# Characteristics of the Older Sands deposits of River Niger delta

## Caractéristiques des dépôts de sables anciens du delta du Niger

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SYNOPSIS: The River Niger delta basin in believed to have spread over the West African coastline from River Volta basin in Ghana to the Nigeria/Cameroun volcanic mountain ridges. Allen (1965) elaborately presented the findings of his detailed geological studies on the unique Nigerian section of this delta formation. Spurred by his remarkable revelation and based on information obtained from hundreds of foundation soil investigation, through penetration testing and boreholes, carried out in the area during the past three decades, the author decided as a complement to appraise the less discussed geotechnical aspects of the Niger delta deposits with particular reference to the stratigraphical succession identified as "Older Sands". These deposits have been most affected by deep foundation construction activities for supporting buildings, highways, bridges, plants for industrial and energy resources as well as oil production facilities which now abound in the area. Parameters for identification, strength and deformation characteristics of these deposits are developed from an analysis of available in situ and laboratory test results. It is hoped that the information presented would assist foundation engineers improve their knowledge of these soils and their design skill from the use of the data presented.

## 1. DELTA GEOLOGY

Allen (1965) described the Niger delta as being of the Late Quartenary and almost perfect in symetry, showing in plain view, a large arcuate 'classical' delta incorporating marginal estuary and barrier island lagoon complexes. By the late Pleitocene time, when the sea level stood lower than at present, the River Niger had built a mass of deltaic sediment extending farther into the Gulf of Guinea ocean basin on the Nigerian coastal plain geosyncline. The delta mass, a lens shaped body with a known maximum thickness of about 60 metres, or probably more near the delta axis and other locations, generally thins towards the flanks and edges of the geosyncline.

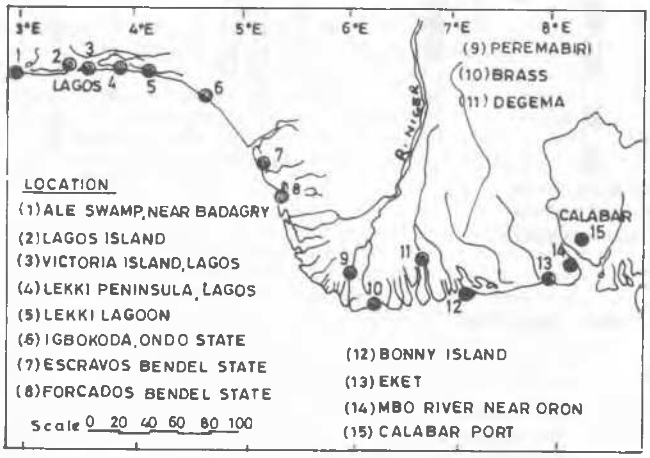

Figure 1. Nigerian section of Niger delta basin.

The entire delta of River Niger is nearly 670 kilometers long on the West African coastline and about 350 kilometers wide. It is bounded on the north by the structural basins in the Rivers Benue and lower Niger valleys. Southwards, it extends into the Gulf of Guinea oceanic basin, where a number of terraces interpreted as drowned barrier island complexes have been identified. On the east, it is bounded by the volcanic Cameroun - Bamenda - Adamawa mountains, stretchning north - south and into the Atlantic Ocean as a long submerged ridge, while westwards it extends to the River Volta basin in Ghana. Figure 1 shows the Nigeria section of this delta area.

Sedimentation in this area dates back to early Cretaceous times with some tectonism from later Cretaceous to mid - Tertiary. Deposits in the modern Niger delta and associated coastal environments comprise the latest accretion dating from the late Pleistocene and Helocene. Stratigraphically, the deltaic pile was begun by a transgressive strandplain deposit, designated "Older Sands", forming the basal unit of the delta pile. Above this are several lithofacies of a regressive nature, known as "Younger Suite". On the edges of the Coastal Plain geosyncline, the deltaic sediments pass into the deposits of estuary and barrier island - lagoon complexes. Allen (1964) classified the stratigraphy of the delta into three units:-

(i) Younger Suite (Helocene) - sands, silts and clays of modern delta and associated barrier island lagoons and estuary complexes.

(ii) Older Sands (Late Pleistocene to earlier Helocene) - quartzose sands with shell debris and glauconite deposited during estuaric rise of sea level following last glaciation.

(iii) Pre Older Sands (Earlier than Late Pleistocene) - Plant bearing clays, silts and sands. Some (?) soils, especially at top. Poorly consolidated.

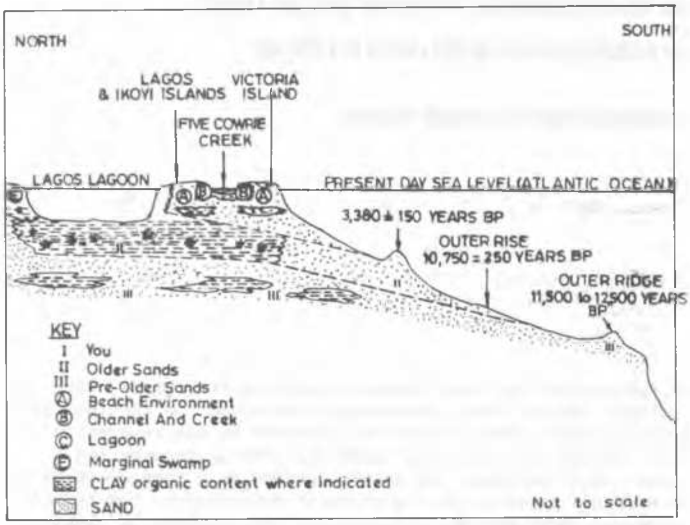

Figure 2. Schematic cross section through Lagos Lagoon and Island.

Evidence from several geotechnical investigation boreholes put down within the area broadly confirms the above stratigraphical succession. Ajayi et al (1983) produced a schematic representation, Figure 2, showing a north-south cross-section through Lagos Island, west of the delta to illustrate the above stratigraphy. Allen (1964) stated that due to the nature of the physical process of sediment accumulation, the interface between (i) and (ii) stratigraphic units above is largely time-transgressive. However, latest information from numerous site investigation boreholes indicate the boundary to be characterised by sudden change in colour from greyish to brownish or mottled brown, yellow and green, or similar coloured verved clays, or by occurence of weakly cemented patches and nodules, at depths of between 10 and 38 metres below present ground level. See Figure 3.

## 1.1 Physiography

Allen (1965) further divided the Niger delta deposits into five main physiographic units which are broadly equivalent to sedimentary super-environments:-

(i) the subaerial delta

(ii) a marginal barrier island - lagoon complex west of the delta and stretching about 420 kilometers to as far as River Volta delta (Ghana).

(iii) a marginal estuary complex east of the delta

(iv) the continental shelf under delta influence

(v) the continental slope.

The first three units are at or close to sea level while the last two are sea floor physiographic units. Many rivers feed the coastal lands forming the coastal belt, which is largely an area of climax swamp forest, characterized by silt-rooted trees. Nearest the sea is a belt about 25 or so kilometers wide, of brackish swamp forest dominated by red mangrove and salt water fern. Sandy islands and beach ridges within this mangrove belt,

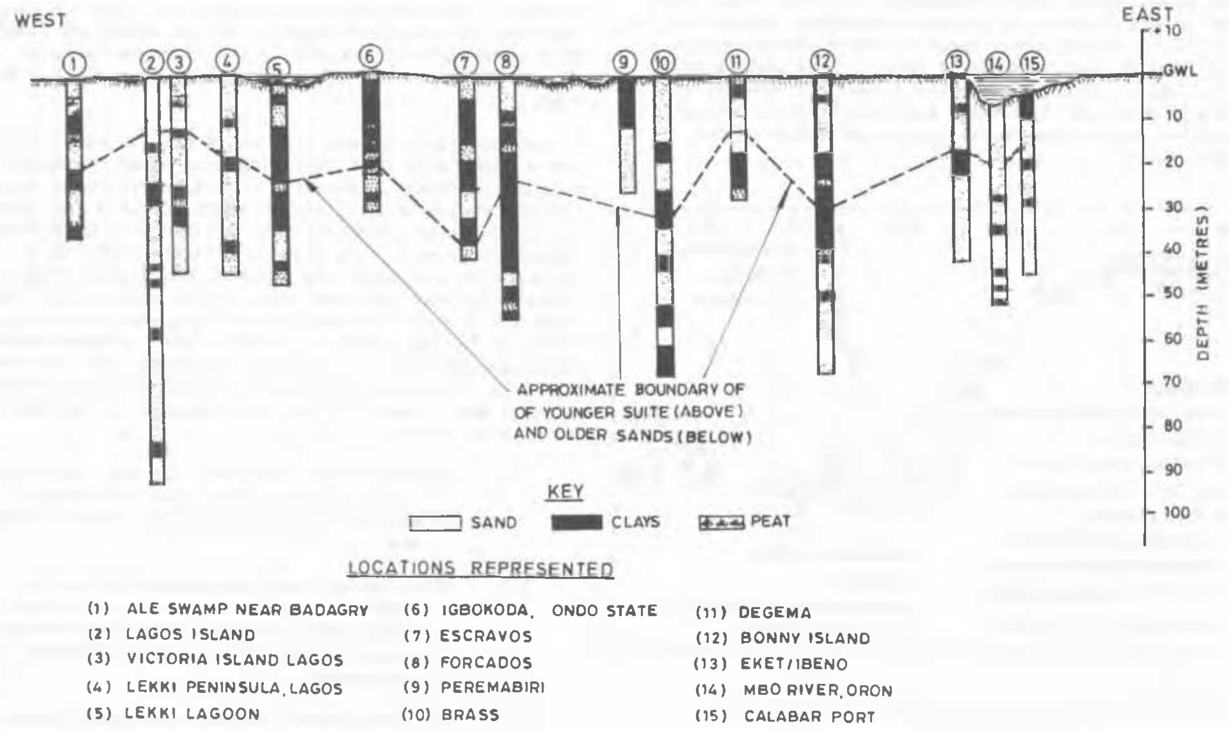

Figure 3. Schematic cross section through Niger Delta Basin in Nigeria.

or at the coast, have a fresh water vegetation of palms with numerous shrubs and herbs.

From observation of the ridges (mostly between 2m and 4m in height) along the coastline two types of ridge may be distinguished:-

(a) Smaller ridges with crests 1 metre or so above adjoining troughs, which may have a linear length of hundreds or thousands of metres along the coast, with crest to crest distance of between 75m and 200m with an average of 150m.

(b) Larger ridges consisting of bundles of smaller ridges, equally as long, having widths reaching about 1.5km. In the troughs between are shallow ponds, lagoons or long narrow creeks.

Fresh-water swamp trees gradually supersede the mangroves farther inland towards the rise in land level northwards. This swamp forest is an edaphic variant of the local rain forest and comprises a wide range of tall and low trees, shrubs, lianas, ferns, floating grasses and reeds.

## 1.2 Sediment Supply

Sediment entering the Niger delta area comes from three independent sources:-

1. the Rivers Niger - Benue drainage basin
2. the drainage basins of rivers east of the delta
3. the drainage basins of the rivers west of the delta, probably as far as and including the Volta (Ghana).

Detritus from the first and second sources is supplied directly through the rivers. River flows form one of the chief agents of distributing sediments in the subaerial part of the Niger delta. As the rivers have flowed over Basement complex metamorphic rocks, thick sand grade Cretacious - Tertiary sediments and basic volcanics, the ensuing sediments are characterised by dominance of brown hornblende and regional metamorphic minerals.

Sediments from the third source reaches the delta area, predominantly of barrier island - lagoon complex (western area), partly through the rivers flowing over Basement Complex rocks and directly moving southwards through the marginal complexes and delta flood plain; partly also through an eastward drift along the coast. There is also a considerable long-shore transport of suspended fines.

In the lower flood plain southwards to the edge of the mangrove swamps, River Niger divides into numerous distributaries. Discharge from the main feeder river, the Niger, is dispersed mainly radially from the head of passes by the various rivers crossing the flood plain. Tidal flows are important for sediment dispersal in the mangrove swamp belt and inshore waters. The tide is diurnal, approaching the coast from the south to southwest and entering the swamps through more than twenty major channels. Tidal movements out to sea occur at high angles to the coast, tending to carry sediments away from shore. Flow directions in the swamp belt show little consistency on account of the intricate channel geometry and the freedom of connection between all parts of the swamps. Tidal flows are strongest on the shallow mouth bars which obstruct the entrance channels to the delta and marginal complexes. The tractive and dispersive powers of the tidal flows tail off with increasing depth and distance from shore.

## 1.3 Sediments Classification

Based on the above background geological information, Allen (1965), classified the sedimentary environments in the Niger delta area on first order of importance thus: See Figure 4.

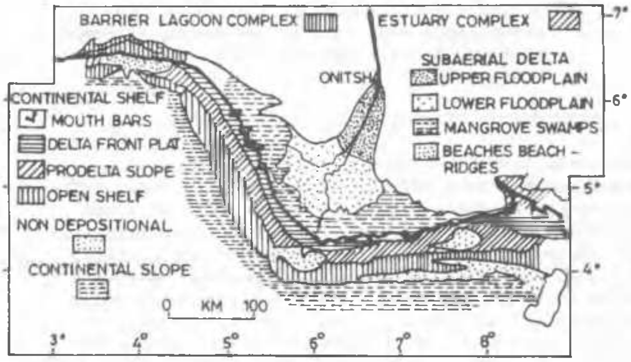

Figure 4. Sedimentary environments of Niger Delta area.

(i) Subaerial delta super-environment which can be subdivided into upper and lower flood plain, mangrove swamp and beach environments. With further minor classification to include channels, point-bars, backswamps, gullies, active beach ridges and transverse channels.

(ii) Marginal barrier island - lagoon complex (super environment), sub-divided into beach, channel and creek, lagoon, lagoon delta and marginal swamp environments.

(iii) Marginal estuary complex (super-environment), sub-divided into marginal swamp and open water environments.

(iv) Continental shelf under delta influence (super-environment), comprising river mouth bars, pro-delta slope, delta front platform and open shelf environments.

(v) Continental slope super-environment.

(vi) Non depositional super-environment.

Allen further identified at least four major facies units contributing to the delta framework:-

(i) a basal sand unit, formed by the Older Sands as a sheet deposit extending from the edge of the continental shelf to within several kilometers of the present shore or coastline and includes infilled stream valleys.

(ii) an offshore clay-sand units, involving Younger Suite lithofacies now being deposited in the open shelf, pro-delta slope, delta-front platform, river mouth bar and beach environments.

(iii) an onshore sand-silt unit formed by the mangrove swamp and tidal channel deposits. Because of the swamp creek meandering the base of this unit is probably erosional. Sand predominate only where the swamps border on the beach ridge barriers or on sediments older than the delta.

(iv) an onshore sand unit, comprising deposits formed in the delta flood plain. Constant shifting of the river channels must have given this unit an erosional base. Sands dominate the lithofacies. Silt and clay predominate over sand in the mangrove swamps, whereas in the flood plain the converse is true.

## 2. GEOTECHNICAL PROPERTIES OF OLDER SANDS

Within the last three decades, extensive subsoil investigations have been carried out in the Niger delta area by the author's firm and results of in situ and laboratory tests on thousands of samples from well over two hundred boreholes have been collated and analysed. On Figure 3, typical borehole logs from the locations indicated have been used to prepare a schematic representation of the subsoil stratigraphy across the Nigerian part of the delta, west to east. As stated earlier, it appears that the boundary between the Younger Suite and Older Sands is characterised by changes in colour from generally greyish to brownish or mottled brown, yellow and green or sometimes, by weakly cemented bands or nodules. The Older Sands comprise medium to very dense sands and stiff or very stiff clays now overlain by recent delta deposits (Younger Suites) and reclamation fill in places. It can be observed that the Older Sands are encountered from about 10m to probably over 90m depth. Previous geotechnical information on the Older Sands deposits were provided by Ajayi et al (1983) on sand deposits and Ajayi (1980) on the organic clays only. With the test results now available further information on both types of soil deposits can be provided.

On Figure 5 is shown depth (D)/vertical effective overburden pressure ($P_o'$) relationship for the Niger delta deposits. The points fall within boundaries defined by two parallel lines whose median can be represented by:

$P_o' = 8.875\ (D-5)$ .......................... (1)

where $P_o$ is expressed in kN/m² and D in metres

This expression is practically the same as the $P_o' = 100 + 8.75\ (D-15)$ of Ajayi (1980) for the organic clays in Lagos area, west of the delta basin.

The Older Sands deposits are indicated to be generally over-consolidated. Figure 6 shows the pre-consolidation pressure ($P_c$) and depth (D) relationship and it can be observed that the points are enclosed by straight lines $P_c = 30D$ and $P_c = 14\ (D-20)$ with mean relationship represented by:

$P_c = 20\ (D-10)$ kN/m² .......................... (2)

Hence, over consolidation effects should normally be considered in foundation settlement analysis involving these deposits.

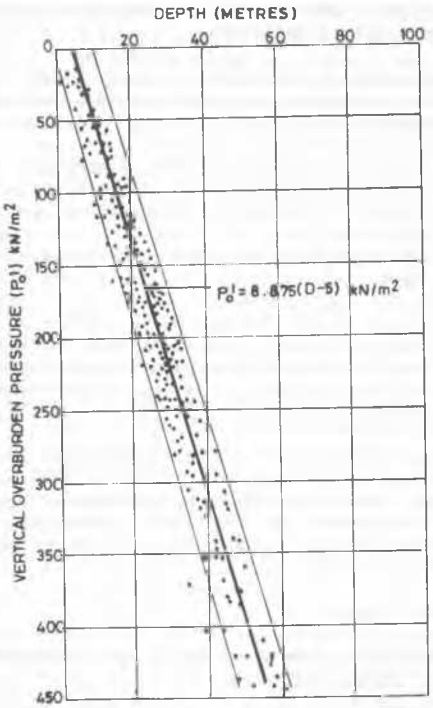

Figure 5. Depth/vertical overburden pressure relationship.

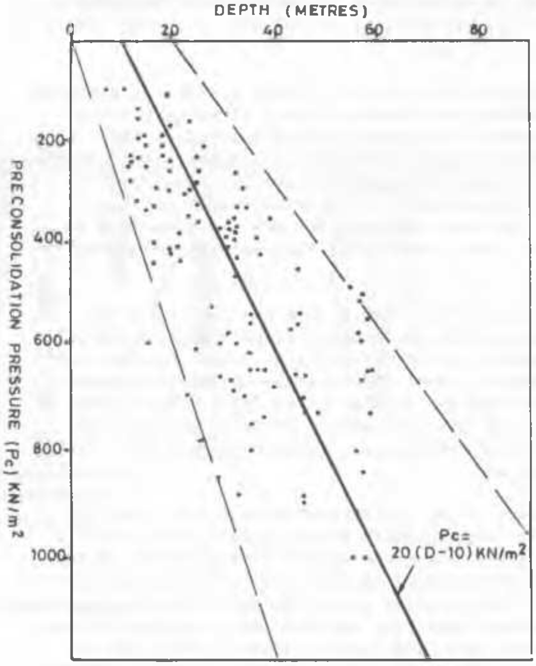

Figure 6. Depth/preconsolidation pressure relationship.

## 3. GRANULAR DEPOSITS

Within the region of Older Sands as quoted above, granular (sand) deposits predominate and are generally encountered as medium dense ranging to very dense. They can be grouped into three zones viz: Upper sands encountered above 30m depth; middle sands at 30 to 50m depths and lower sands encountered general below 50m depth.

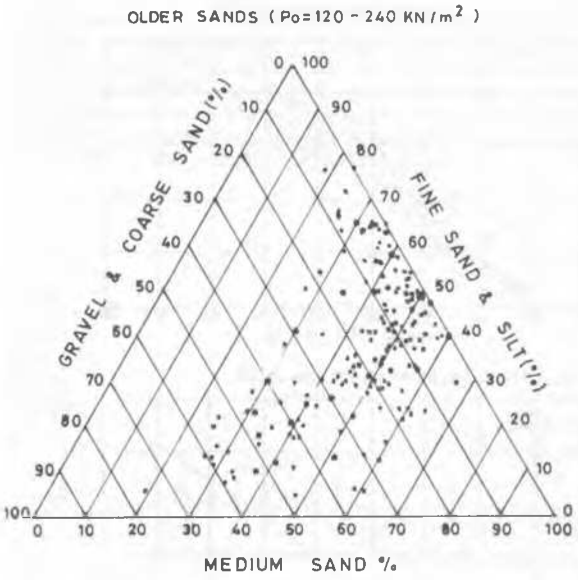

Figure 7. Textural classification

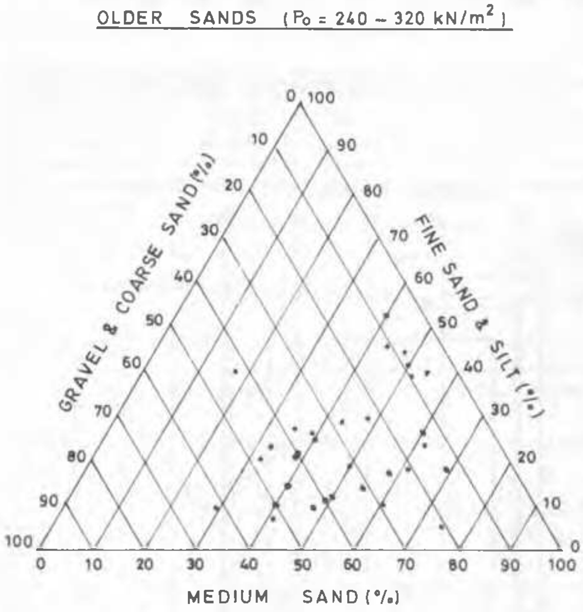

Figure 8. Textural classification.

3.1 Textural Classification

Textural classification of the three groups is shown on Figures 7, 8, and 9. It can be observed that the upper sands at effective overburden pressure $P_o' = 120$ to 240 kN/m² are generally silty or very silty, with not more than about 60% coarse grained particles, 20 to 65% medium grained particles and 5 to 80% fines, being clayey in places.

The middle sands at $P_o'=240$ to 320 kN/m² are generally silty, having 5 to 60% coarse particles, 30 to 75% medium grained particles and 5 to 55% fines due to occasional clay patches and nodules therein.

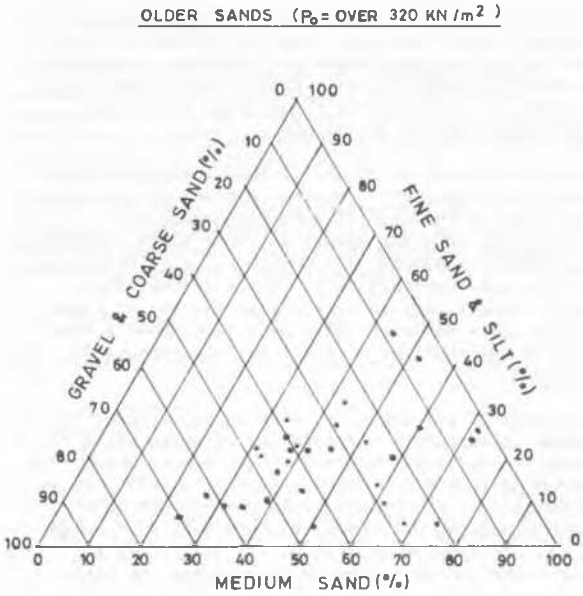

Figure 9. Textural classification.

The lower sands at $P_o'$ greater than 320 kN/m² are usually less silty and most coarser grained at 5 to 70%; with medium grained particles at 25 to 75% and fines generally 5 to 30%. There are evidences of occasional clayey inclusions and appreciable fine gravel content.

3.2 Consistency

Standard penetration test N-values obtained through the use of free falling trip-hammer, have been plotted against effective overburden pressure ($P_o'$) on Figure 10, from which it can be observed that N-values in the granular deposits range between 10 and about 160. The points scatter widely but can be enclosed within two straight lines $N = 0.45\ P_o'$ and $N = 0.023\ P_o'$ both conforming with the norm that N-value increased proportionately with depth or effective overburden pressure. However, by linear regression analysis the 'best fit' line (correlation) for use in design is found to be:

$$N = 0.168\ P_o' - 1.4 \quad \ldots\ldots\ldots\ldots \quad (3)$$

(correlation coefficient (r) 0.51)

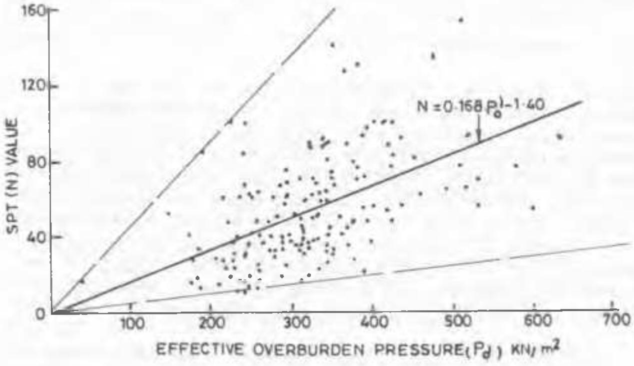

Figure 10. Standard penetration test (N) values and effective pressure ($P_o'$) relationship for older sands granular deposits.

Few relative density test results were available and showed that in situ relative densities generally range between 65% in the upper sands and 100% from within the middle sands through the lower sands. Effective angle of friction (Ø') from direct shear tests at in situ density usually exceed 35 degrees.

As site investigation boreholes have shown, the middle and lower sand deposits contain patches or thin bands of clay, often lenticular in nature and occuring haphazardly at different levels in these sands. Lenses of clay between boreholes can therefore be quite easily missed by a site investigation. There is therefore always the danger present that a pile bearing in these middle and lower sands can terminate just above a clay layer/lense and have its bearing capacity eventually much reduced.

Being aware of the danger of such an occurrence, it is prudent to formulate a foundation solution which minimises the influence of clay lenses should they occur just below pile founding level. In this context, it is important to note that with a pile passing through relatively compressible layers to terminate in a dense layer, the end support derived by the pile after a period of time is the criterion for judging the behaviour of the pile.

Very often, problem arise as to deciding on whether or not to use large diameter heavily loaded piles, or smaller diameter piles of medium to low load carrying capacity in such situation as encountered in the Niger delta formation. The advantage of using smaller diameter lower load carrying pile is that since ultimately a large proportion of the load on the piles will be transferred to the dense sand layer at depth, and since the sand contains unpredictable lenses of clay, it is safer to spread the load as uniformly as possible through the sand. In the case of larger diameter more heavily loaded piles, the effect of a clay lense just beneath the pile base will be very marked (since stresses will extend much deeper than in the case of a smaller diameter pile) and the load transfer to other piles farther away will be much greater.

## 4. COHESIVE DEPOSITS

The cohesive deposits of the Niger delta older sands are sandy, silty or organic clays including compressed peat and clayey silts, generally of varying thickness and deposition, interspersed in the sands described above. For the purpose of this exercise, these deposits are divided into silty and organic clays including peat as one group; sandy clays, clayey sand and silt as the other group.

### 4.1 Classification

Liquid limits ($W_L$) range between 22% and 147% while plastic limits ($W_P$) range between 7% and 86%. However, some of the compressed peats have liquid limit upto 200% and plastic limit 127%. On figure 11 (a) and (b) are plotted liquid limit ($W_L$) against plasticity index ($I_P$) for the two groups. In both cases the points cluster mostly above the Casagrande A-Line, indicating clays of low to high plasticity. Some results of peaty samples plot below the A-line as expected. These graphical presentations are very similar to that shown by Ajayi (1980) for the Lagos area deposits.

Liquidity index ($I_L$) ranges between + 0.8 and - 0.4 confirming the generally overconsolidated nature of the clays.

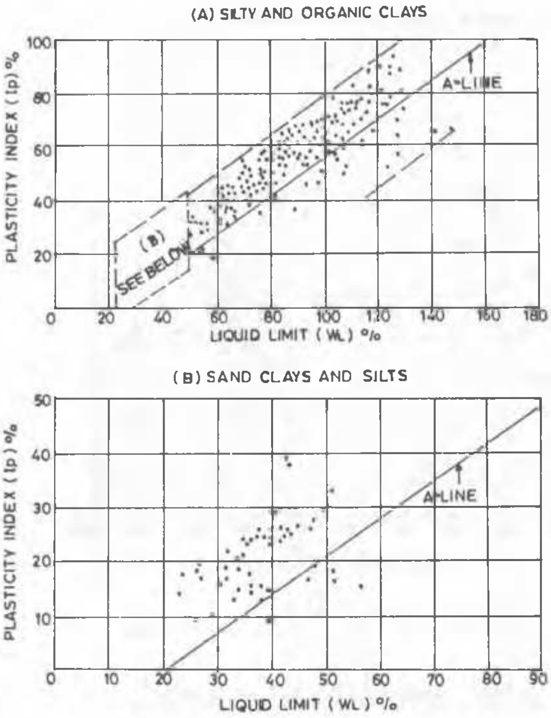

Figure 11. Liquid limit/plasticity index relationship.

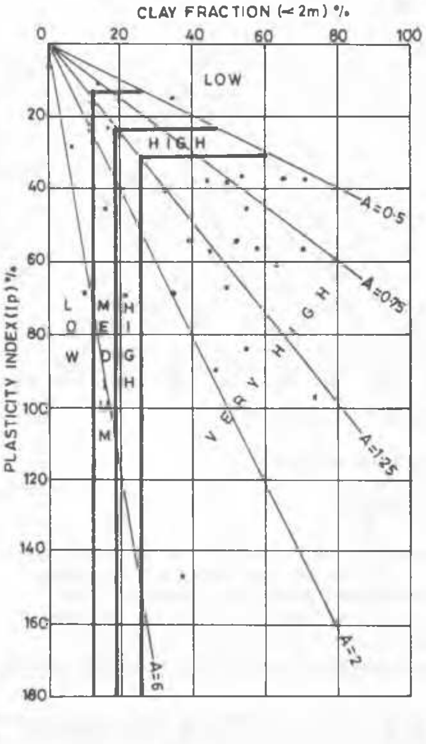

Figure 12. Plasticity index/clay fraction relationship.

For activity classification, clay content ($<2\mu\%$) is plotted against plasticity index ($I_p$) on a Skempton activity chart, figure 12. Although, it can be observed that majority of the points fall within the high to very high activity region, confirming the high compressibility of most of the clays, oedometer tests have shown that they are not the swelling type.

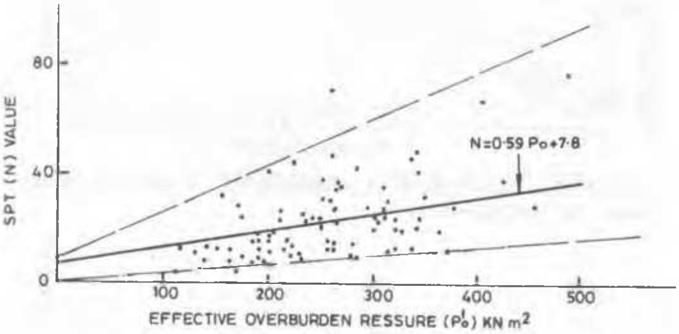

Figure 13. Standard penetration test (N) values and effective pressure ($P_o'$) relationship for older sands cohesive deposits.

## 4.2 Consistency

Standard penetration test N-values for the cohesive deposits are plotted against effective overburden pressure ($P_o'$) on figure 13. As is the case with sands on figure 10, the points are enclosed within two straight lines, $N = 0.167\ P_o'$ and $N = 0.033\ P_o'$. The mean relationship was established by linear regression analysis as:

$$N = 0.059\ P_o' + 7.8 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

(correlation coefficient 0.31).

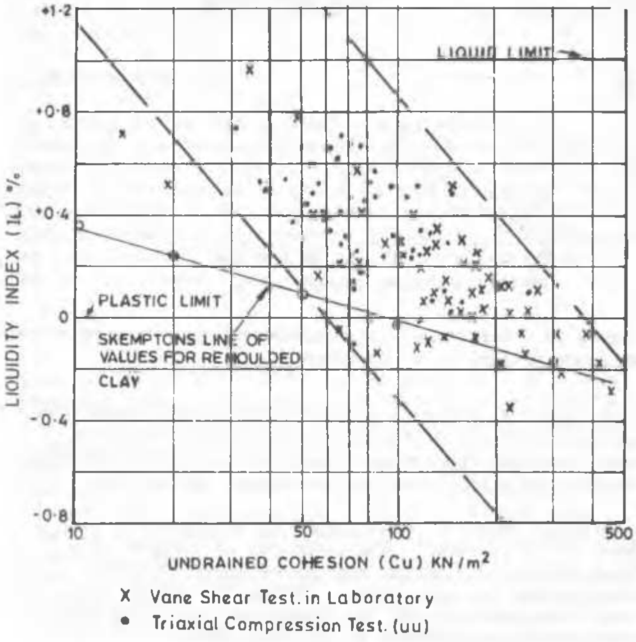

Figure 14. Liquidity index/undrained cohesion relationship.

## 4.3 Shear Strength

Liquidity index ($I_L$) is plotted against undrained cohesion ($C_u$) from laboratory vane and triaxial compression tests on Figure 14. It can be observed that most of the points lie within two parallel lines with slope of 1.5 per log cycle.

The ratio $C_u/P_o'$ ranging between 0.1 and 1.9 is plotted against plasticity index ($I_p$) on figure 15. The points scatter widely and by means of linear regression analysis a relationship:

$$C_u/P_o' = 0.37 + 0.0036\ I_p \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

was obtained, with correlation factor of 0.21.

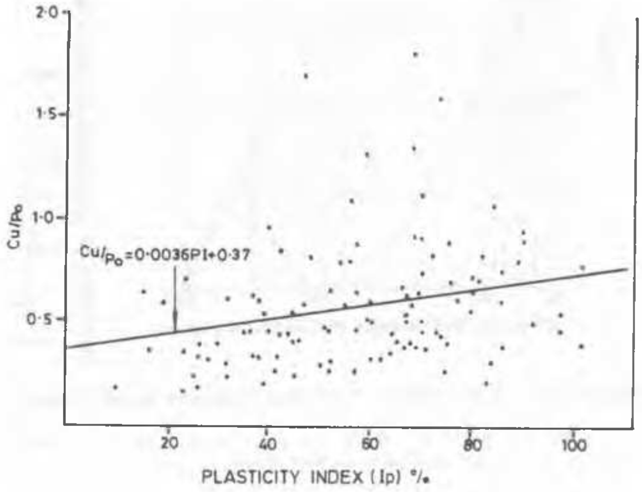

Figure 15. Cohesion/overburden pressure and plasticity index relationship.

It is pertinent to note that these clays are succeptible to sampling disturbance both in situ, due to their depth of occurence and in the laboratory, due to textural non homogeneity, stress relief and fissured structure. Hence, laboratory determined unconsolidated undrained shear strengths are more likely to under-estimate in situ strength. Not withstanding this however, the above $C_u/P_o'$ correlation gives higher values of cohesion than are obtained from Skempton's (1951) $C_u/P_o' = 0.11+0.0037\ I_p$ for normally consolidated clays. Thus, overconsolidation of the clays is once more confirmed.

## 4.4 Compressibility

In situ voids ratio (e) ranges between 0.5 and 2.5, is plotted against effective overburden pressure ($P_o'$) on figure 16. The points fell within two parallel lines represented by $e = 2.22 \log P_o'$.

Coefficient of compressibility ($M_v$) ranges between 0.02 and 0.85, has been plotted against in situ voids ratio (e), liquid limit ($W_L$) and natural moisture content (w) on figures 17, 18 and 19 respectively. In all cases, the results were fed into an APPLE 2 Micro-Computer programme to determine relevant working relationship by means of linear regression analysis and the results are as follows:-

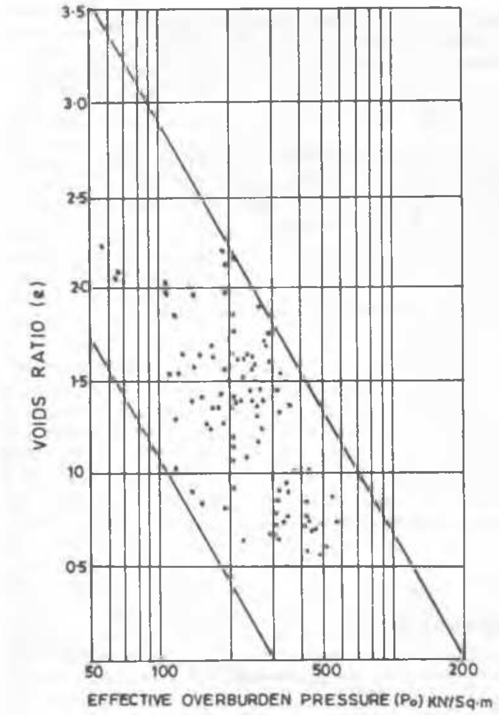

Figure 16. Voids ratio/overburden pressure relationship.

$$Mv = 0.0133e - 0.001 \quad (6)$$

(correlation factor 0.63)

$$Mv = 0.0015W_L + 0.07 \quad (7)$$

(correlation factor 0.42)

$$Mv = 0.004W - 0.024 \quad (8)$$

(correction factor 0.61)

On figures 20 and 21 are plotted the overconsolidation effects on depth (D) and plasticity index ($I_p$). It can be observed from these graphs that the cohesive deposits of the older sands comprise normally consolidated aged clays represented by constant $P_c/P_o$' ratio (1 to 2) with depth, and overconsolidated clays prevalent at depths between 10 and 50 metres, characterised by decreasing $P_c/P_o$ ratio with depth (Figure 20a) and with plasticity index ($I_p$). (Figure 21). Figure 20b shows overconsolidation is fairly constant with depth.

In view of the above, calculation of consolidation settlement of foundations stressing these cohesive deposits must apply some correction factors, such as the Skempton and Bjerrum (1957) coefficient (correction factor of the order 0.2 to 0.6) and Tomlinson's (1975) depth factor, to the calculated oedometer settlement to obtain meaningful estimation of the anticipated settlement

## 5. CONCLUSIONS

The paper discusses the geological features of the River Niger basin in Nigeria, claiming that it is of the Late Quartenary with basal pile comprising sand and clay deposits called Older Sands of early Cretaceous orgin. These are now overlain by latest accretion of soft clays, peats and loose sands called Younger Suite.

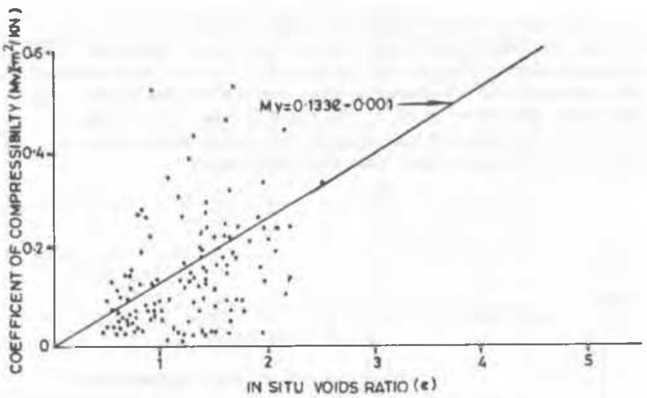

Figure 17. Coefficient of compressibility (Mv) and voids ratio (e) relationship.

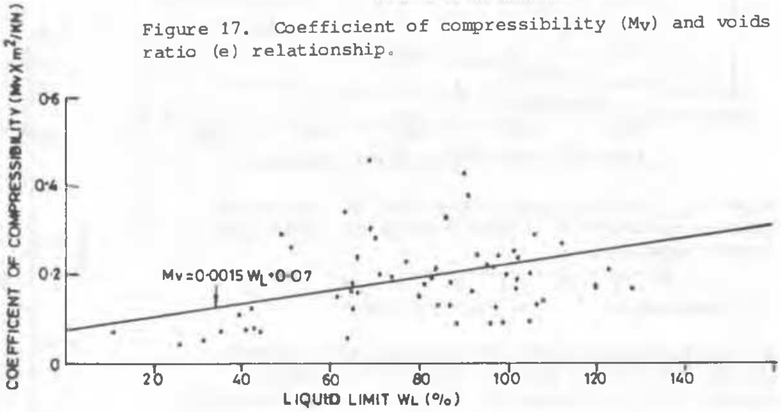

Figure 18. Coefficient of compressibility (Mv) and liquid limit relationship.

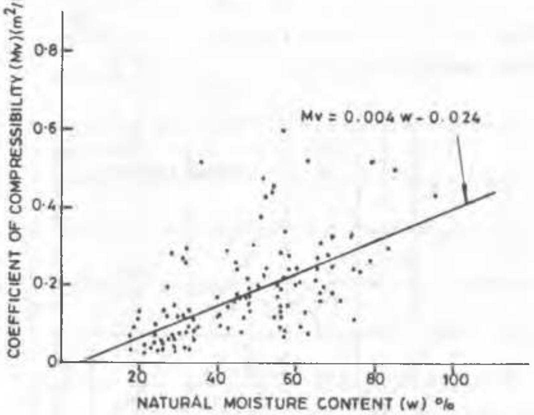

Figure 19. Coefficient of compressibility (Mv) and moisture content (w) relationship.

Geotechnical properties of the Older Sands are discussed on the basis of results of field and laboratory tests obtained from several subsoil site investigations carried out within the last two decads in the area.

Granular deposits predominate the stratigraphy to about 95 metre depth. The sands can be grouped into three segiments - upper, middle and lower deposits interspersed by clay layers. Within the middle and lower sand deposits are thin bands and lenses of clay which constitute dangers to the performance of piles bearing in these deposits.

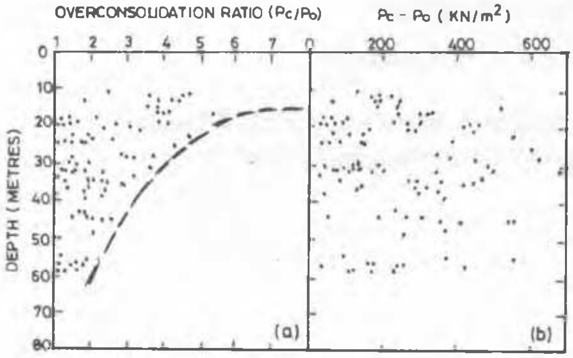

Figure 20. Overconsolidation and depth relationship.

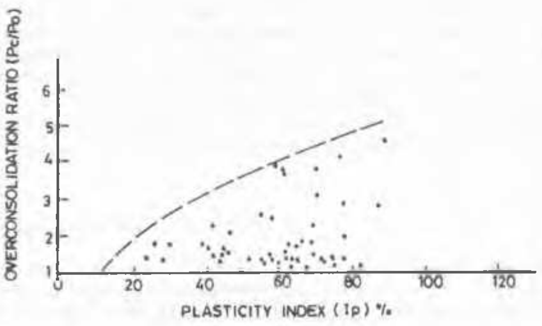

Figure 21. Overconsolidation ratio and plasticity index relationship.

The cohesive deposits are indicated to be highly overconsolidated at upper levels becoming aged normally consolidated from about 50 metre depth. Corresponding corrections to calculated consolidation settlement of foundations stressing these deposits are necessary in order to obtain meaningful estimation of the anticipated settlement.

## ACKNOWLEDGEMENT

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