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Active soils of the Niger Delta

Les Sols Actifs du Delta de Nigeria A. Federico

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ABSTRACT

Active or expansive soils of the freshwater area of the Niger delta in southern Nigeria swell and shrink in the rainy and dry seasons respectively together with any structure constructed with and/or on them. In this paper, data on some natural engineering characteristics of these soils derived from previous soil investigation activities within the region were used to identify, characterize and evaluate them for better and more resourceful engineering applications. Also, disturbed samples taken from four locations were chemically stabilized with $CaCl_2$ and slaked-lime to reduce swelling potential to tolerable level (i.e. 2.5% for 24-hour free swell index) and with cement to improve strength. 24-hour free swell index was found to diminish with increasing stabilizer content while addition of cement was found to enhance continual increase in MDD, soaked-CBR and durability index such that the soil becomes better compactible, stronger and more durable with increasing cement content. About 2.6% and 14.6% cement contents were found needed to respectively produce sub-base and base-course materials in road works.

RÉSUMÉ

Les sols actifs dans la zone d'eau douce du delta du niger au sud du Nigeria se dilatent et se retrecissent respectivement pendant les saisons des pluies et les saisons seches de meme que toute structure construite avec ou sur ces sols. Dans cet article, des donnees sur certaines caracteristiques naturelles de ces sols, derivees d'activites de recherché precedentes sur ces sols dans la region, ont ete utilisees pour identifier, caracteriser et evaluer ceuxci pour des applications techniques meilleures et plus fertiles en resources. En outré, des echantillons troubles preleves sur quatre sites ont ete stabilizes chimiquement avec du $CaCl_2$ et de la chaux eteinte pour reduire le potential de dilatation a un niveau tolerable (exemple: Indice 2,5% pour 24h de dilatation libre) et avec du ciment pour ameliorer la solidite. On a trouve que l'indice de 24h de dilatation libre diminue avec une augmentation du contenu stabilisant tandis que l'addition de ciment facilite l'augmentation continuelle en MDD, CBR trempe et en indice de durabilite de sorte qque le sol deviant mieux ciment. On a aussi observe qu'on avait besoin d'environ 2.6% et 44.6% de contenu de ciment pour produire respectivement des materiaux de sous-couche et de couche de base en construction routiere.

Keywords : Active soils ; Expansive soils ; Engineering characteristics ; Niger Delta

1 INTRODUCTION

A soil is commonly referred to as active, expansive or swelling when it exhibits considerable volume changes as a result of artificial or natural/seasonal moisture variations. Such soils are generally known to be dominated by swelling clay minerals like montmorillonite, vermiculite, etc. which (through laterisation process) are formed at the expense of kaolinite in areas deficient in even one of the three necessary and sufficient conditions (i.e. high rainfall, rolling topography and adequate drainage) for full laterisation – Blight(1982), Townsend(1985). In Nigeria, active soils are predominant in the Niger delta region with very high rainfall but near-flat terrain; Sokoto, Lake Chad basin and environs with relatively low rainfall (Ola, 1983a&b), Isiebu-Umduru and Arondizogu (Imo State) with relatively high rainfall but too steep topography which causes excessive runoff/erosion at the expense of full laterisation (Omotosho, 1991).

Montmorillonite is the most prominent clay mineral in Nigerian active soils generally with montmorillonite:kaolinite ratio of about 7:1 (Ola, 1983a&b). Montmorillonite has a 2:1 crystal lattice comprising gibbsite sheet sandwiched between two silica tetrahedron sheets while each set/sheet of crystal linkage is stacked one above the other with little or no bond between them. As a result, other ions including water molecules (during the rainy season) readily fit into, penetrate and exert enormous pressure at the inter-crystal boundary/interface thereby causing swelling or volume change. In the dry season when this penetrating water evaporates through the soil's capillary pores, crystal sheets shrink or collapse. This seasonal swelling and shrinking are highly destructive to any structure placed on or constructed with them. For instance, buildings at Isiebu-Umuduru in Nigeria (Omotosho, 1991) and railway embankments in some parts of South Africa (Bucher et al, 1991) have been reported to develop wide and destructive cracks which were also observed to visibly expand in the rainy season but close up relatively in the dry months. Abduljauwad(1994) and Abduljauwad et al(1998) also observed heaving of sidewalks, distortion of door frames as well as cracking of masonry fences, gates, etc. in the eastern province of Saudi Arabia where active soils predominate. Also, Meintjes (1991) observed significant settlement and consequently negative skin friction of piles bearing Colinda Primary School in Vryburg, South Africa as a result of this. And in quantitative terms, Jones and Holtz(1973) observed that in the United States alone, annual damages caused by soil expansion to buildings, roads, airports, pipelines and other facilities is in excess of $2billion which far exceeds the combined annual damages caused by floods, hurricanes, earthquakes and tornadoes.

In the Niger delta region of southern Nigeria, active soils are superficial and they extend to considerable/irreplaceable but varying depths within the freshwater zone which constitutes over 50% of the region. Even the local/native building technology recognizes this in that local buildings are

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constructed with wooden skeleton (vertical and horizontal strips) around which the soil is merely moulded like a filler. Also, road embankments constructed on and/or with active soils have been problematic causing destructive pavement collapse under particularly heavy traffic load. A typical example is the East-West Road (directly linking Warri and Port Harcourt) as shown in Fig. 1. Over half of its entire 200 kilometre length lie within the active soils and its performance has been anything but satisfactory. For instance and since 1983 when it was opened to traffic, its 16km long Patani-Kaiama stretch and about 13km long Mbiama-Ahoada stretch have at one time or the other been rendered impassable by this phenomenon. And even now, only the intervention by the Niger Delta Development Commission (NDDC) through continual partial refilling, re-compacting and resurfacing has kept the road opened during every rainy season.

Usually, the soil sandwiched within the "active zone" (or thickness between the uppermost water level in the rainy season and deepest in the dry season) is the most critical. This is actually directly dependent on location but reduces coastwards (Baja, 1999) while an average of about 6.7m to 7.0m have been recorded from past surveying and bathymetry activities in the delta region. Thus better understanding of these soils will no doubt enhance more effective exploitation and present both technological and social breakthrough in design, construction and even maintenance and cost of structures built on or with them.

In this paper and based on studies spanning about a decade, data from 18 different sites scattered across the active soil area of the Niger delta are combined with existing literature to characterize these soils and generate base-line data for evaluating and solving associated problems.

2 MATERIALS

Samples of active soils were taken from several sites across the Niger delta (as shown in Fig. 1) where the author had conducted soil investigations in the past for various purposes or projects (ranging from groundwater scheme to building, shore protection, highway, landing jetty, canalization, etc.) and for various organizations at different times and seasons. The data acquired in the process were used to characterize the soils. Also, bulk soil samples were collected from four (4) randomly selected locations around Mbiama, Kaiama, Odi and Patani along East-West Road for stabilization studies aimed at improving some characteristics of the soils for better engineering applications most especially inhighway design and construction. All samples collected were generally grayish in colour, soft to firm in texture and fine grained. They were thereafter (in the laboratory) air-dried and clumps broken before being subjected to standard classification and other relevant tests.

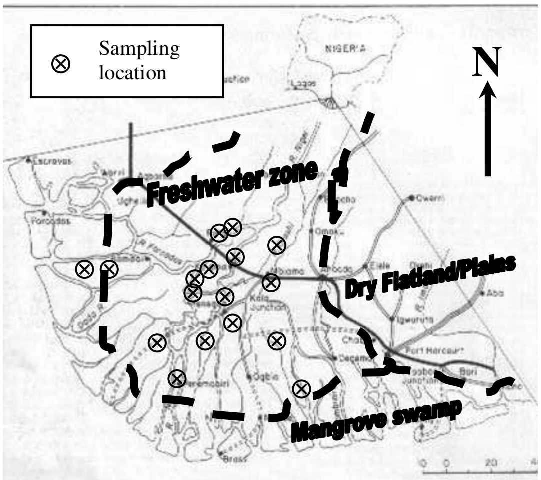

Fig. 1. Active soil zone of the Niger delta including sampling points

Chemical stabilizers used in the stabilization process included beige-coloured and powdery industrial slaked-lime and whitish calcium chloride (of the grade 94/96%) as well as ordinary Portland cement all obtained from the common chemical and cement markets in Port Harcourt.

3 EXPERIMENTAL PROCEDURE

Omotosho and Ogboin subjected all samples to standard classification tests including gradation, Atterberg limits (i.e. LL and PL) and 24-hour free swell (in accordance with Sridharan et al, 1986). For the 24-hour free swell test specifically, about 10g of oven-dried soil was pulverized and transferred into a 100ml graduated cylinder already containing distilled water. After 24 hours, the swollen volume, V was read off from the cylinder while the original volume of dry soil specimen, V_s $\left[= \frac{W_s\ (\cong 10\text{g})}{G_s \gamma_w}\right]$ was computed after conducting standard G_s test on the soil sample. The *24-hour free swell, I_{fs}* was thereafter computed from $I_{fs} = \frac{V - V_s}{V_s}\,(\text{in }\%)$. This procedure was repeated for soils stabilized with 3%, 5%, 8% and 12% of slaked lime and calcium chloride respectively.

After analyzing the result of the 24-hour free-swell tests, each of the bulk samples collected from the 4 selected locations was mixed with the proportion of stabilizer content needed to achieve 2.5% free swell and cement content ranging from 0% to 15% (Omotosho and Ogboin, 2009). For each of this composite mixture, standard Proctor compaction test was carried out and the resulting optimum moisture content (OMC) and maximum dry density (MDD) used to compact specimen for soaked-CBR test conducted to Nigerian standard. By this standard, compacted specimens were first wax-cured for six days, followed by 24 hours of water-curing and left to drain for at least 15 minutes before CBR testing. Also, these composite mixtures were then further examined for durability using the laboratory procedure which forms the basis for durability classification by Franklin and Chandra (1972).

4 RESULTS AND DISCUSSIONS

4.1 *General Classification*

Table 1 summarises the result of general classification tests on the 27 disturbed samples collected from the different locations.

As shown in this table, the soils are generally fine-grained with *percentage fines* in excess of 70% in all cases but increases coastwards. Clay fractions (<2µm) on the other hand are quite low relative to silt content which makes the soil to be more silty than clayey and may explain why liquid limit (LL) and plasticity index (PI) are relatively low. Also. by plotting plasticity on Casssagrade's "A-line," the soils are predominantly inorganic. Similarly, the shear strength parameters c_u and ϕ_u are quite low. It should be noted however that natural moisture content, insitu bulk density and void ratio as well as shear strength characteristics vary with climatic seasons (rainy and/or dry).

Table 1. Summary of soil's physical characteristics

	Characteristics		Min	Max	Avg
1	Nat. moist. Cont. (%)		14.1	48.2	29.8
2	Insitu bulk density (kN/m^3)		15.2	20.83	17.9
3	Percentage fines		74	99.4	84.4
4	Clay fraction - < 2 µm (%)		18.6	31.5	25
5	Atterberg Limits	LL (%)	24.4	75	47
6		PI (%)	7.1	46.2	24.1
7	Undrained Shear	c_v (kN/m^2)	4.2	48.4	26
8		ϕ (deg.)	0.7	7.6	3.2
9	Insitu void ratio, e_0		0.528	3.132	1.086
10	24-hr. free swell (%)		5	16.7	10.8
11	Calculated Pot. swell index (%)		1.4	6.0	3.3

4.2 *Swelling Properties*

Based on various existing criteria in literature, Omotosho(2009) evaluated the soils as summarized in Table 2 which shows them to fall under normal to high activity classification. The lowest levels of activity are recorded from criteria 2, 3 and 4 generally based on the soils' plasticity. However, devastations caused by seasonal swelling and shrinking in these soils are enormous. Thus plasticity or any other parameter related to or derived from it may not be a very good basis for identifying deltaic active soils.

Table 2. Summary of geotechnical evaluation of soil (after Omotosho, 2009)

Criteria	Source	Evaluation scale		Evaluation/ Classification
		Parameter used	Value (%)	
1	Blight (1982)	N	≈ 6	Active soil
2	Skempton(1953), Barnes(2000)	Soil activity, A_c	1.0 → 1.5	Normal activity
3	O'Neill & Poormoayed (1980)	LL PI	35→73 (47 avg.) 7→46 (24 avg.)	Low to high activity (Average ≈ Low)
4	Vijayvergiya and Ghazaaly(1973)	Potential swell, S_p (calculated)	1.4 → 7.8	
5	Balogun(1991	1-hr free swell	9 → 18	High activity (>2%)
6	Sridharan et al(1986)	24-hr free swell	9 → 18	High activity (>2.5%)

4.3 *Stabilisation for better engineering use*

Shown in Fig. 2 are results of stabilising soils with slaked-lime and $CaCl_2$ in order to reduce swelling.

From this figure, it can be generally observed that addition of both stabilizers reduce swelling which is a desired effect. This may be because the stabilizers – through ion-exchange reaction – attracted and absorbed the water molecules at the crystal/plate boundary and precipitate relevant chemical compounds to seal off the interface from further water ingress. Specifically at low stabilizer content, free swell can be seen to decrease much more sharply for $CaCl_2$ than for slaked lime which could be a clear indication that the former is more effective and viable both technically and economically than the latter. However and at higher stabilizer contents (equal to and probably greater than 12%), it appears that the effect of both stabilizers on the free swell of all soil samples tend to converge.

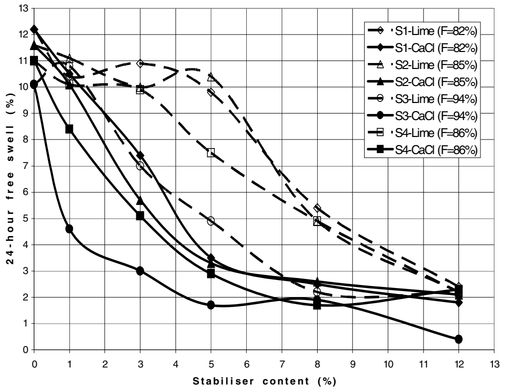

Fig. 2. Free swell and stabilizer content (after Omotosho & Ogboin, 2009)

Also from this figure, effectiveness of each of the stabilizers to reduce free swell can be seen to increase with increasing percentage fines of the soils. This may explain why Odi sample (3) with the highest % fines (94%) responded more positively to this stabilization. If the 2.5% lower limit of 24-hour free swell for normal or non-swelling soil (Sridharan et al, 1986) is applied to the individual soils, then Fig. 3 eventually results.

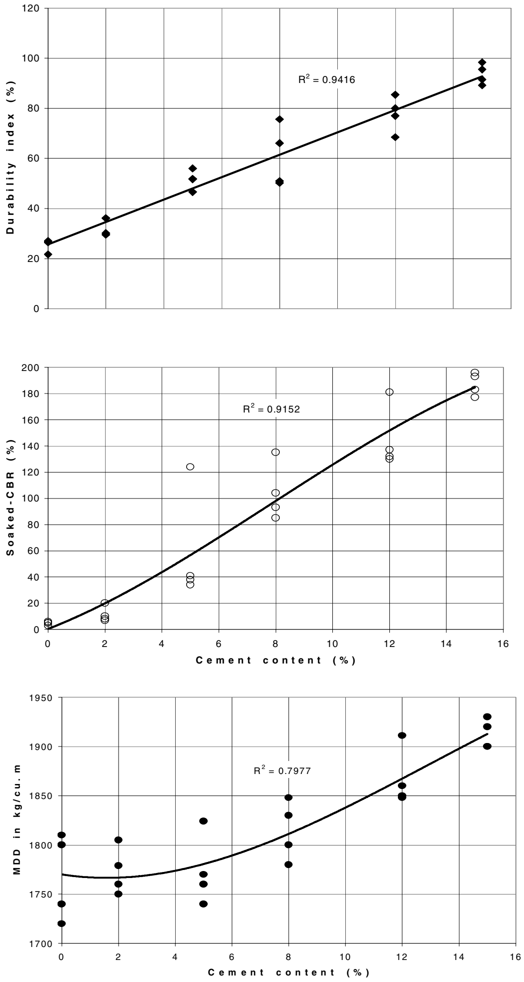

Fig. 3. Cement stabilization graphical model (after Omotosho & Ogboin, 2009)

From Fig.3, it can be seen that the MDD, soaked-CBR and durability index of these active soils stabilized with cement and $CaCl_2$ increase continually (or become stronger and more durable) with increasing cement content but virtually independent of the sampling locations or percentage fines. This may be because all the samples have been brought to a common platform, i.e., 2.5% maximum free swell before addition of cement.

Also from Fig. 3, the minimum soaked-CBR of 30% required for use as sub-base materials can be achieved with about 2.6% cement corresponding to MDD and durability index of about $1769kg/m^3$ and 37.5% respectively. Similarly and by the Nigerian specifications, the 180% soaked-CBR required for use as base-course materials in roadworks can be achieved with about 14.6% cement content corresponding to MDD and durability index of about $1906kg/m^3$ and 90% respectively. This may appear rather high but when compared with the additional cost of hauling better fill materials (i.e. deltaic lateritic soil) over long distances, this approach may be economically visible and/or preferable.

It is obvious from the foregoing that Figs. 2 and 3 constitute a complete graphical model for preparing deltaic active soils for use in road pavement structure. For instance and with the percentage fines of the soil obtained from simple wet-sieving, the stabilizer content required to achieve 2.5% free swell can be read off from Fig. 2. And with the desired soaked-CBR known (i.e. 30% for sub-base), Fig.3 directly gives the corresponding MDD and durability index.

5 CONCLUSIONS

This paper generates base-line data for active soils through past soil investigations within the freshwater zone of the Niger delta region of southern Nigeria where they predominate superficially and to considerable depths. The data so generated were then used to characterize (identify, evaluate, etc.) the soils for future use or control in engineering applications.

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