Akpan Paul P, et. al. International Journal of Engineering Research and Applications
www.ijera.com
ISSN: 2248-9622, Vol. 12, Issue 6, (Series-III) June 2022, pp. 49-55

RESEARCH ARTICLE OPEN ACCESS

Modeling the Swell-Shrinkage Potential of a Stabilized Black Cotton Soil for Subgrade Pavement

Akpan Paul P.[1], Anea-Bari Doland B.[2],Akien-Alli I. J. [3],
Abednego George G.T. [4], Bob Dagogo M. A.[5] and Nwinuka, Barinor[6]
(1, 4, and 6) Department of Civil Engineering Kenule Beeson Saro-Wiwa Polytechnic, Bori, Nigeria.
(2) Department of Surveying, Kenule Beeson Saro-Wiwa Polytechnic, Bori,Rivers State, Nigeria.
(3,) Department of Industrial Safety and Environmental Engineering Technology, Kenule Beeson Saro-Wiwa Polytechnic, Bori, Nigeria.
(5) Department of Electrical/Electronic Engineering Technology, Kenule Beeson Saro-Wiwa Polytechnic, Bori,, Nigeria.

ABSTRACT
An investigative study was under taken on a black cotton soil (BCS) of Eket senatorial district which possessed a swell-shrinkage potential phenomenon that is prone to severe, crack and differential settlement of foundation of any infrastructural facilities. This research is aimed at modeling the swell-shrinkage potential of a stabilized BCS for subgrade pavement. The study adopted multiple regression equation as the empirical model for the formulation and calibration of the developed model. Row reduction method was used for calibration to obtain the material constant, which was used to derive empirical and developed model, $u = kc^{a_1}z^{a_2}$, and $u = 13.552c^{0.170}z^{0.574}$ respectively for determination of swell-shrinkage potential of stabilized BCS. The model was validated and found to be 1, which shows a perfect fit. Hence the model derived can aid in tackling swelling potential of localized weak black cotton soil depending on the environment. Federal ministry of works, and national oil spill detection regulation agency (NOSDRA) in alliance with the legislative arm of government should sponsor bill for the adoption and implementation of the developed swell-shrinkage potentials of stabilized black cotton subgrade pavement like this since it will help fulfill the requirements of ISO 14001:2015 and ISO 9001:2018 standards.

Keyword: Modeling, swell potentials, shrinkage potential, black cotton soil, pavement stabilization, subgrade pavement

---

Date of Submission: 28-05-2022 Date of Acceptance: 10-06-2022

I. INTRODUCTION

Soil investigation is essential before carryout any civil engineering work (Patel, 2019). In the views of Akinwande, and Aderinola (2020), effective utilization of localized weak soil in rural and urban areas has been a challenge for decades to civil engineers. The works of Fulzele, Ghane, and Parkhe (2016), showed that an attempt to construct on weak soil has result to possible severe damage of structures due to its differential settlement in foundation of buildings, road pavement and retaining structures. A possible and observable damage caused by expansive soils includes foundation crack, Heaving and cracking of sidewalks, depression in roads etc. (Akaha, and syveslter,2016).

In India, 20% of its entire land mass is covered with expansive soil known as BCS (Jain, Jha , and Shivanshi,2020). BCS for instance are known to be a notorious soil because of their poor performance as construction materials. This harmonize with the thoughts of Akaha, and syveslter, (2016) which stipulates that localize weak soil appear to be firm in their dry state and subject to large amount of swelling in wetting state. In line with these thoughts, Agunwamba, Okonkwo, and Iro, (2016), suggested that soil stabilization with bagasse ash has come forth as a comely option to foresee low-cost roads construction and achieve sufficient strength.

According to Singh, and Siddique (2022); Siddique, and Cachim (2018), and Patel, (2022), Bagasse ash (BA) is a waste material of sugar manufacturing industry. Sugarcane (Saccharum Officinarum) is the largest crop by production quantity in the world, a large amount of wet bagasse is yielded and the management of this residue is of great importance from environmental point of view.

The thoughts of Ouedraogo, Sawadogo, Sanou, Barro, Nassio, Seynou, and Zerbo (2022) showed that bagasse ash is produced by calcinations of sugar cane bagasse at temperatures ranging from 550^0C to 750^0C with a heating stage of 2 to 3 hours, resulting to the production of pozzolanic ashes, and cementious materials for production of cement. BA contain some proportions of dicalcuim (C2S), tricalcium silicates(C3S), quartz (SiO2), calcite (CaCO3), muscovite (KAl2AlSi3O10(OH)2), microcline (KAlSi3O8), and hematite (Fe2O3). The ashes are rich in amorphous silica with a high Blaine specific area and a density around 2,5 g/cm3 (Patel and Ouedraogo 2022). BA can improve the compressive strength, durability and mechanical properties of soil (Le, Sheen, and Nguyen, 2022; Hussien, and Oan 2022; Bersisa and Zekaria, 2021).

The unstable nature of the swell potential of BCS need to be determine to prevent collapse of civil engineering structures (Diome, and Biaye L, 2022; Fondjo, Theron, and Ray., 2021; Merouane, and Mamoune, 2018). Considering that the swelling stress in foundation design enhances the service life of construction (Darikandeh, and Phanikumar , 2021; Khan,Wang, and Patterson, 2017), some scholars have developed swell potential model using different methods (Wang and Wei, 2015; Weerasinghe, Kodikara, and Bui, 2015). Hence, this research is aimed at develop a mathematical model of swell-shrinkage phenomenon that can aid in tackling swelling potential of localized weak BCS problems using the simplest approach not considered by other scholars.

II. MATERIALS ANDMETHODS

The materials used in carrying this research include BCS obtained from Eket, disturbed soil collector, and all laboratory equipments. The soil samples (BCS) were collected from Obok-idem in Eket local government area of Akwa Ibom state, having coordinates of 4°27'57''N 7°37'45''E. It was collected at a depth not less than 150mm from 8 different locations of about 4m apart using the method of disturbed sampling technique.

The same procedure for compaction and California bearing ratio test (WASC Method) was repeated for swelling test but with different blows of 27 and 54 respectively for the two specimens. After four days, the specimens were measured for swelling. The sample was placed under the penetration piston and surcharge load of about $10 1b$ was introduced on the specimen.

2.1 Swell data

Swell after 4 days = expected value for swell potential

Height of spearmen= (swell after 4 days)/(116.43 cm) x 100% 2.1

Swell-Shrinkage potential is a function of environmental factors, soil properties and stress condition of the soil with reference to the environment. Hence the main variables chosen for the formulation of the model are optimum moisture content (OMC), maximum dry density (MDD) and California bearing ratio (CBR). The average values of the test result carried out for OMC, MDD and CBR were tabulated and present in table 2.1

The approach used for the development of the model was multiple regression analyses. The CBR value is the dependent variable (y), while bagasse ash and lime (Z), and average OMC are independent variable.

Mathematically, it is expressed as

$CBR\ VALUE = Y, MDD = Z\ AND\ OMC = C$

Consider a regression model of the form;

$y = kc^{a_1}z^{a_2}$ 2.2

Where k, a_1 and a_2 are material constants. Thus, summarizing equation (2.2) to multiple regression models, by taking the logarithm of both sides, we have

$\log y = logk + a_1 logc + a_2 logz$ 2.3

The coefficient value estimate of k, a_1 and a_2 were obtained by calibrating the parameter for formulation of model in table.2.1 using row reduction method.

Solving the equations simultaneously, we obtained the developed model from the empirical model.

2.2 Calculation for calibration of the developed model.

Table 2.1. Average Moisture Content, CBR Value For BA and Lime for Ikot Abasi BCS.

Average Mc (c)	19.9	21.0	22.8	23.8	24.4	24.9	25.3
Bagasse Ash and Lime (z)	60	60	120	180	240	300	360
CBR value (7)	136.39	160.65	177.65	194.46	211.19	227.89	149.36

Y= $kc^{a1} z^{a2}$
Log y = logK + ^{a1}logC + ^{a2} log^z

Table 2.2 Log tabulation

Log^{y}	log^{c}	Log^{z}	Log_{x}^{c-} log^{c}	Log_{x}^{z} log^{z}	Log_{x}^{z} log^{c}	Log_{x}^{y} logz	Log^{y} log^{c}
2.135	1.299	1.778	1.687	3.161	2.310	3.796	2.773
2.206	1.322	1.778	1.748	3.161	2.351	3.922	2.916
2.250	1.358	2.079	1.844	4.322	2.823	4.678	3.056
2.289	1.376	2.255	1.893	5.085	3.103	5.162	3.175
2.325	1.387	2.380	1.924	5.664	3. 301	5.534	3.225
2.358	1.396	2.477	1.949	6.136	3.458	5.841	3.292
2.397	1.403	2.556	1.968	6.533	3.586	6.127	3.363
2.428	1.413	2.623	1.967	6.880	3.706	6.369	3.431
18.388	10.954	17.926	14.98	40.942	24.638	41.429	25.231

$$\begin{bmatrix} n & \mathcal{E}x & \mathcal{E}x^2 \\ \mathcal{E}c & \mathcal{E}c^2 & \mathcal{E}z \\ \mathcal{E}z & \mathcal{E}z^2 & \mathcal{E}z.\mathcal{E}_c \end{bmatrix} \begin{bmatrix} k \\ a^1 \\ a^2 \end{bmatrix} = \begin{bmatrix} 18.388 \\ 25.231 \\ 41.429 \end{bmatrix}$$

$n\text{k} + a^1\mathcal{E}c + a^1\mathcal{E}c^2 = \mathcal{E}\text{y}$ (1)
$\text{k}\mathcal{E}c + a^1\mathcal{E}c^2 + a^2\mathcal{E}z = \mathcal{E}\text{y}.\,\mathcal{E}c$ (2)
$\text{k}\mathcal{E}_c + a^1\mathcal{E}z^2 + a^2\mathcal{E}z.\,\mathcal{E}c = \mathcal{E}\text{y}.\,\mathcal{E}z$ (3)

$$\begin{bmatrix} 7 & 10.954 & 14.98 \\ 10.954 & 14.98 & 17.926 \\ 17.926 & 40.942 & 24.638 \end{bmatrix} = \begin{bmatrix} k \\ a^1 \\ a^2 \end{bmatrix}$$

$7K + 10.954\, a^1 + 14.980\, a_2 = 18.388$ (5)
$10.954K + 14.98a_1 + 17.926a_2 = 25$ (6)
$17.926K + 40.9842a_1 + 24.638a_2 = 41.492$ (7)
$\frac{10.954}{7}$ $(7k + 10.954a_1 + 14.980a_{2\,=\,18.388})$
$1.564\,(10.954k + 17.141a_1 + 23.429a_2 = 28.758)$
$\underline{(10.954k + 14.980a_1 + 17.926a2 = 25.231)}$
$0 + 2.161a_1 + 5.503a_{2=3.527}$
$=2.161a_1 + 5.503a_1 = 3.527$ (8)
Again
$\frac{17.926}{7}(7k + 10.954a_1 + 14.980a_2 = 18.388)$
$2.561 = 17.926K + 28.052a_1 + 38.364a_2 = 47.092$
$\underline{17.926K + 40.942a_1 + 24.638a2 = 41.492}$
$0 - 12.890a_1 + 13.726a_2 = 5.663$
$=12.890a_1 + 13.726a_2 = 5.663$ (9)
Therefore,
$2.161a_1 + 5.503a_2 = 3.527$
$=12.890a_1 + 13.726a_2 = 5.663$
$= \frac{12.890}{2.161}(2.161a_1 + 5.503a_2 = 3.527)$
$= 5.965 = 12.890a_1 - 32.824a_2 = 21.039$
$= \frac{(12.890a_1 + 13.726a_2 = 5.663)}{0 - 46.55a_2 = -26.702}$
$\frac{46.550a_2}{46.55} = \frac{-26.7020}{46.550}$
$a_2 = 0.574$
Substituting a_2 back into equation (8)
$2.161a_1 + 5.503\,(0.5+4) = 3.527$
$2.161a_1 + 3.158 = 3.527$
$a_1 = \frac{3.527 - 3.158}{2.161} = \frac{0.369}{2.161} = 0.170$
$a_1 = 0.170$

Substituting a_1 and a_2 back into equation (5)
7k + 10.954(0.170) + 14.980 (0.574) = 18.388
7k + 1.862 + 8.599 = 18.388
$7k = \frac{18.388 - 1.862 - 8.599}{7} = \frac{18.388 - 10.461}{7}$
$K = \frac{7.927}{7} = 1.132$
Log K =1.132
K = 1.132 =13.552
Hence K = 13.552

$\hat{y} = 13.552 C^{0.170} . Z^{0.574}$ developed (10)

$y = kc^{a1} . z^{a2}$ empirical (11)

where
μ= Swell-shrinking potential
C= Moisture content
Z= Bagasse Ash and Limes

y	$\hat{y}$	**[y-y]2**	**$[\hat{y} - y]2$**	$\sqrt{[\hat{y} - y]2}$
136.39	150.860	3316.6081	1855.0249	13.930
160.65	155.590	1110.8889	1473.7921	5.060
177.65	183.991	266.6689	99.7801	6.341
194.46	202.118	0.234	66.2270	7.658
211.190	215.292	296.322	454.2013	4.102
227.890	226.220	1150.6081	1039.4176	1.670
249.600	235.485	3316. 160	1722.6650	14.115
1357.830	1369.556	9234.9109	6.711.108	52.876

$\acute{y} = \frac{\varepsilon y}{n} = 193.98$
$S\varepsilon\varepsilon = \frac{52.876}{7} = 7.553$
$Alternatively$
$R^2 = \frac{\varepsilon\hat{y}/n}{\varepsilon y/n} = \frac{1369.556/7}{1357.830/7} = 1.000$
Pearson (R) = 1.000 percent mode
$R = \frac{[\hat{y} - y]2}{[y - \acute{y}]2} = \frac{6711.108}{9234.9109} = 0.7268$
R= 72.68%
$S\varepsilon\varepsilon$= 7.553%
$\hat{y}$= 13.552 C 0.170 0.574
When x_1= 60, x_2 =19.9
$\hat{y} = 13.552 (60)^{0.170} (19.9)^{0.574} = 150.860$
When x_1 =60, x_2 = 21.0
$\hat{y} = 13.552 (60)^{0.170} (21.0)^{0.574}$
=13.552 x 2.00 x 5.740 =155.59
When x_1=120, x_2 =22.8
$\hat{y}$=13.552 x $(21.0)^{0.170}$ $(22.8)^{0.574}$ = 13.552 (2.256) (6.018)
=183.991 Ans
Where x_1=180, x_2 = 23.8
$\hat{y}$= 13.552 x $(180)^{0.170}$ $(23.8)^{0.574}$
=13.552 (2.418) (6.168)= 202.118 Ans
When x_1= 240, x_2 = **24.4**
$\hat{y}$=13.552 $(2.539)^{0.170}$ $(24.4)^{0.574}$
=13.552 (2.539) (6.257) = **215.292**
Where x_1= 300, x_2 = 24.9
$\hat{y}$=13.552 $(300)^{0.170}$ $(24.9)^{0.574}$=13.552 (2.637) (6.257) = **226.220**
*W*here x_1 = 360, x_2 = 25.3

= 13.552 $(360)^{0.170}$ $(25.3)^{0.574}$ =13.552 (2.720) (6.388) = **235.485**
Where x_1 and x_2 represents percentage replacement of BA and lime admixtures, and the moisture content of stabilized black cotton subgrade pavement respectively.

III. RESULTS AND DISCUSSION

Table 2.1. Average OMC, CBR Value For BA and Lime for Ikot Abasi BCS.

Average Mc (c)	19.9	21.0	22.8	23.8	24.4	24.9	25.3
Bagasse Ash and Lime (z)	0	60	120	180	240	300	360
CBR value (7)	136.39	160.65	177.65	194.46	211.19	227.89	149.36

Discussion of Result in table 2.1

i. Table 2.1 is the average value of the MC, CBR value for BA and lime BCS stabilization carried out on Eket soil.
ii. Row two is the percentage replacement of Bagasse ash used for stabilization of black cotton soil obtained from Eket, ranging from 0% to 360% partial replacement.
iii. Row one is the average OMC of the stabilized BCS for varying percentage replacement of bagasse ash and lime.
iv. Row three is the average CBR value of the stabilized BCS of varying percentage replacement of bagasse ash and lime.

The empirical and developed model for swell-shrinkage potential of Eket stabilized BCS for subgrade pavement are presented below

= 13.552C* 0.170* Z0.574
developed (10)

$y = kc^{a1}. z^{a2}$
empirical (11)

Discussion of equation 10 and 11

i. The empirical model was statistically developed from table 2.1 above.
ii. Equation 10 is the developed model for the swell-shrinkage potential of Eket stabilizes BCS.
iii. Equation 11 is the empirical model for the swell-shrinkage potential of Eket stabilizes BCS
iv. μ, C, and Z represent the swell-shrinkage potential, average OMC and percentage replacement of BA and lime admixtures.
v. The swell-shrinkage potential of stabilized BCS for subgrade pavement can be used to predict for similar soil in other cities, town and villages in the Niger delta.

IV. CONCLUSION

The empirical and developed model for the swell-shrinkage potential of Eket stabilized BCS are $y = kc^{a1}. z^{a2}$ and μ=13.552C* 0.170* Z0.574 respectively. Where μ, C, and Z represent the swell-shrinkage potential of Eket stabilized BCS for subgrade pavement, OMC and percentage replacement of BA and lime admixtures. The developed swell-shrinkage potential model can be used to predict similar soil in other cities, town and villages in the Niger delta where BCS exist.

V. RECOMMENDATION

Federal ministry of works, and national oil spill detection regulation agency (NOSDRA) in alliance with the legislative arm of government should sponsor bill for the adoption and implementation of the developed swell-shrinkage potentials model for black cotton subgrade pavement stabilization like this since it is resourceful and will help fulfill the requirements of ISO 14001:2015 and ISO 9001:2018 standards.

CONTRIBUTION TO KNOWLEDGE

Swell-shrinkage model like this will help geotechnical engineers predict the behavior of black cotton soil for improved foundation analysis and design hereby preventing future collapse of high way and building infrastructures on black cotton soil.

REFERENCES

[1]. Agunwamba, J.C., Okonkwo, U. N., and Iro, U. I. (2016). Geometric Models For Lateritic Soils Stabilized With Cement and Bagasse Ash: Journal of Technology. 35: 769-777
[2]. Akaha, c., and Syveslter, T, (2016) Geotechnical And Chemical Evaluation of Tropical Red Soils In A Deltaic Environment Implications For Road Construction.
[3]. Akinwande, J., and Aderinola O.R. (2020). Sub-Soil Investigation of A Proposed Construction Site At Ado -Ekti, South Western, Nigeria. 7:11471- 11476. https://www.researchgate.net/publication/342571551_Sub-

Soil_Investigation_Of_A_Proposed_Construction_Site_At_Ado_-Ekti_South_Western_Nigeria

[4]. Bersisa A., and Zekaria A. (2021). Assessment of the Mechanical Properties of Bagasse Ash Concrete, Engineering Science. (6) 3: 39-44. doi: 10.11648/j.es.20210603.12

[5]. Darikandeh F., and Phanikumar B. R (2021) Swell-shrink Behaviour of an Expansive Soil Stabilised by CCR-fly ash (FA) Columns and CCR-FA blends, Geomechanics and Geoengineering, DOI: 10.1080/17486025.2021.1928766

[6]. Diome F., and Biaye L.(2022). Study of Shrinkage and Swelling Phenomena in Clay Soils of Fanaye Middle Senegal River Valley): Simulation of Water Transfers in a Soil Column, Open Journal of Soil Science, 12: 151-169, https://doi.org/10.4236/ojss.2022.124006 https://www.scirp.org/journal/ojss

[7]. Fondjo A. A., Theron E., and Ray R.P. (2021). Semi-Empirical Model for Predicting the Swelling Stress of Compacted, Unsaturated Expansive Soils. Civil Engineering and Architecture, 9 (1) : 225 -239. DOI:10.13189/cea.2021.090119

[8]. Fulzele U.G.,.Ghane V.R, Parkhe , (2016). Study of Structures in Black Cotton Soil, International Journal of Advances in Science, D.D.Engineering and Technology(IJASEAT) (4) 2 : 136-140

[9]. Hussien N.T., and Oan A.F. (2022).The use of sugarcane wastes in concrete. J. Eng. Appl. Sci. (69)31 https://doi.org/10.1186/s44147-022-00076-6

[10]. Jain A. K., Jha A. K., Shivanshi(2020). Geotechnical behavior and micro-analyses of expansive soil amended with marble dust, Soils and Foundations 60 (2020) : 737–751, .https://doi.org/10.1016/j. sandf.2020.02.013 http://creativecommons.org/licenses/by-nc-nd/4.0/

[11]. Khan M. ,Wang J., and Patterson W., (2017). A study of the swell-shrink behavior of expansive Moreland clay. International Journal of Geotechnical Engineering. 13: 1-13. 10.1080/19386362.2017. 1351744. https://www.researchgate.net/publication/318715021_A_study_of_the_swell-shrink_behavior_ of_ expansive_Moreland_clay

[12]. Le D.H., Sheen Y.N. And Nguyen,K.H. (2022).Enhancing compressive strength and durability of self-compacting concrete modified with controlled-burnt sugarcane bagasse ash-blended cements. Front. Struct. Civ. Eng. (16):161–174 . https://doi.org/10.1007/s11709-021-0796-7

[13]. Merouane F. Z and Mamoune S.(2018). M. A. Prediction of Swelling Parameters of Two Clayey Soils From Algeria Using Artificial Neural Networks, Mathematical Modelling in Civil Engineering, (14) 3: 11-26, Doi: 10.2478/mmce-2018-0008

[14]. Ouedraogo M., Sawadogo M., Sanou I., Barro M., Nassio S., Seynou M., and Zerbo L. (2022). Characterization of Sugar Cane bagasse ash from Burkina Faso for Cleaner Cement Production: Influence of calcination temperature and duration, Results in Materials, (4) https://doi.org/10. 1016/j.rinma.2022.100275. https://www.sciencedirect.com/science/article/pii/S2590048X22000231

[15]. Patel A.(2019). Geotechnical Investigations and Improvement of Ground Conditions, -Soil stabilization, Woodhead Publishing Series in Civil and Structural Engineering, 19-27, https://doi.org/10.1016/B978-0-12-817048-9.00003-2. https://www.sciencedirect.com/science/article/pii/b9780128170489000032

[16]. Patel D. (2022). Study of partial replacement of bagasse ash in concrete. 3. 983-992. 10.55248/gengpi. 2022.3.3.6. https://www.researchgate.net/publication/359648311_Study_of_partial_replacement_of_bagasse_ash_in_concrete

[17]. Siddique R., and Cachim P. (2018). Waste and Supplementary Cementitious Materials in Concrete, Woodhead Publishing Series in Civil and Structural Engineering,599-621, https://doi.org/10.1016/B978-0-08-102156-9.00034-1. https://www.sciencedirect.com/science/article/pii/B9780081021569000341

[18]. Singh M., Singh J, and Siddique R.(2022). Sustainable Concrete Made with Ashes and Dust from Different Sources, Bagasse ash , Woodhead Publishing Series in Civil and Structural Engineering,: 177-233, https://doi.org/10.1016/B978-0-12-824050-2.00001-2. https://www.sciencedirect.com/science/article/pii/B9780128240502000012

[19]. Wang G. and Wei X. (2015). Modeling swelling–Shrinkage Behavior of Compacted Expansive Soils During Wetting–Drying Cycles , Can. Geotech. J. 52: 783–794, dx.doi.org/10.1139/cgj-2014-0059

[20]. Weerasinghe D., Kodikara J., and Bui, H.. (2015). Numerical Modelling of Swelling /Shrinkage Behaviour of Unsaturated Soils

For Buried Pipe Stress Analysis. 10.1201/b19248-102. https://www.researchgate.net/publication/293530213_Numerical_modelling_of_swellingshrinkage_behaviour_of_unsaturated_soils_for_buried_pipe_stress_analysis