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Foundation Improvement in Coastal Swamp Lands for Housing Construction: The Nigerian Case

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ABSTRACT

Increased industrial activities and the resultant population explosion in major Coastal Cities of the world, such as Amsterdam, London, and locally in Nigeria particularly Lagos, Port Harcourt, Bonny, Okrika, Brass and Warri and the consequent demand for increased residential space, have forced State and Federal Governments to undertake large scale housing development. However, the coastal lands comprising mainly swampy soils can hardly be used in their present condition without ground improvement. The methods of ground improvement have been by excavation and replacement of unsuitable foundation soils, empoldering and reclamation using hydraulic filing with fine to coarse sand. Case histories illustrating the procedures, concerns for quality control and environment are discussed in this paper. The choice of replacement material is dependent upon availability, local weather at time of construction and the load to be supported by the foundation. The minimum sand-fill thickness required to eliminate 97% consolidation settlement of underlying compressible soils in the case of sand filling are computed using graphs developed from Terzaghi's one-dimensional consolidation theory.

Keywords: *Foundation, swamp lands, housing, construction*

1. INTRODUCTION

Infra-structural development of major coastal cities such as Amsterdam, Stockholm and London portray man's struggle to overcome engineering challenges posed by swampy marginal lands (OECD 2010). Floating foundation, made popular by housing development in London involved the excavation of the unsuitable surface soil masses equivalent in weight to the load induced by the structure. In Stockholm, housing construction relied heavily on the use of wooden piles in transmitting the weight of the structures to more competent underlying layers. In contrast, marginal coastal swamp lands are made useable in Amsterdam by empoldering using a network of dykes. Many of these operations can hardly be sustained in Nigeria either because of the sheer cost or the efficiency in power supply required in running the operations. These inadequacies notwithstanding, the necessity for tackling the housing delivery programme for major coastal cities have become very urgent.

Nigeria's total land and water area is 923,768 sq km, with the area of the land being 910,768 sq km while that of water is 13,000 sq km (CIA World Fact Book, 2005). The concentration of petroleum and allied industries and the opportunities that these activities create in the coastal fringes of Nigeria, have led to an unprecedented population drift to the major coastal cities particularly Lagos, Port Harcourt, Bonny, Okrika, Brass and Warri (Fig. 1). As the populations in these cities continue to increase; there is a corresponding increase in the pressure on land. This pressure has led to the use of marginal swampy lands for housing development with sometimes-unfavorable consequences.

Marginal lands are also called; Idle, Degraded, Under-Utilised, Sleeping, wastelands and abandoned croplands (Econexus Briefing 2008). The definition of *marginal land* varies widely by country, local conditions, and the organization studying the issue (Dale et al., 2010). Rutledge (1970) defined a marginal land as one which is unsuitable for development in its original condition. Based on this definition, more than 80% of the landmass in the coastal area of Nigeria can be classified as marginal. This is consequent upon the extensive swampy superficial soil, low and flat terrain and the dense criss-cross network of rivers in the region; conditions that render extensive portions of the landmass seasonally flooded, boggy and unusable.

The widespread occurrences of swampy and marshy grounds that generally have poor load bearing qualities arise from the deposition of silt and clay during the slag periods of floods. Also, most of the rivers are actively eroding, scouring and cutting their banks, thus further restricting housing developments to already low areas within the flood plains and exposing more landmass to flooding.

The diverse peculiarities of the physical environmental conditions that confront the Nigerian coastal area make the adoption of any of the European solutions unwise. This paper therefore explores the scope of the engineering problems that are encountered in housing development in the coastal region for human habitation and the methods of ground improvement of coastal marginal lands in Nigeria for housing construction purposes.

2. OBJECTIVES

The main objective of this study is to discuss the three techniques by which marginal swamplands have been transformed to support housing infrastructure in the coastal areas of Nigeria, carry out tests in other to determine the most effective reclamation method for marginal lands in the coastal area of Nigeria.

PHYSICAL BACKGROUND OF THE COASTAL AREAS OF NIGERIA

The coastal area of Nigeria is located at the southern end of Nigeria along a coastline span of more than 250km (Fig. 1). It is low lying with heights of not more than 3.0 m above sea level. (Dublin- Green *et al*, 1997). It is characterized by an intricate network of rivers, with complex discharge patterns which in combination with other coastal processes have resulted in the formation of several morphological units, the major ones being meander belt, coastal plain sediments, fresh water swamp deposits, mangrove swamp, beach ridges and bars (Abam, 1996). Figure (2) provides the lithological succession in selected locations of the several occurring morphological units. Although housing infra-structure exists in each of these, by far the most utilized with minimum improvement is the coastal plain sediments.

The coastal zone also experience two distinct climatic seasons as reflected on a typical evapo-transpiration and concurrent precipitation graph for a typical community in the coastal area (Fig 3).

The Nigerian coastal zone experiences a tropical climate consisting of rainy season (April to November) and dry season (December to March). High temperatures and humidity as well as marked wet and dry seasons characterize the Nigerian climate. The coastal areas have an annual rainfall ranging between 1, 500 and 4,000 mm (Kuruk, 2004).

The annual mean rainfall is very heavy, amounting to about 4,000mm for Bonny, (Annual Abstract of Statistics 2010), a coastal town in the area and location of the multi-billion Naira Liquefied Natural Gas Project with high prospects of rapidly increased population, (Abam 2014). Today, there are 606 oil fields in the Niger Delta, of which 360 are on-shore and 246 off-shore. (Nigeria Country Analysis Brief, 2005). During the dry season, the soils witness a moisture deficit, frequently resulting in shrinkage and the formation of shrinkage cracks. The moisture deficit results in deceptive high soil strength and bearing capacity. At the inception of rains, much of this strength disappears.

TECHNIQUES OF FOUNDATION IMPROVEMENT

There are broadly three techniques by which marginal swamplands have been transformed to support housing infrastructure in the coastal areas of Nigeria. These are:

(a) Removal and replacement of the unsuitable material.

(b) Filling with dredged sand and raising ground elevation above flood level and at the same time consolidating underlying compressible soils. Sometimes, the selective dumping of waste materials have been employed in reclaming limited land areas for light structures.

(c) Empoldering.

REMOVAL AND REPLACEMENT OF UNSUITABLE MATERIAL

Excavation and replacement of unsuitable sub-soil in a foundation location is readily carried out where the soil cannot be improved in-situ. However, this method of ground improvement is adopted only for large or sensitive and well-funded projects (Brain 2009). Commonly used replacement soils are sand dredged from riverbeds and sandy clay (also called lateritic soils). In a recent ground improvement exercise, laboratory determination of compaction characteristics was carried out for in-situ lateritic soil as well as imported sand to be used in back filling the excavated foundation (Construction Code of Practice 2009). Compaction tests were carried out and these were generally in accordance with ASTM D 1557 (1992) and ASTM D698-91 (1992). These tests established the maximum dry unit weight and suggested a moisture content window in which 95% relative compaction can easily be accomplished during field operation.

The compaction profiles for the lateritic sub-soils showed reasonably homogeneous characteristics with an average maximum dry density of 1.82Mg/m^3 and an average optimum moisture content of 16.8%. The profiles also showed that the degree of compaction was sensitive to the moisture content. Consequently an acceptance criterion for field compaction of the lateritic soil was set out as: γd (field) greater or equal to 1.73Mg/m^3 within a moisture content window of 15.8% (Table 1). Outside this moisture content window, the soil densification can hardly achieve the required 95% relative compaction except the compactive effort is increased by the use of a heavier roller. Progress in the compaction of the lateritic soil was therefore heavily dependent on daily rainfall statistics.

Unlike the lateritic soils the well-graded river sand dredged from surrounding riverbeds was amenable to adequate compaction over a wider moisture content window 6% - 20%. This represents a significantly lower sensitivity to moisture content, implying that progress of compaction of the sand backfill is not eminently dependent on daily rainfall amounts. The low sensitivity of the compaction of sand to water content is accentuated by the relatively high permeability of the sandy material, 2.52 x 10^2 m/sec which ensures rapid drainage.

Strict control over the moisture conditions is essential to successfully provide adequate recompaction of the excavated soil because of the significant clay content which makes the soil very soft when wet. As further illustrated by the steep slope of the compaction curve (Figure 4), the soils dry density deteriorates very fast with small increments of water beyond the optimum moisture content suggesting the soils inability to be effectively compacted when wet. The high rainfall amount in the coastal region of Nigeria (4000mm) which is concentrated in four months (June to September) invariably restricts construction activities requiring earth work, especially compaction to the dry season (December to March) when workability of the soil can be assured.

In order to reduce the influence of weather on the progress of compaction, uniform sand is frequently used as foundation replacement soil. Apart from the higher permeability which allows rapid drainage via infiltration of water, the compaction of sand entertains a wider moisture content range (Figure 4) to achieve effective compaction.

The backfilling operation consists of placing layers of sand or lateritic soil (whichever is eventually selected) not more than 200mm thick. Mechanical compaction and consolidation is then achieved after each layer is placed using a roller. Lift thickness of up to 250mm can be entertained if a heavier roller is used. Soil testing for compaction and appropriate moisture density may be required prior to placement of the next layer.

Grading qualification especially if a target dry density is desired may specify the backfill materials. An additional chemical requirement may be specified if the structure is sensitive to corrosion. In a few cases, an acceptance criteria (Table 2) had been applied to soils and water used in foundation improvement.

FILLING AND RAISING GROUND ELEVATION

Because of the difficulties associated with excavation in the coastal area (Gary, 2004), especially the influx of water and the need to elevate the base of the foundation above maximum expected surface water level, most housing developers prefer to consolidate the underlying weak bearing layer using either sand fill surcharge or any locally available materials. For small holdings at the rural coastal areas, hard organic rich sandy gravelly clay locally called "Chikoko" is generally used. The problems with this material are that, it contains significant organic matter which decomposes with time leaving voids within the foundation. Secondly, it is subject to primary settlement and can hardly be extracted in large quantities. However, settlement is very rapid, since the permeability is high. Due to reasons of availability, it is restricted to the low-income, single plot bungalow development.

Because fresh hydraulic fills are loose, waterlogged and frequently contain finer particles, their engineering properties are generally poor. Consequently, sufficient time is allowed for drainage before redistribution and compaction prior to construction of houses. In instances where the underlying compressible materials are very thick, such hydraulic sand fills can bring about adequate consolidation neither would excavation of the compressible materials be economically justifiable. In Bonny, a fill height of 12m was placed over a 30m thick soft and compressible clay layer in two loading cycles. Consolidation was so slow that sand columns were contemplated. For large and sensitive structures, resort had been made to piling which provides alternative foundation (Abam 1996). The uncertainty of fill height and amount raises pertinent questions which frequently determine the economic feasibility of the sandfill method of ground improvements (Abam and Okogbue 1993).

EMPOLDERING

This practice is not common in Nigeria. It was observed only in Lagos where clay dikes measuring 1.5m in height were built around a marginal ground and drained by surface pumps for the purpose of housing construction. The difficulty facing effective empoldering is the irregular electrical power supply in the sub-region which can not guaranty continuous functioning of the pumps. The sheer cost of this scheme and high efficiency required for its operation prohibits this option for a developing country.

3. GENERAL CONCLUSIONS

From the foregoing discussions, the following conclusions are drawn:

1. Flooding and consolidation settlement are the two most important geotechnical problems militating against housing development in the coastal marginal swamp lands of Nigeria. These problems derive directly from the hydrology, topography and geology of the area.
2. Foundation improvement involving excavation and recompaction of excavated fill consisting of lateritic soils easily leads to delays in project completion. This is because natural moisture content is frequently outside the window where adequate compaction can be achieved, whereas sand can be compacted adequately under a wider moisture content window. Failure to take the local climate into account in planning and selection of materials for such earth works can lead to costly delays.
3. Hydraulic sand filling has been found to be an effective reclamation method for marginal lands in the coastal area of Nigeria. The method, apart from raising the elevation of marginal land above flood level, serves as a pre- load device to reduce detrimental effects of settlement.

REFERENCES

Abam, T.K.S. (1996). On Soil Exploration and Foundations in the recent Coastal area of Nigeria. Bull of the International. Association of Engineering. Geologist. No-53 pp. 3-9.

Abam, T.K.S. and Okogbue, C. 0. (1993): Utilisation of marginal lands for construction in the Niger Delta. Bull of the International Association of Engineering Geologist, No. 84, pp. 5-13.

Abam, T.K.S. (2014). "Stratigraphic Constraints to Shallow Foundation Design in the Coastal Zone of Nigeria" Journal of Environment and Earth science ISSN 2224-3216 (paper) ISSN 2225-0948 (Online). Vol. 4,No.4,

Annual Abstract of Statistics (2010); Federal Republic of Nigeria. www.nigeriastat.gov.ng

ASTM D 1557 (1992): Test method for laboratory compaction characterization of soils using modified effort.

ASTM D 698 (1992): Test method for Laboratory compaction characterization of soils using standard effort.

Brain.P.S (2009): "How to Estimate the cost of Undercutting & backfilling Unstable subgrade soils" technical paper:www.aspenational.org

CIA (2005): The World Fact book -- Nigeria.https://www.cia.gov/library/publications/the-factbook/geos/ni.html

Construction Code of Practice for the Sustainable Use of Soils on Construction Sites (2009): department for Environment, Food and Rural Affairs Nobel House 17 Smith Square London SWIP3JR. www.defra.gov.uk

Dale, V.H., K.L. Kline, J. Weins, and J. Fragione. (2010). Biofuels: Implications for land use and biodiversity. Biofuels and Sustainability Reports. Ecological Society of America, Washington, DC. Available at www.esa.org/

EcoNexus briefing (2008): "*Agrofuels and the Myth of the Marginal Lands*" The Gaia Foundation, Biofuelwatch, the African Biodiversity Network, Salva La Selva, Watch Indonesia and EcoNexus

Gary B.M., (2004): Understanding Soil Risks and Hazards Using Soil Survey to Identify Areas with risks and Hazards to Human Life and Property. The U.S. Department of Agriculture (USDA)

Kuruk, P., (2004): Customary Water Laws and Practices: Nigeria http://www.fao.org/legal/advserv/FAOIUCNcs/Nigeria.pdf.

Nigeria Country Analysis Brief, (2005): Nigeria Country Analysis Brief. http://www.eia.doe.gov/emeu/cabs/nigeria.html

OECD (2010), Cities And Climate Change http://www.oecd.org/education/skills-beyond-school/educationataglance2010oecdindicators.htm

Rutledge P. C,, (1970): Utilization of Marginal Lands for Urban Development, ASCE, Soil Mech. Vol. 96, No. S. M.I. pp. 2-22

Table 1: ACCEPTANCE CRITERIA FOR COMPACTION AND OPTIMUM MOISTURE CHARACTERISTICS OF LATERITIC SOILS FOR FOUNDATION IMPROVEMENT

S/No	MAXIMUM DRY DENSITY, MDD (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)
1.	1.84	16.2
2.	1.83	16.0
3.	1.78	18.0
4.	1.82	17.0
AVERAGES	**1.82**	**16.8**
ACCEPTANCE CRITERIA	**Not less than 95% of laboratory maximum (i.e. Greater than 1.73 Mg/m^3)**	**Operating Moisture Content window 15.8 to 19.8%**

Table 2: ACCEPTANCE CRITERIA FOR SOILS AND WATER USED IN CORROSION SENSITIVE STRUCTURE

PARAMETERS	VALUES ACHIEVED		SPECIFICATION	REMARKS
	Sand and Lateritic Soil	Crushed Rock		
pH	7.0	7.9	Greater than 6.5	Satisfactory
SulphateSO^{2-}_4(PPM)	7.4	7.2	Less than 1000 PPM	Accept material
Chloride Cl^- (PPM)	1.0	7.5	Less than 300 PPM	Accept material

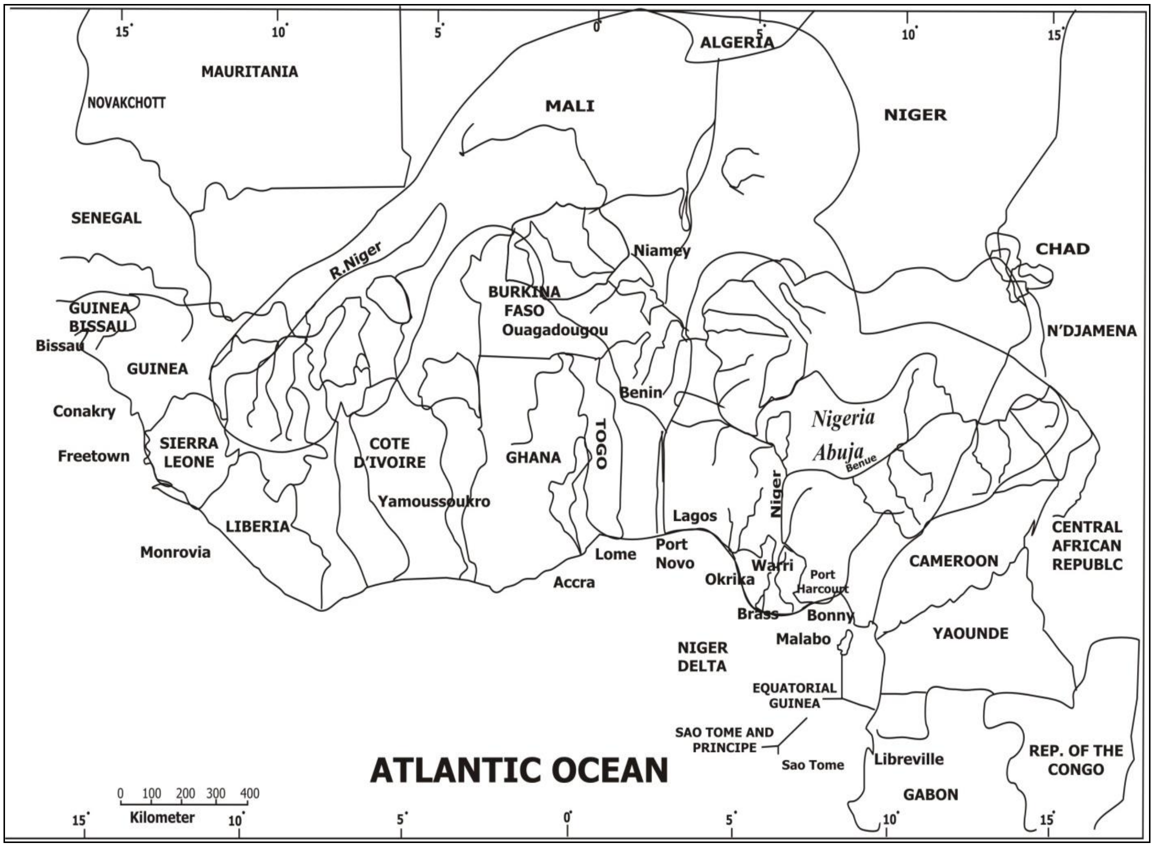

Fig 1: The West African Coast showing Coastal area of Nigeria.

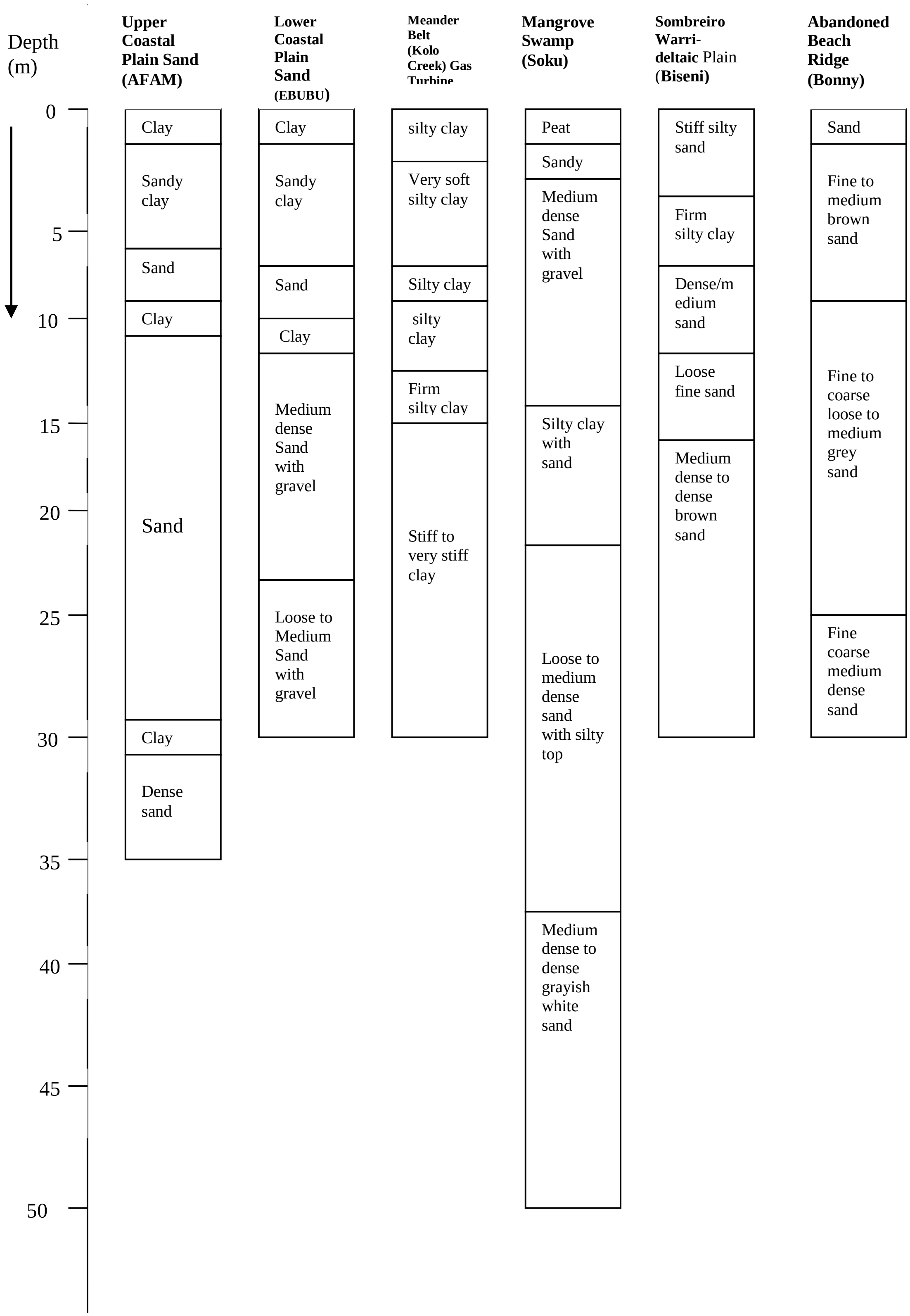

Fig. 2: Comparison of borehole records drilled at various geomorphic units (Data from Enoch George Associates, 1990)

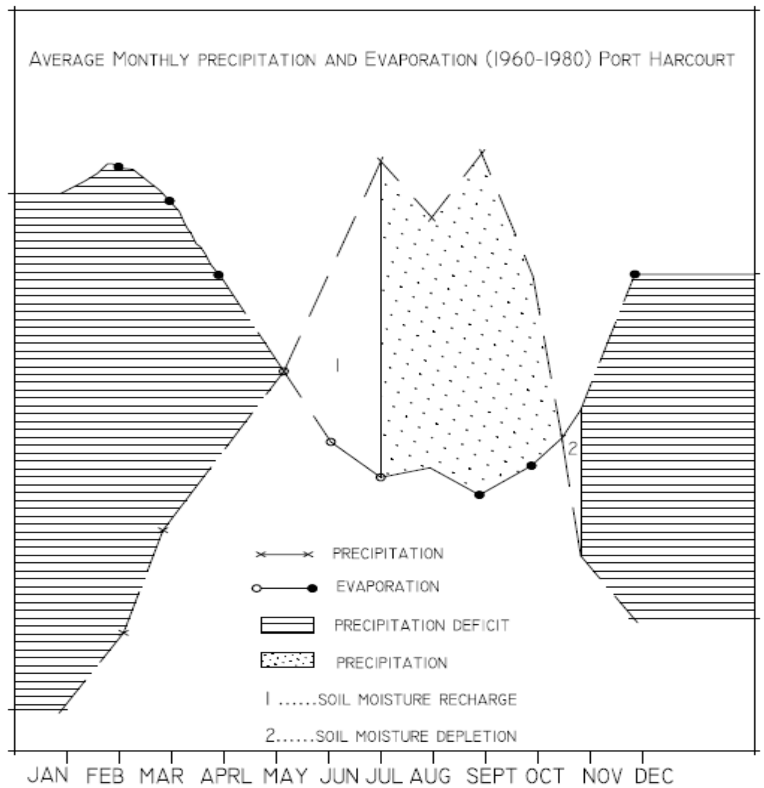

Fig. 3: A Typical Potential Evapo-transpiration and Concurrent Precipitation graph for the Niger Delta

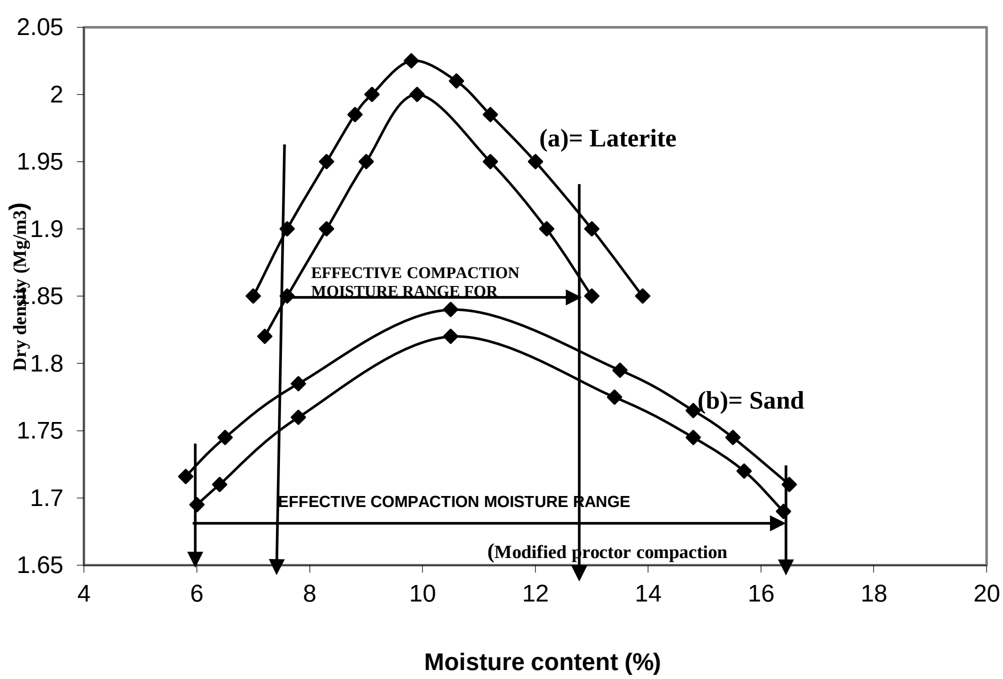

Fig. 4; Comparison of Effective Compaction Moisture Ranges for Lateritic Soil and River Sand