A Review of the Major Problem Soils in Nigeria

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Abstract—This paper intends to produce a compendium of geotechnical properties of major problem soils of Nigeria which have critical influence on the design, performance, lifespan, construction cost and maintenance of civil engineering structures. Apart from the well researched lateritic soils of Nigeria, the black cotton soils (BCS) of north-eastern Nigeria, clay shale of north-western Nigeria, organic clay prominent in Lagos and soft sedimentary deposits of the Niger-Delta areas of Nigeria are also considered. Significant geotechnical properties of major problem soils in Nigeria were discovered to be scattered in different publications, magazines, journals, conference proceedings, research papers etc. Consequently, it is the aim of this paper to collate, correlate, analyze and digitize these important geotechnical properties on digital map of Nigeria. A Geographic Information System (GIS) mapping software called ArcGIS will be used to generate isopleths in form of contours for these soil properties on map of Nigeria.

Keywords—Classification, Compaction, Strength Characteristics, Major Problem Soil

1 INTRODUCTION—Classification, Compaction, Strength Characteristics, Major Problem Soil

In civil engineering, soils with properties that cannot be safely and economically used for the construction of civil engineering structures without adopting some stabilization measures are known as problem soils. They are expansive and collapsible soils. To the geotechnical and highway engineers, a problem soil is one that poses problem to construction. Such problems may be as a result of instability of the soil which makes it unsuitable as a construction material in foundations, buildings, highways, water retaining structures, dams, etc., Ola (1987). Clay is predominant in most of the subgrade soil materials of Nigeria. The clay minerals attract and absorb water, thereby making it highly susceptible to swelling and shrinkage respectively.

The geologic formations considered to have expansive residual soils are shown in Fig. 1 below (Abdulfatai et al., 2014). In Nigeria, some of these soils have been identified. They include the structurally unstable residual lateritic soils Gidigasu (1976), the black cotton soils (BCS) which occur widely in the north-eastern part of Nigeria and the Sokoto soft clay shale (attapulgite) in the north-western Nigeria, Ola (1987). Adesunloye (1987) identified the problem soils in the Lagos area as peaty clays. In Port-Harcourt area, they occur as clayey peat over the mud plains. Adesunloye (1987) also noted that problem soils tend to fall above the Casagrande’s plasticity Chart and this agrees with Chukweze (1991).

Swelling/Expansive soils are one of Nigeria’s prevalent causes of damage to buildings and other construction works, Lorliam et al (2012a and 2012b). Possible damages that can be caused by expansive soils includes; foundation cracks, severe structural damage, heaving and cracking of sidewalks, roads etc. Lateritic soils which occur extensively in tropical climate like Nigeria is well researched, for instance: Adokoya (1987); Ajayi (1985a); Ajayi (1985b); Chukweze (1991); Gidigasu (1976); Ola (1983a); Ola (1988), etc. Laterites and lateritic soils of Nigeria originate from the intense weathering of crystalline rocks of the basement complex which underlain about 60% of the country (Ajayi, 1985b). Black cotton soils (BCS) prominent in the northeastern Nigeria is also well researched and investigated for example; (Adesunloye, 1987; Eberemu and Sada, 2013; Ijimdiya et al, 2012; Lorliam et al, 2012a; Lorliam et al, 2012b; Madedor and Lal, 1985; Ola, 1983c; Ogundalu and Oyekan, 2014; Oyemini-Ayiibiowu and Ola, 2015; Oyekan et al, 2013; etc). They are dark coloured expansive clays rich in kaolinite and expansive montmorillonitic clay minerals (Ola, 1983c; Oyemini-Ayiibiowu and Ola, 2015).

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the clay shales, Ola (1983b and 1987). Organic clays and peaty clays were identified as major problem soils in Lagos by Adesunloye (1987); Ajayi (1985a). Craig (2006) classified peat into three major categories thus: fibrous when plant remains are recognizable and retain some strength; pseudo-fibrous when plant remains are recognizable but their strength has been lost and thirdly as amorphous if recognizable plant remains are completely absent. They are highly compressible soils with low strength and are common in the Niger-Delta, coastal lagoons and channels of the Niger-Delta, and channels of the Niger and Benue rivers. These soils are mainly mixtures of soft to very soft peat, organic silts and clays.

Okunade (2010) in his research highlights the need to implement a web base geotechnical database management system for Nigerian soils. The problem soils reviewed above is a major concern to engineers because of the instability they constitute to civil engineering structures imposed on them. The results of previous researches on geotechnical properties of these soils are scattered in journal publications, conference proceedings, unpublished archives from research institutes such as Nigeria Building and Road Research Institute (NBRRI), etc. Therefore, it the aim of this paper to collate these geotechnical properties of major problem soils in Nigeria and generate a compendium for them in form of contours on digitized map of Nigeria by using geographic information system (GIS) software called ArcGIS.

2 MATERIALS AND METHODS

The study area covers northeast, northwest, southwest and southern parts of Nigeria. Nigeria lies approximately between latitude 4°N and 15°N and longitudes 3°E and 14°E, within the Pan African mobile belt in between the West Africa and Congo cratons, Oyinloye (2011). The geology of Nigeria is dominated by crystalline basement and sedimentary rocks which occur in about equal proportions, (Oyinloye, 2011; Rahaman and Malomo, 1983). The general geology of Nigeria has been well researched for instance; Abdulfatai et al, 2014; Adesunloye, 1985; Adesunloye, 1987; Akpokodje, 1987; Omange et al, 1988; Oyinloye, 2011; Rahaman and Malomo, 1983; etc. The major material required in this work are the scattered data earlier mentioned above.

A sequence of method involved in this work includes; literature work on problem soils; data collation (geotechnical properties) of soils and interpolation of these data using the ArcGIS software to generate isopleths in form of contours on digitized map of Nigeria for some engineering properties of soils. The only data that can be plotted on the digital map were the ones with coordinates for tested samples by past investigators/researchers.

3 RESULTS AND DISCUSSION

3.1 Classification Characteristics

The results for black cotton soils (BCS) indicate that, 92% of the soil passed through No. 200 B.S. sieve and the clay fraction was 59%, (Ola 1988). The composition of the clay were; Sand (0-39%), Silt (0-47%) and Clay fraction (13-100%), (Ola 1987). The liquid limit (LL) ranges from 23% to 78%, plastic limit (PL) from 12% to 36% and plasticity index (PI) 6% to 36%. The AASHTO classification is either A - 7 – 5 or A – 7 – 6 and in the Unified classification system, the soil falls into CL and CH groups, (Ola 1987). The Free Swell is between 30% and 140%, Oluymemi-Aiyibiolu and Ola (2015). The Free Swell rises with clay fraction, plasticity index and liquid limit (Omange et al, 1988). The mineralogy of Sokoto soft clay shale is made up mainly of attapulgite; about 98% of samples passed No.200 BS sieve and the clay fraction is about 58% (Ola, 1983b and 1988).

Test results for Bayelsa and Rivers States soils are summarized as follows; Silts and Clay fraction varies from 5% to 97% with majority falling within the range of 23% to 73%, LL vary between 0 and 71 % with a mean value of 40%, PI (0-39) % with a mean of 24%, Omange et al (1988). A plot of the liquid limit against plasticity index confirms the fact that, soils in the same formation tend to lie parallel to the Casagrande’s A-line. Delta and Edo states soils (i.e. former Bendel State) has the following results; LL (0 – 89.4) % and PL (0 – 36.4) %, PI ranges between (0 and 53) % with a mean value of 17.92%, Omange and Aiteebaomo (1989). Cross Rivers State soils has LL (44-79) %, PL (19-40) % and the materials were classified as A-7 predominantly with a few A-2-7, Sadiku (1985).

Properties of Lagos organic clays indicated, LL ranges from 73% to 250% for peaty clays, PL of 30% to 175% and PI of 20% to 120%, Farrington (1983). Organic content determination by dichromate oxidation method gives results ranging between 10 and 40%, specific gravity ‘G’ generally ranges between 2.20 and 2.68 and values as low as 1.85 has been obtained for highly compressed peaty clay, Ajayi (1983). Abia and Imo states (i.e. former Imo State) have the following properties; LL (20 - 70) %, PL (10 - 50) %, PI (5 - 55) %, (Okunade 2007). Soils of the Federal Capital Territory (FCT) has the following properties; Clay fraction ranges between 3% and 54%, Silts between 20% and 85%, while Sand fraction ranges between 35% and 95%, LL (19.5-80)%, PL (11-45)%, PI (6-47%), activity ratio (0.56-3.68) and free swell (30-70)%, (Omange et al 1988). Isoploth of plasticity index summarized above is shown in Fig. 2.0, and free swell in Fig 3.0.

3.2 Compaction Characteristics

Maximum Dry Density (MDD) of black cotton soils varies from 1530kg/m³ to 2070kg/m³ with corresponding optimum moisture contents (OMC) of 25% and 7% respectively, Omange et al (1988); Madedor and Lal (1985); Ola (1987). Sokoto soft clay shale (Attapulgite) is very light weight with maximum dry density (standard proctor) of 1137kg/m³ and optimum moisture content (standard proctor) of 41%, Ola (1983b and 1988). Delta and Edo State soil has MDD varying between 1.32g/cm³ and 2.29g/cm³ with a mean of 1.94g/cm³. The corresponding moisture content ranges between 6.6% and 24.1% with a mean of 12.7%, Omange and Aiteebaomo (1989). Bayelsa and Rivers State soils has MDD ranging between 1430kg/m³ and 2400kg/m³ with a mean of 1430kg/m³ and corresponding optimum moisture contents of 14.0%, 8.2% and 22.8% respectively, Omange et al (1988). Cross-Rivers State soils have OMC ranging between 10.6 to 46.6% and MDD’s were low with about 1.21mg/m³ mean value. The maximum free swell of the
material after 48-hours soaking ranges from 0% to 4.3%, Omange et al (1988).

Abia and Imo States soils have MDD ranging between 1700kg/m³ and 2100kg/m³ and their corresponding varying OMC are 9% and 24% respectively, NBRRI (1988) and Okunade (2007). Lagos organic clay’s MDD vary between 800kg/m³ and 1600kg/m³ with a value as low as 400kg/m³ being obtained for the highly compressed peat type material, Ajayi (1983). Soils of the F.C.T. have MDD ranging from (1.67 to 2.22) X 10³ kg/m³ and OMC ranges between 8.5 to 28.0%, Omange et al (1988).

Summarily, values of MDD for covered area in Nigeria can be assessed from isopleths shown in Fig. 4.0, so also is their corresponding OMC in Fig. 5.0

3.3 Strength Characteristics

Generally, the CBR values are low for BCS. The 4-day soaked values range between 2% and 5% while the un-soaked CBR values at OMC and MDD range between 8% and 13%, Omange et al (1988); Madedor and Lal (1985).

Sokoto clay shales have the following results; unconfined compressive strength of 100-124.1kN/m², vane shear test gave 120-130kN/m² at OMC and 3.2kN/m² at liquid limit, effective angle of shearing resistance at liquid limit were between 12° - 15°, Ola (1987). Delta and Edo State soils were found to have average 96-hour soaked CBR values ranging between 2.0% and 92.5% with a mean of 34.88%, Omange and Aitsebaomo (1989). The results indicate that, all the ML and OL soils have very low CBR values. Lagos peaty clays have shear strength ranging from 5kN/m² to 12kN/m², (Farrington 1983). Abia and Imo state soils have unsoaked CBR of (10-80) % and the 96 – hour soaked CBR of (5-55) %, Okunade (2007). FCT soils have unsoaked CBR ranging from 9 to 70% and 4-days soaked CBR ranges from 6 to 46%, Omange et al (1988). Data gathered here were not adequate to produce isopleths of strength characteristics when using the geographic information system (GIS) using the ArcGIS software.
Fig. 3. Contours of free swells (%) of Nigerian major problem soils.

Fig. 4. Contours of maximum dry densities (x102 kg/m3) of Nigerian problem soils.
4 Conclusion

This paper collates relevant and basic geotechnical properties of some identified problem soils of Nigeria which have been scattered in different publications and conference proceedings. This compendium will serve as a reference guide for practicing civil engineers and researchers in Nigeria with interest in design and construction of basic infrastructures like roads and railway tracks passing through the studied areas, where some of these problem soils are prominent. Geotechnical properties of Abia, Bayelsa, Borno, and Cross Rivers, Delta, Edo, Imo, Lagos, Niger, Oyo, Rivers, Sokoto states, the Federal Capital Territory (FCT) i.e Abuja and so on can all be accessed in the (isopleths) ArcGIS contour maps presented in Fig. 2.0 to 5.0. However, data gathered on the strength characteristics of these soils are not yet enough to produce contours especially for the CBR and shear strength properties. Recommendation is that, coordinates of subsequent soil test points should be taken into account in other research work on Nigerian soils. Detailed information for concerned states can be obtained from the appropriate references.

References

Abdulfatai, I.A., Okunlola, I.A., Akande, W.G., Momoh, L.O. and Ibrahim, K.O., (2014). Review of Gully Erosion in Nigeria: Causes, Impacts and Possible Solutions, Journal of Geosciences and Geomatics, Vol.2, No.3, pp. 125-129.

Adesunloye, M.O., (1985). Sampling and Testing of Residual Soils in Nigeria, Geotechnical Practice in Nigeria, Golden jubilee edition, pp. 17-25

Adesunloye, M.O. (1987). Investigating the problem soils of Nigeria, 9th Regional Conf. on Soil Mech. & Found. Eng. for Africa. A.A. Balkema/Rotterdam, Vol.1, pp. 103-112

Ajayi, L.A. (1983). Geotechnical Properties of Deep Organic Clay Stratum Underlying Lagos Area of Nigeria. “Tropical Soils of Nigeria in Engineering Practice”, A.A. Balkema/Rotterdam.

Ajayi, L.A. (1985a). Proposal for engineering classification of Nigerian soils. Geotechnical Practice in Nigeria, Golden jubilee edition: pp 37-48.

Ajayi, L.A. (1985b). The laterites and lateritic soils of Nigeria, Geotechnical practice in Nigeria, Golden jubilee edition, pp7-15

Akpokodje, E.G. (1987). Engineering geology of the Niger-delta. 9th regional conf. for Africa on soil mech. & found. eng.: (pp 751-760), A.A. Balkema/Rotterdam/Boston.

Chukweze, H.O. (1991). Geotechnical and Geological Properties of Tropical Soils. 9th regional conf. for Africa on soil
Craig, R.F. (2006), Soil Mechanics. E&FN Spon, New York. pp. 2-430.

Eberemu, A.O. and Sada, H. (2013), Compressibility Characteristics of Compacted Black Cotton Soil Treated with Rice Husk Ash. Nigerian Journal of Technology. Vol.32, No.3, pp. 507-521.

Availabe: http://www.ajol.info/index.php/njt/ar

Farrington, P. (1983). Earthworks and Foundations on recently Deposited Organic Soils in Lagos area. In “Tropical Soils of Nigeria in Engineering Practice”, edited by Ola, S.A. A.A. Balkema/Rotterdam/Boston. pp. 102-112.

Gidigasu, M.D. (1976), Laterite Soil Engineering. Elsevier, Amsterdam.

Ijimdiya, T.S. Ashimiya, A.L. and Abubakar, D.K. (2012), Stabilization of Black Cotton Soil Using Groundnut Shell Ash. EJGE, Vol. 17, pp. 3645-3652. Available: http://www.ejge.com/2012/Ppr12.346ar.pdf

Lorliam, A.Y., Agbede, I.O. and Joel, M. (2012a), Effect of Cement Kiln Dust (CKD) on Some Geotechnical Properties of Black Cotton Soil (BCS). EJGE, Vol.17, pp 967-977. Available: http://www.ejge.com/2012/

Lorliam, A.Y., Obam, S.O. and Owinizi, S.A. (2012b), Improvement of Black Cotton Soil with Cattle Bone Powder, American Journal of Scientific and Industrial Research, Vol. 3, No.3, pp. 175-180. Available: http://www.sciborg.org/AJSIR/PDF/2012/3/

Madedor, A.O. and Lal, N.B. (1985). Engineering Classification of Nigerian Black Cotton Soils for Pavement Design and Construction. Geotechnical Practice in Nigeria. Golden jubilee edition, pp. 49-67.

Madedor, A.O. and Adekale, O.A. (1987). Effect of Hydrated Lime on the Atterberg’s Limit of Black Cotton Soil of Nigeria, 9th regional conf. for Africa on soil mech. & found.Eng, Vol.1.: (pp. 155-160), A.A.Balkema/Rotterdam/Boston.

Nigeria Building and Road Research Institute, (NBRRI), (1988). Report No. 13, (pp.1-30).

Ogunadu, A.O. and Oyekan, G.L., (2014), Mineralogical and Geotechnical Characterization of Maiduguri Black Cotton Soil by X-Ray Diffraction (XRD), X-Ray Photoelectron (XPS) and Scanning Electron Spectroscopy (SEM). International Journal of Engineering and Technology, Vol.4, No.6, pp. 345-353.

Ogunadu, A.O., Oyekan, G.L. and Meshida, E.A., (2013), Effects of Steel Mill Scale on the Strength Characteristics of Expansive Clay Soils (Black Cotton Clay Soil). Civil and Environmental Research, Vol.3, No.12, pp. 52-62. Available: www.ijste.org/Journals/index.php/CER/article/

Okunade, E.A., (2007), Isopleths of Subgrade Soil Properties for Abia and Imo State of Nigeria, International Research Journal in Engineering, Science and Technology (IREJEST), Vol.4, No.2, pp. 190-205.

Okunade, E.A., (2010), Design and Implementation of a Web-Based Geotechnical Database Management System for Nigerian Soils, Modern Applied Science, Vol. 4, No. 11, pp. 36-42. Available: www.ccsenet.org/mas

Ola, S.A. (1980). Some Foundation Problems in Sokoto Area of North-western Nigeria, 7th regional conference of ISSMEFE on soil mechanics and foundation engineering.

Ola, S.A. (1983a), Geotechnical Properties and Behavior of some Nigerian Lateritic Soils, Published in “tropical soils of Nigeria in engineering practice”, edited by Ola, S.A. pp. 61–84.

Ola, S.A. (1983b), Geotechnical Properties of the Sokoto Soft Clay Shales of Northwestern Nigeria. Published in Tropical Soils of Nigeria in Engineering Practice, Vol.1, pp.131 – 144

Ola, S.A. (1983c), Geotechnical Properties of Black Cotton Soils of Northeastern Nigeria. Published in “Tropical Soils of Nigeria in Engineering Practice”, edited by Ola, S.A. (pp. 85-101): A.A. Balkema/Rotterdam.

Ola, S.A. (1987). Laboratory Testing and Geotechnical Characterization of Black Cotton Soil and Expansive Shales in Nigeria, 9th regional conference for Africa on soil mechanics and foundation engineering, Vol.1, (pp. 991-995). A.A. Balkema/Rotterdam/Boston.

Ola, S.A., (1988). Geotechnical Properties of Nigerian soils and Ten Years Collaborative Research with Nigerian Building and Road Research Institute. (NBRRI) (pp189-218).

Oluyemi-Ayibiowu, B.D. and Ola, S.A., (2015), Stabilization of Black Cotton Soils from Northeastern Nigeria with Sodium Silicate, International Journal of Scientific Research and Innovation Technology, Vol.2, No.6, pp. 189-203.

Omane, G.N., Nnuma, S.K. and Aitebeamo, F.O. (1988). Engineering Characteristics of Subgrade Soils of Nigeria and Application to Economic Pavement Design. Ten year of building and road research, a NBRRI publication, (pp. 135-179).

Omane, G.N. and Aitebeamo, F.O. (1989). Engineering Properties of Subgrade Soils in Bendel (Delta & Edo) State of Nigeria, NBRRI report No.18, pp. 3-33.

Oriola, F.O.P. and Moses, G. (2011), Compacted Black Cotton Soil Treated with Cement Kiln Dust as Hydraulic Barrier Material, American Journal of Scientific and Industrial Research, Vol.2, No.4, pp. 521-530. Available: http://www.scihub.org/AJSIR/

Oyekan, GL., Meshida, E.A. and Ogunadu, A.O. (2013), Effect of Ground Polyvinyl Waste on the Strength Characteristics of Black Cotton Clay Soil. Journal of Engineering and Manufacturing Technology, Vol.1, pp. 1-10 Available: www.bluepenjournals.org/jemt/pdf/2013

Oyinloye, A.O. (2011), Geology and Geotectonic Setting of the Basement Complex Rocks in Southwestern Nigeria: Implications on Provenance and Evolution, Earth and Environmental Sciences, pp98–117. Available: http://www.intechopen.com/books/

Rahaman, M.A. and Malomo, S. (1983), Sedimentary and Crystaline Rocks of Nigeria. Published in “Tropical soils of Nigeria in Engineering Practice”, edited by Ola, S.A. A.A. Balkema/Rotterdam, pp. 17-38.

Sadiku, M.J.A. (1985). The Use of Substandard Soil Materials in Road Construction. Geotechnical Practice in Nigeria, pp. 133-137.