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INDEX PROPERTIES AS PREDICTORS OF CALIFORNIA BEARING RATIO IN MAKURDI SHALE

Iorliam, Yala Amos[1*], Azembe, Iorchir Alfred[2] and Edeh, EjelikwuJoseph[1]
[1]Department of Civil Engineering, Joseph SarwuanTarka University Makurdi (Formerly, Federal University of Agriculture Makurdi), Nigeria.
[2]NTA Star TV Network LTD, NTA Makurdi Network Centre, Makurdi Benue State.
***Correspondence: iorliam.yala@uam.edu.ng**

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Abstract

The bearing capacity of subgrade soils is necessary for the design and construction of transportation infrastructure, such as roads, and airfields. The determination of bearing strength of soil could be tedious, expensive and time-consuming. There is need to establish models that would predict the bearing strength parameters such as California bearing ratio (CBR) using simple and less time-consuming laboratory tests. This study examines the relationship between CBR and index properties of Makurdi shale. Forty-five samples of the shale were collected; index properties and CBR were determined and correlated. Using multiple linear regression analysis, it was established that the soaked CBR could be predicted from the shale index properties such as moisture content, specific gravity, liquid limit, shrinkage limit, optimum moisture content and maximum dry density with adjusted $\boldsymbol{R^2}$ *of 0.838. Also, soaked CBR may be predicted from the soil properties like moisture content, liquid limit, plastic limit, shrinkage limit, optimum moisture content and maximum dry density with adjusted* R^2 *of 0.838. Based on the results of this study, it is recommended that models 1 and 2 could be used for prediction of soaked CBR of Makurdi shale using corresponding soil index properties such as moisture content, specific gravity, liquid limit, plastic limit, shrinkage limit, optimum moisture content and maximum dry density.*

Keywords: Makurdi shale, CBR, Soil index properties, Correlation, Multiple linear regressions

1.0 INTRODUCTION

The design and construction of transportation infrastructure, such as highways, roads, and airfields, heavily rely on the evaluation of subgrade soil properties. One of the major properties used to evaluate the strength of subgrade soils is the California bearing ratio (CBR). The CBR value of the soil provides the magnitude of resistance to penetration and its suitability for supporting pavements and other load-bearing structures (Khusru*et al.*, 2020).Soaked CBR is usually used in design of road pavement to simulate the critical and adverse conditions of saturated soil due to intensive rainfall or flooding (Ahmed *et al.*, 2016). Soaked CBR is determined in the laboratory by soaking the soil sample in water, sometimes up to 4 days (96 hours) before testing (Sapta*et al.*, 2023). The strength determined provides a representation of the soil's strength under real–world conditions when pavements are exposed to intense rainfall or flooding. Design pavements with soaked CBR ensures a durable and safe road that can withstand heavy traffic loads and environmental factors, without failure. In regions such as Makurdi, Benue State, where shale formations are abundant, the determination of CBR values becomes crucial for ensuring the design of long-term performance and durability of road infrastructure. However, there is increasing cost associated with determination of geotechnical properties used in the design of engineering infrastructures. This affects the achievement of one of the Sustainable Development Goals (SDG), which is to provide affordable, durable, safe and sustainable infrastructures such as road pavement, particularly in developing nations like Nigeria (Zadawa and Omran, 2019; United Nations, 2016).

Due to high cost, tedious and time-consuming procedure required for the determination of bearing strength of soil such as CBR, there is need to establish models that would predict the CBR using simple and less time-consuming laboratory tests.

Many researchers have been performed to develop models between index properties and CBR of some soils. Research on the correlation between CBR and some geotechnical properties of highly compressible clays (CH) was conducted by Jadhav et al., (2016). Through multiple linear regression analysis (MLRA) the study showed that soaked CBR could be predicted from maximum dry density (MDD) and optimum moisture content (OMC) with an $\mathbf{R^2}$ value of 0.82. Similarly, Egbe *et al.* (2017) conducted research on the relationship between CBR and some index properties of soil in Calabar South, Nigeria. Based on MLRA, the study shows that combined soil index properties like OMC, MDD, liquid limit (LL), plastic limit (PL), coarse sand (CS), medium sand (MS), and fine sand ($\mathbf{F_{200}}$) could be used to predict soaked CBR of Calabar South soil with $\mathbf{R^2}$of 0.9454. Using MLRA, Rakaraddi and Gomarsi (2015) conducted study on the relation between CBR and some geotechnical properties of soil at Bagalkot district, India. It was found that soaked CBR could be predicted from some soil index properties like LL, PL, $\mathbf{F_{200}}$,Gs, OMC and plasticity index (PI) with $\mathbf{R^2}$values from 0.931 to 0.961.

Also, Iqbal (2018) carried a study on the co-relationship between CBR and soil index properties of Jamshoro soil at Mehran University of Engineering and Technology (MUET), Jamshoro, Pakistan. Based on MLRA, the study reported that, soaked CBR could be predicted from the combination of LL, PI and percent finer than 200 *(*$\mathbf{F_{200}}$) with $\mathbf{R^2}$value of 0.984. Additionally, Aderinola*et al.* (2017) in research on the soil at Akure, Ondo state, established that unsoaked CBR could be predicted from index properties such as OMC, MDD, SL, PL and PI using multiple polynomial regression analysis (MPRA). The $\mathbf{R^2}$values werefrom of 0.94 to 0.96.

Other research conducted on alluvial clayey soils at Indo-Gangetic plain, India reported that through graphical plots, CBR could be correlated with $\mathbf{F_{200}}$ and PI (Pal*et al.*, 2020). Although $\mathbf{R^2}$ value was not stated for this study, as such the goodness of fit is unknown. Studies by Hassan *et al.* (2022) on clay with low to high plasticity soil through multivariate statistical analyses, showed that soaked and unsoaked CBR could be predicted with OMC and MDD. The $\mathbf{R^2}$value for this study was not mentioned, as such goodness of fit could not be established (Sapta et al., 2023).

Research conducted on soils (type not mentioned) from Chitwan, and Makwanpur district, India, found that the combination of PL, PI, OMC and MDD could be used to predict soaked CBR with $\mathbf{R^2}$ value of

0.744 (Koirala *et al*., 2023). Paul *et al*. (2024) performed a study on poorly graded sand with non-plastic fines. With simple linear regression analysis (SLRA) model, it was reported that field CBR correlated with field density, having $\mathbf{R^2}$value of 0.4272. This $\mathbf{R^2}$value is lower than 0.80 which is the minimum $\mathbf{R^2}$ valuefor good correlation between variables (Fahrmeir*et al*., 2022)

Research by Yang *et al.* (2024) on coastal soft soil in Jiangdong, Haikou, China showed that with random forest Regression algorithm in machine learning, void ratio can be predicted with water content having R^2 value of 0.9761. Also, consolidation index could be predicted with void ratio having R^2 value of 0.793 (Yang *et al.*, 2024).

Khatti and Grover (2023) used secondary data of different soils obtained from different researchers and developed many models such as Simple Regression, Multiple Regression, Support Vector Regression, Gaussian Process Regression, Decision Tree, Random Forest, and Artificial Neural Network to predict soaked CBR.

Further literature studies established that:

a) CBR can be predicted from soil index properties. Thereby saving time and cost in the determination of CBR which is a time-consuming and tedious task. This indicate that there is potential for the prediction of CBR with index properties on other soils which are yet to be explored including Makurdi shale.

b) Most previous studies on the prediction of CBR with index properties using SLRA, MLRA, Non-Linear Regression Analysis (NLRA) were conducted on lateritic soils, coastal soft soil, clay with low to high plasticity, alluvial clayey soils, poorly graded sand with non-plastic fines. However, the prediction of CBR with index properties in shale soil is scarce

c) Some previous researches on prediction of CBR using index properties of soils were localized in soils at locations like Bagalkot district in India, Calabar South in Cross River State, Nigeria, Akwa Ibom State in Nigeria, Akure in Ondo state Nigeria, Jiangdong New District, Haikou inChina, Jamshoro, Mehran in Pakistan.Bharatpur Chitwan in Nepal. Considering that different soils with different index properties at different locations would need the correlation for prediction of CBR using the corresponding soil index properties. Therefore, there is need to determine the relationship between CBR and index properties of Makurdi shale which has not yet been conducted.

Literature review Endeavour showed there is no known study on the prediction of CBR of Makurdi shale using index properties thereby prompting this study on the correlation between CBR and the index properties of Makurdi shale.

Shale formations possess unique geotechnical properties, which are founded by their mineralogical composition, depositional environment, and diagenetic processes (Das and Khaled, 2021). In turn, these properties can influence the engineering behaviour of shale, including its strength characteristics.

Makurdi shale is a Maastrichtian formation within the Eze-Aku Group of the Benue Trough in Nigeria (Nwankwo and Ekine, 2009). The predominant minerals' compositions of Makurdi shale are smectite, illite and kaolinite (Agbede and Smart, 2007). Previous studies on Makurdi shale reported that its soaked CBR values range from 2.0% - 2.4% (Iorliam et al., 2022; Joel and Otse, 2016). The PI of the shale range from 14.68% to 31.97%. Other index properties like F_200range from 70% to 87%. Additionally, the MDD and OMC of the shale range from 1.49 Mg/m^3 - 1.68 Mg/m^3 and 14.4% to 23.50% respectively (Iorliam et al., 2022; Joel and Otse, 2016; Agbede and Smart, 2007). However, a study on the correlation between CBR and index properties of Makurdi shale is lacking.

This study is set to determine the co-relationship between CBR and index properties of Makurdi shale using laboratory results. Then, develop a model that could predict CBR of Makurdi shale from its index properties. The models from this study will be used to predict soaked CBR values of Makurdi shale or other shale with similar index properties. The determined results would be used by Civil Engineers for cost-efficient and time-saving pavement design, ensuring stable and durable roads. For the policymakers, the models will be used to develop regulatory frameworks that incorporate correlations between CBR and soil index properties of Makurdi shale. This will ensure that construction projects on Makurdi shale or similar shale meet safety and durability standards. Generally, with the developed models, there will be cost-savings associated with extensive soaked CBR testing on Makurdi or similar shale. Also, there will be time efficiency, hence pavement design processes in Makurdi or similar shale would be expedited by using soaked CBR values obtained from the developed models.

2. 0 MATERIALS AND METHODS

2.1 Materials

The soil used in this study was collected from Makurdi, Benue State, Nigeria. The sample collection sites are contained in Figure 1.Makurdi town is located between latitudes 7° and 8°N and longitudes 8° and 90' E.

For successful regression analysis, there are specifications for the minimum number of sample size required for given variables as presented in Table 1 (McLaughlin *et al*., 2018).Previous study (Sagar *et al*., 2019; Bassey et al., 2017; Sapta *et al*., 2023) have shown that some correlations between CBR and index properties of soil with good R-squared values (about 0.8) were achieved with the combination of 4-6 independent variables. In the current study, almost 6 soil parameters were expected to be sufficient for a good prediction of CBR resulting from a good R-squared value as also conducted by Sapta*et al*. (2023).

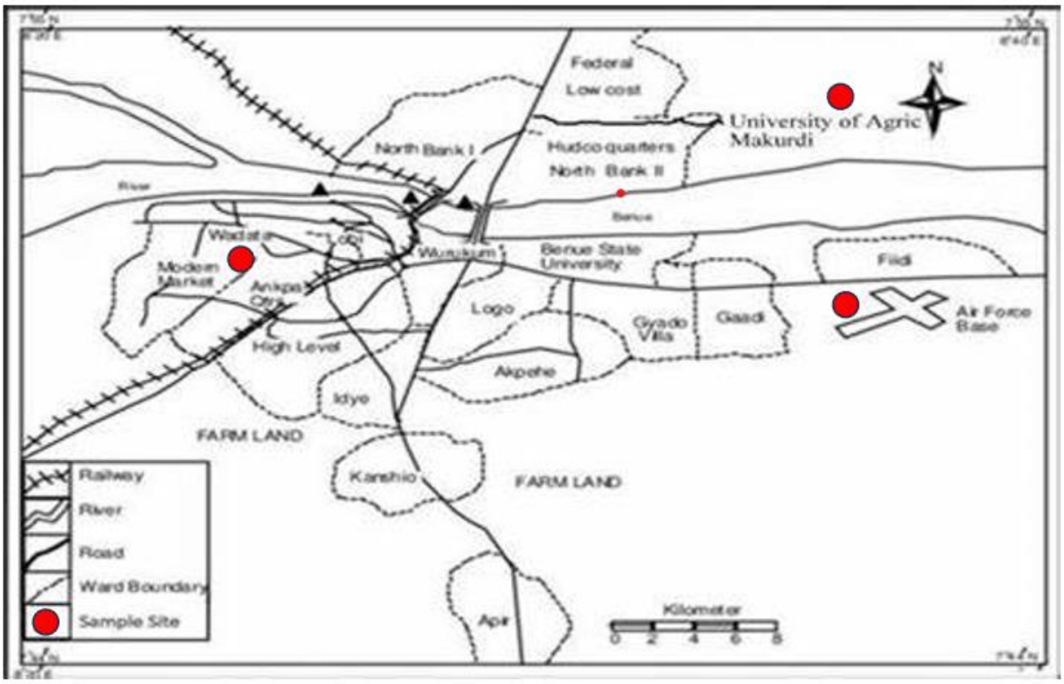


Figure 1: Map of Makurdi Local Government Area showing Sample Locations (AferAbu, 2015)

Table 1. Sample Size for Regression Analysis (McLaughlin *et al.* 2018)

Terms	Minimum sample size
1-3	40
4-6	45
7-8	50
9-11	55
12-14	60
15-18	65
19-21	70

Based on sample size guidelines for regression analysis (McLaughlin *et al.* (2018), at least 45 samples ware required for prediction using 6 independent variables. Therefore, a total of forty-five (45) undisturbed and disturbed representative shale samples were collected at the depth of 2.0 m from three regions in Makurdi metropolis. These include Joseph Sarwuan Tarka University Makurdi (JOSTUM) campus, beside chemistry laboratory at the Anglican Secondary School Wadata, Makurdi, and Airforce Base area, Makurdi. The collected samples were immediately placed in air tight plastic bags to prevent water loss and transported to the soil Mechanics Laboratory at the Department of Civil Engineering, JOSTUM for testing.

2.2. Method

Laboratory tests were conducted on disturbed shale samples in accordance with BS 1377 (BSI, 2016). These include, natural moisture content, specific gravity, sieve analysis using the wet sieving approach, Atterberg limits and compaction test. Compaction was performed using the BS light (2.5 kg rammer) method. This method was applied because it is easy to accomplish in the field. Additionally, CBR was performed on undisturbed sample in accordance with BS 1377 (BSI, 2016).

2.3. Development of Predictive Models

To determine the relationship between CBR and soil index properties, SLRA, Simple Polynomial Analysis (SPA) and MLRA were used. SLRA and MLRA were performed using statistical package for the social science (SPSS) software, while SPA was conducted using Microsoft Excel.

The independent variables were used to predict the dependent variable. The goodness of fit for CBR model using independent variables was quantified with $\mathbf{R}^2$value (Rakaraddiand Gomarsi, 2015). Any correlation with $\mathbf{R}^2$ value of at least 0.80 was considered best fit. The minimum $\mathbf{R}^2$ value of 0.8 was considered for good correlation between variables (Fahrmeir*et al.*, 2022). Correlation was considered unfit, if $\mathbf{R}^2$ value was less than 0.80.

For SLRA, SPA or MLRA model, CBR was the dependent variable, while soil index properties were independent variables. Such soil properties include Gs, MC,F_{200}**,** LL, PL, PI, SL**,** MDD and OMC. The selections of specific independent variables used in the regression model were based on the strength of independent variables obtained from correlation matrix (Frost, 2023). Independent variables that are strongly correlated with the dependent variablewere included in the regression models.

Thus, the models were set to determine if CBR was a function of certain soil properties as expressed in Equation 1.

$$\mathrm{CBR} = f\,(\mathrm{Gs},\ \mathrm{F}_{200},\mathrm{LL},\ \mathrm{PL},\ \mathrm{PI},\ \mathrm{SL},\ \mathrm{OMC},\ \mathrm{MDD}) \tag{1}$$

For MLRA , Equation 1 is generally presented as in equation (2):

$$Y= b_0+b_1\,x_1 +b_2\,x_2 + b_3\,x_3+b_4\,x_4\ldots\ldots\ldots+b_nx_n \tag{2}$$

Where,

Y= CBR (%), $b_{1,}\,b_{2,}\,b_{3,}\,b_{4,}\,b_n$ = constants,

and x_1, x_2, x_3, x_4, x_n. = soil index properties considered for analysis,

From Equation 2, CBR was assigned the dependent variable, while soil index properties like Gs,$\boldsymbol{F}_{\mathbf{200}}$, LL, PL, PI, $\mathbf{S}_{\mathbf{L}}$, MDD and OMC were assigned the independent variables. The constant values were determined using MLRA in SPSS. By inputting the empirical values of CBR and the soil index values, the values for the constants were evaluated.

3. RESULTS AND DISCUSSION

3.1. Index Properties and Classification of Makurdi Shale

Some soil properties of forty-five samples are presented in Table 2. Different combinations of these properties were used to examine the prediction of CBR. Also, the summary results of index properties for the samples are shown in Table 3. From the results, Makurdi shale is classified as A-7-6 and CH soil according to AASHTO and USCS methods respectively. Based on these soil classification, Makurdi shale is similar to Abakaliki and Igumale Shale (Aghamelu and Okogbue, 2011; Joel and Agbede, 2010). Using sieve analysis results, Makurdi shale could be classified as argillaceous shale considering that it contains dominant silt and clay content (Martin e*t al.*, 2016).

The PI of Makurdi shale ranges from 25.15 to 39.01%. This is similar to the results of PI from studies of shale by other researches which is from 20.32 to 24.37% for Enugu shale (Ukor*et al.,* 2023; Joel and Agbede, 2010), and 36-45% for Abakaliki and Igumale Shale (Aghamelu and Okogbue, 2011; Joel and Agbede, 2010). Using the relationship between PI and swelling potential (Murthy, 2008), Makurdi shale has high swelling potential.

Table 3: Index Properties of Natural Makurdi Shale

Properties	Quantity (Range)
Percentage passing BS sieve No.200 (%)	70 – 91
Natural moisture content (%)	26.74 – 28.64
Liquid limit (%)	57.0 - 68.0
Plastic limit (%)	20.4 – 38.48
Plasticity index (%)	25.15 -39.01
Linear shrinkage (%)	15.14 – 19.93
Specific gravity	2.19 – 2.54
Colour	Grey, Dark grey, Brown
AASHTO classification	A-7-6
USCS classification	CH
Group Index (GI)	13.49
Maximum dry density (Mg/m^3)	1.44-1.77
Optimum moisture content (%)	17.58 – 23.5
California bearing ratio (undisturbed)	1.97 – 2.80
Free swell (%)	25 - 53

Similarly, the free swell value of Makurdi shale range from 24 – 51%. This value is similar to studies on Abakaliki shale, and Igumale shale with free swell of 48-52% (Aghamelu and Okogbue, 2011, Joel and Agbede, 2010). Using relationship between expansion potential and free swell property, some Makurdi shale samples with free swell values of at least 50% have moderate expansive potential and can exhibit some noticeable volume change under light loadings (Prasad *et al*., 2017).

The Linear shrinkage (LS) values of Makurdi shale spans from 15.4 to 19.93%. These LS values are similar to that of Abakaliki shale with LS from 18 to 22% (Aghamelu and Okogbue, 2011). Similarly, Igumale shale possesses the LS of 21% (Joel and Agbede, 2010). Based on the relationship between LS and swelling potential, Makurdi shale with LS above 8% possess a critical degree of expansion (Prasad *et al.*, 2017).

The soaked CBR value of Makurdi shale ranges from 1.97 to 2.80%. These values are similar to those of Mamu shale with soaked CBR values from 0.90 to 1.60%. Similarly, the soaked CBR of Enugu shale range from 1.03 to 1.22% (Ukor*et al.*, 2023), while that of Igumale shale is 0.68%. The soaked CBR of Makurdi shale which is about 2% is less than 5%, thus not suitable for subgrade soil in Class A roads for the highways and major roads (Nigerian General Specification for Road and Bridges, 1997).

Table 2: Soil Properties of Makurdi Shale

Sample No	Location Name	Latitude (N)	Longitude (E)	Natural Moisture Content (%)	Specific Gravity (%)	Gains Size $\mathbf{F_{200}}$ (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity index (%)	Shrinkage (%)	OMC (%)	MDD (kg/m3)	CBR (%)
PT1	ENA	7.7926	8.6189	28.25	2.31	96.82	66	32.24	33.76	15.64	23.5	1.68	2.71
PT2	ENA	7.7922	8.6187	27.45	2.43	95.32	64	33.74	30.26	16.52	19.72	1.69	2.46
PT3	ENA	7.79287	8.6183	27.48	2.2	78.34	66	36.01	29.99	15.79	20.75	1.55	2.44
PT4	ENA	7.7923	8.6184	26.74	2.32	79.84	64	35.1	28.9	16.1	19.05	1.6	2.11
PT5	ENA	7.7925	8.6183	27.9	2.44	91	59	20.4	38.6	16.5	18.97	1.48	2.47
PT6	ENA	7.7921	8.6180	27.81	2.4	89.5	68	31.1	36.9	15.3	22.1	1.77	2.66
PT7	EOA	7.79035	8.61928	28.17	2.2	99.24	60	28.99	31.01	19.36	22	1.62	2.65
PT8	EOA	7.79037	8.61934	27.89	2.4	97.74	61	29.72	31.28	19.93	21.52	1.62	2.47
PT9	EOA	7.79030	8.61925	27.17	2.4	88.86	65	27.77	37.23	15.64	18.2	1.66	2.31
PT10	EOA	7.79033	8.61927	27.14	2.4	90.36	64	37	27	16.92	19.57	1.71	2.41
PT11	EOA	7.79035	8.61929	27.62	2.3	87.32	67	36.83	30.17	16.22	19.82	1.67	2.47
PT12	EOA	7.79039	8.61930	26.85	2.43	91.00	60.1	26.74	33.36	17.79	19.8	1.55	2.18
PT13	GH	7.79423	8.62308	27.31	2.34	92.5	59	27.2	31.8	17.5	17.58	1.53	2.33
PT14	GH	7.79425	8.62301	27.77	2.4	98.66	65	34.97	30.03	18.5	18.04	1.53	2.42
PT15	GH	7.79429	8.62421	26.87	2.31	97.16	64	33.27	30.73	18.5	19.24	1.56	2.13
PT16	GH	7.79423	8.62279	27.17	2.47	97.48	63	31.56	31.44	17.5	18.98	1.5	2.19
PT17	GH	7.79417	8.62273	28.64	2.47	98.98	62	31.2	30.8	15.5	23.18	1.57	2.74
PT18	GH	7.79427	8.62313	27.03	2.39	87.4	64	29.85	34.15	15.14	19.4	1.45	2.56
PT19	GH	7.79421	8.62317	27.68	2.46	88.9	63	30.76	32.24	15.71	22.31	1.45	2.38
PT20	BH	7.79724	8.62330	27.37	2.48	83.91	67	30.64	36.36	18.07	18.48	1.67	2.26
PT21	BH	7.79717	8.62341	27.75	2.45	82.41	58	21.72	36.28	15.61	19.48	1.64	2.52
PT22	BH	7.79704	8.62330	26.99	2.25	98.12	65	38.48	26.52	15.21	19.78	1.64	2.39
PT23	BH	7.79700	8.62334	27.00	2.23	96.62	64.3	36.32	27.98	16.7	19.8	1.64	2.38
PT24	BH	7.79707	8.62323	27.59	2.28	89.5	59	21.28	37.72	15.07	18	1.54	2.36
PT25	BH	7.79709	8.62327	27.41	2.51	88	68	32.21	35.79	17.7	19.43	1.63	2.28

Key: ENA: Engineering New Auditorium. EOA: Engineering Old Auditorium. GH: Girls Hostel. BH: Boys Hostel. HC: Health Clinic. AFB:Air Force Base Makurdi.

Table2: Soil properties of Makurdi Shale (Continued)

Sample No	Date of Sampling in Year 2022	Location Name	Latitude (N)	Longitude (E)	Natural Moisture Content (%)	Specific Gravity (%)	Gains Size $\mathbf{F_{200}}$ (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity index (%)	Shrinkage (%)	OMC (%)	MDD (kg/$\mathbf{m^3}$)	CBR (%)
PT26	06/09	BH	7.79709	8.62327	27.41	2.51	88	68	32.21	35.79	17.7	19.43	1.63	2.28
PT27	07/09	WB	7.76563	8.62505	28.11	2.47	92.52	57	30.54	26.46	15.64	22.27	1.69	2.80
PT28	07/09	WB	7.76566	8.62509	27.79	2.43	94.02	61	31.32	29.68	16.62	19	1.72	2.61
PT29	08/09	BH	7.76573	8.62575	27.57	2.54	98.14	59	24.32	34.68	17.93	18.57	1.71	2.59
PT30	08/09	BH	7.76575	8.62578	26.98	2.52	96.64	60	33.4	26.6	15.6	19.7	1.65	2.43
PT31	09/09	GH	7.79427	8.62313	27.03	2.39	87.40	64	29.85	34.15	15.14	19.4	1.45	2.56
PT32	09/09	GH	7.79421	8.62317	27.68	2.46	88.9	63	30.76	32.24	15.71	22.31	1.45	2.38
PT33	10/09	AFB	7.71285	8.64232	28.13	2.4	99.00	61	30.97	30.03	16.36	22.01	1.61	2.59
PT34	10/09	AFB	7.71284	8.64239	27.71	2.4	97.50	60	31.23	28.77	16.44	21.4	1.59	2.49
PT35	13/09	AFB	7.71285	8.64218	27.46	2.4	95.70	59	24.84	34.16	19.21	22.84	1.48	2.30
PT36	13/09	AFB	7.71288	8.64225	26.76	2.4	97.20	59	23.99	35.01	19.52	19.00	1.44	1.97
PT37	16/09	AFB	7.71274	8.64284	26.99	2.5	88.14	60	34.85	25.15	19.36	18.5	1.57	2.06
PT38	16/09	AFB	7.71277	8.64287	27.10	2.4	86.64	67	34.72	32.28	19.57	18.56	1.56	2.22
PT39	21/09	EOA	7.79035	8.61928	28.17	2.2	99.24	60	28.99	31.01	19.36	22.00	1.62	2.65
PT40	21/09	EOA	7.79037	8.61934	27.89	2.4	97.74	61	29.72	31.28	19.93	21.52	1.62	2.47
PT41	23/09	EOA	7.79030	8.61925	27.17	2.4	88.86	65	27.77	37.23	15.64	18.2	1.66	2.31
PT42	23/09	EOA	7.79033	8.61927	27.14	2.4	90.36	64	37.00	27.00	16.92	19.57	1.71	2.41
PT43	28/09	HC	7.78511	8.62278	28.04	2.38	88.34	59	28.23	30.77	15.64	22.32	1.7	2.78
PT44	28/09	HC	7.78517	8.62288	27.37	2.35	86.84	67	27.99	39.01	15.68	21.00	1.56	2.27
PT45	29/09	EOA	7.79035	8.61929	27.62	2.3	87.32	67	36.83	30.17	16.22	19.82	1.67	2.47

Key: ENA: Engineering New Auditorium. EOA: Engineering Old Auditorium. GH: Girls Hostel. BH: Boys Hostel. HC: Health Clinic. North Core, Joseph Sarwuan Tarka University, Makurdi (JOSTUM), AFB: Air Force Base Makurdi.

3.2. Chemical Composition of Makurdi Shale

The chemical composition of Makurdi shale is contained in Table 4. It is shown that, there is high composition of silica (SiO_2)from 48.423 -55.53% and alumina (Al_2O_3) from 16.69-21.10%. This is followed by ferric oxide (Fe_2O_3) from 13.38 -16.34%, potash (K_2O) from 5.81 - 8.83% etc. The contents of silica, alumina, hematite and potash oxides are indication of the presence of quartz, alumino-silicates, hematite and k-feldspars in the shale (Nzeukou*et al.*, 2021). This is typical of shale soil and similar to other studies on shale (Ilevbare and Adeleye, 2023; Hajalilou *et al.*, 2016; Aghamelu and Okogbue, 2011; Joel and Agbede, 2010).

Table 4: Oxide Composition of Makurdi Shale.

Elements	Percentage Composition (%)				
	PT5: GH	PT18: HC	PT29: BH	PT33: AFB	PT40: EOA
SiO_2	48.423	55.531	52.162	53.1	49.191
Al_2O_3	21.099	20.044	16.687	20.612	19.804
Fe_2O_3	15.452	13.379	16.252	15.069	16.34
K_2O	6.079	5.805	8.362	6.333	8.83
MgO	5.381	0	1.435	0	0
TiO_2	1.733	1.789	1.962	2.098	1.988
CaO	0.744	2.03	1.337	1.47	1.847
Rh_2O_3	0.371	0.595	0.746	0.608	0.615
BaO	0.133	0.213	0.124		0.219
SnO_2	0.097	0.003	0.179	0.131	0.215
V_2O_5	0.097	0.118	0.128	0.109	0.134
Zr_2O_2	0.087	0.101	0.174	0.103	0.074
CO_3O_4	0.068	0.061	0.076	0.056	0.068
MnO	0.06	0.156	0.104	0.088	0.061
CuO	0.056	0.042	0.053	0.04	0.049
SrO	0.031	0.028	0.045	0.038	0.028
Cr_2O_3	0.026	0.032	0.055	0.015	0.034
Ta_2O_5	0.023	0.015	0.013	0.008	0.007
ZnO	0.016	0.013	0.019	0.023	0.033
Nb_2O_3	0.012	0.015	0.019	0.021	0.007
Ag_2O	0.005	0.015	0.027	0.045	0.054
NiO	0.005	0.008	0.006	0.002	0.006
MoO_3	0.001	0.003	0.002	0.002	0.003
P_2O_5	0	0	0.33	0.002	0.023
SO_3	0	0	0	0	0.356
WO_3	0	0.02	0	0.01	0.003

Key: PT: Pit,GH: Girls Hostel. HC: Health Clinic, BH: Boys Hostel, AFB:Air Force Base, Makudi. EOA: Engineering Old Auditorium.

3.3. Soil Properties of Makurdi Shale

For validation of the predicted models, the data of soil properties for samples from different locations in Makurdi were used as shown in Table 5.

Table 5: Data for Validation of Model Equations

Sample No	Location Name	Latitude (N)	Longitude (E)	Natural Moisture Content (%)	Specific Gravity (%)	Gains Size $\mathbf{F_{200}}$ (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity index (%)	Shrinkage (%)	OMC (%)	MDD (kg/$\mathbf{m^3}$)	Lab CBR (%)
PT1	ENA	7.7954N	8.6173E	28.75	2.23	96.82	67	30.24	36.26	16.04	24.9	1.72	2.84
PT2	ENA	7.7947N	8.6199E	27.85	2.45	95.39	66	32.24	30.26	16.52	19.72	1.69	2.56
PT3	GH	7.79437N	8.62341E	28.21	2.42	89.57	67	29.6	36.9	15.3	22.1	1.77	2.76
PT4	GH	7.79473N	8.62324E	27.71	2.36	92.57	61	25.7	31.8	17.5	17.58	1.53	2.43
PT5	GH	7.79342N	8.6248E	27.27	2.33	97.23	66	31.77	30.73	18.5	19.24	1.56	2.23
PT6	GH	7.79429N	8.63345E	28.08	2.48	88.97	65	29.26	32.24	15.71	22.31	1.45	2.48
PT7	GH	7.79707N	8.62225E	29.04	2.49	99.05	64	29.7	30.8	15.5	23.18	1.57	2.84
PT8	HC	7.78594N	8.62182E	27.28	2.48	93.67	66	32.8	29.7	19.73	18.8	1.55	2.18
PT9	HC	7.78630N	8.62112E	27.64	2.52	90.71	61	26.78	30.72	19.68	21.68	1.43	2.08
PT10	HC	7.78547N	8.62252E	28.18	2.29	91.45	59	20.34	35.16	18.28	19.5	1.64	2.71
PT11	HC	7.78904N	8.62283E	27.77	2.37	86.91	65	26.49	39.01	15.68	21	1.56	2.37
PT12	HC	7.78602N	8.62317E	28.16	2.3	83.63	66	28.15	34.35	16.7	18.3	1.54	2.52
PT13	BH	7.79700N	8.62334E	27.4	2.25	96.69	66.3	34.82	27.98	16.7	19.8	1.64	2.48
PT14	BH	7.79653N	8.62337E	28.15	2.47	82.48	60	20.22	36.28	15.61	19.48	1.64	2.62
PT15	BH	7.79826N	8.62348E	27.81	2.53	88.07	67	30.71	35.79	17.7	19.43	1.63	2.38
PT16	BH	7.76587N	8.62593E	27.38	2.54	96.71	62	31.9	26.6	15.6	19.7	1.65	2.53
PT17	AFB	7.71292N	8.64324E	28.11	2.42	97.57	62	29.73	28.77	16.44	21.4	1.59	2.59
PT18	AFB	7.71298N	8.64225E	27.16	2.42	97.27	61	22.49	35.01	19.52	19	1.44	2.07
PT19	AFB	7.71289N	8.64841E	27.5	2.42	86.71	69	33.22	32.28	19.57	18.56	1.56	2.32
PT20	EOA	7.79143N	8.61721E	28.29	2.42	97.81	63	28.22	31.28	19.93	21.52	1.62	2.57
PT21	EOA	7.79049N	8.62870E	27.54	2.42	90.43	66	35.5	27	16.92	19.57	1.71	2.51

Key: ENA: Engineering New Auditorium. EOA: Engineering Old Auditorium. GH: Girls Hostel. BH: Boys Hostel. HC: Health Clinic. North Core, Joseph SarwuanTarka University, Makurdi (JOSTUM), AFB:Air Force Base Makurdi

3.4. Regression Analysis between CBR and Soil Properties

To identify the independent variables that would be correlated with the dependent variable for development of regression models (Temizhan, *et al.*, 2022). Correlation matrix was conducted as presented in Table 6. The results show that CBR has a positive and strong correlation with natural moisture content, and OMC, then a positive correlation with MDD, F_{200}etc.Also, CBR has negative correlation with linear shrinkage, LL and PI .Based on the strength magnitude of the soil index properties, it was selected for use in the combination of independent variables for development of regression model (Ahmed *et al.*, 2016).

Table 6: Pearson Correlation Matrix between CBR and index Properties of Makurdi Shale.

	CBR (%)	Natural Moisture Content (%)	Specific Gravity	Gains Size finer than200 (□□□□)	Liquid Limit (%)	Plastic Limit (%)	Plasticity index (%)	Linera Shrinkage (%)	OMC (%)	MDD (kg/□□)
CBR (%)	1									
Natural Moisture Content (%)	0.782943	1								
Specific Gravity	0.1090	-0.0409	1							
% Gains Size finer than sieve 200(□□□□)	0.2328	0.3041	-0.02748	1						
Liquid Limit (%)	-0.1913	-0.2240	-0.1231	-0.3706	1					
Plastic Limit (%)	-0.0493	-0.2051	-0.2078	-0.0516	0.5898	1				
Plasticity Index (%)	-0.1088	0.0527	0.1451	-0.2643	0.1626	-0.7009	1			
Linear Shrinkage (%)	-0.3637	-0.0558	0.0284	0.36101	-0.1745	-0.0462	-0.0977	1		
OMC (%)	0.5671	0.6557	-0.1323	0.2700	-0.1264	0.0218	-0.1387	-0.0868	1	
MDD (kg/□□)	0.3983	0.22161	-0.0054	0.0280	0.1838	0.3068	-0.2125	-0.1153	0.0517	1

From the correlation, it is found that some index properties (natural moisture content, OMC, MDD, LS) displayed stronger correlation with CBR than others (like PL, LL, PI, Gsetc). The reason for this is that MC, OMC, and MDD are more closely related to CBR of Makurdi shale than PL, LL, PI. Also, that index properties (MC, OMC, and MDD) with stronger correlation will better predict CBR (the dependent variable) than those with weak or poor correlations (Field, 2017; Gravetter and Wallnau, 2020).These findings though not exact, its similar to that in the study by Bassey *et al.* (2017) on lateritic soil at Ibiono. Their study shows that MDD, OMC and F_{200} have stronger correlation on the CBR of Ibiono Soil than LL, PL and PI etc. The slight difference could be due to the difference in soil type. While Makurdi shale was used in the current study, Bassey *et al.* (2017) used lateritic soil.

3.4.1 Simple Linear Regression Analysis

The relationship between CBR and each soil property obtained from SLRA is presented in Table 7. As earlier stated, CBR was considered dependent variable while each soil property was considered independent variable. From the results, eight models were analysed and the $\boldsymbol{R^2}$ values were found to be from 0.012 to 0.642. These values are less than 0.80 which is the minimum value specified for strong correlation**(**McLaughlin and Wakefield, 2018**)**.The trend of obtaining lower $\mathbf{R^2}$ than 0.8 in a simple relationship between CBR and single index property of soil is consistent with other studies (Sapta*et al.*, 2023; Koirala *et al.*, 2023).This shows that the SLRA models are not fit for correlation between CBR of Makurdi shale and index properties.

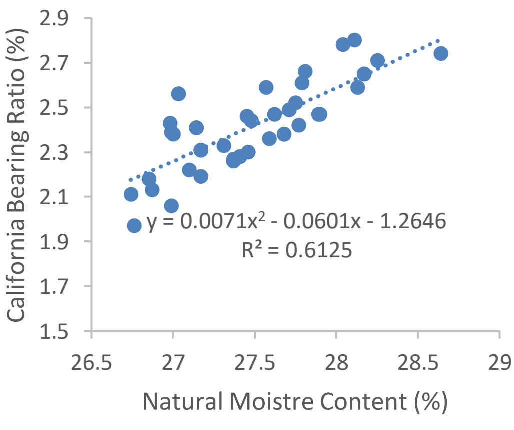
Table 7: Simple Linear Regression between CBR and Soil Properties

S/NO	Soil Properties	Model Summary			ANOVA	
		R	R Square	Adjusted R^2	F	Sig
1	Moisture Content MC	0.801	0.642	0.634	77.145	0.000
2	Specific Gravity GS	0.112	0.012	0.011	0.542	0.466
3	% Passing F200	0.167	0.028	0.005	1.227	0.274
4	Liquid Limit LL	0.183	0.033	0.011	1.484	0.230
5	Plastic Limit PL	0.124	0.150	0.008	0.666	0.419
6	Shrinkage Limit SL	0.570	0.325	0.309	20.716	0.000
7	OMC	0.465	0.216	0.198	11.877	0.001
8	MDD	0.549	0.302	0.285	18.577	0.000

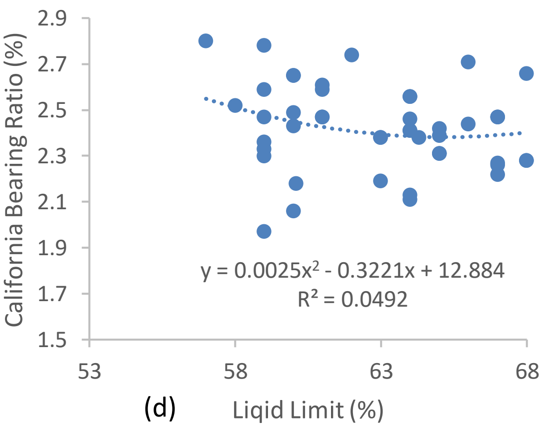
Key: CBR: California Bearing Ratio. MC: Natural Moisture Content. Gs: Specific Gravity. F_{200}: Percentage passing Sieve No. 200. LL: Liquid Limit. PL: Plastic Limit. SL: Shrinkage Limit. OMC: Optimum moisture Content. MDD: Maximum Dry Density.

3.4.2 Simple Polynomial Analysis between CBR and Soil Properties

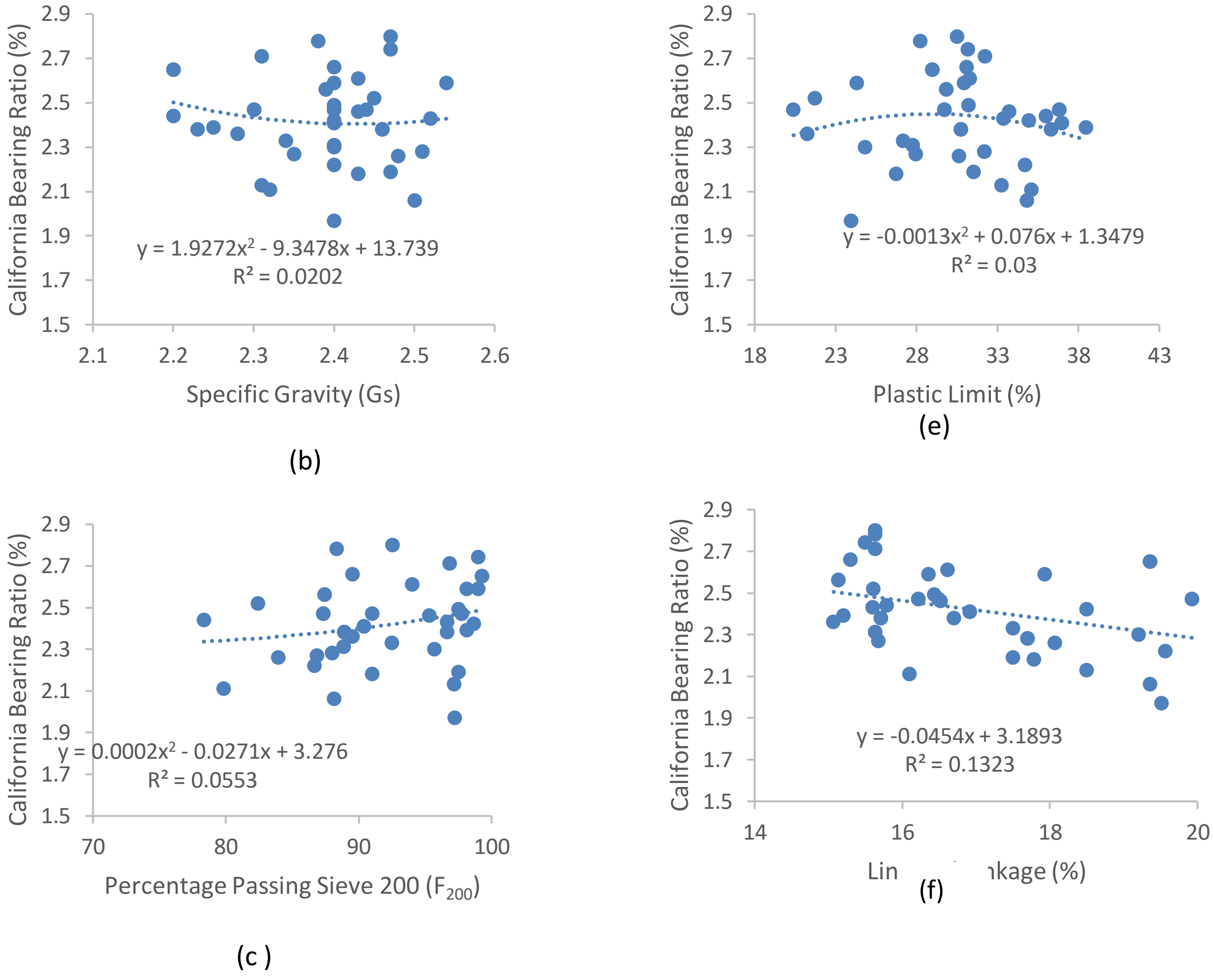
The relationship between CBR and each soil property using second order polynomial is presented in Figure 2 (a-h). The soil properties include MC, Gs, F_{200}, LL, PL, SL, OMC and MDD. From the figures, R^2 values range from 0.0202 to 0.6125. These values are lower than 0.8, which is the minimum value recommended for strong correlation (McLaughlin and Wakefield, 2018).Thus, the use of second order polynomial models are not fit for correlation between CBR of Makurdi shale and index properties.



(a)



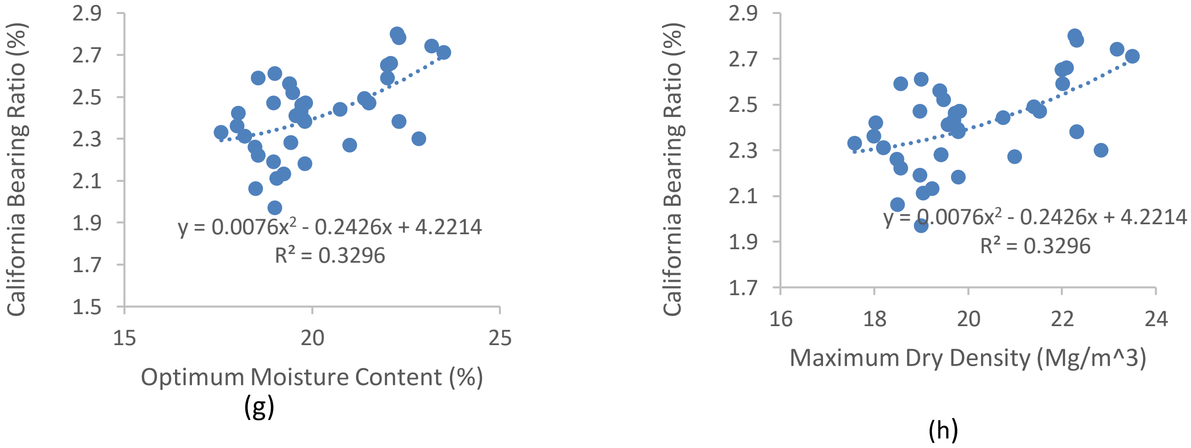
(d)



(b) (e)

(c) (f)

Figure 2: Variation of CBR with index properties of Makurdi Shale: (a) CBR Versus Natural moisture Content (b) CBR Versus Specific Gravity (c) CBR Versus Percentage Passing Sieve 200 (d) CBR Versus Liquid Limit (e) CBR Versus Plastic Limit (f) CBR Versus Linear Shrinkage



(g) (h)

Figure 2: Continued: Variation of CBR with index properties of Makurdi Shale: (g) CBR Versus Optimum Moisture Content (b) CBR Versus Maximum Dry Density

3.4.3 Multiple Linear Regression Analysis (MLRA) between CBR and Soil Properties

From the results of MLRA between soaked CBR and soil properties, nine (1-9) correlations were generated as shown in Table 8. According to Rakaraddi and Gomarsi (2015), two correlations were considered best fit with values of R^2 more than 0.8, namely correlations 1 and 2. This indicates that these correlations are fit for predictions. On the other hand, the values of R^2 for seven correlations (3-9) were less than 0.8, thus have weak R^2 and unfit for prediction. The output of coefficients between CBR and soil properties for the correlations 1-2 are presented in Table 9.From the results, model Equations 3-4 were formulated for the selected correlations with best fit (with $R^2 > 0.8$) as shown in Table 10.

Table 8: Multiple linear regression between CBR and soil properties

S/NO	Soil Properties	Model Summary			ANOVA	
		R	R^2	Adjusted R^2	F	Sig
1	MC, GS, LL, SL, OMC and MDD	0.928	0.860	0.838	38.998	0.00
2	MC, LL, PL, SL, OMC and MDD	0.927	0.864	0.838	38.797	0.00
3	MC, F_{200}, LL, PL, OMC and MDD	0.882	0.779	0.744	22.275	0.00
4	MC, LL and SL	0.882	0.778	0.61	47.766	0.00
5	MC, GS, F_{200}, OMC and MDD	0.876	0.769	0.738	25.797	0.00
6	GS, F_{200}, LL, PL, OMC and MDD	0.876	0.766	0.738	25.797	0.00
7	GS, F_{200}, PL, SL, OMC and MDD	0.825	0.681	0.630	13.499	0.00
8	GS,LL, PL, SL, OMC and MDD	0.825	0.681	0.630	13.499	0.00
9	MC, OMC and MDD	0.963	0.746	0.746	44.019	0.00

Key: CBR: California Bearing Ratio. MC: Natural Moisture Content. Gs: Specific Gravity. $\mathbf{F_{200}}$: Percentage passing Sieve No. 200. LL: Liquid Limit. PL: Plastic Limit. SL: Shrinkage Limit. OMC: Optimum moisture Content. MDD: Maximum Dry Density.

From Model 1 (Equation 3), soaked CBR of Makurdi shale could be predicted from the soil properties such as MC, Gs, LL, SL, OMC and MDD with adjusted R^2 value of 0.838 and p-value of 0.00. Similarly, from Model 2 (Equation 4), soaked CBR could be predicted from the soil properties such as MC, LL, PL, SL, OMC, and MDD with adjusted R^2 value of 0.838 and p-value of 0.00.

Table 9: Coefficients between CBR and soil properties (MC, Gs, LL, SL, OMC and MDD)

Model	**Property**	**Unstandardized Coefficients**		**Standardized Coefficients**	**t**	**Sig. P-Value**
		B	**Std. Error**	**Beta**		
1	(Constant)	-4.787	1.167		-4.101	0.000
	MC	0.276	0.039	0.579	7.122	0.000
	Gs	-0.142	0.140	-0.064	-1.012	0.318
	LL	-0.011	0.004	-0.174	-2.618	0.013
	SL	-0.042	0.009	-0.301	-4.510	0.000
	OMC	0.004	0.010	0.030	0.399	0.692
	MDD	0.795	0.171	0.313	4.641	0.000
2	(Constant)	-5.362	1.088		-4.928	0.000
	MC	0.290	0.041	0.609	7.120	0.000
	LL	-0.013	0.005	-0.202	-2.498	0.017
	PL	0.004	0.004	0.079	0.923	0.362
	SL	-0.043	0.009	-0.214	-4.186	0.000
	OMC	0.001	0.010	0.008	0.098	0.923
	MDD	0.751	0.178	0.296	4.230	0.000

Key: CBR: California Bearing Ratio. MC: Natural Moisture Content. Gs: Specific Gravity. LL: Liquid Limit. PL: Plastic Limit. SL: Shrinkage Limit. OMC: Optimum moisture Content. MDD: Maximum Dry Density.

Table 10: Generated model equations for CBR prediction

Model No	Soil Properties	Model Equation	Adjusted $\boldsymbol{R^2}$	Equation No
1	MC, Gs, LL, SL, OMC and MDD	CBR= -4.787 + 0.276MC – 0.142Gs– 0.011LL – 0.042SL + 0.004OMC + 0.795MDD	0.838	3
2	MC,LL, PL, SL, OMC, and MDD	CBR= -5.362 + 0.290MC– 0.013LL + 0.004PL – 0.043SL + 0.001OMC + 0.751MDD	0.838	4

Predicting CBR of Makurdi shale from index properties using MLRA as contained in Models 1 and 2 in the current study, though not exact is similar with the studies by Koirala *et al.* (2022) and Sapta*et al.* (2023). In Model 1 of the current study, the combination of MC, Gs, LL, SL, OMC and MDDhave been found to predict CBR, while in Model 2 the combination of MC, LL, PL, SL, OMC, and MDD have been found to predicted CBR. Each of the Models 1 and 2 had adjusted R-squared and p-values of 0.838 and 0.00 respectively. However in the study by Koirala *et al.* (2023), the combination of PL, PI, OMC and MDD was observed to predict CBR. Also, the combination of LL, PL, OMC and MDDwas found to predict CBR of the soils from different places of Chitwan, and Makwanpur district, Nepal (soil type not mentioned). The coefficient of determination (R-squared value) and p-values were 0.744 and 0.005 respectively. Additionally, the research by Sapta *et al.* (2023) on clay with low to high plasticity found that CBR could be predicted from the combination of F_{200} and PI, as well as the combination of OMC and MDD.In their research, the R-squared and p-value were not stated.

Furthermore, the study on correlation between CBR and index properties by Bassey (2017) on lateritic soil from Ibiono, Oron, and Onna, Akwa Ibom state, found that the combination of OMC and MDD could be used to predict CBR with adjusted R-squared value of 0.641. Also, that the combination of PI and OMC could be used to predict CBR values of the laterite with adjusted R-squared value of 0.884.

It is observed that studies on correlation of CBR with index properties of soils within similar geological formation as Makurdi shale (example Eze-Aku Shale formation, Bakken formation in USA, Deltaic deposits, Mamu formation or Ajali formation) are scarce. However, the findings from aforementioned studies on the prediction of CBRwith soil index properties such as PL, LL, PI, OMC and MDD, $F_{200}$are within the range of variables that are found to predict CBR of Makurdi shale in the current study.

This shows that MLRA models are suitable for predicting CBR of Makurdi shale using its index properties. It is important to know that the application of MLRA on predicting CBR of Makurdi shale using its index properties is novel, it has not yet been examined.

3.5. Validation of Model Equations

Using the data of properties of shale soil from different locations in Makurdi (Table 11), the formulated model's equations (3-4) were validated. The validated results from the two CBR model equations are presented in Table 11.To compare the similarities between CBR values determined from the laboratory and that from Models 1 and 2 (Equations 3 and 4), a paired T-test was conducted (Table 11).

Statistical significance of the difference in CBR values was examined. For a value of $P \leq 0.05$ it was considered to be significant. The results of t-test (Table 11) show that there was no significance difference between the CBR results from the laboratory compared with that from predicting Model 1 at P =0.94 and Model 2 at P =0.788 respectively. This is due to the consideration that if p-value is greater than 0.05, then the results are similar, if not, then the results are dissimilar. In this case the results show that CBR values from Models 1 and 2 are similar to that determined in the laboratory.

To further validate the predictive models, Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) between the results of predictive models and that of actual values were determined as contained in Table 11.The RMSE for Model 1 (Equation 3) and Model 2 (Equation 4) are 6.27 % and 6.28 % respectively. Considering that these values are less than 10 %, which is the maximum value for excellent model performance (Filó *et al*., 2024), it shows that Models 1 and 2 can perform excellently.

Similarly, the MAE values for Model 1 (Equation 3) and Model 2 (Equation 4) are 4.86 % and 4.6 %respectively. Considering that the MAE values in the current study are less than 10 %,which is the maximum value for a good and acceptable threshold (Filó *et al*., 2024), models 1 and 2 are considered good and acceptable. Based on RMSE and MA Ecriteria, Models 1 and 2 in the current study have demonstrated good performance. This shows that the results of CBR obtained from predictive models is similar to that from the actual determined results.

Table 11: Validation of Model Equations

Sample No	Location Name	Latitude	Longitude	CBR (%) Lab Result	CBR (%) Eqn 3	CBR (%) Eqn 4	Comparison of CBR results	
							Lab versus Eqn 3	Lab versus Eqn 4
PT1	ENA	7.7954N	8.6173E	2.84	2.89	2.85		
PT2	ENA	7.7947N	8.6199E	2.56	2.55	2.56		
PT3	GH	7.79437N	8.62341E	2.76	2.77	2.76		
PT4	GH	7.79473N	8.62324E	2.43	2.41	2.40		
PT5	GH	7.79342N	8.6248E	2.23	2.22	2.21		
PT6	GH	7.79429N	8.63345E	2.48	2.48	2.49		
PT7	GH	7.79707N	8.62225E	2.84	2.86	2.88		
PT8	HC	7.78594N	8.62182E	2.18	2.14	2.16		
PT9	HC	7.78630N	8.62112E	2.08	2.21	2.22		
PT10	HC	7.78547N	8.62252E	2.71	2.63	2.59		
PT11	HC	7.78904N	8.62283E	2.37	2.49	2.47		
PT12	HC	7.78602N	8.62317E	2.52	2.53	2.52		
PT13	BH	7.79700N	8.62334E	2.48	2.41	2.39		
PT14	BH	7.79653N	8.62337E	2.62	2.70	2.68		
PT15	BH	7.79826N	8.62348E	2.38	2.42	2.44		
PT16	BH	7.76587N	8.62593E	2.53	2.46	2.49		
PT17	AFB	7.71292N	8.64324E	2.59	2.60	2.61		
PT18	AFB	7.71298N	8.64225E	2.07	2.10	2.07		
PT19	AFB	7.71289N	8.64841E	2.32	2.19	2.20		
PT20	EOA	7.79143N	8.61721E	2.57	2.52	2.52		
PT21	EOA	7.79049N	8.62870E	2.51	2.47	2.48		
P-value							0.94	0.78
RMSE (%)							6.28	6.27
MAE (%)							4.86	4.60

Key: ENA: Engineering New Auditorium. EOA: Engineering Old Auditorium. GH: Girls Hostel. BH: Boys Hostel. HC: Health Clinic. North Core, Joseph SarwuanTarka University, Makurdi (JOSTUM), AFB:Air Force Base Makurdi RMSE:Root Mean Square Error,MAE:Mean Absolute Error

3.6 Relationship between California Bearing Ratio and Some Index Properties of Makurdi Shale.

When the relationship between simple index properties and mechanical properties of soil like soaked CBR is established, less time and cost is required to determine the mechanical properties, provided the related index properties are known. In the current student, it is shown that some combinations of index properties like liquid limit, plastic limit, percentage of soil finer than sieve 200, moisture content, specific gravity, OMC and MDD could be used to predict the CBR of Makurdi shale. The predictions have a strong goodness of fit of at least R^2 value of 0.8, and a p-value of less than 0.05. The predictions are contained in Models 1 and 2 (Equations 3 and 4) in the current study.

Based on the results of Standardized Coefficients Beta, it was found that moisture content mostly influenced the CBR values of Makurdi shale. This is followed by MDD then linear shrinkage. Generally, moisture content influences the strength like CBR of expansive soils. With very low moisture content (below OMC) the expansive soil may lack the required wetness to lubricate soil grains for high densification. This would cause the soil to crumble and disintegrate under load, thereby resulting in decreased dry density and CBR values.

At moderate or optimum moisture content, the water content is usually just sufficient to lubricate the soil grains, thus allowing easy sliding of soil grains over each other, leading to maximum densification under compaction. This typically results in maximum CBR values. With increased moisture content above OMC, water fills the pore spaces and the soil experiences reduced friction and cohesion, leading to decreased ability to withstand load, hence decreased CBR values.

MDD also influences CBR. MDD is the highest achieved dry density when the soil is compacted to its optimum moisture content (OMC) for a particular compaction effort. Generally, a particular soil compacted at MDD would results in highest CBR value, as the soil particles are more densely packed. Increased MDD for different soils usually would results in increased CBR values. Therefore, if soil index properties such as MC,Gs, LL,PL, SL, OMC, MDD, SL are known, soaked CBR of Makurdi or similar shale would be determined within a short time and less efforts compared with actual laboratory process of determining soaked CBR.

4.0 CONCLUSIONS

The current study examined 45 samples of Makurdi shale; the index properties and soaked CBR of the shale were determined and correlated. From the results, the following can be deduced:

1. Makurdi shale is grouped as an A-7-6 and CH soils according to AASHTO and USCS classification respectively. Based on particle size distribution, Makurdi shale could be classified as argillaceous shale, owing to dominant silt and clay content.
2. Makurdi shale samples have free swell values from 24 – 51%. Since some samples have free swell values of at least 50%, it has moderate expansive potential and can exhibit some noticeable volume change under light loadings (Prasad *et al.*, 2017).
3. The soaked CBR of Makurdi shale is about 2%. This is less than 5%, thus not suitable for subgrade soil (Nigerian General Specification for Road and Bridges, 2009).
4. Using MLRA, two models have been established to predict CBR from some soil index properties of Makurdi shale with best fit ($R^2 > 0.8$). CBR could be predicted from the soil properties such as MC,G_s, LL, SL, OMC and MDD with R^2 of 0.838 and p-value of 0.00. Also, CBR might be predicted from the soil properties like MC, LL, PL,SL, OMC, sand MDD with adjusted R^2 of 0.838, and p-value of 0.00. These are contained in Models 1 and 2 (Equations 3 and 4).
5. To ensure time and cost-savings associated with extensive soaked CBR testing on Makurdi or similar shale, the use of models 1 and 2 (Equations 3 and 4) in the current study are recommended to Civil Engineers for prediction of soaked CBR of Makurdi shale, using its index properties.
6. Models 1 and 2 (Equations 3 and 4) produced in the current study is recommended for use by policy makers to develop regulatory frameworks on correlations between soaked CBR and soil index

properties of Makurdi shale. With the use of these models, road construction projects on Makurdi shale or similar shale could be easily checked to ensure CBR standards are met.

7. Further studies on correlation of CBR with soil index properties need to be conducted on shale from other locations such as that in Abakaliki, Ebonyi State and Obomkpa, Delta State, Nigeria.

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