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Influence of Geosta Addition on Cement-stabilised Chicoco Mud of the Niger Delta

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Abstract: Chicoco is a very soft and extremely compressible organic marine mud found extensively and to considerable depths within the saline tidal flat or mangrove swamp of the Niger delta in southern Nigeria. Natural chicoco is highly undesirable, barely able to support a human of average weight but air-dried chicoco has been used successfully by the indigeneous people for shore protection, etc. especially if placed above water. Plain cement stabilization of most organic soils (including chicoco) is known to be ineffective. In this study, geosta, a chemical stabiliser relatively newly developed for organic soils was combined with ordinary Portland cement to stabilise chicoco. It was observed that neutralisation of acidic "air-dried" chicoco by basic geosta inhibited the expected ion-exchange reaction and its attendant improvement on mechanical properties. As a result and as geosta content increases, maximum dry density (MDD) was found to be only marginally improved but better for higher cement contents while optimum moisture content (OMC) decreases but with higher values for lower cement contents. Unsoaked CBR (but with samples wax-cured for 3 days) on the other hand was found to maximise at low geosta content and thereafter decreases continually – a major cost advantage in earthworks. In fact, the most effective influence was obtained at 4.0% cement plus about 1.5% geosta. This stabilization was also found to produce optimum road sub-base materials.

Key words: Geosta, stabilization, Niger Delta

INTRODUCTION

Chicoco is the local name given to a darkish brown to pitch-black organic *marine* mud that superficially covers over 90% of the saline tidal flat (or mangrove swamp) zone or about 40% of the entire Niger delta region of southern Nigeria. The saline mangrove swamp zone as delineated by Akpokodje [1] is a permanently submerged or water logged flat lowland plain criss-crossed by numerous tidal creeks, rivers and rivulets and sandwiched between the coastal sandy beaches and the freshwater backswamps of the Niger delta. Chicoco comprises at least 50% organic matter (mostly peat derived from partially or completely decomposed rootlets, wood fibres, etc.) while silt, clay and sand constitute the remaining proportion in the ratio 7:28:2, respectively [1-4].

In its natural state, chicoco is very soft and extremely compressible with varying proportions of partially or completely decomposed organic matter or humus including rootlets, wood fibres, etc. The humus exists mostly as humic acid or macro-molecular ion groups including R-OH and R-COOH ions which are contained, circulating or trapped within the normally large volume of water existing between the soil particles. This results in low density, high compressibility and other inferior mechanical properties commonly associated with organic soils.

As a result, chicoco possesses highly undesirable engineering characteristics including natural moisture content and void ratio in excess of 150%, liquid limit, LL in excess of 70%, organic content between 50 and 90% and SPT N-value generally less than unity [2, 3]. With an average allowable bearing pressure far below 20 kPa, natural chicoco is hardly able to support a human of average weight. These inferior engineering properties have rendered natural chicoco highly undesirable and written off for complete replacement by most investigators. However, its considerable thickness above the *coastal plain sand* of the Benin geomorphologic formation [5] most especially around the northern periphery of the saline mangrove swamp makes complete replacement economically unviable.

Despite all these disadvantages, chicoco is not as useless as it appears or behaves naturally and can be made more useful with little improvement. For instance, air-dried chicoco has been used successfully and extensively by the indigenous people for landscaping, shore and slope protection, reclamation, etc. most especially if placed above water level. Also, studies by [3] have shown that chicoco could find a better use as heat-treated structural materials like bricks, etc. In fact when fired at a temperature of about 300°C achievable locally even with firewood, chicoco bricks were observed to exhibit low water absorption capacity (WA) and an average cube strength in excess of 2.0 N mm^{-2} which compares favourably with the most common sandcrete blocks in the Nigerian building industry.

Increased engineering activities through petroleum exploitation within the Niger delta are placing enormous pressure on the less than 10% habitable land available in the tidal flat zone, hence the necessity to increase the engineering performance of chicoco through stabilization. Plain cement stabilization of organic soils is known to be particularly ineffective. This is because the organic matter in the soil (i.e. R-OH and R-COOH macro-molecular ions) retains a large percentage of calcium ions liberated by cement forming impervious films which coats the cement particles surface and inhibits hydration and strength development [6-8].

Geosta is a relatively new chemical stabilizer, chemical composition given in Table 1 developed specifically for organic soils.

Table 1: Chemical Composition of Geosta

Chemical compound	Proportion (%)
NH_4Cl	5
NaCl	20
$FeCl_3$	2
C	1
$MgCl_2$	22
KCl	25
$CaCl_2$	15
Others	10
Total	100

An aqueous solution of geosta liberates exchangeable ions including K^+, Na^+, Mg^{2+} and Ca^{2+} which through isomorphous substitution replace the R-OH and R-COOH ion groups in organic soils. As a result, the ionic double layer thins leading to a reduction in inter-particle distances and electro-kinetic potential hence producing better mechanical properties. Also when used with cement, geosta enhances complete hydration and strength development.

This study presents the results of stabilizing chicoco with a composite stabilizer comprising ordinary Portland cement and geosta.

MATERIALS AND METHODS

Chicoco: The chicoco mud used in this study was obtained from around Bakana, about about 6.5 km south east of Port Harcourt in southern Nigeria. The soil was dark brown in colour, highly spongy and fibrous. The sample was air-dried over a long time period (about 4 weeks) probably necessitated by the highly hygroscopic salts predominant in natural chicoco and its saline water environment. Air-dried samples were then subjected to standard classification tests including natural moisture content, gradation, Atterberg limits and standard proctor compaction all in accordance with BS 1377 of 1990 (Table 2).

Table 2: Summary of Classification Tests on Chicoco

1	Natural moisture content (%)		157
2	Fines (% passing No. 200 sieve)		42
3	Atterberg Limits (air-dried)	Liquid limit, LL (%)	64
		Plastic limit, PL (%)	40
		Plasticity index, PI (%)	24
4	Proctor compaction	MDD (kg m^{-3})	1290
		OMC (%)	30
5	Classification	Unified	OH

Varying proportions of geosta ranging from 1 to 9% were dissolved in about 300ml of water. Each aqueous solution was added to a thorough mixture comprising about 3000 gm of air-dried chicoco and about 300 gm (or 1%) cement. Standard proctor compaction tests were carried out on each composite soil-cement-geosta mixture. The resulting maximum dry density (MDD) and optimum moisture content (OMC) were then used to compact a pairs of specimens for unsoaked CBR tests. The specimens so prepared were tested for CBR after 72 hours of wax-curing to take advantage of the expected chemical reaction between geosta, cement and the soil. Average CBR value was taken at the end of the day. This procedure was then repeated for 4, 6 and 8% cement contents.

RESULTS AND DISCUSSIONS

Table 3 summarises the results of stabilizing the chicoco soil samples with geosta and cement. From this table, it can be observed that plain cement stabilization of chicoco is indeed relatively ineffective. The natural maximum dry density (MDD) was only marginally improved by about 3.9% while the optimum moisture content (OMC) also marginally decreases by about 22% representing the maximum proportion of available moisture actually used up in cement hydration. Infact, this small decrease in OMC is a clear indication of incomplete cement hydration and/or strength development. Though the natural CBR of 2.7% was improved by a factor of approximately 3, the maximum value of about 10.5% falls short of even the minimum requirement in road earthworks. Thus plain cement stabilization of this soil is highly ineffective.

Figure 1 plots the resulting maximum dry density (MDD) against geosta content for each cement content. From this Fig. 1, it can be observed that for every cement content, MDD increases only marginally with increasing geosta content above 1%. For instance, 1 and 4% cement contents only gave about 7% increase over the natural MDD of 1290 kg m^{-3}. Either or both of the following reasons may have been responsible for this.

The air-dried soil is known to be acidic [3] hence the exchangeable ions liberated by the mostly basic geosta (pH $\geq$ 10) may have merely reacted to neutralize the acidity in the soil with little or nothing available for ion-exchange or isomorphous substitution. As a result, the thinning of the ionic double layer and reduction of inter-particle spacing commonly associated with isomorphous substitution was insignificant and hence

Table 3: Summary of Test Results

Geosta content		0	1	4	7	9
0% cement	MDD (kg m^{-3})	1290.0	-	-	-	-
	OMC (%)	30.0	-	-	-	-
	CBR	2.7	-	-	-	-
1% cement	MDD (kg m^{-3})	1330.0	1350.0	1300.0	1380.0	1370.0
	OMC (%)	27.3	25.8	25.2	22.2	22.2
	CBR	5.0	10.0	9.0	10.0	9.0
4% cement	MDD (kg m^{-3})	1335.0	1330	1332.0	1360.0	1380.0
	OMC (%)	25.2	24.3	23.8	23.5	21.6
	CBR	8.0	28.0	25.0	22.0	19.0
6% cement	MDD (kg m^{-3})	1340.0	1490.0	1500.0	1540.0	1490.0
	OMC (%)	24.6	22.6	20.4	17.6	18.8
	CBR	8.9	19.0	14.0	17.0	13.0
8% cement	MDD (kg m^{-3})	1330.0	1310.0	1540.0	1560.0	1540.0
	OMC (%)	23.5	21.4	19.2	18.2	19.4
	CBR	10.5	22.0	27.0	23.0	21.0

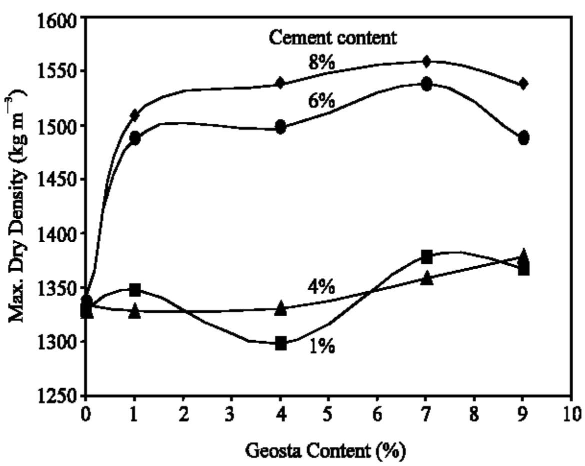

Fig. 1: Maximum Dry Density, MDD and Geosta

dry density only improves marginally. This may be substantiated by the fact that the MDD curves for lower cement contents (1 and 4%) almost concide even as do those for higher cement contents (6 and 8%). Thus the influence of geosta addition on MDD at all cement contents whether lower or higher may be insignificant.

It is strongly expected that the result would be better for non-marine organic soils. This is because such non-marine organic soils may be mostly basic hence no such acid-neutralisation reaction at the expense of ion-exchange would occur, providing an attendant positive influence on mechanical properties.

If geosta addition neutralises the acidity in the air-dried soil, then additional water must have been released within the mixture. As a result, even if significant ion-exchange and its allied influence actually took place, the additional water pressure in the system may have pulled apart the soil grains leading to lower density. This may explain why MDD is lower at lower cement contents (1 and 4%) when compared with its values at higher cement contents. This may be because in all cases, additional water released through geosta addition is constant but the amount or fraction of this used up in cement hydration will depend directly on the cement content. Infact, the higher the cement content, the higher the excess water used up in cement hydration, the lower the excess water available to exert pressure on soil grains and the higher the density as observed.

Also the upward shift of MDD curves could be because after all the acidity in the soil has been neutralised by the liberated exchangeable anions, then the excess (probably supplied by additional cement and not geosta) now goes into isomorphous substitution and its attendant influence which resulted into the almost 21% increase over the natural value of MDD.

Figure 2 plots the optimum moisture content (OMC) against the geosta content for each cement content. From this Fig. 2 and for each cement content, OMC decreases with increasing geosta content. Thus it could be said that generally, geosta withdraws moisture from a cement-stabilised chicoco. This is actually an irony considering the fact that as the acidic air-dried chicoco is neutralised by basic geosta, additional water is also liberated. But both this additional water and even part of the originally added water is absorbed by the highly hygroscopic compounds in chicoco. Thus geosta will be a very useful chemical in dewatering marine soils either by grouting or remoulding. However, this could adversely affect cement hydration and strength development as will be seen later.

Also from this Fig. 2, OMC can be seen to be inversely proportional to the cement content, i.e. the lower the cement content, the higher the OMC. This may be because in all cases, water liberated through geosta addition is constant but only a smaller fraction of this is used up in cement hydration at lower cement contents. The excess thus boosts the OMC as observed.

Figure 3 plots the California bearing ratio (CBR) against geosta contents for every cement content. From this Fig. 3, unsoaked CBR of the mixture only improves

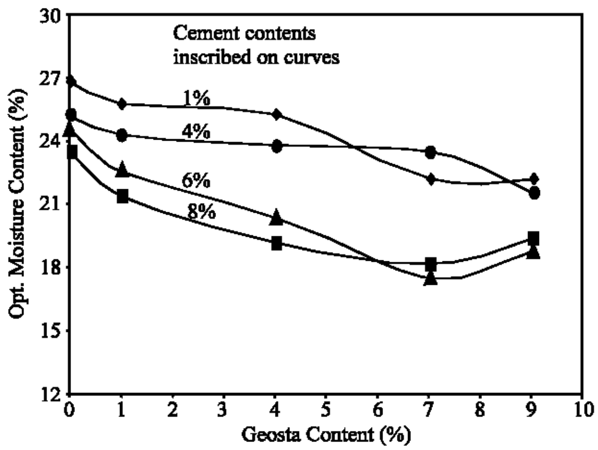

Fig. 2: Optimum Moisture Content (OMC) Versus Geosta Content

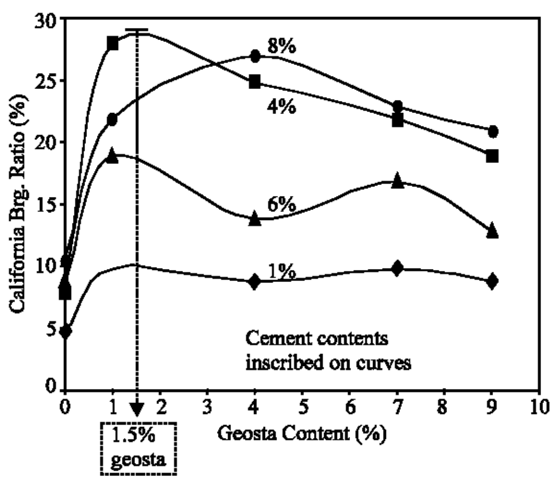

Fig. 3: Variation of CBR with Geosta Content

at very low geosta contents after which it decreases almost continually. This may be because as geosta content increases, the excess water liberated and the accompanying pore-pressure generated through acid neutralisation also increases. After cement hydration has been completed, the excess water then softens the soil resulting in lower CBR as geosta content increases. This to some extent agrees with the deduction from Fig. 1 where the maximum dry density was found to increase with increasing cement content.

However, this theory partially breaks down with 4% cement content exhibiting the highest CBR even higher than 8% cement content which exhibited the highest dry density. Thus it could be said that strength development in organic soil-cement-geosta mixture is not totally density dependent but also depends on the apparent cohesion which develops over time in the mixture due to cement hydration. This actually agrees with previous observations by Leroueil and Vaughan [9] and Consoli *et al.* [10] whereby the shear strength of even natural soils were attributed to soil structure rather than density.

Also from this Fig. 3, this stabilization is most effective at 4% cement and about 1.5% geosta contents which achieves a CBR of about 29%. This is particularly a significant advantage considering the volume of materials that may be required in earthworks and high cost differential between geosta and cement. Currently in Nigeria, geosta is not very popular and it is only available through importation at a landing rate per kilogramme of about 1,500 naira (or about $12.5). Cement on the other hand is available locally at an average cost per kilogram of about 15 naira (or $ 0.12).

The maximum obtained unsoaked-CBR of about 29% only barely meets the minimum requirement or specification for road sub-base materials. However, this value is expected to significantly improve beyond 30% over time as cement hydration progresses. Thus geosta addition to cement-stabilized chicoco can yield at best materials for sub-base in road works.

CONCLUSION

From the foregoing, it can be concluded that chicoco though highly undesirable for engineering applications in its natural state can be improved for use in earthworks with addition of geosta and cement through the mechanism of ion exchange or isomorphous substitution.

However, the effect is slightly retarded because of the acidic nature of air-dried chicoco which basic geosta also neutralises thereby liberating additional water which is in excess of that required for cement hydration and strength development. This excess free water tends to separate the soil grains to give only marginal improvement in the maximum dry density (MDD) though with better values at higher cement contents, continually decreasing optimum moisture content (OMC) but with higher values at lower cement contents.

California bearing ratio (CBR) peaks at a relatively lower geosta content and thereafter decreases continually- a major cost advantage in earthworks. The most effective influence was obtained at 4% cement and about 1.5% geosta contents with an unsoaked CBR of about 29% which is expected to improve over time. Thus geosta addition to cement stabilised chicoco soilcrete would produce materials for road sub-base at the best.

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