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Characterization of Erodibility Using Soil Strength and Stress-Strain Indices for Soils in Some Selected Sites in Anambra State

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Abstract
The purpose of the study are to develop models for predicting the susceptibility or extent of soils to erosion in the selected sites in the state; to measure and observe the relationship between soil strength indices, stress-strain characteristics and changes in moisture content (mc%) and dry density (γ_d) for some selected soil samples in the state; to obtain the jet index (J_i) for the various soil samples and to investigate the relationship between soil strength indices or stress-strain characteristics on the erosion resistance of compacted soils. In this study, initial soil strength indices (q_u) and stress-strain characteristics namely failure strain (ε_f); area under the stress-strain curve up to failure (I_s) and stress-strain modulus between no load and failure (E_s) were investigated as potential indicators for characterizing the erosion resistance of two compacted soils namely sandy clay loam (SCL) and clay loam (CL) in some selected sites in Anambra State, Nigeria. The unconfined compressive strength (used in obtaining strength indices) and stress-strain measurements were obtained as a function of moisture content in percentage (mc %) and dry density (γ_d). Test were conducted over a range of 8% to 30% moisture content and 1.0g/cm^3 to 2.0g/cm^3 dry density at applied loads of 20, 40, 80, 160 and 320kPa. Based on the results, it was found out that initial soil strength alone was not a good indicator of erosion resistance. For instance in the comparison of exponents of mc% and γ_d for jet index or erosion resistance index (J_i) and the strength measurements, q_u and E_s (Table 7) agree in signs for mc%, but are opposite in signs for γ_d. Therefore there is an inconsistency in exponents making it difficult to develop a relationship between the strength parameters and J_i for this data set. In contrast, the exponents of mc% and γ_d for J_i and ε_f and I_s are opposite in signs (Table 7), there is potential for an inverse relationship. The measured stress-strain characteristics however, appeared to have potential in providing useful information on erosion resistance. The models developed for the prediction of the extent or the susceptibility of soils to erosion and subjected to sensitivity test on some selected sites as shown in table 8 achieved over 90% efficiency in their functions. Finally, the contributions to knowledge are the models developed for all the sites in the state that can be used to easily predict the susceptibility or extent of soils to erosion.

Keywords: characterization, erodibility, soil strength, stress-strain, indices, soils, selected sites.

INTRODUCTION

Soil erosion is one of the most important physical and socio-economic problems affecting our development in this part of the world today. Apart from the fact that it constitutes a menace to the environment and despite its destruction of our infrastructure, highways etc, and soil erosion creates a major problem on our agricultural land thereby interfering seriously with mass food production (Abarikwu, 1988) hence the need for predicting the susceptibility of soils to erosion.

An accurate estimate of soil erodibility (the susceptibility or vulnerability of soil to erosion) is important to engineers involved in the design of water management projects. Defining soil erodibility, however, is a difficult task. This is because soil detachment is a complex function of both soil and eroding fluid properties (Egwuonwu and Uzoije, 2009; Akintola, 2001).

Predicting the susceptibility of a soil to erosion prior to a concentrated flow event is an important problem in many engineering projects such as irrigation, channels, levees, highways, railways, spillways, construction sites, mining area reclamation and land management:. In many of these engineering projects not only is the erodibility of the soil at the surface of interest, but also the erodibility with depth (Hanson, 1996). Earth spillways are an example in which erosion exposes different materials with depth and the erodibility of these materials is important in the performance of the spillways under concentrated flow conditions (Hanson, 1996). Measuring erodibility directly is often difficult. Therefore development of measurable soil parameters that indicate erodibility is attractive (Elliot et al, 1990).

Soil strength indices have been a common soil parameter investigated for characterization of soil erodibility. Strength indices are commonly used because they can be easily and rapidly obtained, measured incrementally with depth and related to other soil parameters that affect soil erodibility such as dry density (γ_d) and water content (mc%) (Egwuonwu and Okereke, 2012). Soil strength indices are also appealing because soil erosion is a function of the forces applied by the flow and resistance to erosion is offered by bonding forces between soil particles and other materials in the soil matrix (Hanson, 1996). Since the state of bonding is manifested in the soil strength, resistance to erosion should be characterized by the measurement of soil strength. Although soil strength indices have been used to characterize erodibility of soils, their success have been limited (Elliot et al, 1990; Parker et al, 1995) hence the need for the use of more quantifiable parameters of soil such as strength and stress-strain characteristics. Unconfined compressive strength, triaxial shear test, vane shear strength, pocket penetrometer as well as other tests have been used to characterize soil strength (Nearing and West, 1988).

The objectives of the study are: to measure and observe the relationship between soil strength indices, stress-strain characteristics and changes in moisture content and dry density for the selected sites and to develop models for predicting the susceptibility or extent of soils to erosion in the selected sites.

STATEMENT OF PROBLEM

Soil erosion is one of the most challenging ecological problems affecting the socio-economic development of the South-Eastern Nigeria. It constitutes a menace to the environment and destroys infrastructures, highways and depletes fertility of agricultural land thereby interfering seriously with mass food production. There is therefore need to predict the susceptibility of soil to erosion as a required measure to treat soil according to their capability. The susceptibility of soil to erosion is a measure of its erodibility.

SCOPE OF THE STUDY

The study focused on the characterization of erodibility using soil strength and stress-strain indices for soils in Anambra State in South-Eastern Nigeria and was limited to three sites in the state namely Awka, Agulu Nanka and Nnewi. The study also covered obtaining the jet index (J_i) for the various soil samples and the development of models for predicting the susceptibility of soils to erosion in the selected areas.

MATERIALS AND METHODS

Study Area

Characterisation of erodibility using soil strength and stress-strain indices was studied for some selected towns in Anambra State Nigeria namely: Awka, Agulu Nanka and Nnewi. These towns lie between latitude 5.3°N to 6.5°N and longitude 6.8°E to 8.1°E and are within the tropical rainforest zone. The study was carried out in February 2011.

Soil Materials

The soils used in this study were a sandy clay loam (SCL) and a clay loam (CL) obtained from three (3) sites in Anambra State, Nigeria namely Anambra (1) – Awka; Anambra (2) – Agulu Nanka; Anambra (3) – Nnewi. The influence of compaction (mc% and γ_d) on resistance to erosion of these soils was reported in Hanson and Robinson (1993) and Hanson (1992, 1993).

Soil Preparation

Soil samples were prepared by static load compaction. Thirty test samples of each soil were compacted using a device similar to a fixed ring consolidometer. Static pressure was applied to the soil by pneumatic bellows. Loads of 20, 40, 80, 160 and 320kPa were applied to the samples. The size of prepared soil sample was 445mm in diameter and the final height varied from 100mm to 200mm depending on the load applied and the mc%. Samples were compacted at various mc% ranging from 8 to 30% for each load. The soils were wet by spraying to various mc% mixed thoroughly and stored in polyethylene bags for 24 hours to allow the water to permeate through the soil.

Soil Testing

Test was conducted on the compacted samples. Strength and stress-strain values were measured with the unconfined compression test. The unconfined compressive tests were conducted in accordance with ASTM D2166. In addition to the unconfined compressive strength (q_u), stress-strain characteristics namely failure strain (ε_f), area under the stress-strain curve up to failure (I_s), and stress-strain modulus between no load and failure (E_s) were determined for the unconfined compressive test. Unconfined compressive tests were continued until the load values decreased with increasing strain or until 20% strain was reached.

The samples of soil [sandy clay loam (SCL) and clay loam (CL)] were tested for resistance to erodibility using a submerged jet testing device. Water was fed under a constant head of 0.91m, through a circular nozzle, 13mm in diameter, at a set height of 0.22m above a level bed of prepared soil. The rate of scour was monitored with time. The erosion resistance of the samples was based on a jet index (J_i). The lower the J_i values the less erosion occurred, and the more resistant the material (Hanson, 1991).

Data Analysis

A comparison of nonlinear power curve regression fits or power equation or models for jet index (J_i), failure strain (ε_f), area under the stress-strain curve up to failure (I_s), unconfined compressive strength (q_u)

and stress-strain modulus between no load and failure (E_s) versus the variables mc% and γ_d was developed. The non linear power curve function served as potential for functional relationships. Multiple Linear Regressions in conjunction with Naïve-Gauss Elimination Method and Gauss-Jordan Matrix Inverses were used to obtain the models.

The coefficient of determination (r^2) was computed for each developed model to ascertain the level of accuracy or exactness of each model.

RESULTS

The strength test and stress-strain results as well as the jet index result for SCL and CL soils are shown in Tables 1 – 6 for the sites selected in Anambra State. The comparison of nonlinear power curve regression fits for J_i, ε_f, I_s, q_u, and E_s versus the variables mc% and γ_d is shown in Table 7. The prediction of the extent or the susceptibility of soils to erosion on some selected sites using the J_i models developed is illustrated in Table 8.

The predicted J_i versus q_u and J_i versus ε_f for SCL and CL soils (Anambra) in Figures 1 to 4 and Figures 5 to 8 respectively.

Table 1: Strength and Stress-Strain Indices for SCL Soil as a function of mc% and γ_d for Anambra State (1)

mc (%)	γ_d (g/cm^3)	q_u (kPa)	ε_f	I_s (kPa)	E_s (kPa)
9.0**	1.20	05	0.010	0.15	250
12.7	1.25	07	0.012	0.23	400
14.5	1.29	08	0.018	0.28	500
15.8	1.35	10	0.035	0.35	500
17.0	1.48	16	0.075	0.88	450
19.5	1.61*	18	0.170	3.00	100
21.3	1.65	20	0.200	4.00	50
9.5	1.24	07	0.008	0.18	500
11.6**	1.30	10	0.010	0.25	800
14.3	1.48	18	0.038	0.80	900
16.3	1.61*	27	0.100	2.70	600
18.0	1.70	38	0.180	5.40	200
19.1	1.72	38	0.200	5.40	100
21.4	1.76	38	0.200	6.00	20
8.2	1.33	12	0.010	0.22	1000
11.6**	1.40	18	0.012	0.38	1100
13.7	1.61*	38	0.050	1.70	1250
15.8	1.75	50	0.120	5.20	600
17.0	1.80	55	0.180	6.00	300
19.8	1.86	55	0.200	6.00	60
8.1	1.42	28	0.008	0.32	1700
10.1	1.48	35	0.010	0.50	1800
11.7**	1.62*	48	0.030	1.00	1900
14.1	1.79	70	0.080	5.00	1000
17.1	1.85	70	0.200	6.00	300
8.5	1.57	58	0.001	0.60	2800
10.4	1.65	60	0.018	1.25	2500
11.7	1.72	78	0.040	3.00	2000
13.0	1.81	82	0.070	4.50	1700
15.0	1.88	90	0.120	6.00	800

Table 2: Strength and Stress-Strain Indices for CL Soil as a function of mc% and γ_d for Anambra State (2)

mc(%)	γ_d (g/cm^3)	q_u (kPa)	ε_f	I_s (kPa)	E_s (kPa)
12.8	1.06	07	0.004	0.04	1400
14.7**	1.08	09	0.007	0.10	490
16.4	1.14	12	0.010	0.19	680
18.5	1.23	15	0.024	0.32	650
20.0	1.28	15	0.038	0.40	500
21.0	1.31	10	0.050	0.63	440
22.0	1.39*	10	0.079	1.80	300
11.0	1.11	10	0.001	0.05	480
13.2	1.16	14	0.005	0.17	800
14.7**	1.21	17	0.008	0.20	1000
16.8	1.29	19	0.020	0.35	1100
19.4	1.38*	22	0.042	0.88	820
21.2	1.47	22	0.082	2.20	450
22.0	1.53	22	0.120	3.60	380
9.8	1.19	16	0.010	0.12	900
12.1	1.24	18	0.015	0.20	1200
14.6**	1.38*	38	0.018	0.40	1800
17.2	1.44	40	0.033	0.84	1500
19.3	1.51	40	0.070	2.30	1000
21.0	1.61	50	0.120	5.60	500
9.6	1.33	33	0.001	0.25	1900
12.0	1.39*	40	0.006	0.36	2200
14.7**	1.47	60	0.021	0.70	2300
18.2	1.58	75	0.068	3.50	1800
20.6	1.65	75	0.130	6.40	600
12.1	1.41	50	0.012	0.40	2400
14.7**	1.57	95	0.030	1.50	3000
17.0	1.65	100	0.060	4.00	2200
18.6	1.70	110	0.097	7.00	1700
20.7	1.77	116	0.160	8.50	500

Table 3: Strength and Stress-Strain Indices for SCL Soil as a function of mc% and γ_d for Anambra State (3)

mc(%)	γ_d (g/cm^3)	q_u (kPa)	ε_f	I_s (kPa)	E_s (kPa)
8.5	1.14	0	0.001	0.00	100
10.6	1.19	0	0.004	0.08	210
13.0**	1.25	3	0.007	0.23	375
15.3	1.30	6	0.020	0.31	420
18.0	1.38	10	0.057	0.50	190
20.0	1.45*	12	0.100	0.80	100
21.5	1.61	18	0.200	4.00	60
9.0	1.20	0	0.001	0.09	250
11.5	1.28	6	0.003	0.24	500
13.0**	1.38	14	0.016	0.38	830
15.0	1.45*	19	0.040	0.78	720
17.0	1.53	19	0.090	1.90	380
19.5	1.60	19	0.180	4.00	300
21.0	1.70	26	0.200	5.70	120
8.0	1.30	13	0.010	0.20	700
10.0	1.38	18	0.016	0.33	1140
13.0**	1.45*	24	0.024	0.61	1000
15.8	1.60	27	0.095	2.40	715
17.0	1.70	37	0.160	5.10	300
19.8	1.78	40	0.200	6.00	100
10.0	1.45*	28	0.005	0.38	1460
12.0	1.50	29	0.020	0.70	1390
14.0	1.60	33	0.052	2.10	1170
16.5	1.71	40	0.140	5.10	500
18.5	1.80	45	0.200	6.00	240
9.0	1.55	50	0.013	0.63	2400
11.0	1.65	60	0.020	1.70	2500
13.0**	1.72	60	0.052	3.60	1630
15.0	1.80	66	0.110	5.40	810
17.4	1.87	70	0.200	6.00	400

Table 4: Values of J_i for SCL Soil as a function of mc% and γ_d for Anambra State (1)

mc(%)	γ_d (g/cm^3)	J_i
11.6	1.29	0.024
10.6	1.54	0.024
9.8	1.65***	0.024
8.7	1.88	0.024
11.4	1.43	0.023
10.0	1.71	0.023
12.6	1.32	0.021
10.9	1.71	0.021
13.1**	1.31	0.020
11.5	1.65***	0.020
10.6	1.85	0.020
13.5	1.37	0.017
11.5	1.76	0.017
13.9	1.37	0.016
13.0**	1.54	0.016
11.6	1.79	0.016
15.6	1.32	0.013
14.2	1.51	0.013
13.1**	1.70	0.013
11.9	1.87	0.013
15.6	1.40	0.011
14.0	1.65***	0.011
12.6	1.85	0.011
14.8	1.60	0.010
16.8	1.49	0.009
14.5	1.72	0.009
17.9	1.47	0.008
15.5	1.65***	0.008
14.5	1.78	0.008
13.1**	1.90	0.008

Table 5: Values for J_i for CL Soil as a function of mc% and γ_d for Anambra State (2)

mc(%)	γ_d (g/cm^3)	J_i
16.5	1.21	0.016
14.0**	1.22	0.016
11.0	1.45***	0.016
9.4	1.70	0.016
14.8	1.21	0.015
11.8	1.53	0.015
17.1	1.20	0.013
11.8	1.45***	0.013
12.0	1.60	0.013
15.0	1.31	0.011
17.9	1.25	0.010
14.0**	1.42	0.010
12.4	1.66	0.010
19.4	1.26	0.009
16.0	1.34	0.009
14.0**	1.55	0.009
10.9	1.76	0.009
20.9	1.31	0.008
15.3	1.45***	0.008
12.8	1.70	0.008
19.1	1.45***	0.007
15.2	1.60	0.007
20.0	1.50	0.006
15.3	1.65	0.006
20.9	1.58	0.005
15.0	1.68	0.005
18.8	1.74	0.004
14.0**	1.76	0.004

Table 6: Values for J_i for SCL Soil as a function of mc% and γ_d for Anambra State (3)

c(%)	γ_d (g/cm^3)	J_i
13.3	1.31	0.019
12.4	1.51	0.019
11.3	1.70***	0.019
13.7	1.35	0.017
11.6	1.75	0.017
14.0**	1.33	0.016
12.8	1.62	0.016
11.6	1.80	0.016
15.4	1.35	0.013
13.0	1.70***	0.013
11.7	1.90	0.013
16.4	1.31	0.012
14.0**	1.57	0.012
12.1	1.90	0.012
15.2	1.56	0.011
13.3	1.80	0.010
16.4	1.43	0.009
14.0**	1.70***	0.009
13.2	1.85	0.009
18.0	1.46	0.008
15.5	1.65	0.008
13.0	1.90	0.008
18.5	1.70***	0.004
14.0**	1.88	0.004
12.0	1.97	0.004
17.8	1.76	0.003
13.5	1.94	0.003
17.1	1.85	0.002
13.0	1.98	0.002

Table 7: Power Curve functions of Parameters J_i, q_u, ε_f, I_s, and E_s for SCL and CL Soils Anambra State

ANAMBRA (1) SCL SOIL	
$J_i = 8.44* 10^2 (mc)^{-4.26} (\gamma_d)^{-0.12}$	$r^2 = 0.93$
$\varepsilon_f = 4.57* 10^{-7} (mc)^{4.22} (\gamma_d)^{0.85}$	$r^2 = 0.92$
$I_s = 4.12 * 10^{-3} (mc)^{0.89} (\gamma_d)^{7.75}$	$r^2 = 0.93$
$q_u = 1.83*10^2 (mc)^{-2.12} (\gamma_d)^{8.19}$	$r^2 = 0.94$
$E_s = 3.84 * 10^7 (mc)^{-5.21} (\gamma_d)^{5.38}$	$r^2 = 0.81$
ANAMBRA (2) CL SOIL	
$J_i = 15.16 (mc)^{-2.28} (\gamma_d)^{-3.28}$	$r^2 = 0.98$
$\varepsilon_f = 3.38 * 10^{-7} (mc)^{3.53} (\gamma_d)^{4.20}$	$r^2 = 0.92$
$I_s = 2.65 * 10^{-4} (mc)^{1.84} (\gamma_d)^{8.64}$	$r^2 = 0.96$
$q_u = 1.64 * 10^2 (mc)^{-1.40} (\gamma_d)^{6.67}$	$r^2 = 0.97$
$E_s = 1.54 * 10^5 (mc)^{-2.24} (\gamma_d)^{3.45}$	$r^2 = 0.83$
ANAMBRA (3) SCL SOIL	
$J_i = 7.06 * 10^2 (mc)^{-3.49} (\gamma_d)^{-4.14}$	$r^2 = 0.99$
$\varepsilon_f = 8.71 * 10^{-7} (mc)^{3.08} (\gamma_d)^{6.00}$	$r^2 = 0.94$
$I_s = 3.79 * 10^{-3} (mc) (\gamma_d)^{7.53}$	$r^2 = 0.98$
$q_u = 4.32 (mc)^{-0.75} (\gamma_d)^{8.23}$	$r^2 = 0.92$
$E_s = 2.78 * 10^5 (mc)^{-3.21} (\gamma_d)^{5.03}$	$r^2 = 0.89$

Table 8: Prediction of the Extent or the Susceptibility of Soils to Erosion on some selected sites using the J_i Model Developed for Anambra State

Location	Average mc%	Average (γ_d)	J_i Model
Anambra (1) – A	12.10	1.29	0.020
Anambra (1) – B	20.10	1.74	0.002
Anambra (2) – A	11.10	1.38	0.022
Anambra (2) – B	15.40	1.86	0.004
Anambra (3) – A	14.00	1.34	0.021
Anambra (3) – B	17.60	1.78	0.003

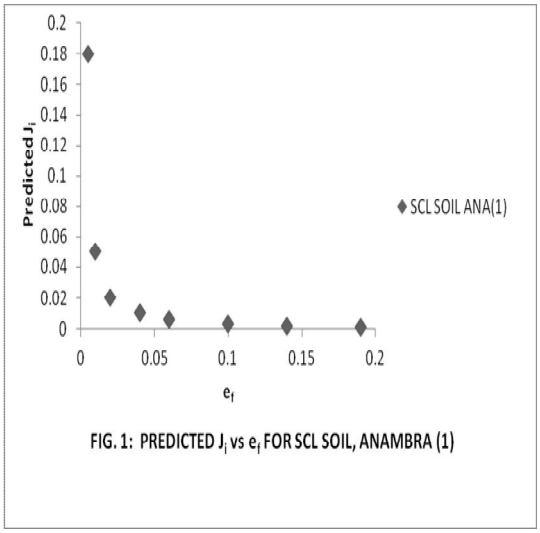

FIG. 1: PREDICTED J_i vs e_f FOR SCL SOIL, ANAMBRA (1)

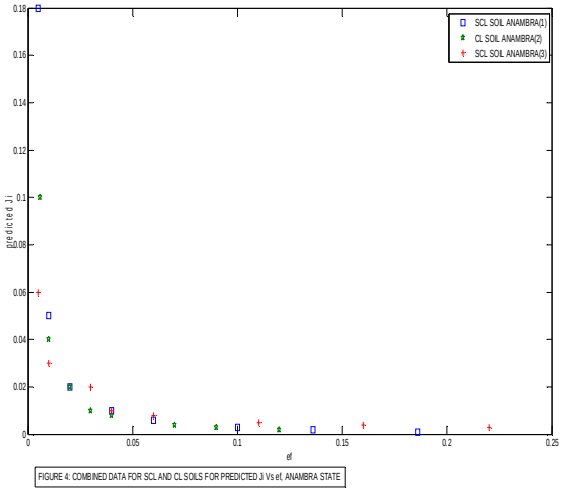

FIGURE 4: COMBINED DATA FOR SCL AND CL SOILS FOR PREDICTED Ji Vs ef, ANAMBRA STATE

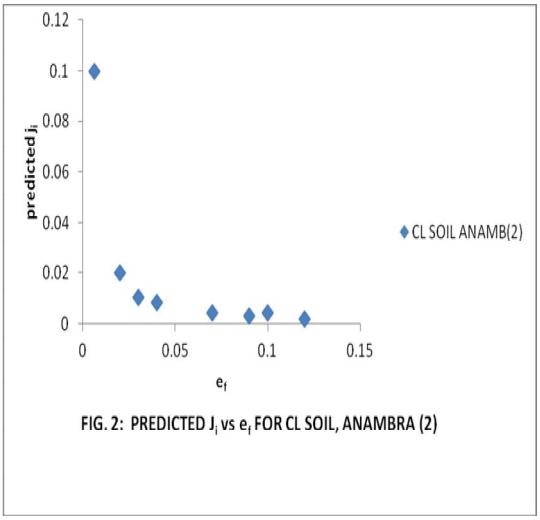

FIG. 2: PREDICTED J_i vs e_f FOR CL SOIL, ANAMBRA (2)

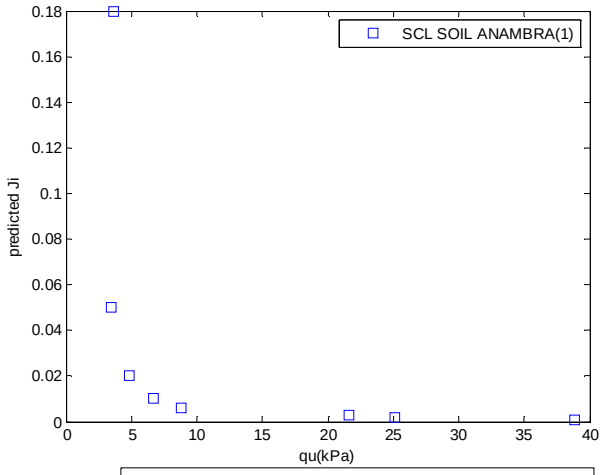

FIGURE 5: PREDICTED Ji Vs qu FOR SCL SOIL, ANAMBRA(1)

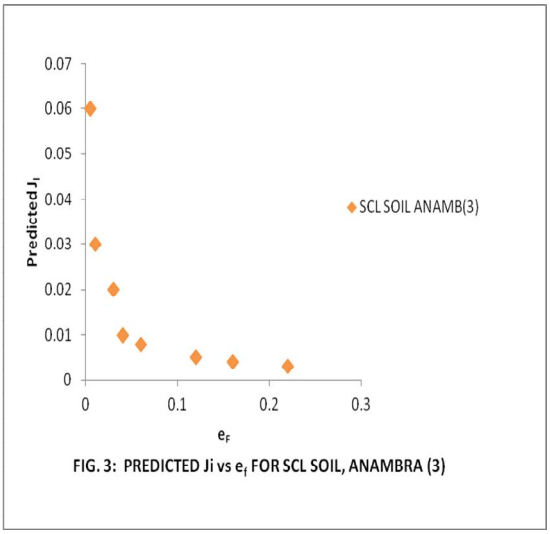

FIG. 3: PREDICTED Ji vs e_f FOR SCL SOIL, ANAMBRA (3)

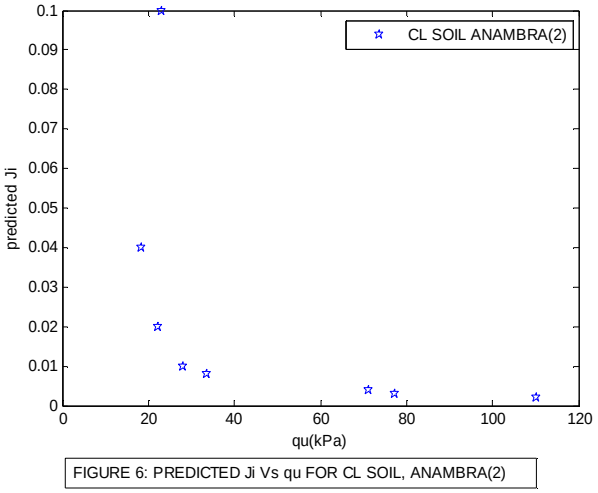

FIGURE 6: PREDICTED Ji Vs qu FOR CL SOIL, ANAMBRA(2)

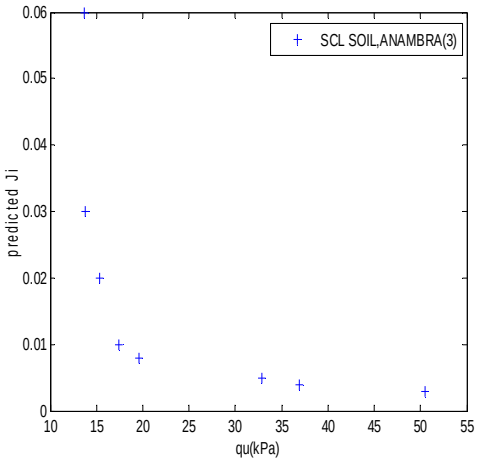

FIGURE 7: PREDICTED Ji Vs qu FOR SCL SOIL, ANAMBRA (3)

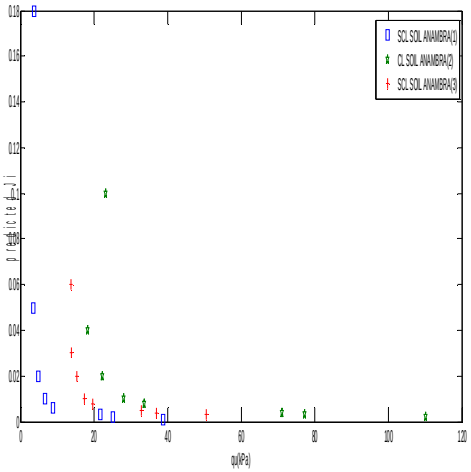

FIGURE 8: COMBINED DATA FOR SCL AND CL SOIL FOR PREDICTED Ji Vs qu, ANAMBRA STATE.

DISCUSSION

The strength indices (q_u) for the SCL and CL soils for the sites selected followed similar trends (Tables 1 – 3). Strength indices increased as the γ_d increased for a given mc and as the mc decreased for a given γ_d (the asterixed values * and ** in Tables 1-3). It was observed that q_u, ε_f, I_s and E_s increased as γ_d increased. The values of q_u and E_s decreased as mc% increased for a constant γ_d, whereas ε_f, and I_s tended to increase (the asterixed values * and ** in Tables 1-3). . At low mc%, the soil tended to fail by brittle fracture. At high mc%, the soil failed plastically.

The relationship of ε_f, I_s and E_s to γ_d and mc% for the same set of samples shown in the tables listed for strength indices are shown in Tables: 1 – 3. The E_s values were observed to have similar relationship as the strength indices (q_u) had to γ_d (Tables 1 – 3). Soil strength indices decreased with increases in mc% (the asterixed values * and ** in Tables 1-3), whereas the resistance to erosion increased with increases in mc% within the same range ((the asterixed values ** and *** in Tables 4-6). The conclusion is that the soil strength indices alone, although affected by mc% and γ_d, would make poor erosion characterization indicators.

The stress-strain characteristics ε_f and I_s, tended to increase with increases in γ_d and mc% (Tables 1-3) and these concur with that of the erosion resistance index (J_i) (Tables 4-6). Whereas E_s tended to increase with γ_d and decrease with mc%. Based on these test results, E_s has the same potential problems as strength indices, q_u. However, ε_f and I_s have potential for indicating erosion resistance of a soil.

A comparison of nonlinear power curve regression fits for J_i, ε_f, I_s, q_u, and E_s versus the variables mc% and γ_d are shown in Table 7. The nonlinear power curve function served as potential for functional relationships and was consistently a good fitting function in all cases and allowed comparison between parameters.

The exponents of mc% and γ_d indicate their functional relationship to J_i, ε_f, I_s, q_u, and E_s. Based on the exponents J_i decreases as mc% increases holding γ_d constant. This comparison indicates that even though the exponents of mc% and γ_d for J_i and ε_f and I_s are opposite in signs, there is potential for an inverse relationship. In contrast, the comparison of the exponents for mc% and γ_d for J_i and the strength measurements, q_u and E_s agree in signs for mc%, but are opposite in signs for γ_d. Therefore, there is an inconsistency in exponents making it difficult to develop a relationship between the strength parameters and J_i for this data set.

The jet index (J_i) test results and the strength (q_u) and stress-strain (ε_f) test results are independent data sets, a prediction of J_i can be made for the strength and stress-stain data using the functional relationships in Table 7 for the SCL and CL soil. As an example of the potential relationships for J_i versus ε_f and q_u a comparison of the predicted J_i versus ε_f and predicted J_i versus q_u for Anambra State is shown in Figures 1 to 4 and Figures 5 to 8 respectively for SCL and CL soil.

These plots show that there does appear to be a general trend as q_u increases J_i decreases (Figures 5 to 7), but there is quite a bit of scatter. For a parameter to be effective in predicting erodibility, it must also be consistent between soils. Combing the data in Figures 1 to 3 for predicted J_i versus ε_f brings the data for SCL and CL soils together (Figure 4). However,

combining the data in figures 5 to 7 for q_u versus J_i does not bring the data together (Figure 8).

Using the erosion prediction model J_i obtained for the three sites in Anambra State, two locations in each of the sites were each tested for the mc% and γ_d. The two sites included one that had visibly undergone erosion (A) and one that had not visibly undergone or partially undergone erosion (B). The parameters mc% and γ_d were obtained at random locations (20) on the site. The average values of the parameter were imputed in the J_i model to ascertain the extent of or the susceptibility of soils to erosion and to also verify the efficacy or exactness of the model obtained. This is shown in table 8.

Based on the jet index (J_i), a highly erodibile soil will have a J_i of approximately 0.020 whilst an erosion resistant soil will have a J_i of approximately 0.002. From table 8; Anambra 1A, Anambra 2A and Anambra 3A had J_i values close to 0.020 or slightly above it. This explains the adverse extent of erosion on these soil to the extent it was glaringly visible. Anambra 1B, Anambra 2B and Anambra 3B had J_i values close to 0.002 or slightly above it with no visible signs of erosion. These soils are still erosion resistant.

CONCLUSION AND RECOMMENDATIONS

The soil strength indices (q_u) for SCL and CL soil in the sites increased with increases in dry density (γ_d) (Tables 1 to 3). The resistance to erosion (J_i) of the SCL and CL soils in the region also increased with increases in γ_d (Tables 4 to 6). q_u decreased with increases in moisture content (mc%) (Tables 1-3), whereas J_i increased with increases in mc% within the same range (Tables 4-6).

Soil strength (q_u) and erodibility (J_i) are both affected by mc% and γ_d, but not necessarily in the same functional manner (Table 7). The comparison of the exponents for mc% and γ_d for J_i and the strength measurements; q_u and E_s agree in signs for mc%, but are opposite in signs for γ_d. Therefore, there is an inconsistency in exponents making it difficult to develop a relationship between the strength parameters and J_i for the data set.

Furthermore, the predicted J_i versus q_u for SCL and CL (Figures 5 to 7) soils does not indicate potential for a relationship between soils. For a parameter to be effective in predicting erodibility it must also be consistent between soils. However, the combined data in Figures 5 to 7, for J_i and q_u does not bring the data together (Figure 8). This does not discard soil strength as a potential indicator, but it does indicate that it should not be solely relied upon for prediction of soil erodibility.

The results from compacted samples of SCL and CL soils indicate that stress-strain characteristics namely failure strain (ε_f) and area under the stress strain curve up to failure (I_s) are helpful in predicting erodibility. The stress-strain indices (ε_f and I_s) increased with increases in both γ_d and mc% (Tables 1 to 3). The resistance to erosion (J_i) of the SCL and CL soil also increased with increase in both γ_d and mc% within the same range (Tables 4 to 6).

ε_f and I_s had similar functional relationships to J_i (Table 7). Even though, the exponents of mc% and γ_d for J_i, and ε_f and I_s are opposite in signs, there is potential for an inverse relationship. The predicted J_i versus ε_f for SCL and CL soils (Figures 1 to 3) indicate potential for a relationship between stress-strain and erodibility for a soil and between soils. The combined data in figures 1 to 3 for predicted J_i versus ε_f brings the data for SCL and CL soils together (Figure 4). These results indicate that stress-strain characteristics should be included alongside strength indices in studies when developing relationships between soil erodibility and other soil parameters.

The models developed for the prediction of the extent or the susceptibility of soils to erosion and subjected to sensitivity test on some selected sites as shown in Table 8 achieved over 90% efficiency in their functions.

From the discoveries made in this project, it is appropriate to recommend the following:

- Similar studies should be extended to other areas in the country that are prone to erosion in order to develop models that will ascertain the susceptibility or extent of soils to erosion. Since the control of erosion is capital intensive, early detection will minimize cost and ultimately save the environment from its menace.
- Studies in soil erosion are usually intensive and expensive in terms of finance. Government through institutions, agencies and parastatals should make available adequate funds to sustain such studies. With proper funding results of such studies will go a long way in totally annihilating the menace of soil erosion in our environment if sincerely implemented?
- Soil strength should not be solely relied upon for measuring erodibility of soils. However, other parameters i.e. stress-strain characteristics etc should be included alongside strength indices when developing relationships between soil erodibility and other soil parameters.

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