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Suitability techniques for transforming marginal lands to support building infrastructures in parts of Rivers State, Nigeria

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Abstract

This study examined sustainability techniques for transforming marginal lands to support building infrastructures in parts of Rivers State, Nigeria. The study adopted the cross-sectional survey research design method employing the use of standard penetration approach utilizing Geographic Information System analysis. Marginal lands were delineated as margins of watrbodies using the polygon method in ArcGIS, and were created as a feature class for polygon data (shape file). The locations, river margins and roads formed point data, polygon data and line data respectively. Digitisation was achieved using Orthophoto Image in ArcGIS 10.0 software where seven geotechnical boreholes were located and drilled using permission rig to a depth of 10.5m in five local government areas of Rivers State. In-situ standard penetration testing and soil sampling for laboratory geotechnical properties was done using standard laboratory techniques. Findings of the analysis show that silty and sandy clay are the dominant soil within the foundation depth of 1-2.5m which are underlained by clays and sands of varying densities and grain sizes with their specific gravity value of ranges of 1.9 – 2.66 depicting that the areas are underlined by organic, diatomaceous and high porosity permeability soils deposits under water logged conditions. The cohesive strength of the soils vary from 65KN/m ^{2} - 115KN/m ^{2}, angle of internal friction ranged from 0^o – 10^o and shear strength ranged from 110KN/m ^{2} – 147.46KN/m ^{2} and the allowable bearing capacities of 180.22KN/m ^{2} – 236.05KN/m ^{2}. The stability techniques for the transformation of the land to support building infrastructures are pre-construction soil stabilization and marginal land reinforcement. The study thus recommends for building summation of consolidated techniques for sustainability of infrastructures.

Keywords: Sustainability; Techniques; Transformation; Marginal Lands and Infrastructure

1 Introduction

As urban population increased, there is the need to provide housing and infrastructure to accommodate the rising population. Buildings and indeed all infrastructures are very important in any human society underscoring their designation as sustainable development goals 9 and 11 by the United Nations Agenda 2030. Sustainability implies that a building has to satisfy the housing needs of today without compromising those of the future generations (Abija, 2019). Geotechnically, sustainability translates into robust design and construction, involving minimal financial burden and inconveniences, minimal use of resources and energy in planning, design, construction and maintenance of geotechnical facilities; and the use of materials and methods (Abija, 2023). Building infrastructures also are to be resilient especially in the face of current climate change induced realities, an objective which can only be achieved by choosing, designing and constructing suitable foundations to bear and transmit all the structural loads (live and dead) from the superstructure to the ground without causing any form of failure. Because all buildings are founded on the

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ground, there is continuous pressure on the non-renewable land resources in most-urban cities occasioned by people migrating and settling on lands that were termed marginal. Buildings development and construction and the built up environment have a direct linkage with increasing population growth rate as well as a geometrical decrease in land use and land cover forcing new areas to be acquired with every new development including areas that were termed marginal lands. Rutledge (1970), defined marginal land as one which is unsuitable for development in its original condition. The ground conditions prevalent in such areas present problematic geotechnical conditions for design and construction so geometrically. It is the land which has minimal to nil industrial or agricultural value and would be of very less potential of providing profits to the owners as it is characterized by poor soil and unconducive features for both agricultural and industrial uses. Generally, marginal lands are found at the edges of places where there are lots of sand deposits, deserts, and other barren areas. Lands that are located at a distance which is considered prohibitive is generally considered to be a marginal one (Pimentel, 2012). Land may be marginal for a number of reasons, including poor water supply, poor soil quality, pollution from previous industrial activities, terrain challenges such as excessive slope, or excessive distance from means of transportation (Pimentel, 2012).

Typical foundation ground conditions prevalent in such lands include flood plain and their metastable soils (organic, collapsible and expansive soils), liquefiable ground, reclaimed ground and dilatant soils. The design of building foundations is concerned with both the ability of the soil to support the load and ensuring that the probability of failure of the structure is kept at the barest minimum or an acceptably low value under ultimate limit state condition (bearing capacity) and satisfactory serviceability (settlement) behavior guaranteed (Abija, 2023). Geotechnical challenges of marginal lands include (1) bearing failures, (2) large total and differential settlements, (3) instability, (4) liquefaction, (5) erosion, and (6) water seepage. Bearing failure phenomenon inherent in pressure application in soil at the foundation and exceeding the ultimate bearing capacity of soil and caused by high applied pressure, inclined loading condition, small loading area and low-strength or weak soil. Large total and differential settlements due to compressible soil grain and or particle re-arrangement upon water expulsion when loaded by high applied building pressure in the large loading foundation area and non-uniform soil creep deformation, are subject to building failure and collapse (Abam, 2014).

Rivers State has several swampy and marginal lands were developments are tilting towards, and development has infringed on them, therefore there is the need to provide technical and suitability support for marginal land in order to transforming them to support building infrastructure. This study examined suitability techniques for transforming marginal lands to support building infrastructures in parts of Rivers State, Nigeria.

2 Materials and Methods

2.1 Description of Study Area: Location and Geohydrology

Rivers State lies in the southern parts of Nigeria within the Niger Delta basin in the Niger Delta region (Fig. 1).

Figure 1 Niger Delta showing Rivers State and its Environ

Source: Author's Design (2023)

The inland part of the state consists of tropical rainforests, and towards the coast, the typical Niger Delta environment features many mangrove swamps. Rivers state has a total area of 11,077km ^{2} (4.277m ^{2}); with 34 major marginal (land) settlements spread across the city (Kio-Lawson, 2013) (Not in reference list). It is bounded on the south by the

Atlantic Ocean, to the north by Imo, Abia and Anambra states, to the east by Akwa Ibom state, and to the west by Bayelsa and Delta states (Fig 2).

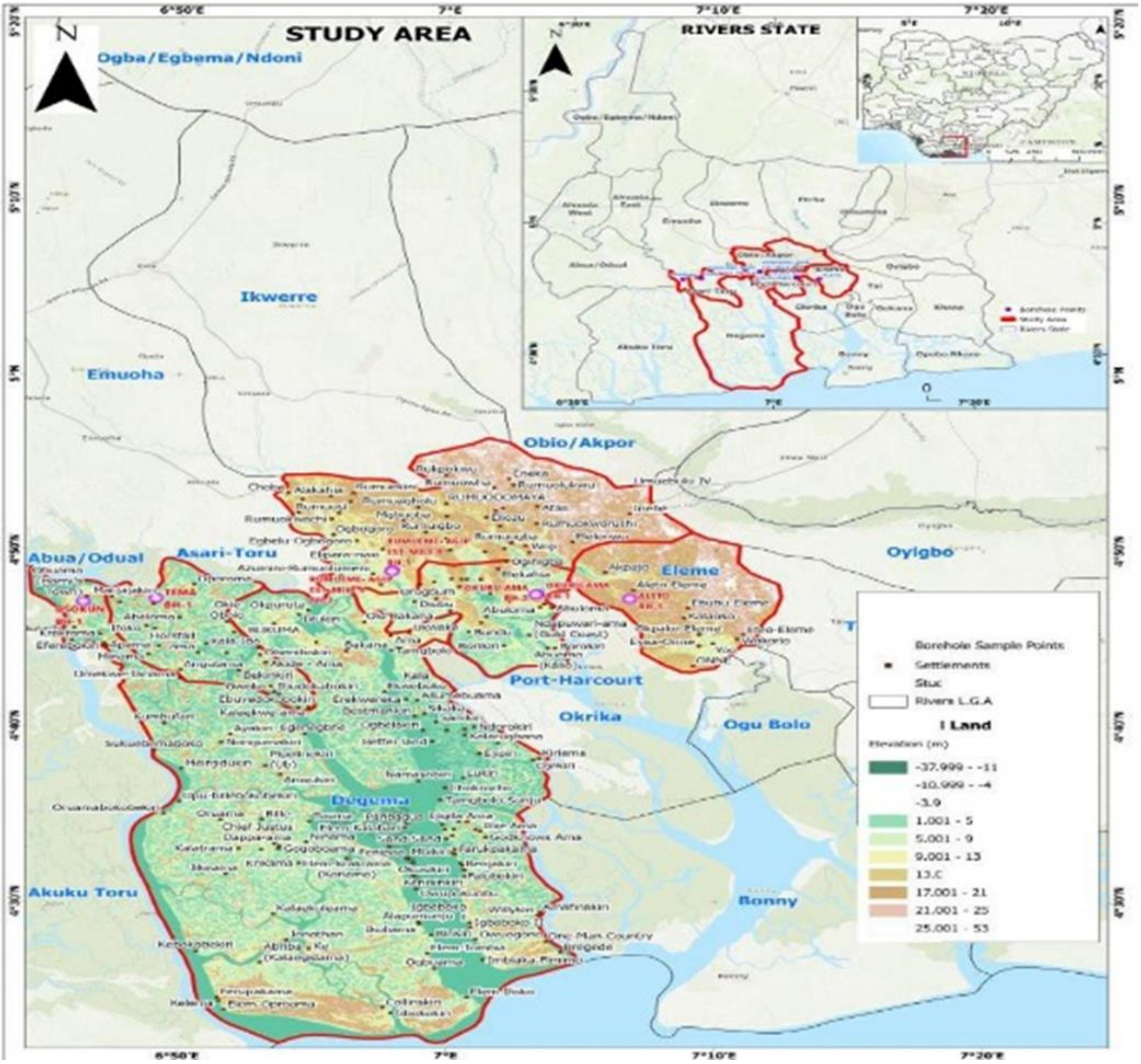

Figure 2 Study Area Showing Rivers and Neighbouring States

Source: Author's Design (2023)

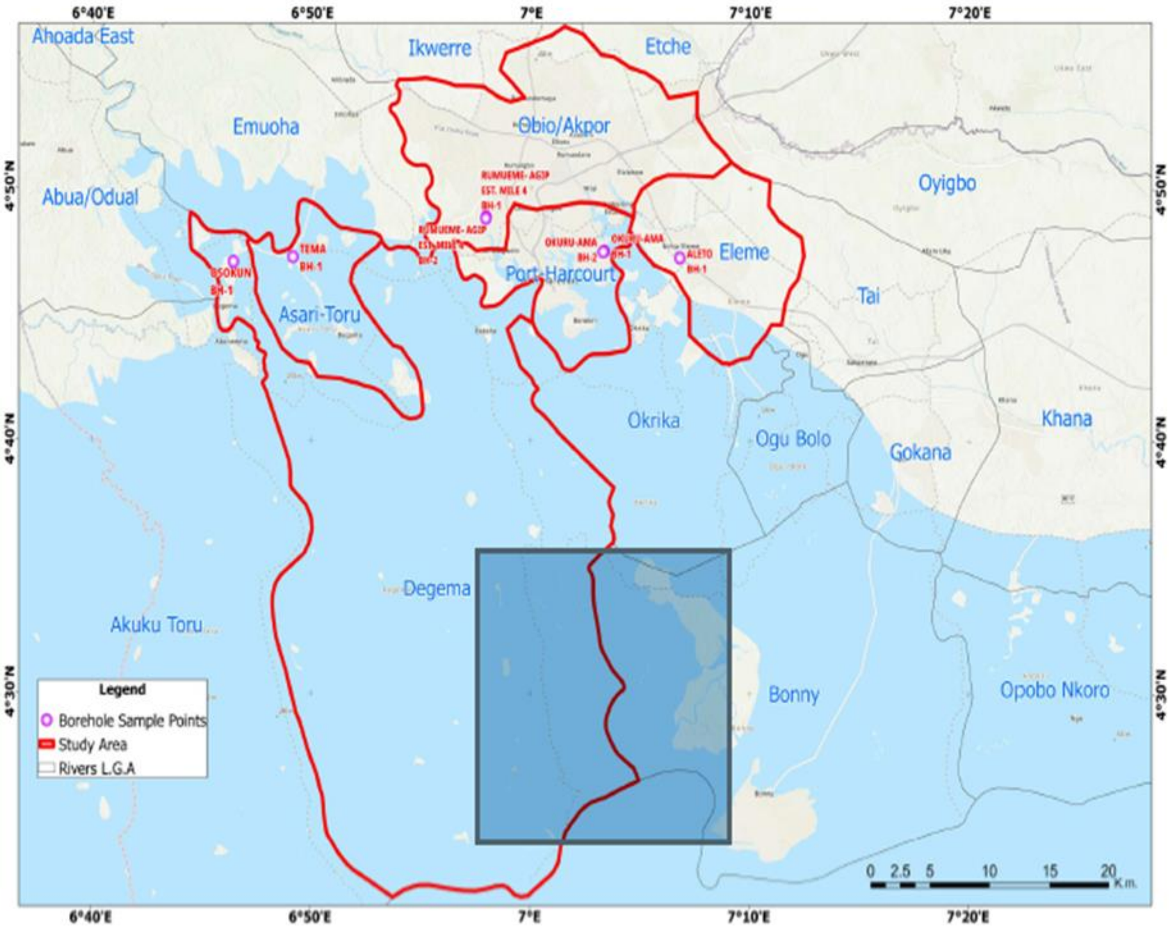

Figure 3 Rivers State showing the selected Local Government with Geotechnical Borehole locations

Source: Author's Design (2023)

Geohydrologically, the study area is crisscrossed by an intricate network of rivers and their discharge patterns result in the formation of several morphological units, the major ones being the Meander belt, deltaic plain, fresh water and back swamp deposits, mangrove swamp, beaches and bars (Abam, 2016, Akpila, 2013; Chris 2013 & Das 2011). There are two distinct climatic seasons namely the rainy season which occurs between the months of April all through to November: while the dry season lasts between Decembers through to March. The annual mean rainfall is very heavy, measuring about 4.2mm for Bonny, a coastal town in Rivers State. During the dry season, soil moisture deficit frequently occurs resulting in shrinkage and the formation of shrinkage cracks. These cracks are later filled with water resulting most often to the swelling of the soils and a further deterioration of the soil's conditions. Swamps distribution is widespread in the Niger Delta due to the abundance of near surface silt and clay deposits, a general flat topography and consequent insufficient drainage capacity (Dale et al., 2010; Galvin, 2016 & Han, 2015).

The study adopted the cross-sectional survey research design method employing the use of standard penetration approach utilizing Geographic Information System analysis. Marginal lands were delineated as margins of waterbodies using the polygon method in ArcGIS, and were created as a feature class for polygon data (shape file). The locations, river margins and roads formed point data, polygon data and line data respectively. Digitization was achieved using Orthophoto Image in ArcGIS 10.0 software where seven geotechnical boreholes were located and drilled using permission rig to a depth of 10.5m in five local government areas of Rivers State. In-situ standard penetration testing and soil sampling for laboratory geotechnical properties was done using standard laboratory techniques (Figure 3).

3 Results and Discussion

3 . 1 Index, identification, classification and strength properties of the foundation soils

Results of the geotechnical analysis of soil samples retrieved from the borings indicates that the moisture content (W_n%) varies as 21.3%, 21.48%, 17.42%, 29.99%, 21.8%, 35.9% in Obio/Akpor borehole 1, Obio/Akpor borehole 2, Asalga borehole 2, Phalga borehole 1, Phalga borehole 2, Eleme borehole 1, while Degema borehole 1 recorded moisture content of 25.8%, 25.52% and 35.82% at 6.0 – 10.5m, 2.25m – 4.4m, and 7.5m – 9m depths respectively (Table 1, Figure 4).

The density of the soils was 1619kg/m^3 in Obalaga 1, 1815kg/m^3 in Obalga 2, 1948kg/m^3 in Tema Asalga, 1925kg/m^3 in Phalga 1, 1945kg/m^3 in Phalga 2, 1705kg/m^3 in Eleme and 1800kg/m^3 in Degema Osokun locations (Table 4.1, Figure 4.4 and Appendix 1). The dry unit weight of the soil samples was 16.0kN/m^3, 18.5kN/m^3, 15.6kN/m^3, 11.31kN/m^3, 11.31kN/m^3, 13.94kN/m^3, and 17.6kN/m^3 in Obio/Akpor borehole 1, Obio/Akpor borehole 2, Asalga borehole 2, Phalga borehole 1, Phalga borehole 2, Eleme borehole 1, and Degema borehole 1 respectively (Table 1, Figure 5). The bulk unit weight was 20.6 in Obala 1, 21.0 in Obalga 2, 19.2 in Tema Asalga, 15.4 in Phalga 1, 19.1 in Phalga 2, 15.5 in Eleme and 19.6 in Degema Osokun. The specific gravity (G_s) was 2.35, 2.31, 2.57, 2.66, 2.29, 2.46, 2.23 and 1.9 in Obio/Akpor borehole 1, Obio/Akpor borehole 2, Asalga borehole 2, Phalga borehole 1,

Phalga borehole 2, Eleme borehole 1, and Degema borehole 1 respectively (Table 1, Figure 6). Soil classification based on the specific gravity (ASTM D-854-9192) depicts that 87.5% of the sampled locations are underlain by organic, diatomaceous and high porosity/permeability soils deposited under waterlogged conditions while the remaining 12.5% are inorganic soils deposited from the continents. The liquid limit was 33.7%, in Obalga 2, 33.1%bin Obalga 1, 33.1% in Phalag 1, 35.1% in Phalga 2, 36% in Eleme, 33.2% in Degema Osokun while Non Plastic materials dominate the Tema Asalga location.

The Plastic limit was 13.49% in Obalga 1, 12.78% in Obalga 2, non-plastic in Tema Asalga, 12.78% in Phalga 1, 21.16% in Eleme, 17.81% in Phalga 2 and 21.36% in Degema Osokun. The Plasticity index was 20.21% in Obalga 2, 20.32% in Obalga 1, non-plastic in Tema Asalga, 20.32% in Phalga 1, 14.84% in Eleme, 17.79% in Phalga 2 and 11.84% in Degema Osokun boreholes. The amount of soil passing sieve number 200 depicting clay and fines content was 75.03%, 67.97%, 67.97%, 68.97%, 53.7% and 52.1% in Obalga 2, Obalga 1, Asalga 2, Phalga 1, Eleme, Phalga 2, and Degema, Osokun sites at the in the top 1 - 4.4M depth that often form the foundation level for all shallow foundations respectively. The undrained cohesive strength of the soils was 110kN/m^2, 65kN/m^2, 110kN/m^2, 115kN/m^2, 80kN/m^2, 80kN/m^2 and 110kN/m^2 in Obalga 2, Obalga 1, Asalga 2, Phalga 1, Eleme, Phalga 2, and Degema, Osokun (Table 1 Figure 7). Similarly, the angle of internal friction of the soil samples was 0%, 10%, 4%, 3%, 5%, 8% and 3% respectively in the sampled locations. Their shear strength values were 110kN/m^2, 135.53kN/m^2, 140kN/m^2, 138.06kN/m^2, 116.74kN/m^2, 147.46kN/m^2 and 132kN/m^2 (Table 1, Figure 8) respectively. The amount of soil passing sieve number 200 depicting clay and fines content was 75.03%, 67.97%, 67.97%, 68.97%, 53.7% and 52.1% in Obalga 2, Obalga 1, Asalga 2, Phalga 1, Eleme, Phalga 2, and Degema, Osokun sites at the in the top 1 - 4.4M depth that often form the foundation level for all shallow foundations respectively. The coefficient of uniformity of the soil samples were 2.42 in Obalga 1, 2.40 in Obalga 2, 3.41 in Tema Asalga, 2.22 in Phalga 1, 3.41 in Phalga 2 and 3.41 in Eleme study locations depicting uniformly graded marginal land soils in all the study locations. Similarly, the coefficient of curvature was 0.6 in Obalga 1, 0.72 in Obalga 2, 1.10 in Phalga 1, 0.80 in Phalga 2, 0.52 in Eleme and 0.53 in Degema Osokun. Implicitly, particle sizes D60 and D10 were missing in subgrades from all of the borehole samples but those from Phalga 1 borehole.

Table 1 Geotechnical index and strength properties of the foundation subgrades

Sample location	**Obio/Akpor BH2**	**Obio Akpor BH1**			**Asalga BH2**		**Phalga BH1**		**Eleme BH1**		**Phalga BH 2**	**Degema BH1**		
Parameters\depth	1.5M	9M	9-10.5M	1.5M-2.5M	1-2.25M	3.75-7.5M	2.25-5.5M	6.7-10.5M	9-10.5M	3-5M	1-1.5M	6-10.5M	2.25-4.4M	7.5-9M
% Passing for no. 200 sieve	75.03	0.43	0.37	67.97	26.95	0.8	68.97	2.38	0.27	53.7	1.33	1	52.1	0.75
Density (g/cm ^{3})	2.094	2.225			2.178	1.665	2.080	1.571	1.710 – 2.019		1.733 - 2.132	1.690	1.909	
Liquid limit (%)	33.7	33.1			NOT PLASTIC		33.1		36		35.10	33.20		
Plastic limit (%)	13.49	12.78					12.78		21.16		17.81	21.36		
Plasticity index (%)	20.21	20.32					20.32		14.84		17.79	11.84		
Cohesion intercept (kN/m ^{2})	110	65			110		115		80		80	110		
Coefficient of curvature cc	0	0.6	0.73	0.73	0.53	0.53	0	1.09	0.53	0	1.07	0.82	0.53	0.53
Coefficient of uniformity cu	0	2.44	2.4	2.4	3.42	3.42	0	2.22	3.42	0	1.67	2.04	3.42	3.42
Angle of Internal Friction (deg.)	0	10			4		3		5		8	3		
Shear strength kN/m ^{2})	110	135.53			140		138.06		116.74		47.46	132		
Normal stress (kN/m ^{2})	428.48	455.18			449.55		446.68		430.29		455.18	441.09		
Bulk unit weight (kN/m ^{3})	20.6	21			19.2		15.37		15.37		19.09	19.6		
Dry unit weight (kN/m ^{3})	16	18.5			15.6		11.31		11.31		13.94	17.6		
Moisture content (%)	21.3	21.48			17.42		29.99	21.8			35.9	25.8	25.52	35.82
Specific gravity	2.35	2.31			2.57		2.66	2.29	2.46		2.23	1.9		

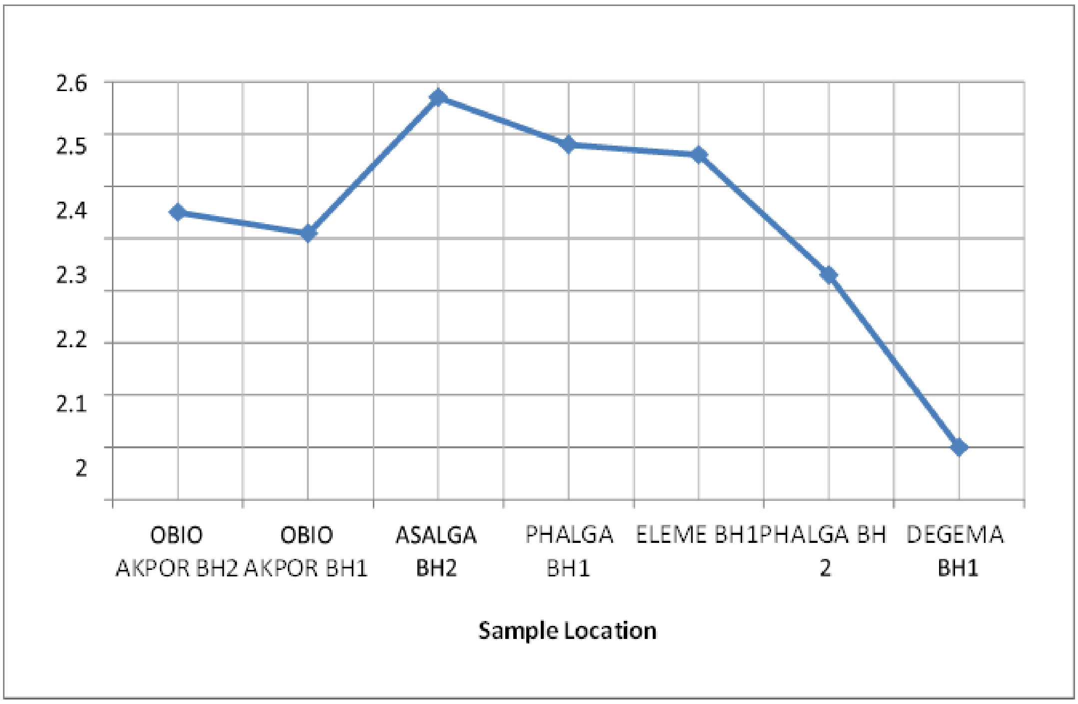

Figure 4 Spatial variation of specific gravity

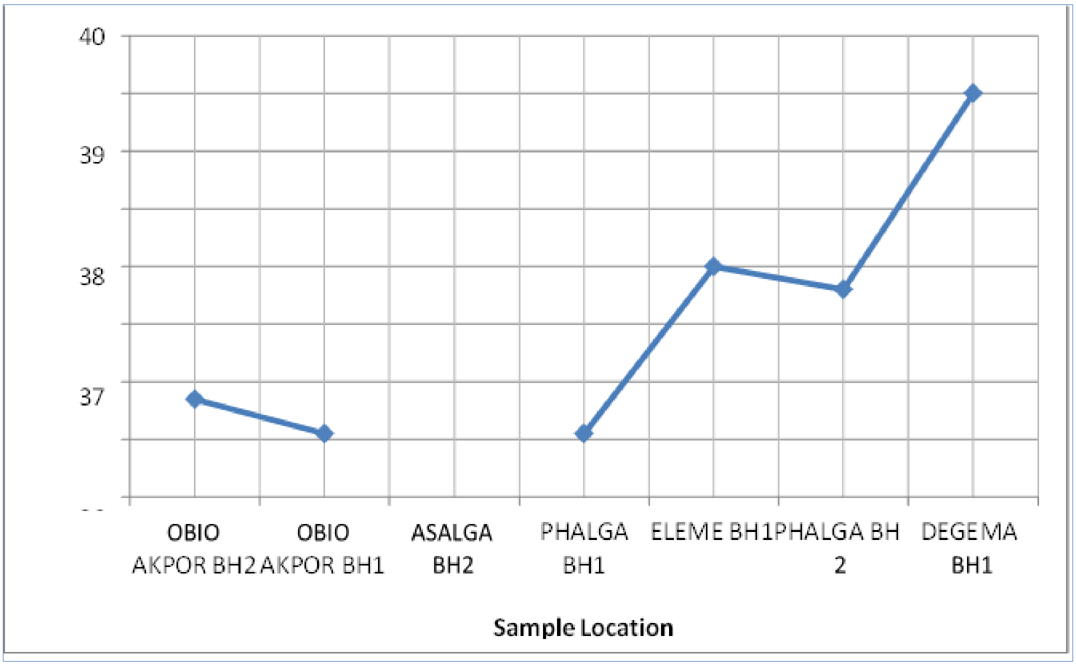

Figure 5 Spatial variation of liquid limit

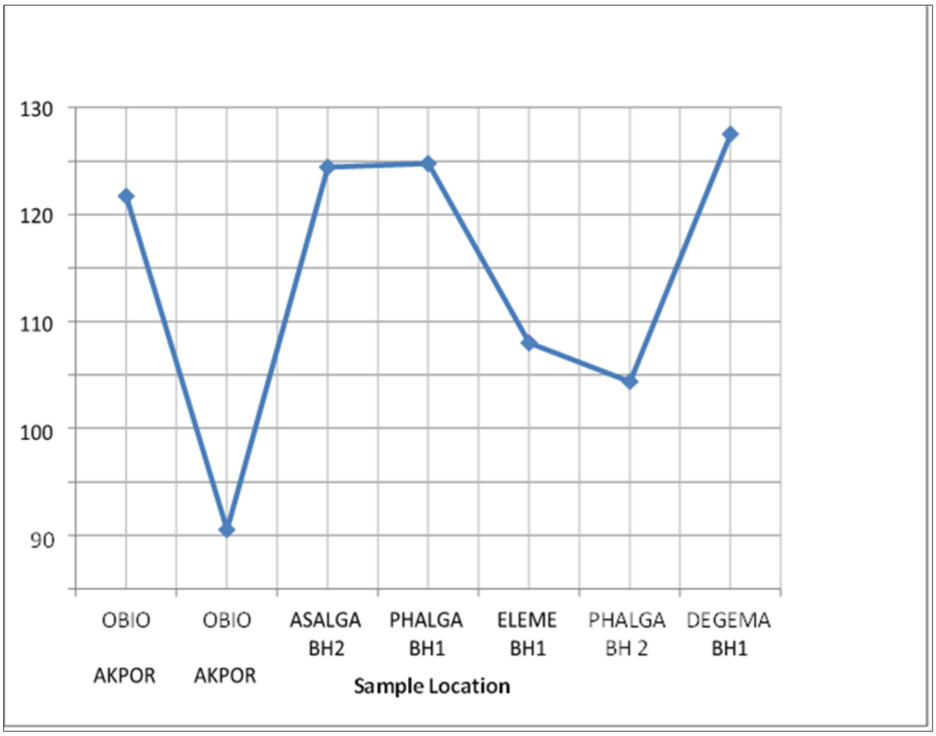

Figure 6 Spatial variation of cohesive strength

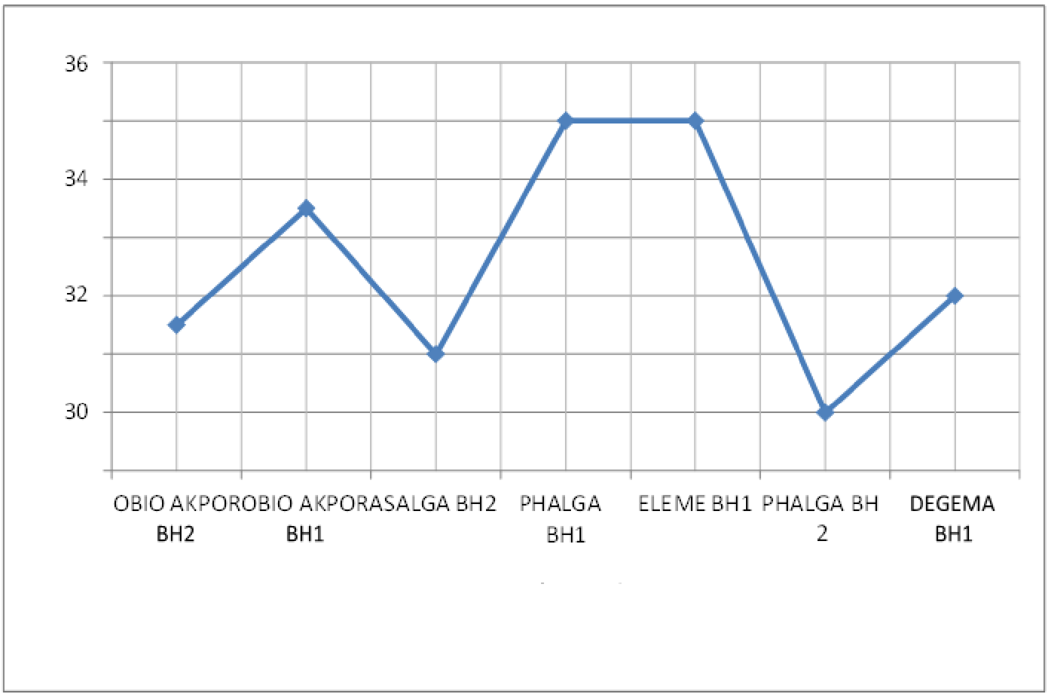

Figure 7 Spatial variation of angle of internal friction

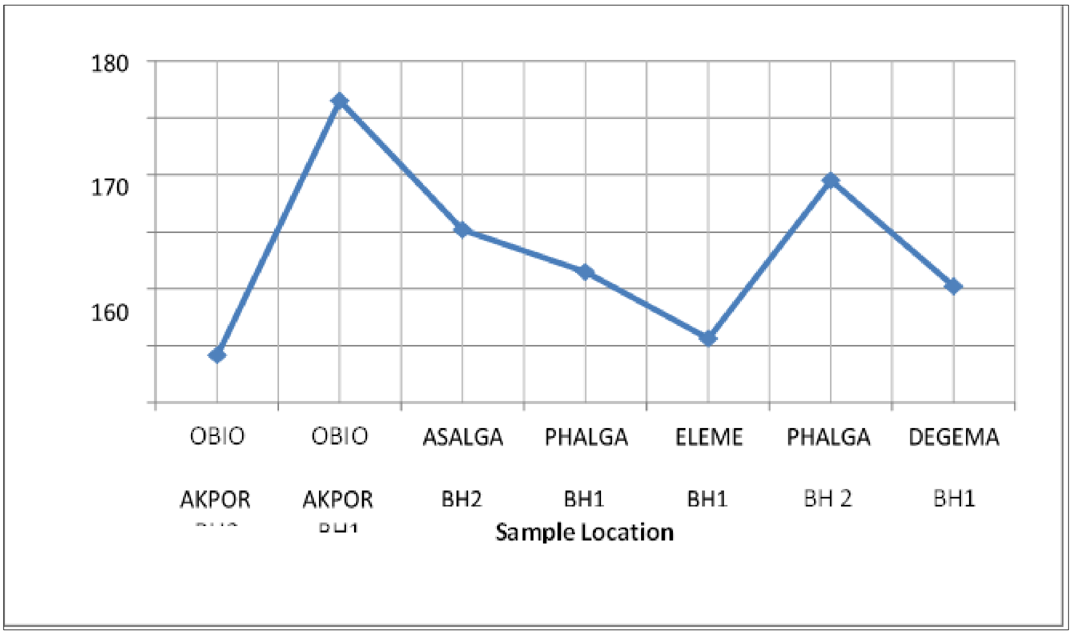

Figure 8 Spatial variation of shear strength

3.2 Suitability Techniques for Transforming Marginal Land

3.2.1 Bearing Capacity

The Ultimate bearing capacity of continuous strip footings was found to be 605.465kN/m ^{2},582.193kN/m ^{2}, 702.70kN/m ^{2}, 662.29kN/m ^{2}, 708.14kN/m ^{2}, 670.17kN/m ^{2} and 540.66kN/m ^{2} in Obalga, 1, Obalga 2, Phalga 1, Phalga 2, Tema Asalga, Degema Osukun and Eleme borehole locations respectively. Their corresponding allowable bearing capacities were 201.82, 194.06kN/m ^{2}, 234,233kN/m ^{2}, 220.76kN/m ^{2}, 236.05kN/m ^{2}, 223.39kN/m ^{2} and 180.22kN/m ^{2}. The total maximum load (qmax) equivalent to safe bearing capacity that will not cause shear failure at the foundation level in the studied locations was found to be 247.02kN/m ^{2}, 227.645kN/m ^{2}, 275.97kN/m ^{2}, 270.395kN/m ^{2}, 285.68kN/m ^{2}, 246.61kN/m ^{2} and 204.064kN/m ^{2} in Obalga, 1, Obalga 2, Phalga 1, Phalga 2, Tema Asalga, Degema Osukun and Eleme borehole locations respectively.

3.2.2 Rectangular and Square Foundations

The ultimate bearing capacity of square foundations (aspect ratio = 1) was 766.911kN/m ^{2}, 751.813kN/m ^{2}, 906.05kN/m ^{2}, 827.74kN/m ^{2}, 912.41kN/m ^{2}, 864.37kN/m ^{2} and 695.96kN/m ^{2} in Obalga, 1, Obalga 2, Phalga 1, Phalga 2, Tema Asalga, Degema Osukun and Eleme borehole locations respectively. Similarly, the allowable bearing capacity was 255.64kN/m ^{2}, 250.604kN/m ^{2}, 302.02kN/m ^{2}, 275.91kN/m ^{2}, 304.14kN/m ^{2}, 288.122kN/m ^{2}, and 31.99kN/m ^{2}. The total maximum ground loading or safe bearing capacity devoid of shear failure was found to be 300.84kN/m ^{2}, 281.189kN/m ^{2}, 343.76kN/m ^{2}, 315.893kN/m ^{2}, 353.77kN/m ^{2}, 311.34kN/m ^{2} and 255.83kN/m ^{2} respectively. The ultimate bearing capacity of rectangular foundations with AR = 1.5 was 851.66kN/m ^{2}, 836.625kN/m ^{2}, 1007.24kN/m ^{2}, 921.11kN/m ^{2}, 907.76kN/m ^{2}, 969.91kN/m ^{2} and 763.14kN/m ^{2}. Their corresponding allowable bearing capacities were 283.88, 278.87, 335.75, 307.04, 302.59, 323.30, and 254.38 respectively. The total load inclusive of ground surcharge for rectangular foundation with aspect ratio 1.5 was 329.08kN/m ^{2}, 312.46kN/m ^{2}, 377.49kN/m ^{2}, 347kN/m ^{2}.02kN/m ^{2}, 352.22kN/m ^{2}, 346.24kN/m ^{2} and 277.60kN/m ^{2}.

3.3 Raft foundations

The ultimate bearing capacity of raft foundations with aspect ratio of 1 was 718.65kN/m ^{2}, 1081.48kN/m ^{2}, 988.55kN/m ^{2}, 884.49kN/m ^{2}, 999.97kN/m ^{2}, 999.97kN/m ^{2}, and 565.4kN/m ^{2}. The allowable bearing capacity (Qall) of raft with aspect ratio = 1 was 239.55kN/m ^{2}, 360.49kN/m ^{2}, 329.54kN/m ^{2}, 294.83kN/m ^{2}, 333.32kN/m ^{2}, 333.32kN/m ^{2}, 188.49kN/m ^{2}. Correspondingly, the safe bearing capacity (Qmax) was found to be 284.75kN/m ^{2}, 395.10kN/m ^{2}, 371.26kN/m ^{2}, 334.81kN/m ^{2}, 382.95kN/m ^{2}, 356.54kN/m ^{2} and 211.72kN/m ^{2} respectively. The ultimate bearing capacity of the raft foundations with aspect ratio of 1.5 was 661.99kN/m ^{2}, 1169kN/m ^{2}, 1171.44kN/m ^{2}, 1169.25kN/m ^{2}, 964.629kN/m ^{2}, 1011.40kN/m ^{2} and 727.19kN/m ^{2}. While the allowable bearing capacity was 220.67kN/m ^{2}, 389.75kN/m ^{2}, 390.48kN/m ^{2}, 389.75kN/m ^{2}, 321.54kN/m ^{2}, 337.13kN/m ^{2} and

242.40kN/m ^{2}. The total maximum load or safe bearing capacity without any risk of shear failure for raft foundation at the founding plane was 265.86kN/m ^{2}, 423.34kN/m ^{2}, 432.22kN/m ^{2}, 429.73kN/m ^{2}, 371.17kN/m ^{2}, 360.35kN/m ^{2} and 266.28kN/m ^{2} respectively.

4 Discussion of Findings

On the basis of soil type and stratigraphic succession in the soil profile, peaty soils occur from ground surface to the usual excavated depths of 1-2m and beyond in most areas in marginal lands in the study area. This is the region of foundation of buildings and posing impending danger of ultimate limit state (bearing capacity) and serviceability (settlement) Failures. Peat is an organic material amenable to failure due to their weak bearing strength, state of incipient soil structure collapse, high compressibility, high heave potential and collapsibility. The design, excavation and construction of foundations, must consider reduction of heave. In this respect, shallow foundations are not a plausible alternative for multi-floor, large load buildings. However, if economics favor their construction, the study therefore suggested for the following for the sustainability of the building structure

- The structure should be stiff enough to provide rigidity in case of heaving.
- Soil should be stabilized to produce less expansion
- Stiffened raft foundations or reinforced slab-on-grade are recommended to provide rigidity to withstand heave else deep foundations are recommended.
- Foundations should be design to isolate the structure from expansive soils.

These suggestions are in lines with the recommendation of Abija (2023) who noted that to reduce heave and collapsibility, and improve strength foundation excavation, the structure should extended to 30cm below the foundation level and trench filled with free draining granular materials such as sand and gravel up to bottom of the foundation level, compacted and reinforced concrete placed above the footing level. Abija (2023), further noted that the second option is to stabilize the foundation subsoil by treatment with lime or bitumen or fly ash following which compaction using mechanical compactor before.

5 Conclusion and Recommendations

This study is focused on suitability techniques transforming marginal lands to support building infrastructure in part of Rivers State. The study adopted cross-sectional research design and apply the use of standard laboratory analysis utilizing GIS in the analysis of data. The study relied on the fact that in its in situ state, marginal lands in Rivers state are composed dominantly of clayey silts, clays with high water content, weak strength and high compressibility; and sands of varying densities. Concrete durability is affected by aggregates which readily absorb water with groundwater table very high at ground surface which increases soils water content, high capacity for retention and reduction in concrete strength which leads to structural failure and building collapse. Therefore, it can be concluded that clay inclusion in the aggregates soil should be avoided at all cost as it enhances concrete saturation due to enhanced permeability and capacity for moisture uptake and retention. The study recommends Building development must be preceded by site specific geotechnical and geological investigations and no rule of thumb application at any site.

Compliance with ethical standards

Disclosure of conflict of interest

There no conflict of interest to be disclosed.

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