade
S_3	8.2	2.183	16	Fair to good	S5 Subgrade
S_4	8.3	2.069	25	Excellent	S5 Subgrade
S_5	12.2	2.010	12	Fair to good	S5 Subgrade
S_6	10.3	2.127	6	Poor	S5 Subgrade
S_7	10.1	2.055	5	Poor	S5 Subgrade
S_8	10.2	2.003	13	Fair to good	S5 Subgrade
S_9	10.3	2.059	27	Excellent	S5 Subgrade
S_10	10.3	2.057	4	Very poor	S5 Subgrade
S_11	12.6	2.071	3	Very poor	S5 Subgrade
S_12	12.5	2.026	6	Poor	S5 Subgrade
S_13	28.1	1.619	5	Very poor	S5 Subgrade
S_14	22.3	1.874	10	Fair to good	S5 Subgrade
S_15	25.4	1.730	6	Fair to good	S5 Subgrade
S_16	25.6	1.776	11	Fair to good	S5 Subgrade
S_17	12.3	2.106	53	Good	S5 Subgrade
S_18	14.9	2.037	54	Good	S5 Subgrade
S_19	30.1	1.558	8	Fair to good	S5 Subgrade
S_20	10.3	2.255	27	Excellent	S5 Subgrade

3.2 Modeling

Section 3.2.1 shows the summary output of the Excel sheet and the multiple regression model is presented in Equation (1)

3.2.1SUMMARY OUTPUT

Regression Statistics	
Multiple F	0.834744
R Square	0.696797
Adjusted I	0.519929
Standard E	10.28991
Observati	20

ANOVA

	df	*SS*	*MS*	*F*	*gnificance F*
Regressio	7	2919.963	417.1376	3.939638	0.018342
Residual	12	1270.587	105.8822		
Total	19	4190.55			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-155.238	81.59267	-1.90259	0.081358	-333.013	22.5374	-333.013	22.5374
X Variable	-1.86429	2.244266	-0.83069	0.422369	-6.75412	3.025548	-6.75412	3.025548
X Variable	-192.664	80.7867	-2.38485	0.034457	-368.683	-16.6448	-368.683	-16.6448
X Variable	192.3056	80.91105	2.376754	0.034969	16.01561	368.5957	16.01561	368.5957
X Variable	192.8955	80.85178	2.385792	0.034398	16.7346	369.0564	16.7346	369.0564
X Variable	0.849135	0.238926	3.553963	0.003968	0.32856	1.369711	0.32856	1.369711
X Variable	1.576346	0.88935	1.77247	0.10168	-0.36138	3.514073	-0.36138	3.514073
X Variable	74.48394	34.5376	2.156605	0.052026	-0.76702	149.7349	-0.76702	149.7349

RESIDUAL OUTPUT

Observatio	*Predicted Y*	*Residuals*
1	23.43735	-2.43735
2	11.08593	-0.08593
3	19.6662	-3.6662
4	18.44769	6.552311
5	14.19871	-2.19871
6	26.76134	-20.7613
7	11.91356	-6.91356
8	7.952735	5.047265
9	21.17551	5.824494
10	7.135511	-3.13551
11	4.971527	-1.97153
12	-1.13387	7.133868
13	-1.26746	6.267457
14	2.091106	7.908894
15	17.47129	-11.4713
16	16.63035	-5.63035
17	47.77118	5.228821
18	36.61339	17.38661
19	10.27902	-2.27902
20	27.79893	-0.79893

$$C = -155.238 - 1.86429S - 192.664L + 192.3056P + 192.8955I + 0.849135N + 1.576346M + 74.48394D \quad (1)$$

Where,
C = California bearing ratio
S = Linear shrinkage
L = Liquid limit
P = Plastic limit
I = Plasticity Index
N = Percentage passing sieve No 200 (75µm)
M = Optimum moisture content
D = Maximum dry density

From the output, the coefficient of correlation, coefficient of determination and standard error were 0.834744, 0,696797 and 10.28991 respectively. These are the properties that are used in evaluation of the model and they showed that the model predicted fairly well. The summary also showed the predicted values and the residuals. The residuals were quite low which showed that the predicted values are quite close to the actual values. The P-value for the intercept, linear shrinkage, liquid limit, plastic limit, plasticity index, percentage passing sieve number 200 (75µm), optimum moisture content and maximum dry density were 0.08138, 0.422369, 0.034457, 0.034969, 0.034398, 0.003968, 0.10168 and 0.052026 respectively. The p-value for all the variables and constant were less than 0.5, thus they have high level of significance. These imply that all the independent variables and the constant were highly involved in predicting the dependent variable (California bearing ratio).

4.0 CONCLUSION

After the study on developing multiple regression model, the following conclusions were drawn

i. The soils were characterized to range from very poor to excellent for subgrade purposes.
ii. The coefficient of correlation, coefficient of determination and standard error of the model were found to be 0.834744, 0,696797 and 10.28991 respectively.
iii. All the dependent variables were very significant in predicting the California bearing ratio.

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