

Correlation Analysis of Index Properties and Bearing Capacity of Makurdi Shale for Building Foundations

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Abstract: The bearing capacity of soils is necessary for the design and construction of building foundations. The determination of bearing capacity of soil could be tedious, expensive and time-consuming. There is need to establish models that would predict the bearing capacity of soils using simple and less time-consuming laboratory tests. This study examines the relationship between bearing capacity and index properties of Makurdi shale. Forty-five samples of the shale were collected; index properties and bearing capacity were determined and correlated. Using multiple linear regression analysis, it was established that bearing capacity of the shale could be predicted from different combinations of the shale index properties. These include maximum dry density (MDD), moisture content (MC), specific gravity (G_s), liquid limit (LL), plastic limit (PL) shrinkage limit (SL), optimum moisture content (OMC) percentage of soil finer than sieve (F_{200}), with adjusted R^2 values of 0.805 – 0.875 as expressed in Models 1-4. Results of the Models' evaluation show root mean square error (RMSE) and mean absolute error (MAE) of 0.7923 % to 2.9478 %, and 0.6157 to 2.8457 respectively. Based on the results of this study, it is recommended that models 1 to 4 could be used for prediction of bearing capacity of Makurdi shale using corresponding soil index properties such MDD, MC, G_s , LL, PL, SL, OMC and F_{200} .

KEYWORDS: Makurdi shale, Bearing capacity, Soil index properties, Correlation, Multiple linear regression analysis, Building foundations.

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1. INTRODUCTION

The design of civil engineering infrastructure such as buildings largely depends on the geotechnical properties of the underlying soil and rock (Das and Khaled, 2021). Considering that each type of soil has a distinct corresponding geotechnical and mechanical properties, it is important to determine the geotechnical properties for each type of soil. One important geotechnical property is the bearing capacity of the soil underlying building foundation. The determination process of bearing capacity can be tedious, time and cost demanding. To achieve a simplified, cost-effective and time saving determination process, there is a need

to develop correlation equations using simple index properties of soil that could predict the bearing capacity

Many studies have developed models to predict the bearing capacities of soils. Ibrahim *et al.* (2022) used 45 secondary data (soil type not mentioned) from seven researches at Civil Engineering Library of Kano University of Science and Technology, Wudil, Nigeria. The authors conducted studies on the relationship between soil bearing capacity and soil properties such as soil index properties, shear strength parameters and varied depths. Minitab software was used, while multiple linear regression analysis (MLRA) approach was applied. It was found that, bearing

capacity of soil for strip, circular and square foundations could be predicted from the combination of depth, PI, cohesion, phi (ϕ), and unit weight of the soil with R^2 values of 0.97, 0.97 and 0.96 for strip, square and circular foundations respectively

Omar *et al.* (2019) performed a study on the prediction of allowable bearing capacity using the number of blows in a standard penetration test, unit weight of soil and foundation width. The study was conducted on granular soil from 650 boreholes at different locations in Sharjah, United Arab Emirates. Using SPSS package, multiple linear regression analyses (MLRA) approach established that allowable bearing capacity could be predicted from the combination of SPT number of blows, effective unit weight of soil and foundation width with R^2 is 0.85. Also, settlement of the soil could be predicted from combined number of blows from SPT, foundation width, and allowable bearing capacity with R^2 is 0.75

Güner and Özgan (2025) examined the relationship between bearing capacity or settlement property of gravel soils with different soil parameters such as excavation depth, moisture content, particle size distribution (PSD), groundwater levels, soil unit weight, cohesion and angle of internal friction. SPSS statistical software was used. With cubic model, it was found that bearing capacity could be predicted using the soil parameters (with $p < 0.05$), and R^2 values of 0.79, while settlement could be predicted with the soil parameters having R^2 values 0.904.

The prediction of ultimate bearing capacity (UBC) of shallow foundations in cohesionless soils was assessed using Random Forest (RF) statistical learning model by Kohestani *et al.* (2017). 112 secondary data of soil properties such unit weight of sand, internal friction angle (ϕ), footing width (B), footing depth (D), and footing length to breadth ratio (L/B). The results from RF model were compared to analytical traditional equations developed by Terzaghi (1943), Meyerhof (1963), and Vesic (1974). The authors reported that RF model produced UBC results that is more dependable, faster and more accurate than the traditional equations.

Additionally, Adarsh (2022) examined the prediction of UBC of cohesionless soils using some soft computing techniques such as support vector machines (SVMs) and genetic programming (GP). The performance was compared with artificial neural networks (ANNs), and fuzzy inference system (FIS). The study used 97 secondary data of load test in sand beds for square, rectangular, and strip footings. Based on multiple error criteria, GP was found to predict UBC more efficient and accurately than SVM, ANN and FIS techniques.

Makurdi shale, a Maastrichtian formation within the Eze-Aku Group of the Benue Trough in Nigeria (Nwankwo and Ekine, 2009), is primarily composed of smectite, illite, and kaolinite minerals (Agbede and Smart, 2007). Previous studies have reported the following geotechnical properties: soaked CBR values ranging from 2.0 % to 2.4 % (Iorliam *et al.*, 2022; Joel and Otse, 2016), plasticity index (PI) values between 14.68 % and 31.97 %, and fines content (F_{200}) ranging from 70 % to 87 %. Additionally, the maximum dry density (MDD) and optimum moisture content (OMC) of the shale have been found to range from 1.49 Mg/m^3 to 1.68 Mg/m^3 and 14.4 % to 23.50 %, respectively (Iorliam *et al.*, 2022; Joel and Otse, 2016; Agbede and Smart, 2007).

Foundational studies by Terzaghi on the determination of soil's bearing capacity have been established for strip, square and circular foundations as expressed in Equations 1, 2 and 3 respectively (Das and Khaled, 2021).

$$q_u = CN_c + \gamma zN_q + 0.5\gamma BN_\gamma \quad (1)$$

$$q_u = 1.3CN_c + \gamma zN_q + 0.4\gamma BN_\gamma \quad (2)$$

$$q_u = 1.3CN_c + \gamma zN_q + 0.3\gamma BN_\gamma \quad (3)$$

Where, q_u is ultimate bearing capacity (kPa), C = cohesion (kPa); γ = unit weight of soil (kPa)

z = depth of footing (m); B = width of footing (m), N_c , N_q and N_γ = bearing capacity factors.

Nnamani *et al.* (2023) conducted a study on bearing capacity determination of Enugu shale using Terzaghi's equations. The study found the bearing capacity of the shale to range from 23-108 kPa.

However, studies on the correlation between bearing capacity and index properties of shale are scarce. A study on the correlation between bearing capacity and index properties of shale needs to be conducted to provide a model for predicting bearing capacity of shale.

Previous studies (Güner and Özgan 2025; Ibrahim *et al.*, 2022; Omar *et al.*, 2019; Kohestani *et al.* 2017) have shown that some correlations between

bearing capacity 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, at most 6 soil parameters were expected to be sufficient for a good prediction of bearing capacity resulting from a good R-squared value.

We have established from literature that :

1. Computing software like SSPS, Minitab
2. , RF, GP can be successfully used to conduct the analyses for prediction of bearing capacity which are to support building foundations.
3. Prediction of bearing capacity in different soils mainly cohesionless (granular, gravel and sandy) soils have been reported. This prompted the need to examine prediction of bearing capacity on cohesive soils such as shale.
4. Different models such as MLRA and cubic predictive models have been established to predict bearing capacity using soil parameters, with efficient and good performance.

However, we have not found any literature with prediction of bearing capacity of shale using soil index properties. This has prompted the current research on co-relation between bearing capacity and index properties of Makurdi shale for building foundation designs.

The research aimed to determine whether bearing capacity of Makurdi shale could be predicted from its index properties. This was achieved through the determination of index properties of Makurdi shale. Determination of bearing capacity parameters, followed by the calculation of safe bearing capacity at different shale deposits in Makurdi metropolis. Then perform regression analysis to assess the correlations between bearing capacity and index properties of the shale.

Makurdi shale, a Maastrichtian formation within the Eze-Aku Group of the Benue Trough in Nigeria (Nwankwo and Ekine, 2009), is primarily composed of smectite, illite, and kaolinite minerals (Agbede and Smart, 2007). Previous studies have reported the following geotechnical properties: soaked CBR values ranging from 2.0 % to 2.4 % (Iorliam *et al.*, 2022; Joel and Otse, 2016), plasticity index (PI) values between 14.68 % and 31.97 %, and fines content (F_{200}) ranging from 70 % to 87 %. Additionally, the maximum dry density (MDD) and optimum moisture content (OMC) of the shale have been found to range from 1.49 Mg/m^3 to 1.68 Mg/m^3 and 14.4 % to 23.50 %, respectively (Iorliam *et al.*, 2022; Joel and Otse, 2016; Agbede and Smart, 2007).

A study on co-relationship between bearing capacity and index properties of Makurdi shale, intends to develop a model that could predict bearing capacity of Makurdi shale from its index properties. The predictive models developed will enable estimation of bearing capacity values for Makurdi shale and similar shales having comparable index properties. These models will benefit civil engineers by providing a cost-efficient and time-saving approach to foundation design, ultimately ensuring cheap, stable and durable foundations. For policymakers, the models can inform regulatory frameworks that integrate correlations between bearing capacity and soil index properties, thereby ensuring construction projects meet stringent safety and durability standards. The practical implications of these models include significant cost savings by reducing the need for extensive bearing capacity testing, as well as enhanced time efficiency in building foundation design processes. By leveraging these models, construction projects on Makurdi shale or similar formations can be expedited, streamlining the design process.

II. MATERIALS AND METHODS

2.1 Materials

The shale samples used in this study were collected from three locations in Makurdi, Benue State, Nigeria: Joseph Sarwuan Tarka University Makurdi (formerly Federal University of Agriculture Makurdi), Air Force Base Makurdi, and Anglican Secondary School Wadata, Makurdi (see Fig. 1). Makurdi town is situated between latitudes 7° and 8°N and longitudes 8° and 9°E.

To conform to the standard meant for the minimum number of sample size required when 4 to 6 independent parameters are involved in regression analysis, 45 samples were obtained (McLaughlin *et al.*, 2018).

Based on sample size guidelines for regression analysis (McLaughlin *et al.* (2018), 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.

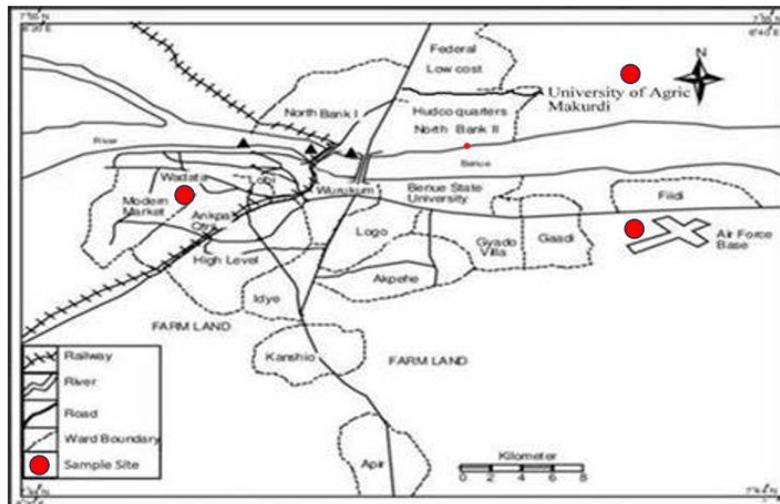


Fig. 1: Map of Makurdi Local Government Area showing sample locations (Afer Abu, 2015)

2.2 Methods

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. To determine cohesion (C) and angle of internal friction (ϕ) for bearing capacity calculation, triaxial test was performed on undisturbed sample in accordance with BS 1377 (BSI, 2016).

In the current study, the bearing capacity of a square footing (1.2 m by 1.2 m) was considered and determined using Terzaghi’s equations as presented in Equation (2). The safe bearing capacity was determined by dividing the ultimate bearing capacity by factor of safety of 3 (Smith, 2021).

2.3. Development of Predictive Models

To determine the relationship between SBC and soil index properties, simple linear regression analysis (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 SBC model using independent variables was quantified with R^2 value. Any correlation with R^2 value of at least 0.80 was considered best fit and considered for good correlation between variables. Correlation was considered unfit, if R^2 value was less than 0.80.

For SLRA, SPA or MLRA model, bearing capacity was the dependent variable, while soil index properties were independent variables. Such soil properties include MDD, Gs, MC, F_{200} , LL, PL, SL and OMC. The selection 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 variable were included in the regression models. Thus, the models were set to determine if the value of SBC was a function of certain soil properties as expressed in Equation 4.

$$q_s = f(Gs, F_{200}, LL, PL, PI, SL, OMC, MDD) \tag{4}$$

For MLRA, Equation 4 is generally presented as in equation (5):

$$Y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_4 x_4 + \dots + b_n x_n \tag{5}$$

Where,

$Y = q_s$ (%), $b_1, b_2, b_3, b_4, b_n =$ constants, and $x_1, x_2, x_3, x_4, x_n =$ soil index properties considered for analysis,

From Equation 5, q_s was assigned the dependent variable, while soil index properties like MDD, MC, Gs, F_{200} , LL, PL, SL and OMC were assigned the independent variables. The constant values were

determined using MLRA in SPSS. By inputting the empirical values of q_s and the soil index values, the values for the constants were evaluated.

III. RESULTS AND DISCUSSION

3.1 Index Properties and Classification of Makurdi Shale

Table 1 presents the properties of 45 shale samples from Makurdi, which were used in various combinations to predict bearing capacity. The bearing capacity factors and parameters, empirical values of ultimate and safe bearing capacity for the 45 samples are presented in Table 2, while summary of the index properties of Makurdi shale is shown in Table 3. According to the AASHTO and USCS classification systems, Makurdi shale is categorized as A-7-6 and CH soil, respectively. This classification is consistent with other shales in the region, such as Abakaliki and Igumale Shale (Aghamelu and Okogbue, 2011; Joel and Agbede, 2010). The high silt and clay content (Table 3) further supports the classification of Makurdi shale as argillaceous (Martin *et al.*, 2016). The plasticity index (PI) of Makurdi shale ranges from 25.15 % to 39.01 %, which is comparable to other regional shales like Enugu shale with PI from 20.32 %-24.37 % (Ukor *et al.*, 2023; Joel and Agbede, 2010) as well as Abakaliki and Igumale shale (36 %-45 %; Aghamelu and Okogbue, 2011; Joel and Agbede, 2010). Based on the relationship between PI and swelling potential (Das and Khaled, 2021), Makurdi shale exhibits high swelling potential.

Makurdi shale exhibits free swell values ranging from 24 % to 51 % (From Table). This is comparable to Abakaliki and Igumale shales which has free swell value from 48-52 % (Aghamelu and Okogbue, 2011; Joel and Agbede, 2010). Samples with free swell values $\geq 50\%$ have moderate expansive

potential, potentially exhibiting noticeable volume changes under light loads (Prasad *et al.*, 2017). The linear shrinkage (LS) values of Makurdi shale range from 15.4 % to 19.93 %, similar to Abakaliki shale which is 18-22 % (Aghamelu and Okogbue, 2011) and Igumale shale which is 21% (Joel and Agbede, 2010). Given that Makurdi shale's LS exceeds 8 %, it possesses a critical degree of expansion (Prasad *et al.*, 2017). The soaked CBR values of Makurdi shale range from 1.97 % to 2.80 %, comparable to other regional shales: Mamu shale (0.90-1.60%), Enugu shale with soaked CBR value from 1.03-1.22 % (Ukor *et al.*, 2023), and Igumale shale with a value of 0.68 % (Joel and Agbede, 2010).

The safe bearing capacity (SBC) of Makurdi shale values ranges from 111.56 to 114.11 kPa. Based on the presumed SBC standard (BSI 8004:2015+A1: 2020), these values are within 75–150 kPa and are classified as firm clays. The SBC values in the current study are similar to those in Enugu shale, which range from 23 to 108 kPa (Nnamani *et al.*, 2023)

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, aluminosilicates, 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 1: Soil Properties of Makurdi Shale

Sample No	Loc	Lat (N)	Long(E)	MC (%)	GS (%)	F ₂₀₀ (%)	LL (%)	PL (%)	PI (%)	LS (%)	OMC (%)	MDD (Mg/m ³)	q _s (kPa)
PT1	ENA	7.7926	8.6189	28.25	2.31	96.82	66	32.24	33.76	15.64	23.5	1.68	113.98
PT2	ENA	7.7922	8.6187	27.45	2.43	95.32	64	33.74	30.26	16.52	19.72	1.69	113.15
PT3	ENA	7.7929	8.6183	27.48	2.2	78.34	66	36.01	29.99	15.79	20.75	1.55	112.85
PT4	ENA	7.7923	8.6184	26.74	2.32	79.84	64	35.1	28.9	16.1	19.05	1.6	112.31
PT5	ENA	7.7925	8.6183	27.9	2.44	91	59	20.4	38.6	16.5	18.97	1.48	113.03
PT6	ENA	7.7921	8.6180	27.81	2.4	89.5	68	31.1	36.9	15.3	22.1	1.77	113.90
PT7	EOA	7.7904	8.6193	28.17	2.2	99.24	60	28.99	31.01	19.36	22	1.62	111.56
PT8	EOA	7.7904	8.6193	27.89	2.4	97.74	61	29.72	31.28	19.93	21.52	1.62	112.69
PT9	EOA	7.7903	8.6193	27.17	2.4	88.86	65	27.77	37.23	15.64	18.2	1.66	112.73
PT10	EOA	7.7903	8.6193	27.14	2.4	90.36	64	37	27	16.92	19.57	1.71	112.37
PT11	EOA	7.7904	8.6193	27.62	2.3	87.32	67	36.83	30.17	16.22	19.82	1.67	112.41
PT12	EOA	7.7904	8.6193	26.85	2.43	91	60.1	26.74	33.36	17.79	19.8	1.55	113.88
PT13	GH	7.7942	8.6231	27.31	2.34	92.5	59	27.2	31.8	17.5	17.58	1.53	112.51
PT14	GH	7.7943	8.6230	27.77	2.4	98.66	65	34.97	30.03	18.5	18.04	1.53	113.23
PT15	GH	7.7943	8.6242	26.87	2.31	97.16	64	33.27	30.73	18.5	19.24	1.56	111.85
PT16	GH	7.7942	8.6228	27.17	2.47	97.48	63	31.56	31.44	17.5	18.98	1.5	111.91
PT17	GH	7.7942	8.6227	28.64	2.47	98.98	62	31.2	30.8	15.5	23.18	1.57	112.58
PT18	GH	7.7943	8.6231	27.03	2.39	87.4	64	29.85	34.15	15.14	19.4	1.45	111.70
PT19	GH	7.7942	8.6232	27.68	2.46	88.9	63	30.76	32.24	15.71	22.31	1.45	111.90
PT20	BH	7.7972	8.6233	27.37	2.48	83.91	67	30.64	36.36	18.07	18.48	1.67	113.80
PT21	BH	7.7972	8.6234	27.75	2.45	82.41	58	21.72	36.28	15.61	19.48	1.64	112.95
PT22	BH	7.7970	8.6233	26.99	2.25	98.12	65	38.48	26.52	15.21	19.78	1.64	112.85
PT23	BH	7.7970	8.6233	27.00	2.23	96.62	64.3	36.32	27.98	16.7	19.8	1.64	113.08
PT24	BH	7.7971	8.6232	27.59	2.28	89.5	59	21.28	37.72	15.07	18	1.54	113.00
PT25	BH	7.7971	8.6233	27.41	2.51	88	68	32.21	35.79	17.7	19.43	1.63	113.06

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.

Table 1: Soil Properties of Makurdi Shale (Continued)

Sample No	Loc	Lat (N)	Lon(E)	MC (%)	GS (%)	F ₂₀₀ (%)	LL (%)	PL (%)	PI (%)	LS (%)	OMC (%)	MDD (Mg/m ³)	q _s (kPa)
PT26	BH	7.7971	8.6233	27.41	2.51	88	68	32.21	35.79	17.7	19.43	1.63	112.28
PT27	WB	7.7656	8.6251	28.11	2.47	92.52	57	30.54	26.46	15.64	22.27	1.69	114.11
PT28	WB	7.7657	8.6251	27.79	2.43	94.02	61	31.32	29.68	16.62	19	1.72	113.71
PT29	BH	7.7657	8.6258	27.57	2.54	98.14	59	24.32	34.68	17.93	18.57	1.71	113.74
PT30	BH	7.7658	8.6258	26.98	2.52	96.64	60	33.4	26.6	15.6	19.7	1.65	113.15
PT31	GH	7.7943	8.6231	27.03	2.39	87.4	64	29.85	34.15	15.14	19.4	1.45	112.45
PT32	GH	7.7942	8.6232	27.68	2.46	88.9	63	30.76	32.24	15.71	22.31	1.45	113.00
PT33	AFB	7.7129	8.6423	28.13	2.4	99	61	30.97	30.03	16.36	22.01	1.61	113.68
PT34	AFB	7.7128	8.6424	27.71	2.4	97.5	60	31.23	28.77	16.44	21.4	1.59	113.53
PT35	AFB	7.7129	8.6422	27.46	2.4	95.7	59	24.84	34.16	19.21	22.84	1.48	112.97
PT36	AFB	7.7129	8.6423	26.76	2.4	97.2	59	23.99	35.01	19.52	19	1.44	111.91
PT37	AFB	7.7127	8.6428	26.99	2.5	88.14	60	34.85	25.15	19.36	18.5	1.57	111.99
PT38	AFB	7.7128	8.6429	27.1	2.4	86.64	67	34.72	32.28	19.57	18.56	1.56	112.20
PT39	EOA	7.79035	8.6193	28.17	2.2	99.24	60	28.99	31.01	19.36	22	1.62	113.55
PT40	EOA	7.79037	8.6193	27.89	2.4	97.74	61	29.72	31.28	19.93	21.52	1.62	113.20
PT41	EOA	7.79030	8.6193	27.17	2.4	88.86	65	27.77	37.23	15.64	18.2	1.66	112.79
PT42	EOA	7.79033	8.6193	27.14	2.4	90.36	64	37	27	16.92	19.57	1.71	113.13
PT43	HC	7.78511	8.6228	28.04	2.38	88.34	59	28.23	30.77	15.64	22.32	1.7	114.18
PT44	HC	7.78517	8.6229	27.37	2.35	86.84	67	27.99	39.01	15.68	21	1.56	112.58
PT45	EOA	7.79035	8.6193	27.62	2.3	87.32	67	36.83	30.17	16.22	19.82	1.67	113.10

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.

Table 2: Empirical Bearing Capacity of Makurdi Shale

Sample No	MDD (Mg/m ³)	γ (kN/m ³)	C (kN/m ²)	φ (degree)	N _c	N _q	N _γ	Z (m)	B (m)	q _u (kPa)	q _s (kPa)
PT1	1.68	16.4808	27.46	9	8.2	2.32	0.42	1.2	1.2	341.94	113.98
PT2	1.69	16.5789	26.79	8	7.63	3.57	0.34	1.2	1.2	339.45	113.15
PT3	1.55	15.2055	26.49	10	8.4	2.5	0.5	1.2	1.2	338.55	112.85
PT4	1.6	15.696	27.21	9	8.2	2.32	0.42	1.2	1.2	336.93	112.31
PT5	1.48	14.5188	27.64	8	7.64	3.57	0.34	1.2	1.2	339.09	113.03
PT6	1.77	17.3637	27.19	9	8.2	2.32	0.42	1.2	1.2	341.7	113.90
PT7	1.55	15.2055	26.89	8	7.64	3.57	0.34	1.2	1.2	334.68	111.56
PT8	1.55	15.2055	33.92	6	6.9	1.78	0.18	1.2	1.2	338.07	112.69
PT9	1.53	15.0093	27.33	8	7.64	3.57	0.34	1.2	1.2	338.19	112.73
PT10	1.56	15.3036	33.79	6	6.9	1.78	0.18	1.2	1.2	337.11	112.37
PT11	1.5	14.715	31.87	7	7.26	1.96	0.26	1.2	1.2	337.23	112.41
PT12	1.57	15.4017	34.27	6	6.9	1.78	0.18	1.2	1.2	341.64	113.88
PT13	1.67	16.3827	32.17	6	7.2	1.78	0.18	1.2	1.2	337.53	112.51
PT14	1.64	16.0884	31.77	7	7.26	1.96	0.26	1.2	1.2	339.69	113.23
PT15	1.49	14.6169	26.39	10	8.4	2.5	0.5	1.2	1.2	335.55	111.85
PT16	1.55	15.2055	31.67	7	7.24	1.96	0.26	1.2	1.2	335.73	111.91
PT17	1.49	14.6169	34.03	6	6.9	1.78	0.18	1.2	1.2	337.74	112.58
PT18	1.43	14.0283	36.39	5	6.5	1.6	0.1	1.2	1.2	335.10	111.70
PT19	1.6	15.696	26.83	8	7.64	3.54	0.34	1.2	1.2	335.70	111.90
PT20	1.64	16.0884	26.49	10	8.4	2.5	0.5	1.2	1.2	341.40	113.80
PT21	1.59	15.5979	31.81	7	7.26	1.96	0.26	1.2	1.2	338.85	112.95
PT22	1.54	15.1074	26.52	10	8.4	2.5	0.5	1.2	1.2	338.55	112.85
PT23	1.64	16.0884	27.01	8	7.64	3.54	0.34	1.2	1.2	339.24	113.08
PT24	1.64	16.0884	36.37	5	6.5	1.6	0.1	1.2	1.2	339.00	113.00
PT25	1.54	15.1074	36.62	5	6.5	1.6	0.1	1.2	1.2	339.18	113.06

Key: MDD: Maximum dry density. C: Cohesion. Φ: Angel of internal friction. N_c, N_q, N_γ: bearing capacity factors.

γ=Unit weight of the soil, Z: depth of sample. B: width. q_u= ultimate bearing capacity, q_s=safe bearing capacity

Table 2: Empirical Bearing Capacity of Makurdi Shale (Continued)

Sample No	MDD (kN/m ³)	Y (Mg/m ³)	C (kN/m ²)	ϕ (degree)	N _c	N _q	N _{γ}	Z (m)	B (m)	q_u (kPa)	q_s (kPa)
PT26	1.63	15.9903	36.14	5	6.5	1.6	0.1	1.2	1.2	336.84	112.28
PT27	1.69	16.5789	31.92	7	7.26	1.96	0.26	1.2	1.2	342.33	114.11
PT28	1.72	16.8732	26.79	8	7.64	3.57	0.34	1.2	1.2	341.13	113.71
PT29	1.71	16.7751	26.27	10	8.4	2.5	0.5	1.2	1.2	341.22	113.74
PT30	1.65	16.1865	26.93	8	7.64	3.57	0.34	1.2	1.2	339.45	113.15
PT31	1.45	14.2245	32.01	7	7.26	1.96	0.26	1.2	1.2	337.35	112.45
PT32	1.45	14.2245	34.27	6	6.9	1.78	0.18	1.2	1.2	339	113.00
PT33	1.61	15.7941	36.68	5	6.5	1.6	0.1	1.2	1.2	341.04	113.68
PT34	1.59	15.5979	24.40	11	8.92	2.8	0.7	1.2	1.2	340.59	113.53
PT35	1.6	15.696	26.38	10	8.4	2.5	0.5	1.2	1.2	338.91	112.97
PT36	1.44	14.1264	24.45	11	8.92	2.8	0.7	1.2	1.2	335.73	111.91
PT37	1.57	15.4017	26.81	9	8.32	2.32	0.42	1.2	1.2	335.97	111.99
PT38	1.56	15.3036	24.15	11	8.92	2.8	0.7	1.2	1.2	336.6	112.20
PT39	1.62	15.8922	26.48	10	8.4	2.5	0.5	1.2	1.2	340.65	113.55
PT40	1.62	15.8922	24.22	11	8.92	2.8	0.7	1.2	1.2	339.6	113.20
PT41	1.66	16.2846	23.99	11	8.92	2.8	0.7	1.2	1.2	338.37	112.79
PT42	1.71	16.7751	27.04	9	8.23	2.32	0.42	1.2	1.2	339.39	113.13
PT43	1.7	16.677	27.02	8	7.64	3.57	0.34	1.2	1.2	342.54	114.18
PT44	1.56	15.3036	31.77	7	7.26	1.96	0.26	1.2	1.2	337.74	112.58
PT45	1.67	16.3827	27.24	9	8.2	2.32	0.42	1.2	1.2	339.3	113.10

Key: MDD: Maximum dry density. C: Cohesion. ϕ : Angel of internal friction. N_c, N_q, N _{γ} : bearing capacity factors. Y=Unit weight of the soil, Z: depth of sample. B: width. q_u = ultimate bearing capacity, q_s =safe bearing capacity

Table 3: Summary of 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
Bearing capacity (kPa)	111.56-114.11

Table 4: Oxide Composition of Makurdi Shale.

Elements	Percentage Composition (%)				
	PT5: GH	PT18: HC	PT29: BH	PT33: AFB	PT40: EOA
SiO₂	48.423	55.531	52.162	53.1	49.191
Al₂O₃	21.099	20.044	16.687	20.612	19.804
Fe₂O₃	15.452	13.379	16.252	15.069	16.34
K₂O	6.079	5.805	8.362	6.333	8.83
MgO	5.381	0	1.435	0	0
TiO₂	1.733	1.789	1.962	2.098	1.988
CaO	0.744	2.03	1.337	1.47	1.847
Rh₂O₃	0.371	0.595	0.746	0.608	0.615
BaO	0.133	0.213	0.124	0	0.219
SnO₂	0.097	0.003	0.179	0.131	0.215
V₂O₅	0.097	0.118	0.128	0.109	0.134
Zr₂O₂	0.087	0.101	0.174	0.103	0.074
CO₃O₄	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
Cr₂O₃	0.026	0.032	0.055	0.015	0.034
Ta₂O₅	0.023	0.015	0.013	0.008	0.007
ZnO	0.016	0.013	0.019	0.023	0.033
Nb₂O₃	0.012	0.015	0.019	0.021	0.007
Ag₂O	0.005	0.015	0.027	0.045	0.054
NiO	0.005	0.008	0.006	0.002	0.006
MoO₃	0.001	0.003	0.002	0.002	0.003
P₂O₅	0	0	0.33	0.002	0.023
SO₃	0	0	0	0	0.356
WO₃	0	0.02	0	0.01	0.003

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

3.3. Soil Properties of Makurdi Shale

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	Loc	Lat (N)	Long (E)	MC (%)	GS (%)	F ₂₀₀ (%)	LL (%)	PL (%)	PI (%)	LS (%)	OMC (%)	MDD (Mg/m ³)	q _s (kPa)
PT1	ENA	7.7954	8.6173	28.75	2.23	96.82	67	30.24	36.26	16.04	24.9	1.72	113.49
PT2	ENA	7.7947	8.6199	27.85	2.45	95.39	66	32.24	30.26	16.52	19.72	1.69	112.78
PT3	GH	7.79437	8.62341	28.21	2.42	89.57	67	29.6	36.9	15.3	22.1	1.77	112.72
PT4	GH	7.79473	8.62324	27.71	2.36	92.57	61	25.7	31.8	17.5	17.58	1.53	112.51
PT5	GH	7.79342	8.6248	27.27	2.33	97.23	66	31.77	30.73	18.5	19.24	1.56	112.62
PT6	GH	7.79429	8.63345	28.08	2.48	88.97	65	29.26	32.24	15.71	22.31	1.45	113.24
PT7	GH	7.79707	8.62225	29.04	2.49	99.05	64	29.7	30.8	15.5	23.18	1.57	112.46
PT8	HC	7.78594	8.62182	27.28	2.48	93.67	66	32.8	29.7	19.73	18.8	1.55	112.38
PT9	HC	7.78630	8.62112	27.64	2.52	90.71	61	26.78	30.72	19.68	21.68	1.43	112.50
PT10	HC	7.78547	8.62252	28.18	2.29	91.45	59	20.34	35.16	18.28	19.5	1.64	112.43
PT11	HC	7.78904	8.62283	27.77	2.37	86.91	65	26.49	39.01	15.68	21	1.56	112.41
PT12	HC	7.78602	8.62317	28.16	2.3	83.63	66	28.15	34.35	16.7	18.3	1.54	113.04
PT13	BH	7.79700	8.62334	27.4	2.25	96.69	66.3	34.82	27.98	16.7	19.8	1.64	112.94
PT14	BH	7.79653	8.62337	28.15	2.47	82.48	60	20.22	36.28	15.61	19.48	1.64	113.26
PT15	BH	7.79826	8.62348	27.81	2.53	88.07	67	30.71	35.79	17.7	19.43	1.63	111.70
PT16	BH	7.76587	8.62593	27.38	2.54	96.71	62	31.9	26.6	15.6	19.7	1.65	112.11
PT17	AFB	7.71292	8.64324	28.11	2.42	97.57	62	29.73	28.77	16.44	21.4	1.59	112.87
PT18	AFB	7.71298	8.64225	27.16	2.42	97.27	61	22.49	35.01	19.52	19	1.44	111.83
PT19	AFB	7.71289	8.64841	27.5	2.42	86.71	69	33.22	32.28	19.57	18.56	1.56	113.07
PT20	EOA	7.79143	8.61721	28.29	2.42	97.81	63	28.22	31.28	19.93	21.52	1.62	112.96
PT21	EOA	7.79049	8.62870	27.54	2.42	90.43	66	35.5	27	16.92	19.57	1.71	113.27

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, q_s=safe bearing capacity

3.4. Regression Between Bearing Capacity and Soil Properties

To identify the independent variables (soil index properties) that would be correlated with the dependent variable (SBC) for development of regression models (Temizhan, *et al.*, 2022). Correlation matrix was conducted as presented in Table 6. The results show that SBC has a moderate positive correlation with MDD, and weak positive correlation

with natural moisture content. Also, SBC has a very weak positive correlation with OMC, Gs and F_{200} etc. Additionally, SBC has very weak negative correlation with LS, LL and PL. Based on the strength magnitude of the soil index properties, the combination of independent variables was selected for development of regression model (Ahmed *et al.*, 2016).

Table 6: Pearson correlation Matrix between bearing capacity and index Properties of Makurdi Shale

	Safe bearing capacity q_s (kPa)	Moisture Content (%)	Specific Gravity (Gs) (%)	Gains Size F_{200}	Liquid Limit (%)	Plastic Limit (%)	Linear Shrinkage (%)	OMC (%)	MDD (Mg/m3)
Safe Bearing capacity q_s (kPa)	1								
Moisture Content (%)	0.4174	1							
Specific Gravity (Gs) (%)	0.1149	-0.0409	1						
Gains Size F_{200}	0.1135	0.3041	0.02748	1					
Liquid Limit (%)	-0.1498	-0.2240	-0.1231	0.37063	1				
Plastic Limit (%)	-0.1102	-0.2051	-0.2078	-0.0516	0.5898	1			
Linear Shrinkage (%)	-0.2022	-0.0558	0.0284	0.3610	-0.1745	-0.0462	1		
OMC (%)	0.2770	0.6557	-0.1323	0.2798	-0.1264	0.0218	-0.0868	1	
MDD (kg/m3)	0.5308	0.2216	0.00539	0.0280	0.1838	0.3068	-0.1153	0.0517	1

Furthermore, it is found from the correlation that some index properties such as MDD, moisture content (MC), OMC, Gs, F_{200}) displayed stronger correlation with bearing capacity than others like LS, PL, LL etc). The reason for this is that MDD, MC and OMC are more closely related and will better predict bearing capacity of Makurdi shale than PL, LL, PI (Field, 2017; Gravetter and Wallnau, 2020). These findings though not exact, its partly similar to that in the study by Güner and Özgan (2025) on gravel soil at Düzce Province in Turkey. The partial similarity could be due to the different types of soils used by the different authors. While in the current study, Makurdi shale was used, Güner and Özgan (2025) used gravel soil in their research.

Generally, the correlation in the current study provides a guide on the independent variables to be used in the correlation with the dependent variable (bearing capacity) for development of regression models.

3.4.1 Simple Linear Regression Analysis

The relationship between SBC and each soil property obtained from SLRA is presented in Table 7. As earlier noted, SBC was considered dependent variable while each soil property was considered independent variable. From the results, eight models were analysed and the R^2 values ranged from 0.012 to 0.282 These values are less than 0.80 which is the minimum value specified for strong correlation (McLaughlin and Wakefield, 2018). The trend of obtaining R^2 value lower than 0.8 in a simple relationship between bearing capacity and single index property of soil is consistent with other studies (Güner and Özgan (2025). This shows that the SLRA models are not fit for correlation between bearing capacity of Makurdi shale and index properties.

Table 7: Simple Linear Regression between Safe Bearing Capacity and Soil Properties

S/NO	Soil Properties	Model Summary			ANOVA	
		R	R Square	Adjusted R ²	F	Sig
1	MDD (Mg/m ³)	0.531	0.282	0.265	16.868	<0.001
2	OMC (%)	0.277	0.077	0.055	3.574	0.065
3	Specific Gravity (GS)	0.115	0.013	-0.010	0.575	0.452
4	F ₂₀₀	0.114	0.013	-0.010	0.562	0.458
5	Liquid Limit LL (%)	0.150	0.022	0.000	0.987	0.326
6	Plastic Limit PL (%)	0.110	0.012	-0.011	0.529	0.471
7	Shrinkage Limit SL (%)	0.202	0.041	0.019	1.833	0.183
8	Natural Moisture Content (%)	0.417	0.174	0.155	9.073	0.004

Key: MDD: Maximum Dry Density, OMC: Optimum moisture Content, F₂₀₀: Percentage passing Sieve No. 200.

3.4.2 Simple Polynomial Analysis between Safe Bearing Capacity and Soil Properties

The relationship between SBC and each soil property using second order polynomial is presented in Fig. 2 (a-h). The soil properties include MDD, NMC, Gs, F₂₀₀,

OMC, LL, PL, SL. From the Figures, R² values range from 0.0112 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 is not fit for correlation between SBC of Makurdi shale and its index properties.

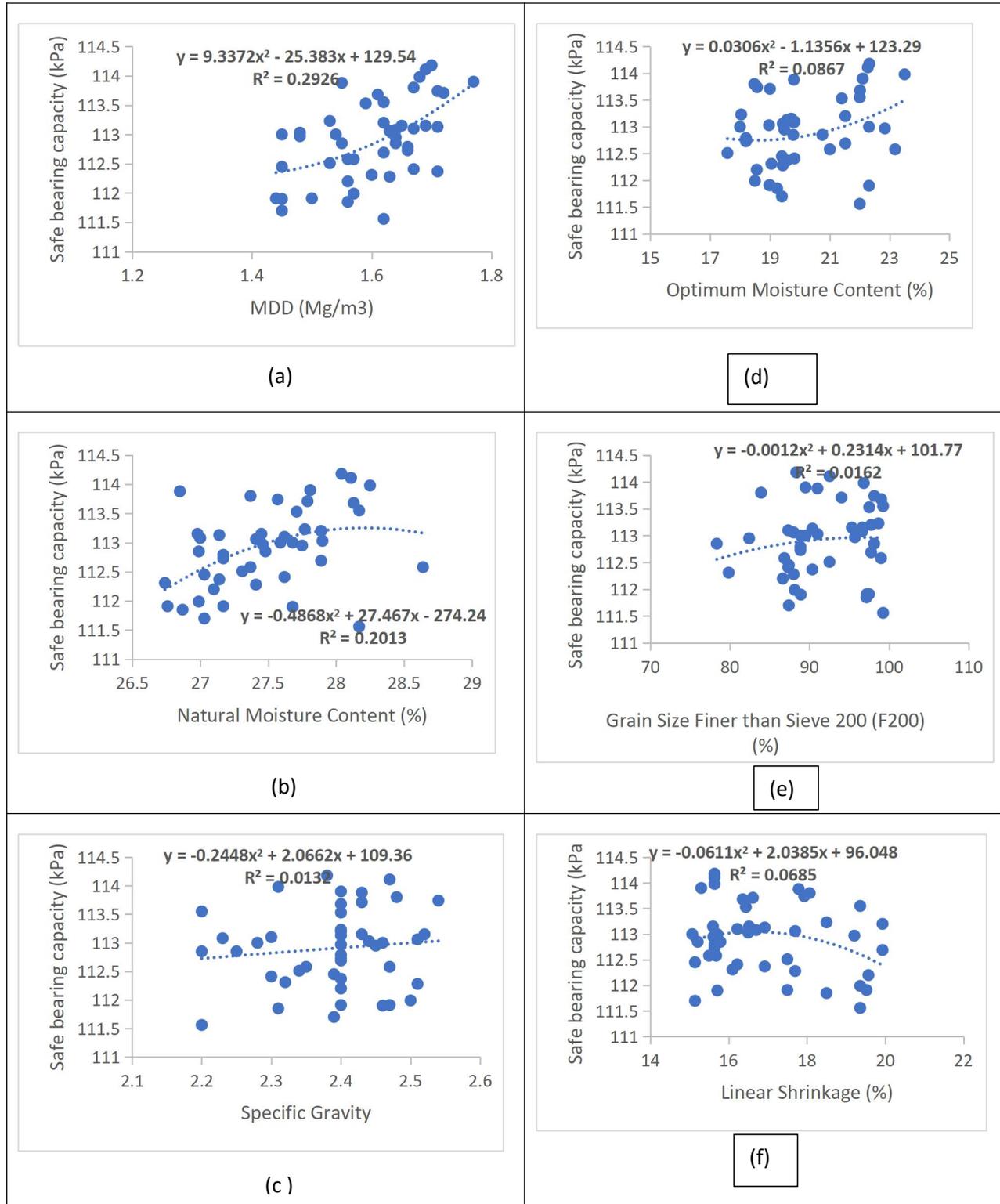


Fig. 2: Variation of safe bearing capacity (SBC) with index properties of Makurdi Shale: (a) SBC versus Maximum Dry Density (b) SBC versus Natural Moisture Content (c) SBC versus vs Specific Gravity (d) SBC versus vs Optimum Moisture Content (%) (e) SBC Versus vs Percentage Passing Sieve 200 (f) SBC Versus Linear Shrinkage.

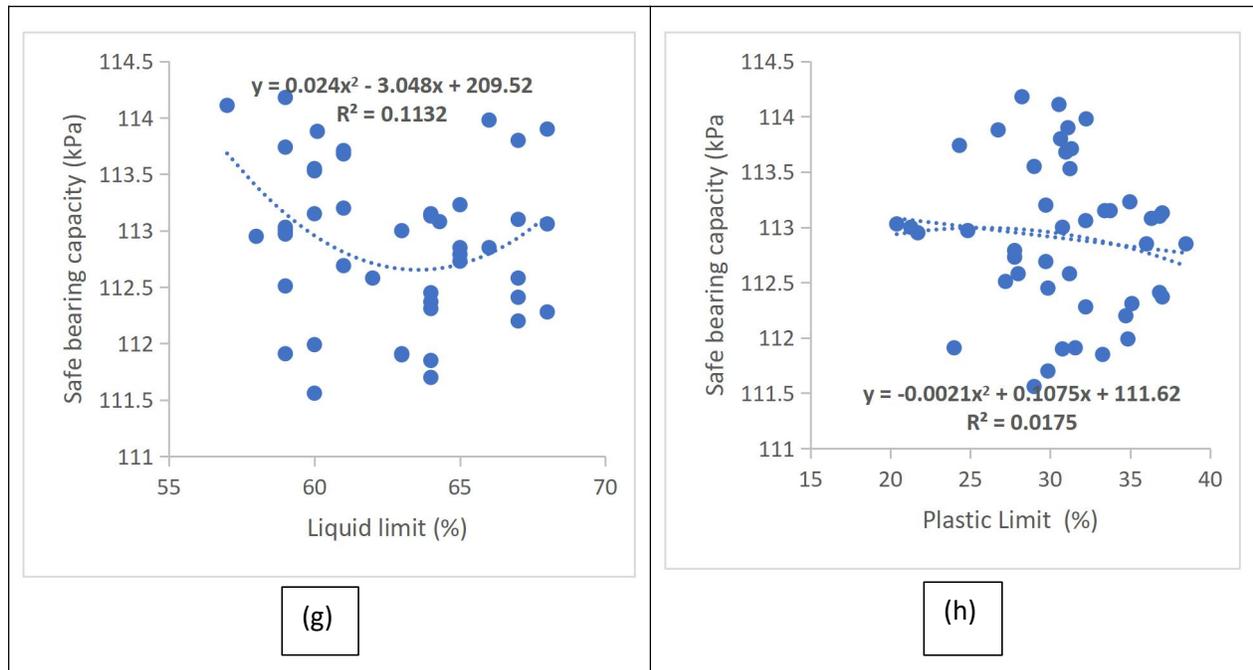


Fig. 2 Continued: Variation of safe bearing capacity (SBC) with index properties of Makurdi Shale: (g) SBC versus Liquid Limit (%) (h) SBC versus Plastic Limit (%)

(Equations 6-9). Each model had R^2 value of at least 0.80 and p-value of less than 0.05.

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

From the results of MLRA between SBC and soil properties, nine (1-11) correlations were generated as shown in Table 8. According to Rakaraddi and Gomarsi (2015), four correlations were considered best fit with values of adjusted R^2 more than 0.8, namely correlations 1, 2, 3 and 4. This indicates that these correlations are fit for predictions. On the other hand, the values of adjusted R^2 for seven correlations (5-11) were less than 0.8, thus have weak R^2 and unfit for prediction. The output of coefficients between bearing capacity and soil properties for the correlations 1-4 are presented in Table 9. From the results, model Equations 6-9 were formulated for the selected correlations with best fit (with $R^2 > 0.8$) as shown in Table 10.

From Model 1 (Equation 6), the safe bearing capacity of Makurdi shale could be predicted from the combination of index properties such as MDD, OMC, MC, Gs, LL and SL with adjusted R^2 value of 0.875 and p-value of 0.00. Similarly, from Models 2-4, different combination of index properties of the shale like MDD, NMC, Gs, LL, PL, SL, OMC and MDD have been found to predict safe bearing capacity

Table 8: Multiple linear regression between Bearing capacity and soil properties

S/NO	Index Properties	Model Summary			ANOVA	
		R	R^2	Adjusted R^2	F	Sig
1	MDD, OMC, MC, Gs, LL, SL	0.944	0.892	0.875	52.293	0.00
2	MDD MC, LL, PL, and SL, OMC.	0.941	0.885	0.867	48.767	0.00
3	MDD MC, LL, SL and OMC	0.940	0.883	0.868	58.931	0.00
4	MDD, MC, F_{200} , LL, PL and OMC.	0.912	0.832	0.805	31.270	0.00
5	MDD MC, GS, F_{200} and OM	0.896	0.802	0.777	31.623	0.00
6	NMC, GS, F_{200} , LL, PL and SL	0.888	0.789	0.756	23.701	0.00
7	MC, LL, and SL	0.855	0.731	0.711	37.069	0.00
8	GS, F_{200} , LL, PL OMC and MDD	0.827	0.682	0.643	16.818	0.00
9	GS, F_{200} , PL, SL, OMC and MDD	0.881	0.776	0.741	21.941	0.00
10	GS, LL, PL, SL, OMC and MDD	0.879	0.772	0.736	21.482	0.00
11	MC, OMC and MDD	0.883	0.780	0.764	48.478	0.000

Key: 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.

Table 9: Coefficients between bearing capacity 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)	93.756	3.294		28.462	.000
	MDD	3.537	0.483	0.434	7.317	0.000
	MC	0.725	0.109	0.473	6.622	0.000
	Gs	-0.698	0.395	-0.098	-1.765	0.086
	LL	-0.058	0.012	-0.279	-4.787	0.000
	SL	-0.110	0.026	-0.249	-4.245	0.000
	OMC	0.040	0.028	0.095	1.438	0.159
2	(Constant)	91.218	3.161		28.861	0.000
	MDD	3.423	0.516	0.420	6.635	0.000
	MC	0.767	0.118	0.501	6.472	0.000
	LL	-0.060	0.015	-0.289	-3.950	0.000
	PL	0.010	0.012	0.062	0.802	0.428
	SL	-0.117	0.027	-0.264	-4.357	0.000
	OMC	0.032	0.030	0.076	1.066	0.293
3	(Constant)	91.524	3.123		29.305	0.000
	MDD	3.529	0.496	0.433	7.112	0.000
	MC	0.737	0.112	0.482	6.576	0.000
	LL	-0.053	0.012	-0.253	-4.369	0.000
	SL	-0.115	0.027	-0.259	-4.319	0.000
	OMC	0.038	0.029	0.091	1.344	0.187
4	(Constant)	85.102	3.631		23.434	0.000
	MDD	4.042	0.600	.496	6.735	0.000
	MC	0.819	0.143	0.535	5.741	0.000
	F200	0.009	0.009	0.069	0.943	0.352
	LL	-0.044	0.020	-0.213	-2.257	0.030
	PL	0.001	0.015	0.008	0.083	0.934
	OMC	0.039	0.036	0.094	1.088	0.283

Key: MDD: Maximum Dry Density, MC:Moisture Content. Gs: Specific Gravity. F₂₀₀: Percentage passing Sieve No. 200. LL: Liquid Limit. PL: Plastic Limit. SL: Shrinkage Limit. OMC: Optimum moisture Content

Table 10: Generated model equations for bearing capacity prediction

Model No	Soil Properties	Model Equation	Adjusted R^2	Equation No
1	MC, Gs, LL, SL, OMC and MDD	$q_s = 93.756 + 0.725NMC - 0.698Gs - 0.058LL - 0.110SL + 0.040OMC + 3.537MDD$	0.875	6
2	MC, LL, PL, SL, OMC, and MDD	$q_s = 91.218 + 0.767NMC - 0.060LL + 0.010PL - 0.117SL + 0.032OMC + 3.423MDD$	0.867	7
3	MC, LL, SL, OMC and MDD	$q_s = 91.524 + 0.737NMC - 0.053LL - 0.115SL + 0.038OMC + 3.529MDD$	0.868	8
4	MC, F_{200} , LL, PL, OMC and MDD	$q_s = 85.102 + 0.819NMC + 0.009F_{200} - 0.044LL + 0.001PL + 0.039OMC + 4.042MDD$	0.805	9

The Prediction of bearing capacity of Makurdi shale from index properties using MLRA as contained in Models 1 to 4 in the current study, though not exact has some predictors similar to the studies by Güner and Özgün (2025), and Ibrahim *et al.* (2022). In the current study, different combinations of index properties of the shale including MDD, MC, Gs, LL, PL, SL and OMC have been found to predict the bearing capacity. While in Güner and Özgün (2025), bearing capacity was predicted by the combination of cohesion, percentage soil finer than sieve 200 (F_{200}), water content, excavation level, sieve No.10, unit weight of soil, ground water level and internal friction angle. Soil parameters like F_{200} , water content have been found to partly predict the bearing capacity of shale in the current study and in the sandy soil from the study by Güner and Özgün (2025). The predictors in either of the studies were not exactly the same. The reason is that, sand was used by Güner and Özgün (2025), while in the current study, shale was used for the study. Also, in either of the studies, some soil parameters were exclusively used per study. In the study by Ibrahim *et al.*, (2022) the soil type was not mentioned, because it was secondary data.

It is observed that studies on correlation of bearing capacity 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 bearing capacity with soil index properties such as MDD, MC, Gs, F_{200} , LL, PL and SL are within the range of variables that are found to predict bearing capacity of Makurdi shale in the current study.

This shows that MLRA models are suitable for predicting of bearing capacity of Makurdi shale using its index properties. It is important to know that the application of MLRA on the prediction of bearing capacity on 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 (6-9) were validated. 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 6), Model 2 (Equation 7), Model 3 (Equation 8) and Model 4 (Equation 9) are 2.9461 %, 0.7923 %, 2.9478 % and 1.1816 % 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, 2, 3 and 4 can perform excellently.

Similarly, the MAE values for Model 1 (Equation 6), Model 2 (Equation 7), Model 3 (Equation 8) and Model 4 (Equation 9) are 2.8441 %, 0.6157 %, 2.8457 % and 1.0413 % respectively. Again, considering that the MAE values in the current study are less than 10 %, which is the maximum value for a good and acceptable criteria (Filó *et al.*, 2024), Models 1, 2, 3 and 4 are considered good and acceptable. Based on RMSE and MAE criteria, Models 1-4 in the current study have demonstrated good performance. This shows that the results of bearing capacity obtained

from predictive models is similar to that from the experimentally determined results.

Table 11: Validation of Model Equations

Sample No	Loc	Lat (N)	Long (E)	q_u (kPa) Lab Result	q_u (kPa) Eqn 6	q_u (kPa) Eqn 7	q_u (kPa) Eqn 8	q_u (kPa) Eqn 9	Comparison of CBR results			
									Lab versus Eqn 6	Lab versus Eqn 7	Lab versus Eqn 8	Lab versus Eqn 9
PT1	ENA	7.7954	8.6173	113.49	116.80	114.36	116.8	114.46				
PT2	ENA	7.7947	8.6199	112.78	115.46	113.42	115.46	111.93				
PT3	GH	7.7943	8.6234	112.72	116.41	114.11	116.41	112.45				
PT4	GH	7.7947	8.6232	112.51	115.49	112.82	115.49	111.43				
PT5	GH	7.7934	8.6248	112.62	114.69	112.28	114.69	111.02				
PT6	GH	7.7943	8.6335	113.24	115.19	112.99	115.19	111.37				
PT7	GH	7.7971	8.6223	112.46	116.29	114.25	116.29	112.71				
PT8	HC	7.7859	8.621	112.38	114.43	112.11	114.43	110.96				
PT9	HC	7.7863	8.6211	112.5	115.02	112.31	115.02	111.12				
PT10	HC	7.7855	8.6225	112.43	116.93	113.59	116.93	112.31				
PT11	HC	7.7890	8.6229	112.41	115.68	113.06	115.68	111.43				
PT12	HC	7.7860	8.6232	113.04	115.65	113.04	115.65	111.55				
PT13	BH	7.7970	8.6233	112.94	114.81	112.9	114.81	111.39				
PT14	BH	7.7965	8.6233	113.26	116.80	113.82	116.8	112.16				
PT15	BH	7.7983	8.6234	111.7	115.32	112.97	115.32	111.58				
PT16	BH	7.7659	8.6259	112.11	114.95	113.27	114.95	111.60				
PT17	AFB	7.7129	8.6432	112.87	115.66	113.56	115.66	112.04				
PT18	AFB	7.7130	8.6422	111.83	115.14	111.87	115.14	110.76				
PT19	AFB	7.7129	8.6484	113.07	114.61	112.15	114.61	110.97				
PT20	EOA	7.7914	8.6172	112.96	116.06	113.32	116.06	112.25				
PT21	EOA	7.7905	8.6287	113.27	114.96	113.24	114.96	111.69				
P-value												
RMSE (%)									2.9461	0.7923	2.9478	1.1816
MAE (%)									2.8441	0.6157	2.8457	1.0413

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. RMSE: Root Mean Square Error, MAE: Mean Absolute Error

The results of RMSE and MAE from the current study is slightly different from that obtained by Kohestani *et al.*, (2017), which used Random Forest (RF) Based Approach on cohesionless soils for the prediction of bearing capacity. The authors reported RMSE and MAE values of 65.33 and 32.12 respectively. Also, the study by Adarsh (2012) which applied genetic programming (GP) on cohesionless

soils for the prediction of bearing capacity reported RMSE and MAE values of 44.967 and 7.69 respectively.

It is observed that the results for RMSE in Kohestani *et al.*, (2017) and Adarsh (2012) were higher and weaker in performance than that in the current study. Except for the research by Adarsh (2012) with MAE of 7.69, the MAE result of 44.967 higher than

that in the current study. The difference in these results could be that the soil used in Kohestani *et al.*, (2017) and Adarsh (2012) were cohesionless soil while that used in the current study is cohesive (shale) soil. Generally, the current study exhibits low RMSE and MAE values from 0.7923 to 2.9478 and 0.6157 to 2.94 respectively. This shows that the results of bearing capacity obtained from predictive models in the current study have demonstrated good performance.

3.6 Relationship between Bearing Capacity and Some Index Properties of Makurdi Shale

The establishment of a correlation between bearing capacity and index properties of particular soil usually enables rapid estimation of bearing capacity, potentially streamlining geotechnical investigations and conserving resources for similar soil formations. In the current student, it is shown that the combinations of some index properties like MDD, MC, specific gravity, OMC, liquid limit, plastic limit and percentage of soil finer than sieve 200 could be used to predict the bearing capacity of Makurdi shale. The predictions have a strong goodness of fit of R^2 value of at least 0.8, and a p-value of less than 0.05. The predictions are contained in Models 1 and 2, 3 and 4 (Equations 6,7,8 and 9) in the current study.

Based on the results of Standardized Coefficients Beta, it was found in all the models (Table 11) that moisture content, followed by MDD mostly influenced the bearing capacity values of Makurdi shale.

Generally, moisture content influences the strength like the bearing capacity 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 bearing capacity 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 bearing capacity 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 bearing capacity values.

MDD also influences bearing capacity. 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 bearing capacity value, as the soil particles are more densely packed. Increased MDD for different soils usually would results in increased bearing capacity

values. Therefore, if soil index properties such as MC, MDD, G_s, LL, PL, SL, OMC and F₂₀₀ are known, bearing capacity of Makurdi or similar shale would be determined within a short time and less efforts compared with actual laboratory process of determining bearing capacity.

IV CONCLUSION AND RECOMMENDATIONS

This study evaluated 45 Makurdi shale samples. The index properties and bearing capacity of the shale were determined and correlated. The key findings are:

1. According to the AASHTO and USCS classification systems, Makurdi shale is categorized as A-7-6 and CH soils, respectively. Its particle size distribution indicates a dominant silt and clay content, classifying it as an argillaceous shale.
2. The free swell values of Makurdi shale samples range from 24 % to 51 %. Given that some samples exhibit free swell values of at least 50 %, the shale has moderate expansive potential. Thus, can exhibit some noticeable volume change under light loadings (Prasad *et al.*, 2017).
3. The safe bearing capacity of Makurdi shale values ranges from 111.56 to 114.11 kPa. Based on the presumed SBC standard (BS 8004:2015+A1:2020), these values are within 75–150 kPa and are classified as firm clays.
4. Using MLRA, four models were established to predict safe bearing capacity from various soil index properties of Makurdi shale, with a best fit ($R^2 > 0.8$). Safe bearing capacity can be predicted from different combinations of the soil properties such as MC, MDD, G_s, LL, PL, SL, OMC and F₂₀₀, with adjusted R² values ranging from 0.805 to 0.875 and a p-value of less than 0.05. These models are presented in Equations 6, 7, 8, and 9.
5. To ensure time and cost serving, which is associated with extensive bearing capacity testing on Makurdi or similar shale, Models 1 to 4 (Equations 6 to 9) developed in this study are recommended to civil engineers for predicting the bearing capacity of Makurdi shale using its index properties.
6. Models 1 to 4 (Equations 6 to 9) produced in this study are recommended for use by policymakers to develop regulatory frameworks on correlations between bearing capacity and soil index properties of Makurdi shale. With the use of these models, building construction projects on Makurdi shale or similar shale can be easily checked to ensure that bearing capacity criteria

are met.

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