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Optimal stabilisation of deltaic laterite

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Deltaic laterite is the most suitable and most widely used soil material for road embankment in the Niger Delta. Usually, its natural characteristics fall short of the minimum requirements for such applications hence it has to be stabilised to improve its properties. In this study, samples of deltaic lateritic soils were subjected to mechanical (with or without controlled sand addition), cement and cement-sand (composite) stabilisation methods to improve strength for improved engineering applications. Mechanical stabilisation was found to satisfy subgrade requirements while the addition of sand produced sub-base material quality at best depending on compacted maximum dry density (MDD), which itself is dependent on the optimum sand content (OSC). The OSC was also shown to affect the optimum moisture content (OMC) and the soaked California bearing ratio (CBR) of stabilised specimens. Combination of the test results produced a graphical model to predict the influence of mechanical stabilisation on the soil materials using the percentage fines (that is, passing through a 75 µm sieve) obtainable from wet sieving. Cement stabilisation of the soil (by indigenous highway standard) produced base-course quality materials with cement content in excess of 12 %, which is economically unviable. However, the addition of controlled proportions of sharp sand (also abundant in the Niger Delta) to the soil-cement mixtures produced base-course quality materials with 6 % cement (less than half of that obtained through only cement stabilisation) and about 40 % sand content. A model was also presented to predict the other constituents of sand-cement stabilisation using the percentage fines obtainable from wet sieving.

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INTRODUCTION

Deltaic lateritic soils are the superficial lateritic soil deposits found in the flatland/plains of the Niger Delta region of southern Nigeria. They have been found to differ markedly from the other more matured lateritic soils on which most previous reported studies have concentrated. The major differences are due to the following:

- They are derived from much more recent (younger) non-crystalline or clastic parent materials commonly referred to as the coastal plain sand obviously deficient in chemically degradable rock-forming minerals such as feldspars, which are the major contributors to laterisation process
- They are formed in a near-flat terrain (characteristic of the Niger Delta region) hence deficient in two of the three necessary and sufficient conditions for full laterisation (Little 1969; Tuncer & Lohnes 1977; Blight 1982; Mitchell & Sitar 1982; Townsend 1985)
- They are less matured in the lateritic soil vertical profile and probably much more sensitive to all forms of manipulation that other lateritic soils are known for (Ola 1974; Allam & Sridharam 1981; Omotosho & Akinmusuru 1992; Omotosho 1993)
- They do not conform to the widely reported parent-rock-related gradation trend common to other lateritic soils (Ola 1974; Lohnes *et al* 1971; Tuncer & Lohnes 1977; Akpokodje 1986; Omotosho 1993; Leton & Omotosho 2004)

They are, however, the most suitable and most widely used soil materials for road earthworks in the entire Niger Delta (Arumala & Akpokodje 1987).

Except in very rare and exceptional cases, soils (including deltaic lateritic soils) in their natural states hardly possess characteristics

***Table 1** Specifications for road pavement structural materials (after FMW 1997)*

	Pavement structural component	Minimun value of soaked CBR (%)
1	Base course (natural or unstabilised soil material)	80
2	Base course (cement-stabilised soil)	180
4	Sub-base	30
5	Subgrade and/or foundation soil	5–11

***Table 2** Classification characteristics of soils*

Sample location		1	2	3	4	5	6	7
Location		**Artillery area, PHC**	**Rumuodara, PHC**	**Choba**	**After Omoku**	**Emuohua**	**Ahoada**	**Eneka near PHC**
Percentage fines (F)		39,3	44,8	41,3	36,4	39,4	36,8	47,1
Liquid limit (%)		45,0	53,6	49,5	39,4	55,2	35,6	35,8
Plastic limit (%)		21,4	29,5	23,0	18,9	23,0	15,3	22,5
Plasticity index (%)		23,6	24,1	26,5	20,5	32,2	20,3	13,3
Classification	Unified	CH	CH	CI	CI	CI	CI	CI
	AASHTO	A-2-6	A-5	A-2-7	A-2-6	A-2-6	A-2-6	A - 5

suitable for desired engineering applications, particularly for roadworks. Table 1 summarises the minimum requirements for soils or soil-based materials usable in road pavement structures required by the FMW specifications (1997).

To achieve the required standards, soils have to be improved before use. Stabilisation is an obvious option and could be mechanical (if simply compacted with or without the addition of sand addition), chemical (if compacted with controlled proportions of stabilising agents, including bitumen, lime and cement), thermal (which could produce dehydrated hard-pans) and even electrical (through, for example, electro-osmosis).

For several years, cement has remained one of the most important, widely used and relatively cheap chemical stabilising agents for improving the strength of soils in general. For lateritic soils specifically, observations by Ola (1974) have opened up new opportunities for tropical residual soils when compared with their temperate counterparts. It was observed that cement stabilisation not only improved the natural CBR of the selected lateritic soil material by over 1 500 %, but that only about half of the 14 % cement content suggested for similar temperate soils by the PCA (1956) to achieve 80 % CBR was actually needed. This of course is a major economic advantage for the tropics considering the relative cost of cement and the large volume of materials usually employed in road earthworks.

For a temperate soil to be suitable for cement stabilisation and useful in the construction of road pavement structure, the HRB (1943) specify that the percentage fines, liquid limit and plasticity index must not exceed 50 %, 40 % and 18 % respectively, while Millard and O'Reilly (1965) specify that the product of the plasticity index and the percentage passing through a 425 μm sieve (no 40) must not exceed 1 000. However, these specifications may not be appropriate for tropical residual soils considering the widely observed and reported disparities between them and their temperate counterparts from which these specifications were actually derived. A typical example is the 'abnormal' but advantageous behaviour observed by Terzaghi (1958) for Kenyan Sasumua clay that exhibited very high plasticity but abnormally low compressibility and superior mechanical strength.

In addition to the abovementioned and other requirements based on results of classification tests, the Nigerian specifications on roadworks (FMW 1997) specify that for any cement stabilised soil to be usable in a road pavement structure, its hand-mixed specimens must achieve soaked CBR (tested to the same FMW specifications) of 30 % and 180 % for sub-base and base-course respectively. The specific testing procedure (FMW 1997) specifies that the compacted CBR specimen should be wax-cured for six days, soaked in water for 24 hours (after removal of wax) at the end of which it must be drained for about 15 minutes before CBR testing.

Plain mechanical stabilisation is also known to improve soil strength far above the in situ conditions with the controlled addition of sharp sand during this process being even more effective. Sharp sand is abundant in the Niger Delta basin. Of the over 6 km thick and most recent Benin formation (Short & Stauble 1967), sharp coastal plain sand constitutes over 50 %. In fact, deltaic lateritic soils are not just derived from but are actually underlain by considerable thickness of this coastal plain sand that exists naturally in well-sorted or uniformly graded form with uniformity coefficient less than 5 in almost all cases. Sharp sand can be obtained in the Niger Delta by direct excavation, especially at sandbanks or sandy outcrops scattered around and within the many rivers, creeks and rivulets that constitute the delta. It can also be commercially dredged or pumped from beneath the beds of these rivers and creeks at relatively very low cost when compared with imported or import-substituted materials such as cement and lime. Thus sand stabilisation of deltaic lateritic soils is economically viable.

This paper presents a report of studies carried out on the influence that the addition of sand and cement has on some engineering characteristics of deltaic laterite.

MATERIALS

The deltaic lateritic soil samples used in this study were obtained from seven existing and active borrow-pits from which materials have been and still are still being quarried for various road earthworks within the Niger Delta. For instance, sample 1 was collected from around the Artillery area in the north-central part of Port Harcourt city, samples 2 and 7 from Rumuodara and Eneka respectively, both located around the northern fringe of the city, sample 3 from Choba, about 15 km westwards, sample 4 from somewhere between Omoku and Ebocha (near Ndoni) about 100 km north-eastwards, sample 5 from Emuohua about 20 km westwards, and sample 6 from Ahoada, about 70 km westwards.

All samples were air dried for about two weeks to take advantage of the aggregating potentials of lateritic soils upon exposure (Allam & Sridharan 1981; Omotosho & Akinmusuru 1992). The results of the preliminary laboratory investigation of the samples are summarised in table 2.

The sand sample used in this study is the coastal plain sharp river sand type obtained from the Mile 3 aggregate market in Port Harcourt. First the sample was thoroughly washed to remove any deleterious coatings, after which it was air dried and sieved mechanically. The results of standard sieve analysis showed the sand to have a percentage fines (passing no 200 sieve), mean diameter (d_{50}) and effective diameter (d_{10}) of 3,4 %, 0,33 mm and 0,18 mm, respectively. Typical of the coastal plain sand of the Niger Delta, the sand is uniformly graded with a uniformity coefficient (U) of 2,61.

The cement used in this study was the ordinary Portland type bulk-imported cement from Britain, bagged and marketed by Eastern Bulkcem Nigeria Ltd, based in

***Table 3** Summary of mechanical stabilisation test results*

Sample number	Sand content (%)	MDD (kg/m^3)	OMC (%)	CBR (%) soaked for 24 hours
1 (Artillery near Port Harcourt)	0	1 910	14,0	7
	10	1 890	14,4	13
	30	1 980	13,4	23
	40	1 980	13,0	28
	50	2 010	11,0	31
	60	1 965	9,1	26
	70	1 867	6,8	14
	80	1 680	4,3	7
2 (Rumuodara near Port Harcourt)	0	1 890	14,8	12
	10	1 880	15,8	9
	20	1 890	14,0	13
	30	1 940	13,2	18
	40	1 950	14,0	16
	50	1 960	13,4	21
	60	1 914	9,1	6
	70	1 930	7,8	18
	80	1 952	11,6	2
3 (Choba near Port Harcourt)	0	1 960	14,2	12
	10	1 936	15,3	9
	20	1 895	14,7	15
	30	1 904	14,5	17
	40	1 968	13,5	28
	50	2 000	14,5	30
	60	2 053	9,8	2
	70	2 311	9,3	4
	80	1 880	10,8	2
4 (near Ndoni)	0	1 940	12,6	7
	15	1 990	12,0	10
	20	2 020	12,0	18
	25	2 030	10,8	21
	30	2 000	11,3	25
	50	2 110	10,4	34
	60	2 070	9,4	12
	70	1 970	9,4	5
	80	1 890	8,8	4

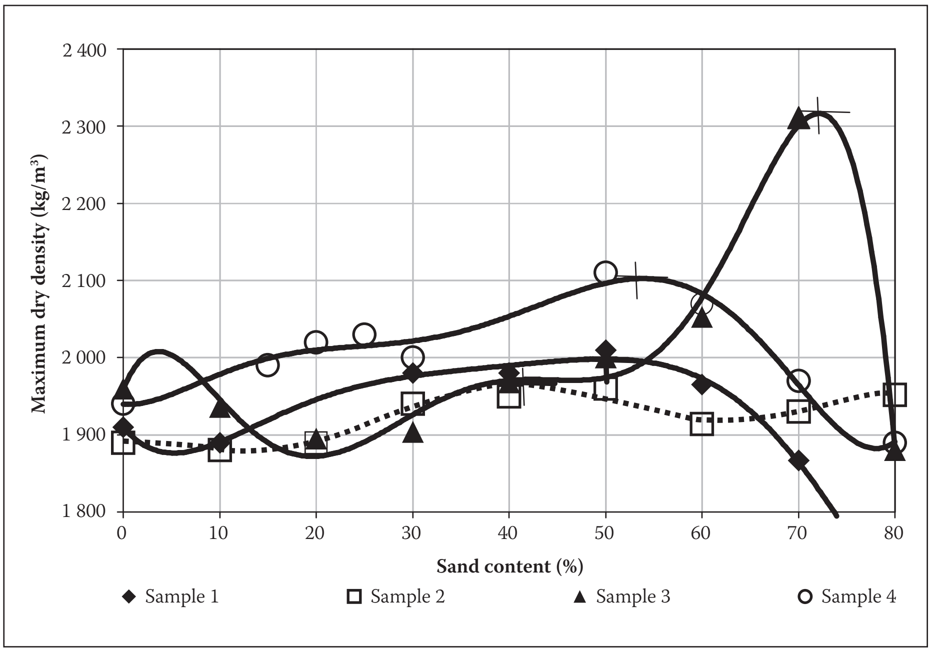

***Figure 1** MDD and sand stabilisation*

Port Harcourt. According to the importer's quality control analysis, this cement complies with BS 12 (1992). The cement was purchased from the local cement market at the Mile 3 area of Port Harcourt.

EXPERIMENTAL PROCEDURES

Mechanical stabilisation

Controlled proportions of sharp sand ranging from 0 % to 8 % were each mixed thoroughly with about 3 000 g of deltaic lateritic soil samples from locations 1, 2, 3 and 4 while standard Proctor compaction tests (in accordance with BS 1377 1992) were then carried out on each mixture. The OMC and MDD determined from each compaction were then used to compact specimens for standard CBR tests conducted after 24 hours of soaking in water, in accordance with FMW specifications (1997).

Plain cement stabilisation

Five deltaic lateritic soil samples from locations 1, 3, 5, 6 and 7 were used in this part of the study. Specimens of 3 000 g of deltaic laterite from each of these locations were weighed out and thoroughly mixed with the added cement portion in steps of about 2 % from 0 % to 15 % and the standard Proctor compaction test was carried out on each mixture. The OMC and MDD determined from each compaction were then used to compact specimens for standard CBR tests conducted in accordance with FMW specifications (1997).

Sand-cement stabilisation

Samples of 3 000 g of deltaic laterites from location 1 (Artillery area of Port Harcourt) and location 2 (Choba) were weighed out. Each sample was thoroughly mixed with sharp sand in proportions ranging in steps of 10 % from 0 % to 50 %. Each mixture of laterite and sand was then mixed with portions of cement in steps of 2 % from 0 % to 8 %. The standard Proctor compaction test was then carried out on each controlled soil-cement-sand mixture. The OMC and MDD determined from each compaction were then used to compact specimens for standard CBR tests conducted in accordance with the FMW specifications (1997).

RESULTS AND DISCUSSION

Mechanical stabilisation

Table 3 summarises the results of the mechanical stabilisation, with and without the addition of sand, for all four deltaic laterite samples used. From this table it can be observed that

***Table 4** Optimum sand content and sand stabilisation*

Sample number	Percentage fines (F)	OSC (%)	Corresponding MDD (kg/m^3)	Corresponding OMC (%)	Corresponding CBR (%)
1	39,3	50	2 010	11,0	31
2	44,3	42	1 967	14,0	19
3	41,3	73	2 320	9,8	30
4	36,4	54	2 100	10,0	34

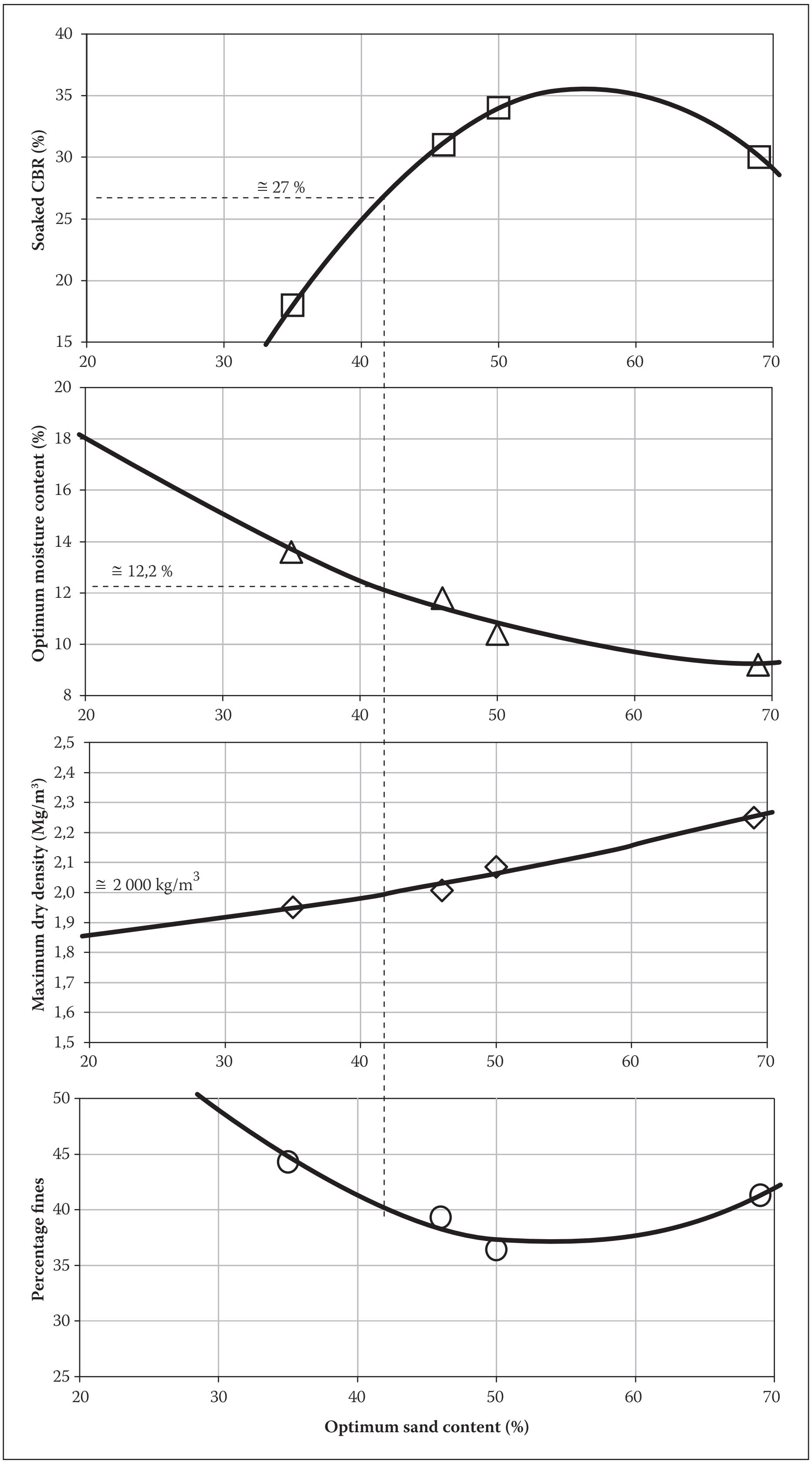

***Figure 3** Sand stabilisation model*

plain mechanical stabilisation (that is, compaction only) of deltaic lateritic soils produces soaked CBR values between of 7 % and 12 %, which makes the materials suitable for use as subgrade in road pavement only. Thus it can be said that modified subgrade structural element can be omitted in highways constructed over deltaic lateritic soils.

From table 3, it can be observed that the addition of controlled sand proportions prior to compaction (or sand stabilisation) improves the strength beyond plain mechanical stabilisation. In fact, the maximum soaked CBR value achievable through sand stabilisation is 34 %, which is suitable for use as sub-base materials in roadworks. Thus sand stabilisation of deltaic lateritic soils would produce materials suitable for use as sub-base in roadworks.

Also from table 3, and for each sample, the OMC can be observed to continually decrease with increasing sand content. This may be because the addition of sand increases the coarse fraction and reduces the proportion of fines in the mixture. As a result, the specific surface is reduced and the water required to lubricate the fines reduces considerably and hence the reduction in OMC.

Figure 1 presents a plot of maximum dry density MDD against sand content for the four samples used in this part of the study. From this figure, a number of conclusions could be drawn. First and for all four samples used, MDD could be seen to increase with increasing sand content, reaching a maximum and thereafter decreasing continually. This may be because as coarser sand is added to the well-graded lateritic materials, the coarse fraction of the mixture increases, natural microclusters break up, grains come closer together with voids or interstices filled by the abundant fines in the soil and hence increase in dry density. With time, all the fines in the lateritic soil are used up, more voids are created by the increased proportion of sand and hence the reduction in the dry density. Second, the MDD curves reach maxima at different sand contents for the different soil samples that have different percentages of fines. These maximum points correspond to the most effective or what could be referred to as the optimum sand content (OSC) beyond which sand stabilisation of these soils becomes detrimental. In fact, beyond the OSC, the issue is no longer that of sand stabilisation but of outright sand replacement of the deltaic lateritic soils.

From table 3 it can also be observed that the CBR exhibits the same trend as the MDD, namely increasing, reaching a maximum and then decreasing continually with increased sand content. It can thus be concluded that the strength of sand-stabilised deltaic lateritic soil is highly dependent on compacted density which, by extension, is also dependent on the OSC which itself varies with the percentage fines. Like compacted density, the OMC and the soaked CBR are also dependent on the OSC.

The values of OSC from figure 1 allowed the corresponding values of MDD, OMC and CBR to be extracted from table 3 and summarised in table 4, which was then used to develop a general graphical model for sand stabilisation of deltaic lateritic soils (figure 2). From this figure and with the percentage of fines (that is, the portion of soil materials passing or finer than sieve no 200 with 75 µm openings) obtained from wet sieving of the dry soil samples, the various embankment design and construction parameters (MDD, OMC soaked CBR) can be read off direct. For instance, if a soil has a percentage fines of 40 %, the optimum sand content from figure 2 will be about 42 %, maximum dry density about 2 000 kg/m^3, optimum moisture content about 12 % and soaked CBR about 27 %.

Cement stabilisation

Table 5 summarises the results of this plain cement stabilisation for all five deltaic lateritic soil samples from locations 1, 3, 5, 6 and 7. No sand was added to the soils during these tests.

Figure 3 shows the maximum dry density against cement content for the five samples used. Generally from this figure and within experimental errors, MDD first decreases with increasing cement content, reaches a minimum at different cement contents and thereafter increases continually. This may be due to the fact that at low cement content and as the fine-grained cement is added to the already well-graded soil materials, the primary cement hydration compounds catalyse and/or supplement the natural microclustering potentials of the abundant sesquioxides in the deltaic laterite. As a result, the soil's natural fine grains are clustered together to form loosely bound and porous coarser grains, hence the decrease in maximum dry density. However, as the cement content increases further, the significantly increased portion of cementing agents, including the secondary hydration compounds, give rise to further but competitive microclustering. As a result, micropeds reduce in size but increase numerically with more fines available to fill their earlier porous interstices, porosity reduces and consequently density increases. This rather peculiar behaviour actually confirms the various observations in literature about the structure-dependent behaviour of residual soils, either in the natural form or when chemically stabilised, especially with cement (Ola 1974; Allam & Sridharam 1981; Leroueil & Vaughan 1990;

***Table 5** Summary of plain cement stabilisation results*

Sample number	Cement content (%)	MDD (kg/m^3)	OMC (%)	CBR$_{FMW\ spec.}$ (%)
1 (Artillery near Port Harcourt)	0	1 910	14,2	7
	2	1 690	17,1	24
	4	1 650	15,0	35
	6	1 640	15,5	55
	8	1 670	17,0	64
	10	1 831	13,8	79
	12	1 793	9,5	128
	15	1 780	11,7	162
3 (Choba near Port Harcourt)	0	1 960	14,2	6
	2	1 905	15,1	22
	4	1 940	15,2	50
	6	2 045	14,8	72
	8	1 980	13,1	96
	10	1 980	13,6	122
	12	1 966	12,8	143
	15	1 929	14,4	186
5 (Emuohua)	0	1 875	17,0	5
	2	1 890	16,6	20
	4	1 881	17,2	40
	6	1 880	16,8	55
	8	1 890	16,6	154
	10	1 885	16,8	170
	12	1 960	10,1	182
	15	1 890	13,8	192
6 (Ahoada)	0	1 898	11,7	2
	2	1 800	16,4	6
	4	1 733	15,6	27
	6	1 800	13,7	99
	8	1 840	15,0	103
	10	1 826	13,4	124
	12	1 851	14,6	154
	15	1 768	16,5	168
7 (Eneka near Port Harcourt)	0	1 850	15,0	5
	2	1 886	11,0	10
	4	1 939	8,0	68
	6	1 937	8,0	130
	8	1 967	6,0	141
	10	1 906	9,0	95
	12	1 937	14,1	133
	15	1 975	10,7	172

***Table 6** Cement requirements for FMW specification*

Sample number	Percentage fines (F)	Cement content for 180 % CBR	Cement content for 80 % CBR
1	39,3	16,0	10,0
2	47,1	15,2	4,6
3	41,3	14,8	6,9
4	39,4	12,5	7,0
5	36,8	16,0	5,5

***Table 7** Results of cement-sand stabilisation*

Sample	Cement content (%)	Parameter	Sand content (%)					
			0	10	20	30	40	50
1 Artillery	0	MDD (kg/m^3)	1 910	1 890	1 920	1 960	1 980	2 010
		OMC (%)	14,2	14,4	14,4	13,4	13,0	11,0
		CBR (%)	7	13	19	23	28	31
	2	MDD (kg/m^3)	1 690	1 899	1 903	1 940	2 000	1 997
		OMC (%)	17,0	12,8	11,5	11,8	10,0	9,4
		CBR (%)	24	45	63	52	90	99
	4	MDD (kg/m^3)	1 650	1 880	1 958	1 870	1 840	1 940
		OMC (%)	15,0	12,3	14,0	13,8	14,0	13,0
		CBR (%)	35	28	33	32	31	33
	6	MDD (kg/m^3)	1 640	1 920	1 950	1 938	1 865	1 965
		OMC (%)	15,5	12,0	12,5	11,0	12,4	12,8
		CBR (%)	55	39	118	127	114	116
	8	MDD (kg/m^3)	1 670	1 945	1 938	1 958	1 970	1 992
		OMC (%)	17,0	11,6	13,0	11,8	10,8	9,7
		CBR (%)	64	50	119	115	136	201
3 Choba	Sand content		0	10	25	40	50	
	0	MDD (kg/m^3)	1 960	1 936	1 902	1 968	2 000	
		OMC (%)	14,2	15,3	14,6	13,5	14,5	
		CBR (%)	6	9	16	28	30	
	2	MDD (kg/m^3)	1 905	1 850	1 840	1 840	1 860	
		OMC (%)	15,1	13,4	13,4	12,8	12,3	
		CBR (%)	24	62	51	88	98	
	4	MDD (kg/m^3)	1 940	1 800	1 850	1 910	1 920	
		OMC (%)	15,2	14,7	13,4	13,6	13,2	
		CBR (%)	50	41	70	66	72	
	6	MDD (kg/m3)	2 045	1 738	1 898	1 958	1 998	
		OMC (%)	14,8	12,5	11,4	11,5	11,5	
		CBR (%)	72	118	167	184	184	

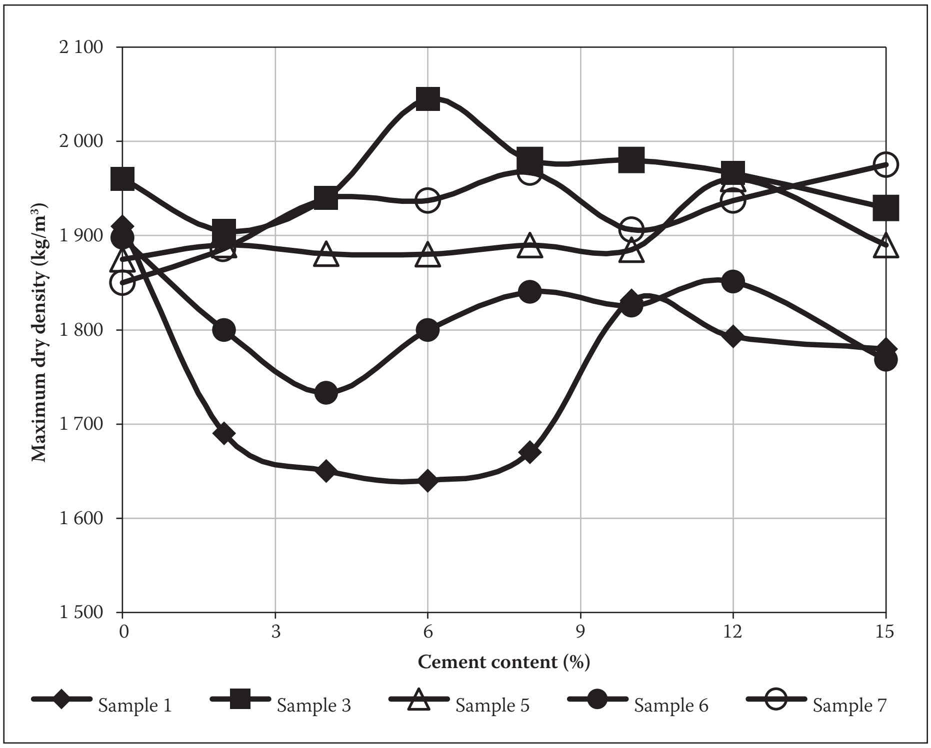

***Figure 3** MDD and plain cement stabilisation*

Viana da Fonseca *et al* 1997; Consoli *et al* 1998; Zhu & Anderson 1998; Brandl 1999; Rotta *et al* 2003). The MDD can also be seen to increase with an increasing percentage of fines, probably because the sesquioxide content also increases and hence the rate or potential for microclustering increases leading to a proportionate increase in MDD.

Figure 4 shows the OMC against the cement content for the five samples. From this figure it can be generally observed that at low cement content, the OMC increases significantly, maximises and thereafter decreases. But ideally, as finer-grained cement is added to the fine-grained soil, the portion of fines should increase together with the specific surface of the mixture and so should the quantity of water (or OMC) required to lubricate such increasing specific surface. However, Ola (1974) observed that such an increase is only marginal (between 1 % and 2 %) and just within 2 % and 4 % cement content after which the OMC remains constant. Thus this observed trend virtually agrees with the observations by Ola (1974).

Figure 5 shows the FMW-derived soaked CBR against the cement content for all results given in table 5. From this figure it can be observed that the soaked CBR generally increases continually with increasing cement content. However, the relationship is nonlinear, which is at variance with the linear one obtained by Ola (1974) for the more matured lateritic soils of Zaria area. Also from this figure, the cement requirement to achieve soaked CBR of 80 % and 180 % for these hand-mixed specimens can be summarised as shown in table 6. The cement requirements for 80 % soaked CBR were specifically included to highlight the effect of the disparity between the FMW specifications (1997) for natural (unstabilised) and cement-stabilised soils to satisfy the same requirements for use as base-course materials in roadworks.

Table 6 shows that the cement contents necessary to achieve the required CBR of 180 % ranges from 12,5 % to 16 %, which are far in excess of the 7 % ceiling specified by the FMW (1997). Although this ceiling might have been based on purely economic considerations, the cement content obtained here is rather high considering the relative cost of cement and the large volume of earthworks usually employed in roadworks. Thus it can be concluded that cement-stabilised deltaic lateritic soils are unlikely to be economically viable for use as road base-course materials.

Sand-cement stabilisation

Failure of the cement stabilisation of deltaic lateritic soils to meet the economic ceiling set by FMW (1997) prompted this part of the study using composite cement-sand

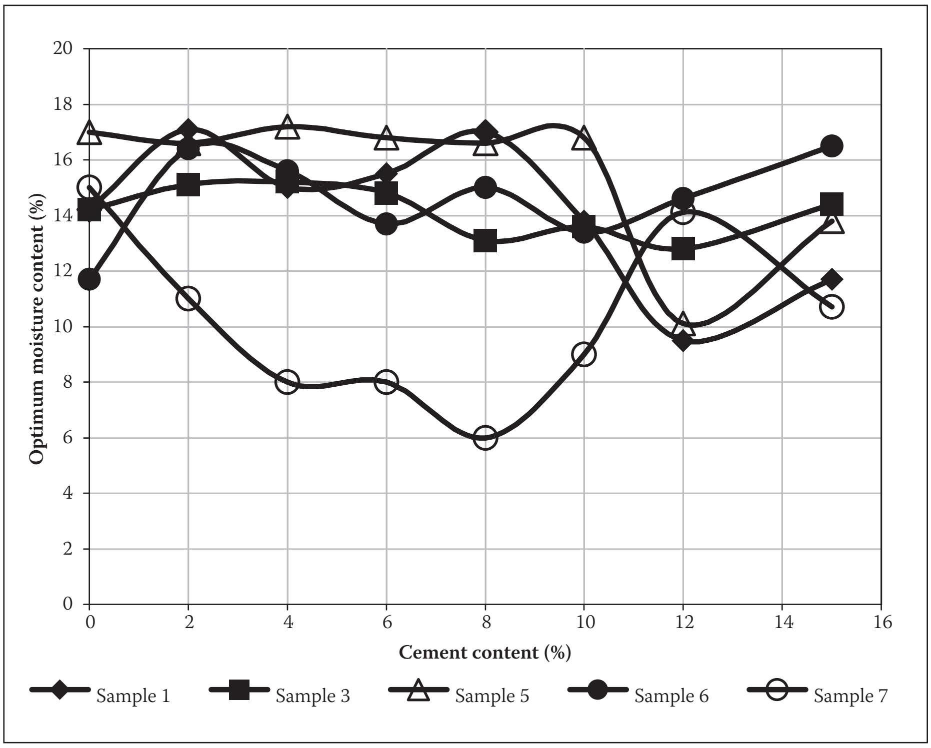

***Figure 4** OMC and plain cement stabilisation*

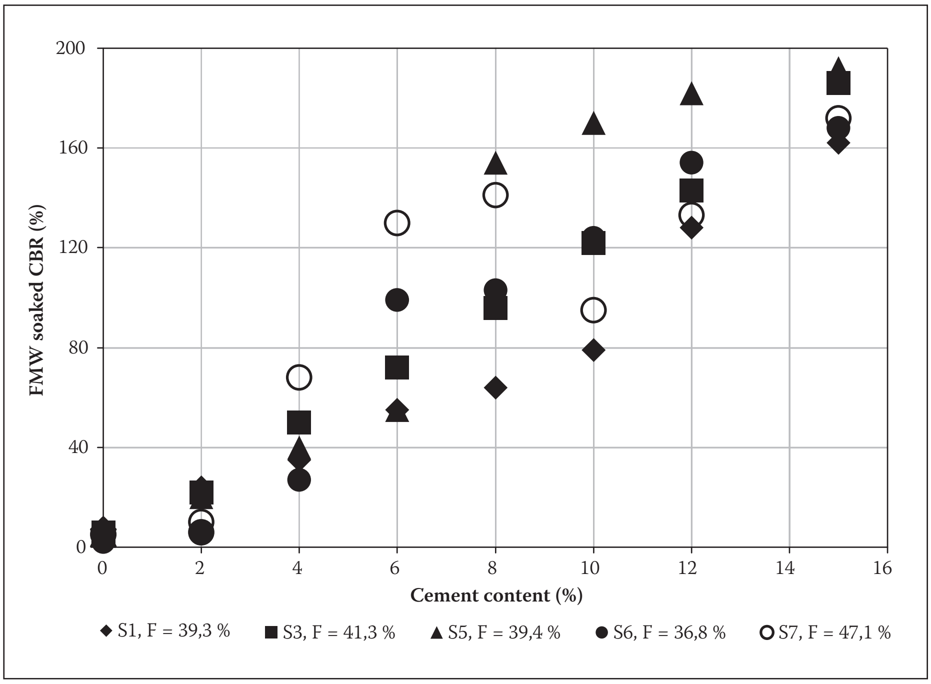

***Figure 5** FMW soaked CBR and plain cement stabilisation*

stabilisation. It should be noted that sharp sand is abundant and readily available in the Niger delta basin and at relatively low cost.

Samples from locations 1 and 3 were randomly selected and used in this part of the study. The results obtained from the sand-cement stabilisation tests are summarised in table 7. From this table, MDD maintained the same trend as observed for plain cement stabilisation, namely decreasing at low cement content, then minimising and thereafter increasing continually. Thus the influence of the addition of sand to cement-stabilised deltaic lateritic soil is not dependent on the compacted density. OMC on the other hand can be seen to generally decrease continually with increasing sand content. The reason may be that as sand is added to the soilcrete, the relative portion of fines decreases and so does the specific surface and the affinity of the resulting mixture to absorb water.

Figure 6 presents a plot of soaked CBR against cement content for all specimens and sand contents extracted from table 7. From this figure a number of conclusions can be drawn. First, it can be seen that cement-sand stabilisation gives a considerable improvement in strength compared to plain cement stabilisation (0 % sand content) of the deltaic lateritic soils. Second, the soaked CBR increases continually but also non-linearly with increasing cement content for virtually all sand contents. Thirdly, a soaked CBR of 180 % required for use as base-course materials can only be achieved at a higher cement content, starting from 6 %. This could be regarded as the most effective cement content (ECC) for this stabilisation and is about half of that required to achieve the same strength using cement stabilisation only. It can thus be concluded that the addition of sand to cement-stabilised deltaic lateritic soils may be both technically and economically viable for use as road base-course materials.

Using the relevant data for 6 % cement content for the two soil samples from table 7 carrying out polynomial regression analysis gave the following equation ($R^2 \cong 0{,}81$):

$$CBR = F\left(-0{,}005S^3 + 0{,}3121S^2 + 2{,}7977S + 152{,}74\right) \qquad (1)$$

Where F and S are the percentage fines and sand contents, respectively

From this equation, the family of curves shown in figure 8 was generated to model cement-sand stabilisation of deltaic lateritic soils. With the percentage fines known from wet sieving, the sand content required to achieve base-course material quality can be determined direct.

CONCLUSIONS

In this study, samples of deltaic lateritic soils were subjected to mechanical (with or without controlled sand addition), cement and cement-sand (composite) stabilisation to improve their strengths for improved engineering applications.

The influence of mechanical stabilisation has been shown to be highly dependent on the compacted MDD, which is dependent on the OSC. The OSC is shown to depend on the percentage fines while the OMC and soaked CBR also depend on it (OSC). Mechanical stabilisation was found to produce subgrade quality materials only while sand stabilisation produced sub-base materials at best. A general graphical model was also presented to predict the influence of mechanical stabilisation using the percentage fines obtainable from wet sieving.

Cement stabilisation of the soil was found not to be economically viable since the observed cement content required to produce base-course quality materials in roadworks (in compliance with FMW specifications 1997) was in excess of 12 %, that is, higher than the economic ceiling specified by the Nigerian FMW. However, the addition of controlled portions of sharp sand (also abundant in the Niger

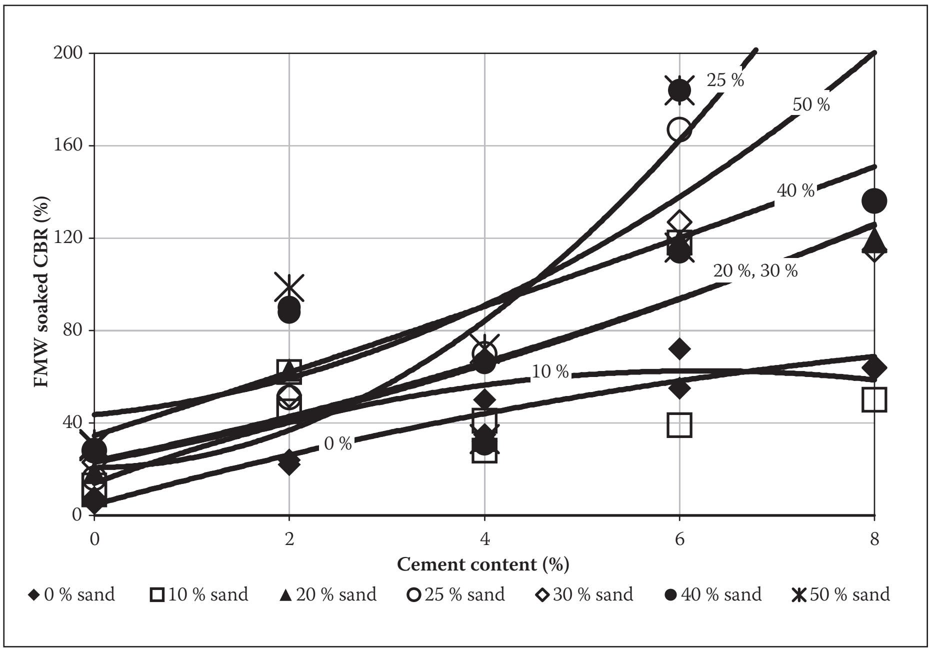

***Figure 7** Influence of sand addition to soilcrete*

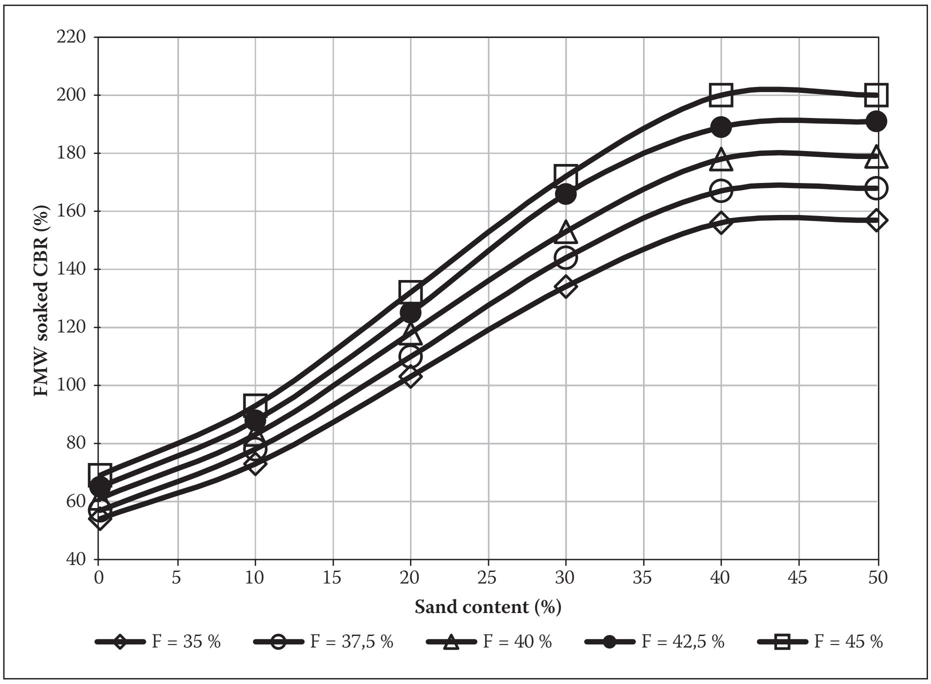

***Figure 7** Graphical model for 6 % cement content in cement-sand stabilisation*

delta) to the soilcrete was found to comply with the required specifications. For instance, base-course materials could be achieved with 6 % cement (less than half of that obtained through plain cement stabilisation) and about 40 % sand content. With the abundance of sand in the Niger Delta, this composite (cement-sand) stabilisation can be technically and economically attractive. A model was also presented to predict the other constituents of sand-cement stabilisation using the percentage fines obtainable from wet sieving.

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