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Site Investigation Studies for the Design of Raft-On-Pile Foundation for Elevated Water Tank in the Coastal Areaof Opuama, Warri North, Western Niger Delta, Nigeria

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Abstract: *In this paper site, investigation was carried out to reveal the site subsurface condition, determine bearing strength, predict settlement and recommend foundation for a 20,000us gallons elevated Braithwaite water tank. Method involved the boring of 3geotechnical boreholes to a depth of 10m, sampling and laboratory analysis.Results indicatethat very soft, organic sensitive to extra-sensitive, highly collapsible, high compressibility overconsolidated clays underlie to a depth of 8m. The moisture content of these clays varies from 120.15 – 128.0%, wet unit weight from 13.99 – 18.63KN/m^3, and specific gravity of 2.35 - 2.56. Liquid limit ranges from 66.9 – 67.1%, plastic limit from 29 – 31%, plasticity index from 36.1 – 37.9% on the basis of which they classify as ilmenites. Their linear shrinkage ranges from 10 – 13.1%, collapse potential from 0.161 – 0.234 with allowable bearing capacity of 113.22KN/m^2 and total settlement of 166.14cm, raft foundation with pre-treatment of foundation or raft on reinforced bore concrete pile has been recommended. Pre-treatment of the foundation to include excavation and carting away to spoil; filling with good quality granular materials, compaction with vibratory roller compactor and stabilization with lime because of the high liquid and plastic limits.*

Keywords: *site investigation, bearing capacity, settlement, collapse potential, raft foundation*

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I. Introduction

The design and construction of any civil engineering structure requires investigation of the ground on which the structure shall be founded. This is necessary because soil's response to load determines the performance of the foundation and [1] stated that soil mechanics theories involve idealized conditions. Their application to foundation engineering problems requires detailed evaluation of site conditions and subgrade properties. A fundamental consideration is the geological processes under which the soils and or rocks at the proposed project site were formed. Site investigationis carried out to assess these processes and the soil and or rock characteristics. It forms the basis for judging the suitability of a site for a proposed engineering project and for preparation of adequate and economic designs [2]. Other important factors includethe nature, physical and engineering characteristics of the subgrades, their vertical and lateral distributions and variations; topography, excavations around the site, quarries, escarpments, evidence of erosion, geohydrologic, flood marks, drainage ditches, adjoin vegetation, underground workings and tectonic regimes in seismically active areas[3]; soil stratigraphy, abandoned dump sites, shrinkage cracks, tension cracks and existence of cracks in walls [2]. [4] noted that urban planning and development should be preceded by slope instability and landslide susceptibilityassessment for sustainability and this can be investigate during the pre-design site investigation.

Site investigation (1) judges a site's suitability for any proposed structure (2) forms the basis for preparing adequate and economic designs (3) provides input data for safety analysis and failure investigation of existing projects and (4) serves as a tool for selecting construction materials and most appropriate method. Site investigation involves four main stages (1) desk study and review of available geological, topographic, geotechnical, aerial photographs, surface mapping, remote data, geophysical information and test pits for needs, (2) site reconnaissance aimed at recognizing potential geological and other problems to guide the planning the scope, method and execution of the main investigation; (3) detailed exploratory boring involving in situ testing, drilling, coring, sampling and laboratory analysis on cores and or soil samples to reveal the soil profile, types and engineering properties of geological materials, groundwater level; and (4) site monitoring during the service life of the project. The scope of the investigation depends on the type of structure, site geology and topography. The intensity (drilling and sampling intervals) of the investigation depends on the type of structure, uniformity of materials on the site, the importance and cost of the proposed engineering works, relations between ground properties and geotechnical requirements of the proposed construction in order to arrive at a conclusive choice of the most feasible site, develop workable and satisfactory design, construct and operate engineering works with maximum economy and safety. During the construction stage, if any significant variations in ground conditions occur, modifications are introduced and incorporated into the design [5, 1, 6].

The stability of any structure depends on the supporting subgrade hence a foundation must be stable against shear failure and must not settle beyond tolerable limits [7, 6]. [7]also noted that for sustainable infrastructure, design and construction must be carried out against bearing capacity failure due to compromised shear strength of the subgrades, and against time dependent displacement of the foundation soil element which could result to differential settlement when the specified maximum acceptable amount of settlement is exceeded.The choice of the type of foundation in the design process is based on the design load, subsoil bearing strength, settlement and economy of construction. The location and depth of the foundation are important considerations because erosive channels, root holes, unconsolidated fill and presence of expansive clays are critical in the ability of the soil to carry the superstructure.

Raft or mat foundation is a shallow foundation (depth < width of the structure) that constitutes one of the combined footings. It can be designed as flat plate (uniform thickness); flat plate thickened under the columns, beam and slab with beams running both ways and columns located at the beam intersection; and slab with basement walls as part of the mat with the walls acting as stiffeners. They may be supported by piles in high compressibility soils or in high water table zones to control buoyancy [1].

The proposed project is 20,000 gallons 30m high Braithwaite elevated steel water tank. This investigation was carried out a commissioned studies aimed at determining the site’s soil profile, characterize the subgrades, predict the settlement, recommend best location and depth of foundation, and appropriate construction method.

II. Study Area

The study area is located between latitude 5.905518° and 5.907794° and longitude 5.0681999° and 5.061563°Warri North area ofWestern Niger Delta (Figure 1). The Niger Delta falls under the three geomorphic zones including the coastal or lower delta zone, Transition or Mangrove zone and the Upper deltaic plain or freshwater zone. The freshwater zone consists of dry flatlands and plains with abundant fresh water swamps, meander belts, and alluvial swamps, salts and mangrove swamps, and active/abandoned coastal ridges [8, 9, 10].

It is a tropical rainforest area with wet season (April - October) and dry (November - March) with occasional rains during the dry season. The mean rainfall varies from 2000mm to over 4000mm at the coastal with about 85% occurring in wet season. It falls under zone 4 of Nigeria's climatological zones with the highest rainfall of 1,185 – 2,788mm under warm and humid climate (Fig. 1) [11]. The climate of Nigeria coast is tropical equatorial with rainfall intensity being highest (≥3500mm) between April and October, the values being 5 - 7 times higher than in November to March (500mm). Temperatures range on average, between 26 and 270C during the dry months of February to March and about 240C during wet months of June and September. Daily temperatures oscillate between 310C and 230C in the dry season. Highest average values of humidity reach 90% in August as against an average minimum of 74% in February [12, 13]. Geologically, it is a sedimentary structure of clastic fills. The basin, one of the largest regressive deltas is estimated to cover an area of 300,000 km^2 with a sediment volume of 500,000 km^3[14] and a sediment thickness of over 10 km in the basin depocenter[15]. The lithostratigraphic sequences are the basal Akata shale Formation, middle intercalated sandstone/shale Agbada Formation and Benin sands and sandstone Formation each of which range from Tertiary to Recent[16].

The foundations of civil engineering structures in the area located within deltaic alluvium of the coastal plains sands made up of sands and clays of the quaternary deposits of the basin[17].

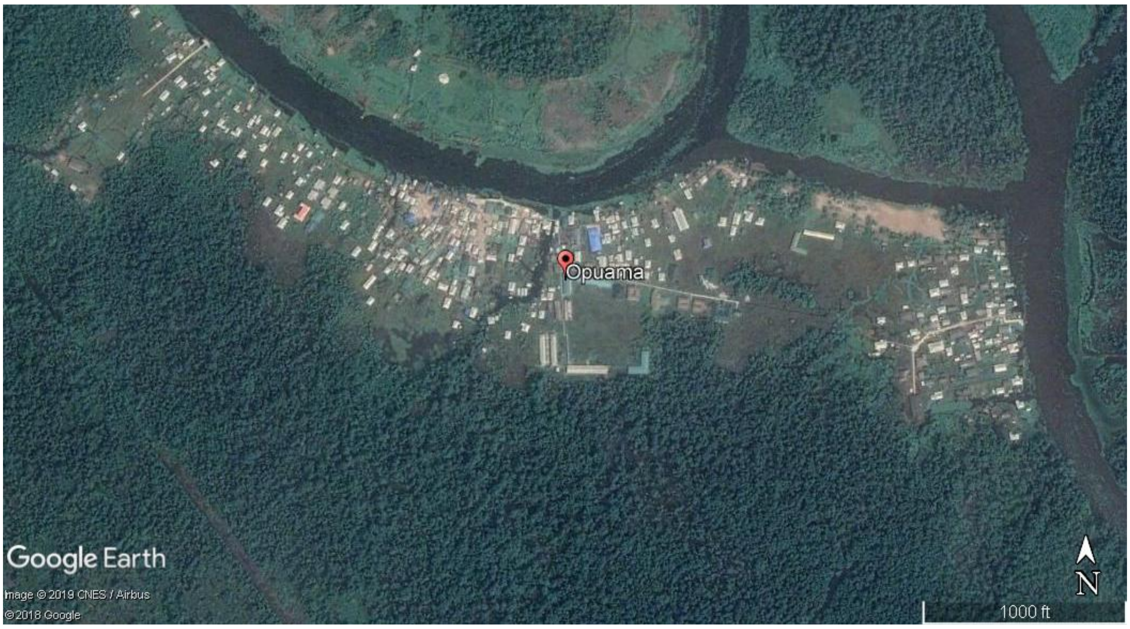

Figure 1: Google image of the study area showing study location

III. Materials and Methods

(i) Field Investigations and laboratory Analysis

Methods involved field geotechnical boring using light hells auger rig and sampling at 0.75m and 1m intervals to a depth of 8m to derive disturbed and undisturbed samples. Undisturbed samples were collected with conventional open tube sampler 100mm in diameter and 450mm in length by advancing a core cutter into the substratum at the bottom of the hole. All samples were roughly examined. Identified and classified in the field. The undisturbed samples were used for triaxial shear strength and oedometer consolidation tests. All the laboratory analysis were carried out as specified by the [18, 19] and ASTM methods.

Soil PH was determined to predict acidity using glass electrode PH meter [20, 21,]. Organic carbon content influences the physical properties of the soils such as soil structure, compressibility and shear strength. When present in a soil in large amounts, it causes high plasticity, shrinkage and compressibility; and low shear strength and permeability. This effects are due to complex chemical and biological behaviours which impart on the soil strength and response to imposed structural load. At high moisture content, organic matter behaves as reversible swelling system which reverses when dry. The organic matter content was determined in accordance with the Walkley – Black method [22, 23, 24]. Cations in soils are adsorbed onto the surface of soils forming adsorption complexes upon reaction with water and influencing the volume change characteristics of the clays. The effects increase in high activity and expansive clays. Cationconcentration in the soil sampleswere measured in the laboratory using buck scientific atomic adsorption spectrophotometer and or emission spectrophotometer 205.

(ii). Methods of Data Analysis

The ultimate bearing capacity of the foundation subgrades was determined for strip (1), square (2) rectangular footing (3) and raft foundation footings wasevaluated using equation (4) [1]**.** Asafety factor of 3.0 was applied to determine the allowable bearing capacities of the foundation subgrades at the proposed depth of the footing for foundation engineering design.

$$Qu = CNc + {}_{\gamma}D_fNq + 0.5_{\gamma}BN_{\gamma} \quad \ldots\ldots (1)$$

$$Qu = 1.3CNc + {}_{\gamma}D_fNq + 0.4_{\gamma}BN_{\gamma} \quad \ldots\ldots (2)$$

$$Qu = CNc\,(1+0.3B/L) + {}_{\gamma}D_fNq + 0.5_{\gamma}BN_{\gamma}(1 - 0.2B/L) \quad \ldots\ldots (3)$$

$$Q_u = 5.14C_u(1 + 0.195B/L)(1+0.4Df/B) \quad \ldots\ldots (4)$$

N_c, N_q, N_γ = Bearing capacity factors
ϕ = angle of internal friction
σ_n = normal stress

C	=	undrained shear strength
B	=	Foundation Breadth
L	=	Foundation length
D_f	=	Depth of foundation

(iii).Prediction of Collapse Potential and Settlement

Results from oedometer consolidation tests (ASTM; 1997) conducted on the clay samples retrieved from the field and tested in a 75mm diameter x 20mm high ring over a pressure range of 40kPa – 320kPa were analyzed using Taylor square root of time fitting method [25] to derive the consolidation indices. Pre-consolidation pressures were determined from void ratio versus log of pressure curves using Cassagrande's method of construction [26]. Soft and organic soils are susceptible to varying degrees of volume change behavior when inundated by water causing breakdown and change in soil structure, collapse and structural settlement. The collapse potential of these soft organic clays have been evaluated based on [27] criteria (equation 5) which specifies three classes of soils on te basis of their collapse characteristics. Classes of soils under this criterion include highly collapsible soils ($K_D < 0$), non-collapsible soils ($K_D > 0$) and swelling soils ($K_D > 1$).

The elastic settlement **(S_e)** was determined based on results of oedometertest using equation (6) [28] and equation (7) while total settlement (S_T) was evaluated using equation (8) for pre-consolidated clays ($P_0 < P_c < P_0 + P_c$) [1]. Time rate of settlement due to dissipation of excess pore water pressurefrom the clay layer accompanies increase in effective stress due to applied vertical stress (ΔP) with time. Equations (9) and (10) were used in predicting the rates of settlement for 50% (t_{50}) and 90% (t_{90})of the clay substratum respectively. The coefficient of permeability permits water infiltration into the foundation. It was evaluated using equation (10).

$$K_D = \frac{W_n\% - PL}{I_p} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

$$S_c = 0.7 \times S_{oed} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$$S_{oed} = M_v H \sigma \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

$$S_T = \frac{C_s H_c}{1 + e_0} Log \frac{P_c}{P_0} \frac{C_C H_c}{1 + e_0} \log \frac{(P0 + \Delta P_{av})}{P_c} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

$$t_{50} = \frac{0.197 T_{50} H_c}{C_v} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(9)$$

$$t_{90} = \frac{0.848 T_{50} H_c}{C_v} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

$$K = C_v M_v \gamma_w \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

M_v	=	Coefficient volume compressibility
H	=	thickness of strain under consideration
σ	=	applied load
C_s	=	Swell index
H_c	=	thickness of the clay layer
P_c	=	Pre-consolidation pressure
CC	=	Compression index = $0.3(e_0 – 0.27)$ [29]
P_0	=	Surcharge on the clay layer before foundation construction
ΔP_{av}	=	average vertical stress at the middle of the clay stratum under the foundation
e_0	=	initial void ratio
C_v	=	Coefficient of consolidation
γ_w	=	Unit weight of water
K	=	permeability
K_D	=	Collapse potential
Wn%	=	Moisture content
PL	=	Plastic limit
I_p	=	Plasticity index

(iv). Determination of Vertical stress

The magnitude of the average vertical stress increase below the foundation acting on the centre of the clay stratum as an input parameter for the prediction of the total structural settlement of the foundation due to imposition of the load by the construction was determined using the 2:1 method equation (12) [1, 6]**.** This method is based on the assumption that the stress from the foundation spreads out along the lines with a 2 vertical to 1 horizontal slope was adopted for the studies.

$$\Delta P_{av} = \frac{q_o BL}{(B + z)(L + Z)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

where, q_o = load, B = bread of the foundation, L = Length, z = depth.

Proposed Elevated Water Tank Design Specifications and load calculations

Specifications

Tank floor top bearer beams	=	203 x 133 x 25kg/m UB
Tank floor bottom bearer beams	=	305 x 165 x 37kg/m UB
Ties to struts	=	76 x 76 x 8mm equal angle cleats
Unit weight of steel	=	77KN
Design steel grade	=	43 steel
Permissible stress of steel in tension	=	165N/mm^2

LIVE LOAD

Volume of tank = 20,000 gals equivalent of 784.8KN

DEAD LOAD

Tank base + top	=	6.1 x 6.1 x 0.004 x 77 x 2 equivalent of 22.92KN
Tank sides (4)	=	2.44 x 6.1 x 0.004 x 4 x 77 equivalent of 18.34KN
Guard rails at 4KN/m	=	7.1 x 4 x 0.5 equivalent of 14.2KN
Walkway	=	0.5 x 0.003 x 77 x 6.6 x 4 equivalent of 3.05KN

FLOOR BEAMS

Main Beams		305 x 165 x 37kg
	=	(7 x 2 x 37 x 9.81)/1000 equivalent of 5.08KN
Secondary Beams	=	203 x 133 x 24kg x 7number equivalent of 12.02KN
Stanchions	=	203 x 203 x 46kg/m equivalent of 2.7KN
Braces and ladder,	=	1.5KN
Bolts, gussets, cleats	=	0.5KN

Total dead and live loads **865.11KN**

IV. Results and Discussion

(i) Soil stratigraphy and geotechnical characteristics

The soil stratigraphy indicates a black soft humus organic matter layer overlying from ground surface to 0.014m. This is underlain a soft brown organic clay layer from 0.014 – 0.7m while soft gray clay layer with organic matter underlies to a depth of 8m. The groundwater table was at 0.8m. These clays are sensitive to extra-sensitive Illites on the basis of Atterberg limits and compression index with very high swell potential (plasticity index >35%). Their moisture content ranges from 120.15 – 128.8% with an average of 101.96%, wet density of 1.427 – 1.801g/m^3 averaging 1.614g/m^3, dry density varying from 0.72 – 1.90g/m^3, wet unit weight of 13.99 – 18.63KN/m^3, dry unit weight range of 7.06 – 18.1NK/m3, and specific gravity ranging from 2.35 – 2.56. Consistency limits depicts the liquid limit varying from 66.9 – 67.1%, plastic limit from 29.0 – 31.0% and plasticity index from 36.1 – 37.9. These clays classify as high compressibility under the unified soils classification system with shrinkage limit range of 10 – 13.1%. Sand, silt and clay sized particles were most dominant with percentages ranging from 68.6 – 82.3%, 13.5 – 31.4% and 4.2 – 7.8% respectively (Table 1).

Table 1: Index and classification properties

Parameter	Minimum	Maximum	Average
Natural Moisture Content %	120.15	128.8	124.22
Dry Density (g/m3)	0.72	1.90	1.31
Wet density (g/m3)	1.427	1.8	1.614
Wet Unit Weight (KN/m^3)	13.99	18.63	16.31

Dry Unit Weight (KN/m^3)	7.06	18.1	12.58
Specific Gravity	2.35	2.56	2.45
Liquid limit %	66.9	67.1	67.0
Plastic Limit %	29.0	31.0	30.02
Plasticity index %	36.1	37.9	37.2
Linear shrinkage %	10	13.1	12.9
% Clay	4.2	7.8	6.9
% Silt	13.5	31.4	23.2
% Sand	68.6	82.3	74.1
% Gravel	0	0	0
USCS classification	CH	CH	CH
Effective particle size (d_{10}) mm	0.013	1.47	0.88
D_{30}	0.164	0.196	0.18
D_{60}	0.134	0.242	0.188
Coefficient of curvature (CC)	1.08	10.72	6.0
Coefficient of Uniformity (CU)	1.65	10.72	6.19
Clay Activity	4.86	9.02	6.99

The shear strength characteristics indicatea frictional strength range of 10 – 12 degrees and undrained cohesion of 48 – 52KN/m^2. The collapse potential [28] clays are highly collapsing soils with collapse potential of 0.161 - 0.263. Oedometer consolidation tests results depicts a coefficient of consolidation of 0.007 – 0.229 cm^2/min, coefficient of volume compressibility of 6.01 x 10^{-3} to 6.098 x 10^{-3} kPa$^-$. Permeability varies from 1.330 x $10^{-3}$to 1.425 x 10^{-3}cm/sec while compression index ranges 1.0939 to 1.1563. Over-consolidation pressures range from 141.32 – 144.44kPa while surcharge load at 1.2m varies from 16.788 to 22.355KN/m^2 yielding over-consolidation ratio ranging from 6.46 – 8.42 (Table 2). Beyond this depth, a silty clay layer occur which grade into sand of varying densities and grain sizes at ≥ 9.5m.

Table 2: Results of triaxial shear strength and Oedometer consolidation tests

Geotechnical Property	**Minimum**	**Maximum**	**Average**
Angle of internal friction (deg)	10	12	11.3
Undrained cohesion (KN/m^2)	48	52	49.7
Coefficient of Consolidation (C_v) cm^2/min	0.007	0. 229	0.119
Coefficient of Volume Compressibility(M_v) (kPa$^-$)	6.01 x 10^{-3}	6.098 x 10^{-3}	6.054 x 10^{-3}
Permeability (cm/sec)	1.330 x 10^{-3}	1.425 x 10^{-3}	1.39 x 10^{-3}
Initial Void Ratio	3.9162	4.1243	4.0203
Compression index	1.0939	1.1563	1.1251
Surcharge	16.788	22.356	19.572
Pre-consolidation pressure (kPa)	141.32	144.44	143.89
Over-consolidation ratio	8.42	6.46	7.35
Collapse potential	0.161	0.263	0.211

(ii) Soil acidity, Organic carbon content and exchangeable cation capacity

The PH of the clay soils varies from 8.66 at 0.7m depth to 1m depth and maintained a constant value to 4m. This alkaline range depicts that soils are not corrosive. The organic matter and cation concentrations increased with depth (Table 3 and Figure 2) to 4m for the samples tested. The high amount of organic matter which increases with depth is consistent with the increasing compressibility of the clays. This trend is predictably in agreement with increasing cationsconcentration as the depth increases. Engineeringimplications are the high swelling and shrinkage characteristic of these organic clays upon seasonal wetting and drying cycles. It also portends a reversal in soil plasticity with increasing moisture content at the foundation level.

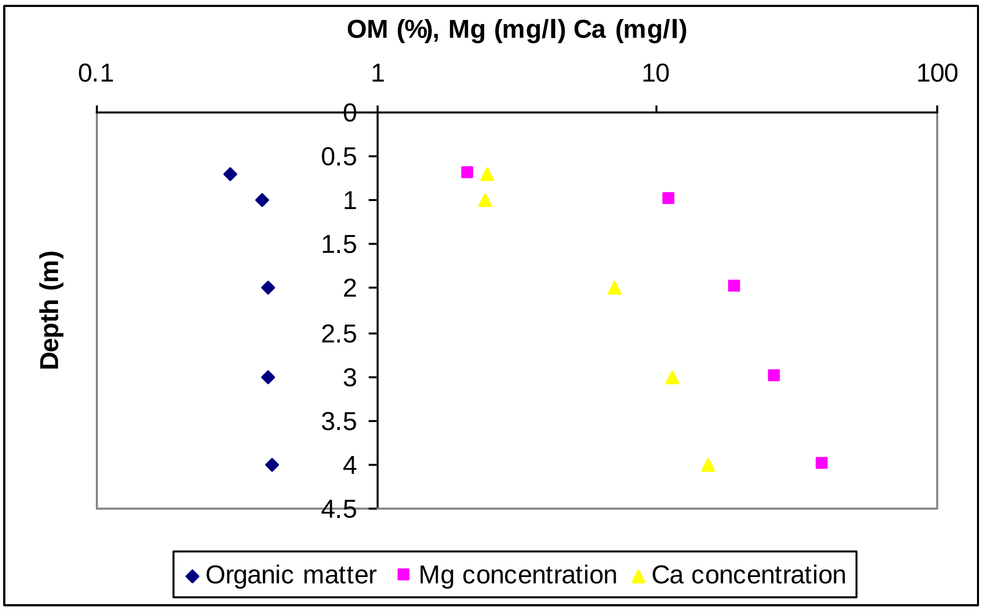

Figure 2: Variation of soil organic matter, Ca and Mg concentrations with depth

Table 3: Results of soil acidity and exchangeable cation characteristics

Parameter	Depth	Result
Soil PH	0.7	8.66
	1m	7.69
	2m	7.69
	3m	7.69
	4	7.69
Organic matter (%)	0.7	0.3
	1m	0.39
	2m	0.41
	3m	0.41
	4	0.42
Mg (mg/l)	0.7	2.15
	1m	11.22
	2m	19.2
	3m	26.7
	4	39.28
Ca (mg/l)	0.7	2.47
	1m	2.42
	2m	7.1
	3m	11.3
	4	15.26

(iv). Bearing capacity and settlement of the foundation footings

The ultimate and allowable bearing capacity of the foundation subgrades are presented in tables 4 and 4. Strip footing's ultimate bearing strength was 652.4KN/m^2 at 1.2m and 471.4KN/m2 at 3m while the allowable was 217.5KN/m^2 and 157.1 KN/m^2 respectively. The ultimate and allowable bearing capacity of square and rectangular footing which varies with aspect ratio was 754.5KN/m^2 and 251.5KN/m^2 respectively with footing aspect ratio of 1. At aspect ratio of 1.5, the ultimate and bearing capacity were 834.27KN/m^2 and 278.09KN/m^2 respectively at a depth of 1.2m. At 3m depth, the ultimate bearing capacity and allowable of the square and rectangular foundation were 685.9KN/m^{2}and 228.7KN/m^2(B/L = 1) and 754.8KN/m^{2}and 251.6KN/m^2(B/L = 1.5) respectively (Table 4).

Table 4: Bearing capacity of square, rectangular and strip foundations

Depth (m)	Undrained cohesion (KN/m^2)	Angle of internal friction (deg)	Ultimate Bearing Capacity (KN/m^2)		Allowable Bearing capacity (KN/m^2)		Strip Footing	
			B/L = 1.0	B/L = 1.5	B/L = 1	B/L = 1.5	Ultimate	Allowable
1.2	52	12	754.5	834.27	251.5	278.09	652.4	217.5
3	48	10	685.9	754.8	228.7	251.6	471.4	157.1

Raft foundation ultimate and allowable bearing strength were 367.95KN/m^2 and 122.64KN/m^2 (L/B = 1); z and 397.9KN/m^2 and 132.66KN/m^2 (L/B = 1.5) respectively at 1.2m foundation level. The ultimate bearing strengths at 3m was 339.645KN/m^2 and allowable of 113.22KN/m^2 (L/B = 1); and ultimate bearing strength of 367.36KN/m^2 and allowable of 122.454KN/m^2 (L/B = 1.5) (Table 5).

The elastic and total settlements are presented in Table 6. Results indicate that the elastic settlement varies from 1.4308 to 1.6415cm while the total settlement ranges from 150.99 cm to 166.14cm. These settlement values are above tolerable limits and design must consider load transfer to the sand substratum at 9.5m depth.

Table 5: Bearing Capacity of raft foundations

Depth (m)	UndrainedCohesion (KN/m^2)	Angle of internal friction (deg)	Ultimate Bearing Capacity (KN/m^2)		Allowable Bearing Capacity (KN/m^2)	
			L/B = 1.0	L/B = 1.5	L/B = 1	L/B = 1.5
1.2	52	12	367.95	397.9	122.64	132.66
3	48	10	339.645	367.36	113.22	122.454

Table 6:Settlementcharacteristics of the raft foundation subgrades

Sample Depth (m)	B	L	Z	Total Load KN	ΔP_{av} KN	S_{oed}	S_e (cm)	S_T (cm)
BH 1	6	6	1.2	865.11KN	600.771	2.345	1.6415	166.14
BH2	6	6	1.2	865.11KN	600.771	2.044	1.4308	150.99
BH3	6	6	1.2	865.11KN	600.771	2.117	1..4819	161.03

(v) Foundation design and construction

The foundation subgrades under investigation are metastable,[30] sensitive to extra-sensitive and highly collapsible organic clays amenable to volume change upon wetting and drying with seasonal variations in the groundwater table. Factors needed to produce collapse which includes open, partially unstable, unsaturated fabric, high enough net total stress and a bonding or cementing agent that destabilizes the soil must be considered. Pre-treatment of the foundation to include excavation and carting away to spoil; filling with good quality granular materials, compaction with vibratory roller compactor and stabilization with lime because of the high liquid and plastic limits.

In consideration of excessive settlement, foundation design must consider soil improvement options for raft or raft-on-pile footings have been recommended to found the 20,000gals elevated Braithwaite water tankat a depth of 9.5 – 10m. Reinforced, bored concrete piles to be terminated at 9m depth for the raft-on-pile foundations to support the raft footings are recommended for economy and sustainability.

V. Conclusion

The significance of site investigation throughout the life cycle of a project from pre-design through construction and monitoring have been predictably demonstrated with the results of this studies. The high linear shrinkage and collapse potential, even though allowable bearing stratum occurs at 1.2m, excessive total settlement has informed the choice of either raft foundation with pre-treatment of foundation or raft-on-.pile. The pre-treatment include excavation and carting away to spoil, stabilization with lime, filling with good quality granular materials and compaction with vibratory roller compactor. Economy is recommended to guide the preferred option between the two. This underscores the need for pre-design site investigation studies for cost optimization and sustainability of the proposed project.

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References

[1]. B. Das (1999). Principles of Foundation `Engineering, 4th edn. California: Brooks/Cole Publishing Company. 862pp.
[2]. B. C. Punmia, A. K. Jain and A. K. Jain(1994).Soil mechanics and Foundations. New Delhi: Laxmi Publications (P) Ltd. 970pages.
[3]. B. Look(2006). Handbook of geotechnical investigations and design tables.London: Taylor and Francis. 356pages
[4]. F. A. Abija, J. I.Nwosu, A. I. Ifedotun and C. C. Osadebe ()2019Landslide susceptibility assessment of Calabar, Nigeria using Geotechnical, Remote Sensing and Multi-Criteria Decision Analysis: Implications for urban planning and development. Journal of Earth Sciences & Environmental Studies 4(6) p:774-788
[5]. F. G. Blyth and M. H. de Freitas(1982). A Geology for Engineers, 7th edn. Oxford: Butterwoth -Heineman, Imprint of Elsevier, 325 pages.
[6]. V. N. S. Murthy (2012). Textbook of Soil Mechanics and Foundation Engineering. New Delhi: CBS Publishers and Distributors PVt Ltd 1043pages.
[7]. Abija, F. A., Teme, S. C and Oborie, E. (2018). Geotechnical considerations for the design and construction of foundation in a marshy stream channel of Iwochang-Ibeno, Eastern Niger Delta, Nigeria. J. of Civil, Construction and Environmental Engineering Vol. 3(6), pp. 154 -170. [16]

[8]. E. G. Akpokodje (1987). The Engineering Geological characteristics and classification of major superficial soils of the Niger Delta. Engineering Geology, Vol. 23, pp. 193 – 211.
[9]. Teme, S. C. (2002). Geotechnical considerations on foundation design in the Niger Delta. A paper presented at the special technical session of the 39th Annual international conference of the NMGS in Port Harcourt., pp. 51.
[10]. D. M. J. Fubara, S. C. Teme, T. Mgbeke, and T. K. S. Abam (1998). Hydrometeorological zones of the Niger Delta. Technical Bulletin No1., Institute of Flood, Erosion and Transportation, Rivers State University of Science and Technology, Port Harcourt.
[11]. Highway design Manual (2013). Nigeria's Federal Ministry of Works, Pavement and Material design, Vol. III., Nigeria, Pp. 1 – 165.
[12]. Adefolalu, D. O. (1981). The weather and climate of Calabar: a study of coastal microclimatology in equatorial tropics. Senate Research Project, University of. Calabar.
[13]. [F. A. Abija(2019). Assessment of Coastal Modification and Surf Zone Induced Erosion in ItakAbasi Beach, Eastern Niger Delta, Nigeria. Environmental and Earth Sciences Research Journal Vol. 6, No. 2, June, 2019, 83-88
[14]. J. Hospers (1965). Gravity field and structure of the Niger Delta, Nigeria, West Africa: Geological Society of American Bulletin, Vol. 76, p. 407-422.
[15]. A. Kaplan, C. U. Lusser and I. O. Norton, (19940. Tectonic map of the world, panel 10: Tulsa, American Association of Petroleum Geologists, scale 1:10,000,000.
[16]. K. C. Short and A. J. Stäuble 91965). Outline of geology of Niger Delta: American Association of Petroleum Geologists Bulletin, Vol. 51, Pp. 761-779.
[17]. F. A. Abija (2019b). Abija, F. A. (2019). Geotechnical assessment of subgrade and sub-base quality for the design and construction of road pavement in parts of the coastal section of AkwaIbom State, Eastern Niger Delta, Nigeria. International Journal of Scientific & Engineering Research Volume 10, Issue 7 pp. 1864 – 1877.
[18]. British Standards Insititute (1990).Methods for tests for soils for Civil engineering Purposes, BS 1377 (1990).
[19]. British Standards Institute (1999) Code of practice for site investigations. BS 5930 (1999).
[20]. R. G. Bales (1954). Electromagnetic PG determinations. New York: John Wiley and sons INC
[21]. W. M. Clark (1923). The determination of Hydrogen ions. Ed 3. Williams and Wilkins Company, Baltimore.
[22]. A. Walkley and I. A. Black (1934).Examination of the method for determining soil organic matter and proposed modification of the chromic acid titration method. Soil Sc. 37, 29 – 38.
[23]. C. S. Piper (1944). Soil and plant analysis, pp. 221 -222. New york: Interscience publishers.
[24]. C. A. Black (1965). Methods of soil analysis. Agronomy No. 9, part 2. American society of Agronomy.Madson, Wisconsin
[25]. D. W. Taylor (1948). Fundamentals of Soil Mechanics: New York: John Wiley and Sons..
[26]. A. Cassagrande, A. (1948). Classification and identification of soils. Transactions, ASCE, Vol. 113, pp. 901 – 991.
[27]. V. A. Priklonski (1952). Gruntoredenia-Vtoraid chest.Gosgeolzdat, Moscow, U.S.S.R. Conshoshocken, Pa.
[28]. A. W. Skempton and D.H. MacDonald (1986).Allowable settlement of buildings.Proceedings of Institute of Civil Engineers, part 3 pp. 727 – 784.
[29]. B. K. Hough (1957). Basic Soil Engineering. New York: Ronald Press
[30]. R. B. Peck, W. E.Hanson, and T. H. Thornburn (1974).Foundation engineering. New York: John Wiley and Sons.

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