DOI: https://dx.doi.org/10.4314/gjgs.v21i1.10

GLOBAL JOURNAL OF GEOLOGICAL SCIENCES VOL. 21, 2023: 143-148
COPYRIGHT© BACHUDO SCIENCE CO. LTD PRINTED IN NIGERIA ISSN 1596-6798
www.globaljournalseries.com.ng, Email: globaljournalseries@gmail.com

EMPIRICAL MODELLING OF GEOTECHNICAL STRENGTH BASED ON INDEX PROPERTIES: A CASE OF PATTI FORMATION, SOUTHERN BIDA BASIN, NIGERIA

D. O. OBASAJU., R. AYUBA, B. O. JEREMIAH., O. A DANGA AND S. O. IBRAHIM

(Received 7 December 2022; Revision Accepted 23 January 2023)

ABSTRACT

The strength properties of geo-materials are paramount to the stability or otherwise of civil engineering structures. However, the determination of some of these properties such as California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) is costly and time-consuming. This necessitates the generation of models that can quickly predict the strength properties from cost-effective and less time-consuming index properties of the same geo-materials. In this study, an attempt has been made to predict the CBR and UCS values from Atterberg limit tests for sediments derived from Patti Formation, Southern Bida Basin, Nigeria. The tests were performed following appropriate codes of the British Standard Method for testing materials. Both linear and polynomial fitting models were employed for regression analysis between the index and strength parameters. The results showed that Liquid Limit (LL), Plastic Limit (PL), and Shrinkage Limit (SL) are strongly correlated with UCS and CBR, having R^2 ranging from 0.8-0.91. The equations can be used to quickly predict UCS and CBR in areas with similar geology. Similar studies are recommended in other parts of the country to aid the regional evolution of models for rapid strength characterization of geo-materials.

KEYWORDS: Patti Formation, Bida Basin, Atterberg limit, regression equation, Nigeria

INTRODUCTION

The knowledge of the strength properties of soils is paramount in geotechnical engineering designs. For example, a holistic flexible pavement design test requires Compaction, California Bearing Ratio and Unconfined Compression Strength tests. Unfortunately, these important tests are oftentimes avoided in many soil investigation programs as a result of the required time, huge cost and inadequate skilled personnel (Attah *et al.,* 2020). The consequences of this include untimely failure of engineering structures, loss of lives, properties and wastage of resources.

In order to overcome this limitation, there is a need for a less costly and time-efficient alternative to reliably predict soil strength properties. A prediction tool such as a model can be a vivacious and efficient means for making proper engineering decisions (Rehman *et al*., 2017). Several authors (e.g. Obasaju *et al*., 2022, Attah *et al*., 2020 and Ige *et al*., 2018) have shown that index properties of soils are related to their strength properties. Since the index properties can be quickly determined in the laboratory, it is possible to establish mathematical models for predicting strength properties using statistical methods.

D. O OBASAJU., Department of Earth Sciences, Kogi State University, Anyigba
R. AYUBA, Department of Earth Sciences, Kogi State University, Anyigba
B. O. JEREMIAH, Department of Earth Sciences, Kogi State University, Anyigba
O. A DANGA, Department of Earth Sciences, Kogi State University, Anyigba
S. O. IBRAHIM, Department of Earth Sciences, Kogi State University, Anyigba

Several studies including stratigraphy, sedimentology, mineralogy, hydrocarbon potential, hydrogeology have been conducted by several authors within the Southern Bida Basin of Nigeria (e.g., Jones 1953, 1958; Adeleye, 1974., Jan du Chene *et al*. 1978., Braide, 1992, Ladipo *et al.,* 1994., Abimbola *et al.* 1999., Ojo and Akande 2009., Obaje, 2009., Akande *et al.,* 2005., Okunlola and Idowu, 2012., Ige *et al.,* 2018). There is however a paucity of knowledge about the geotechnical properties of the formations within the basin, vis-à-vis the relationship between the index and strength characteristics. The studies have shown that the Patti Formation consists of thick sediments of sandstone, clay and shale (70 – 100 m) around Koton-Karfe and Abaji area, where the present study area is situated (Obaje, 2009). This research is aimed at filling this knowledge gap (using the sediments - clays of the Patti Formation) and contributing to the database for strength predictions of geo-materials in Nigeria. The objectives are to develop mathematical models to estimate strength properties (Unconfined Compression Strength test and California Bearing Ratio) using index properties (Liquid limit, Plastic limit, Plastic Limit and Shrinkage Limit). Other models for relationships between CBR, UCS and some geotechnical properties (e.g. Natural moisture content, Optimum Dry Density, Maximum Dry Density, Bulk Density and Plasticity Index) were also developed and presented in this paper but not discussed.

STUDY AREA

The study area is situated around Koton-Karfe – Abaji area Environs, along Lokoja – Abuja Highway within Latitude N 08°19' 00" – 8°21' 00'' and Longitude E 006° 52' 30'' – 6° 53' 30'' (Fig. 1). The major river in the area flows in the NE-SW direction. The rock exposures in the study area belong to the Patti Formation and consist of siltstone, clay, shale and bioturbated ironstones. The topography of the study area is made up of high and lowlands of altitude ranging from 88 -148 m above sea level.

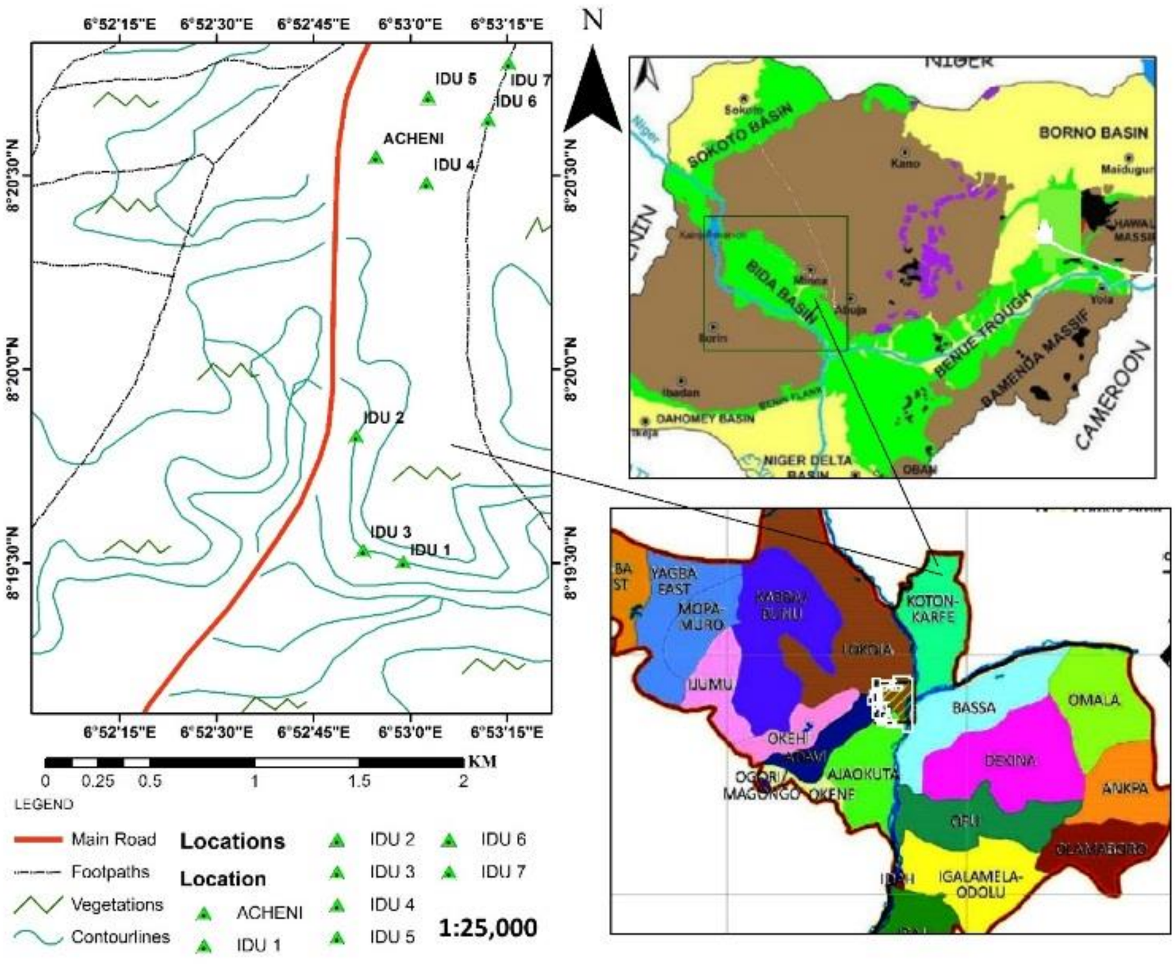

Fig.1: Map of the study area/Sample locations

MATERIALS AND METHODS

Field and Laboratory Investigations

Lithologic logging of each bed of outcrops was done. Five bulk clayey samples were randomly obtained from different outcrop locations belonging to Patti Formation. The obtained samples were air–dried before being subjected to laboratory index and strength geotechnical tests. All tests were done in accordance with the British Standards procedures (BS 1377, 1990). The results of the laboratory tests were analyzed using the linear and non-linear or polynomial regression model as appropriate. This was to know the relationship between the dependent variables which are the strength properties (Unconfined Compressive Strength, California Bearing Ratio) and independent variables which are the index properties (Liquid Limit, Plastic Limit, Shrinkage Limit, Plasticity Index). Although several models were generated for different soil properties, the discussion is however limited to the Atterberg limit and the UCS and CBR tests in this paper. Origin Pro software was used for the purpose of analysis. Linear models were found to be suitable for the relationship between UCS and Atterberg limits, on the other hand, second-order polynomial fittings were the most suitable models for the relationship between CBR and Atterberg limits because they gave a better value of R^2 (> 0.7).

RESULTS AND DISCUSSION

The results of the laboratory tests are presented in Table 1. Some of the regression plots are presented in this paper, while all the results including the regression models and interpretations are summarized in Table 2. The regression plots of UCS against PL and LL are presented in Figs 2 a and b. The plots show that PL and LL have strong negative correlations with UCS (r = -0.94). This implies that as PL and LL increase, UCS decreases. Also, the value of R^2=0.89 suggests that 89% of the variance in UCS can be accounted for by PL and LL. Therefore, PL and LL are reliable predictors of UCS. In the same vein, the linear regression between UCS and SL (Fig. 2c) shows a strong negative correlation of r = 0.90 and R^2=0.81. This implies that 81% of the variance in UCS can be accounted for by SL. SL is therefore a reliable predictor of UCS.

Table 1: Geotechnical properties of clayey samples

Sample	UCS (KN/m^2)	CBRs	CBRu	SG	NMC (%)	OMC (%)	MDD (g/cm^3)	SL	PI (%)	LL (%)	PI (%)	BD (g/cm^3)
S1	1065	5	21	2.53	15.79	14.8	1.7	5.1	5	16	11	1.2
S2	475.8	6	20	2.82	13.56	24.1	1.7	7.3	7.5	31	23.5	1.5
S3	779.55	9	22	2.71	14	22	1.7	5.73	7.9	29	21.5	1.3
S4	1113	8	18	2.55	15.63	22.8	1.8	3.82	4.9	15	10.1	1.5
S5	920.75	9	29	2.83	11.43	21.43	1.8	4.14	5.4	22	16.6	1.4

*BD = Bulk density, OMC = Optimum Moisture Content, NMC = Natural Moisture Content, MDD = Maximum Dry Density, SG = Specific Gravity, PI = Plasticity Index, PL = Plastic limit, LL = Liquid limit, SL = Shrinkage limit

The regression plots of unsoaked CBR (CBRu) against PL, LL and SL are presented in Figs 2d-f. The polynomial fittings' model revealed values of R^2 = 0.86, 0.91 and 0.8 for CBRu against PL, LL and SL respectively. These values suggest that 86%, 91% and 80% of variance in CBRu can be accounted for by PL, LL and SL respectively. Therefore, PL and LL are reliable predictors of CBRu.

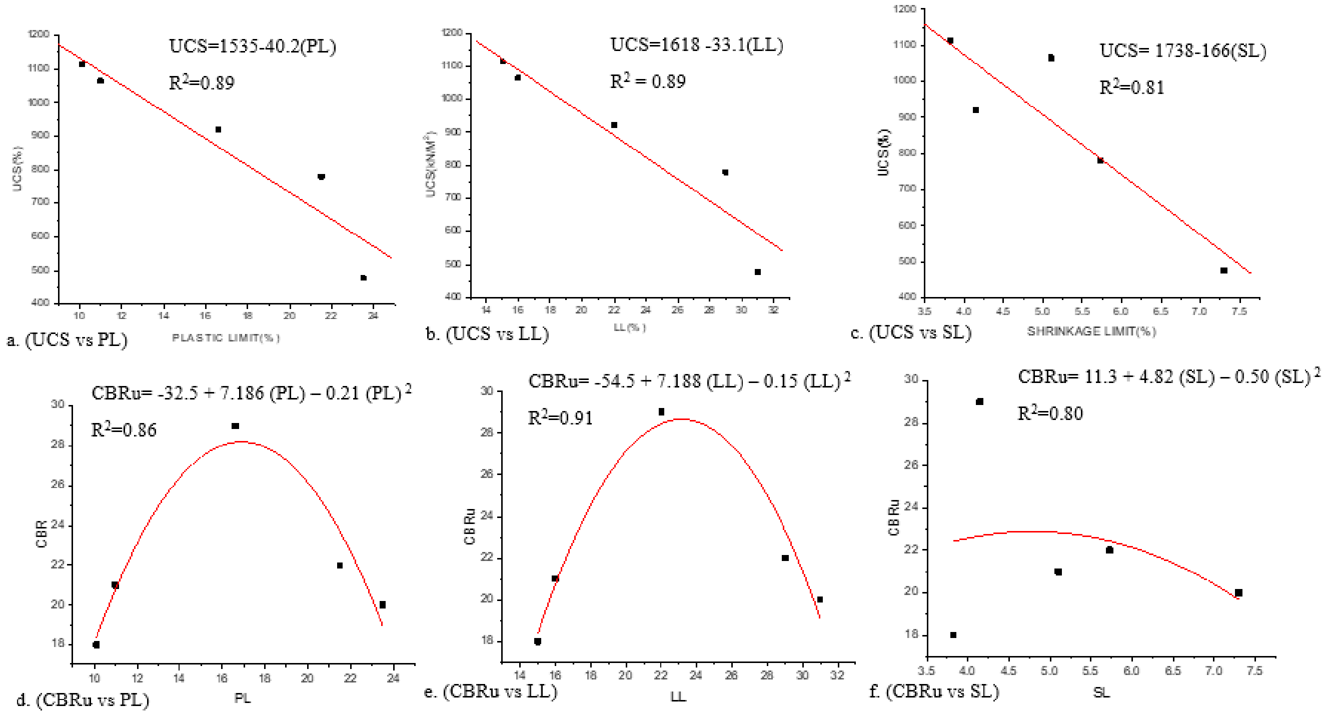

Fig 2. Regression plot of (a): UCS vs PL (b) UCS vs LL (c) UCS vs SL (d) CBRu vs PL (e) CBRu vs LL (f) CBRu vs SL

According to Rehman *et al*., (2017), correlation coefficient between two variables with $r^2 > 0.9$, 0.7 – 0.89, 0.4 – 0.69, 0.2 – 0.39 and < 0.2 are statistically classified as excellent, good, fair, poor and very poor respectively (Rehman *et al.,* 2017). Thus, the models generated for relationships between UCS and CBRu with PL, LL and SL are excellent. Other models generated and their interpretation based on this classification has been used to interpret the relationships between the geotechnical properties presented in Table 3.

Rehman *et al*., (2017) obtained a correlation coefficient (R^2) of 0.85 between CBR with Liquid limit for some soils from Asia. While Ige *et al.,* (2018) obtained r^2 of 0.2 from Southwestern Basement Complex of Nigeria. This present study reveals R^2 of 0.91 for the same parameters. The result aligns more with Rehman *et al*., (2017). Differences in obtained geotechnical properties and coefficient of correlation between soil properties can be largely attributed to differences in geology. Therefore, the equations with $r^2 > 0.7$ may thus be used as a quick predictor of another variable, when a variable is available but with similar geology. The equations however require validation through further field and laboratory studies.

Table 3: Summary of regression analysis models and interpretation of their relationships

Parameters	R	R^2	Regression type	Linear equation	Interpretation
UCS vs LL	-0.94	0.89	Linear	UCS=1618-33.1LL	LL a reliable/good predictor of UCS
UCS vs BD	-0.34	0.13	Polynomial	$UCS=3532BD^2-1026BD+8256.7$	BD a weak predictor of UCS
UCS vs PL	-0.94	0.89	Linear	UCS=1535-40.2PL	PL a reliable/good predictor of UCS
UCS vs PI	0.85	0.72	Linear	UCS=1796-150PI	PI a reliable/good predictor of UCS
UCS vs SG	-----	0.60	Polynomial	$UCS=5062SG^2-28482SG+40772$	SG a reliable/good predictor of UCS
UCS vs OMC	----	0.51	Polynomial	$UCS=-14.7OMC^2+521OMC-3433$	OMC a fair predictor of UCS
UCSvs NMC	----	0.84	Polynomial	$UCS=84.79NMC^2-2257NMC+1564$	NMC a reliable/good predictor of UCS
UCS vs SL	0.90	0.81	Linear	UCS=1738-166SL	SL a reliable/ good predictor of UCS
UCS vs MDD	0.52	0.27	Linear	UCS=-3364+2434Mdd	MDD a weak predictor of UCS
CBRs vs LL	----	0.35	Polynomial	$CBRs=-0.039LL^2+1.856LL-12.62$	LL a fair predictor of CBRs
CBRs vs PL	----	0.37	Polynomial	$CBRs=0.056PL^2+1.923PL-7.38$	PL a fair predictor of CBRs
CBRs vs PI	0.16	0.03	Linear	CBRs=6.13+0.21PI	PI a weak predictor of CBRs
CBRs vs SL	0.43	0.19	Linear	CBRs=10.35-0.57SL	SL a weak predictor of CBRs
CBRs vs OMC	0.53	0.28	Linear	CBRs=1.826+0.265OMC	OMC a fair predictor of CBRs
CBRs vs NMC	-0.53	0.28	Linear	CBRs=14.99-0.539NMC	NMC a weak predictor of CBRs
CBRs vs SG	-----	0.39	Polynomial	$CBRs=-102.98SG^2+556.41SG-742.5$	SG a fair predictor of CBRs
CBRs vs BD	0.25	0.06	Linear	CBRs=2.53+3.53BD	BD a weak predictor of CBRs
CBRs vs MDD	0.55	0.31	Linear	CBRs=-24.5+18.33MDD	MDD a fair predictor of CBRs
CBRu vs LL	-----	0.91	Polynomial	$CBRu= -54.5+ 7.88LL-0.15 LL^2$	LL is a good predictor of CBRu
CBRu vs PL	------	0.86	Polynomial	$CBRu=-32.5 +7.18PL-0.21PL^2$	PL is a good predictor of CBRu
CBRu vs SL	------	0.8	Polynomial	$CBRu=11.3+4.82SL-0.5SL^2$	SL is a good predictor of CBRu
CBRu vs MDD	0.34	0.11	Linear	CBRu=25MDD-21.5	MDD a weak predictor of CBRu
CBRu vs OMC	0.07	0.07	Linear	CBRu=23.68-0.08OMC	OMC a weak predictor of CBRu
CBR_U vs NMC	0.86	0.73	Linear	CBRu=50.35-2.01NMC	NMC a reliable/good predictor of CBRu
CBR_U vs SG	0.60	0.36	Linear	CBRu=17.54S.G-25.16	SG a fair predictor of CBRu
MDD vs SL	0.81	0.66	Linear	MDD=1.91-0.03SL	SL a reliable/good predictor of MDD
MDD vs PI	0.63	0.39	Linear	MDD=1.89-0.023PI	PI a fair predictor of MDD
MDD vs PL	0.48	0.23	Linear	MDD=0.007PL + 1.903	PL a weak predictor of MDD
MDD vs LL	-0.51	0.26	Linear	MDD=1.81-0.004LL	LL a weak predictor of MDD
MDD vs OMC	0.27	0.08	Linear	MDD=1.65+0.004OMC	OMC a weak predictor of MDD
BD vs SG	0.39	0.15	Linear	BD=0.44+0.35S.G	SG a weak predictor of BD
BD vs NMC	-----	0.10	Polynomial	$BD=-0.01NMC^2+0.268NMC-0.294$	NMC a reliable/strong predictor of BD
BD vs OMC	0.86	0.75	Linear	BD=0..73+0.03OMC	OMC a reliable /strong predictor of BD
BD vs MDD	0.49	0.24	Linear	BD=1.17MDD-0.65	MDD a weak predictor of BD
BD vs SL	----	0.90	Polynomial	$BD=0.084SL^2-0.931SL+3.812$	SL a reliable/strong predictor of BD
BD vs PI	0.09	0.007	Linear	BD=1.33+0.008PI	PI a weak predictor of BD
MDD vs NMC	0.28	0.08	Linear	MDD=1.86-0.009NMC	NMC a weak predictor of MDD
MDD vs BD	-----	0.32	Polynomial	$MDD=-1.41BD^2+4.038BD-1.128$	BD a fair predictor of MDD
BD vs LL	0.19	0.04	Linear	BD=1.29+0.004LL	LL a weak predictor of BD
BD vs PL	0.21	0.04	Linear	BD=1.30+0.005PL	PL a weak predictor of BD

*BD = Bulk density, OMC = Optimum Moisture Content, NMC = Natural Moisture Content, MDD = Maximum Dry Density, SG = Specific Gravity, PI = Plasticity Index, PL = Plastic limit, LL = Liquid limit, SL = Shrinkage limit.

CONCLUSION

The present study has shown that it is possible to predict costly and time-consuming geotechnical parameters such as California Bearing Ratio and unconfined compressive strength from cheap and less time-consuming index tests. Equations generated may only be reliably used when dealing with soils from similar geology and when the coefficient of correlation r^2 is greater than 0.7. Similar studies are recommended in other parts of the country to aid the regional evolution of models for rapid strength characterization of geo-materials. Further field and laboratory studies are recommended to validate the generated equations.

REFERENCES

Abimbola, A. F., Badejoko, T. A; Elueze, A. A., and Akande, S. O., 1999. The Agbaja Ironstone Formation, Nupe Basin, Nigeria. A product of replacement of a Kaolinite precursor. Global Journal of Pure and Applied Sciences 5: 375-384.

Adeleye, D. R., 1974. Sedimentology of the fluvial Bida Sandstones (Cretaceous) Nigeria. Sedimentary Geology 12, 1-24.

Akande, S. O. Ojo, O. J and Ladipo, K., 2005a. Upper Cretaceous Sequences in the Southern Bida Basin, Nigeria. A Field Guidebook. Mosuro Publishers, Ibadan. 60p.

Attah, F., Ige, O and Ogunsanwo, O., 2020. Multivariate assessment of California bearing ratio with contracted geotechnical properties of soils in Ilorin-Lokoja Highway. Doi:/http/DX.doi.org/10.5772/intechopen.93523.

British Standard (BS) 1377, 1990. Methods of testing soils for civil engineering purposes. British Standards Institution, London.

Braide, S. P., 1992. Geological development, origin and energy mineral resources potential of the Lokoja Formation in the Southern Bida Basin. Journal of Mining and Geology 28, 33– 44.

Falconer, J. D., 1911. The geology and geography of Northern Nigeria. Macmillan, London, 135.

Ige O. O., Attah F. and Ogunsanwo O., 2018. Geotechnical Assessment of some soil along Ilorin-Lokoja Highway-Implication on Suitability for road construction. Bulletin of the science Association of Nigeria .29, 149- 162.

Jan du Chene, R. E., Adegoke, O. S., Adediran, S. A. and Petters, S. W., 1978. Palynology and foraminifera of the Lokoja Sandstone (Maastrichtian), Bida Basin, Nigeria. Revista Espanola de Micropaleontotologia 10, 379–393

Jones, H. A., 1953. The occurrence of oolitic ironstone in Nigeria: their origin, geological history and petrology. D. Phill thesis, Oxford University, 244pp

Jones, H. A., 1958. The oolitic ironstone of Agbaja Plateau, Kabba Province. Record of the Geological survey of Nigeria, pp.20 – 43

Ladipo, K. O., Akande S. O. and Mucke, A., 1994. Genesis of ironstones from the MidNiger sedimentary basin: evidence from sedimentological, ore microscopic and geochemical studies. Journal of Mining and Geology, 30, 161-168.

Obaje, N. G., 2009. Geology and Mineral Resources of Nigeria. Springer, Heidelberg, (Ed.), Geology of Nigeria. 2nd edition, Elizabethan Publishers, Lagos, pp. 347358. pp.221

Obasaju D. O., Oloruntola M. and Oladele S., 2022. Integrated Resistivity, Index and Strength Characteristics of Subgrade Soils: Implication for Highway Pavement Failure Studies in North-Central Nigeria. Geoscience Engineering 68:1, 46-57. DOI: 10.35180/gse-2022-0068

Ojo, O. J and Akande, S. O., 2009. Sedimentology and depositional environments of the Maastrichtian Patti Formation, Southern Bida Basin, Nigeria. Cretaceous Research, 30, 1415-1425.

Okunlola, O. A. and Idowu, O., 2012. The geochemistry of claystone-shale deposits from the Maastritchian Patti Formation, Southern Bida basin, Nigeria. Earth Sci. Res. SJ. 16 (2): 57 – 67

Rehman, Z. U., Khalid, U., Farooq, K and Mujtaba, H., 2017. Prediction of CBR value from Index Properties of different soils. Technical Journal, University of Engineering and Technology (UET) Taxila, Pakistan. 22 (11), 17 - 26