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Geotechnical Investigation To Determine Stable Depth Of Embedment For Bridge Piles Foundation In Nsit Ibom Local Government Area, Akwa Ibom State, Nigeria

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***Abstract*— The decision to introduce a bridge across Ababa River was informed by engineering considerations. The river crosses the access road linking Ikot Akpan-Ikot Iko -Enen Nsit in Nsit Ibom Local Government Area. Deep-soil investigation was carried out to determine the suitability and adequacy of the soil bearing strata. Results from the sub-soil investigation indicate a cohesionless formation with light-brown medium-dense sand except borehole number 3. The consistency limit values (LL=56, PL=34, PI=22) revealed a light brown silty clay deposit at 7.5m depth. SPT N values from 10m depth ranged between 20 to 36. Undrained shear strength (Cu) is observed to be 52KN/m^2 with corresponding angle of soil friction (δ) as 32^o. The compressibility index (Cc) derived is 13 and the compressibility coefficient (Mv) ranged from 1.55x10^{-4} to 2.37x10^{-4}. The summary of tests result are presented on Tables 2 to 4. Some of the parameters were deployed in Terzaghi's pile design expressions to determine the carrying capacity of working loads on both circular and square piles within prevailing soil conditions. Results are presented in figures 3 to 12. In conclusion, square piles were found to exhibit comparatively higher carrying capacity of working loads compared to circular piles and hence recommended for utilization in execution of the bridge project.**

Keywords: bridge, deep-soil, investigation, pile, parameters

I. INTRODUCTION

A. *Pile Foundation*

The need for pile foundation is predicated on structural loads that must be transmitted beyond a shallow bearing stratum. Pile foundation is the part of a structure used to carry and transfer the load of the structure to the bearing strata located at some depth below ground surface. The main components of the foundation are the pile cap and the slender shaft. The relatively slender shaft, cylindrical or square in shape is, driven or bored into the ground to the required depth. Piles are used to carry vertical loads through weak soil to dense strata having high bearing capacity. In normal ground conditions, they can resist large uplift and horizontal loads, hence can be used as foundations of multi-storeyed buildings, transmission line towers, retaining walls, bridge abutments. Ababa river is located about forty- three kilometres away from the coastal plains of the Atlantic Ocean in Akwa Ibom State. The river separates two neighbouring villages within Nsit Ibom Local Government Area. The bridge is meant to aid economic activities within the areas. At inception eight boring logs were considered. The number was reduced to four due to financial constraint.

B. *End Bearing Piles*

These piles transfer their loads on to a firm stratum located at a considerable depth below the base of the structure and they derive most of their carrying capacity from the penetration resistance of the soil at the toe of the pile. The pile behaves as an ordinary column and should be designed as such. Even in weak soil a pile will not fail by buckling and this effect need only be considered if part of the pile is unsupported, i.e. if it is in either air or water. Load is transmitted to the soil through friction or cohesion. But sometimes, the soil surrounding the pile may adhere to the surface of the pile and causes "Negative Skin Friction" on the pile. This, sometimes have considerable effect on the capacity of the pile. Negative skin friction is caused by the drainage of the ground water and consolidation of the soil. The founding depth of the pile is influenced by the results of the site investigated on and soil test.

C. *Friction Piles*

These piles transmit most of their load to the soil through skin friction. Negative skin friction is usually the downward shear drag acting on a pile because of downward movement of surrounding soil relative to the pile. It is more pronounced in compressible soil layer that can consolidate. The process of driving such piles close to each other in groups greatly reduces the porosity and compressibility of the soil within and around the groups. Therefore, piles of this category are sometimes called compaction piles. During the process of driving the pile into the ground, the soil becomes moulded and, as a result loses some of its strength. Therefore, the pile is not able to transfer the exact amount of load which it is intended to immediately after it has been driven. Usually, the soil regains some of its strength three to five months after it has been driven.

D. Project Description

A proposal to carry out the construction of a road project from Ikot Akpan Abia-Ikot Iko-Enen Nsit and thirty-meter bridge across Ababa river, which spans Mbiakok Community, Nsit Ibom Local Government Area, Akwa Ibom State was initiated by the Akwa Ibom State Government. As part of generating relevant data inputs for the design and construction of the proposed bridge, it became imperative that the site be geotechnically characterized through subsoil investigation in order to establish significant subsoil types and profile beneath the site. This demand ignited the need to investigate engineering characteristics of all such subsoils; and to generate the required data relevant to the design and construction of the project. Hensek Integrated Services, the main Contractor commissioned Esudo Engineering Ventures to carry out comprehensive geotechnical investigation of the site.

E. The Scope of the Subsoil Investigations

Percussion drilling of four boreholes down to depth of thirty meters, were carried out, obtaining undisturbed samples in clays, representative samples in sand, and conducting standard penetration tests (SPT) in sand. Laboratory tests and analysis were conducted on the disturbed and undisturbed samples obtained from the boreholes. A comprehensive soil investigation report must be prepared. The report presented the summary of the field investigation, (percussion drilling and SPT), lithologic logs, results of laboratory analysis, conclusion and recommendations.

F. Site Description and Geology

The proposed road project spans through Ikot Akpan Abia-Ikot Iko-Enen Nsit in Mbiakok Community, Nsit Ibom Local Government Area, Akwa Ibom State. Geologically, the soil deposits of the site belong to the recent sediments of the coastal and Niger Delta regions which were deposited during the Quaternary under coastal, shallow marine and deltaic environments and is locally referred to as coastal plain sands. The formation consists of alternating sequences of fine and coarse sand of various grain sizes.

Figure (1): Location Map Showing Borehole Position

II. FIELD INVESTIGATION

The Investigation took place by the bank of Ababa River in Mbiakok Community, Nsit Ibom Local Government Area, Akwa Ibom State. Boreholes were drilled at the specified positions, using manual conventional light cable percussion rig. Shell and auger tools were used in retrieving the soil samples. Disturbed samples were collected at regular intervals of 0.75m and also at changes in soil stratigraphy. Undisturbed samples were obtained with the conventional open tube sampler, which measures 100mm in diameter and 450mm long. The open tube sampler consists of metal tube with screw threads at each end. A cutting shoe is fitted to the lower end of the tube while the upper end is screwed into a drive head attached to the drill rods. The head has an overdrive space and incorporate a non-return valve to permit escape of air or water as the sample enters the tube. The sampler is driven into the soil by dynamic means using a drop hammer. On withdrawal of the sampler the non-return valve assists in retaining the soil sample in the tube. All the soil samples were examined and identified in the field.

A. Location of Boring Points

Generally, the boring points were positioned in such a way to enable comprehensive coverage of the area of the proposed bridge.

TABLE1: Survey Coordinate of Test Points

Test Point	UTM Coordinates	
	Easting (E)	Northing (N)
BH1	377695	544778
BH2	377710	544767
BH3	377724	544763
BH4	377741	544748

B. Standard Penetration Test (SPT)

This test was performed on the sandy soils. Standard penetration tests can be used to assess the relative density of the soil strata. In the test a 50mm diameter spoon sampler was driven 450mm into the soil with a 63.5kg hammer falling freely through a height of 760mm. The initial 150mm penetration is the seating drive. The number of blows required to effect the remaining 300mm penetration was recorded as the SPT(N) value, The SPT results are presented in the borehole logs. Four boreholes were drilled at the specified location shown in figure 1.

C. Laboratory Tests

The laboratory tests were conducted to evaluate the physical and engineering properties of the soils encountered. The tests were carried out in accordance with the relevant British Standards as specified in the BS1377(1990) and the American Society for Testing and Material (ASTM) (1990). The samples obtained in the field were carefully preserved and transported to the laboratory where they were subjected to more detailed visual inspection and descriptions. Thereafter, representative samples were selected from each stratum for laboratory analysis. Disturbed and undisturbed samples so selected were subjected to the following standard laboratory classification tests.

D. Particle Size Analysis

Particle size analysis was carried out on the representative soil samples as an aid to soil classification. Generally, the method adopted included wet and dry sieving. Sieve analysis of cohesive soils particularly involved soaking oven-dried samples in water for twenty-four hours and washing through sieve No.200 (75microns opening) while remnants retained on sieve no.200 were oven-dried and sieved mechanically. This procedure accords with specifications in BS 1377 (1990) and ensures greater accuracy in determining actual proportion of fines or materials finer than sieve number 200.

E. Consistency Limits Tests

Atterberg limit test was carried out to determine the water contents at which the soil changes from one state to the other.

F. liquid limit test (LL)

This was carried out using Casagrande's apparatus which consist of a brass Cup which drops through a height of 10mm on a hard base when operated by the handle (a cam operated mechanism), the water content at which the penetration is 25mm is the liquid limit.

G. The Plastic Limit Test (PL)

This is determined by air-dried sample and sieved through No. 40 sieve (ASTM). It is mixed thoroughly with distilled water till it becomes plastic and can easily be molded with fingers. The water content at which the soil can be rolled into a thread of approximately 3mm in diameter without crumbling is known as the Plastic Limit.

H. Undrained Triaxial Test

Undrained triaxial tests were carried out on the undisturbed clay specimens that measured 38mm in diameter and 76mm in height. In the test the soil specimen was encased in a thin plastic cylindrical chamber filled with water. The sample was subjected to confining pressure, and deviator stress was applied, axially, until shear failure occurred without drainage. The method adopted meets specification of BS 1377: Part 7: 1990 and ASTM D2850-70. The results of the tests were analyzed using Mohr–Coulomb criteria to determine the shear strength parameters of the soil.

I. Consolidation Test

One dimensional consolidation test was performed on the undisturbed cylindrical sample measuring 20mm high and 75mm in diameter in accordance with BS 1377: Part 6:1990 specifications. The specimen was placed in a standard double drainage fixed ring Oedometer that confines the specimen to zero lateral deformation during the test. Porous stones were placed at the upper and lower parts of the test specimen in order to permit the dissipation of water contained in the sample, thus allowing volume change. In the tests, increments of vertical stresses were applied and vertical displacements were recorded for each of these increments. The parameters obtained from the results of the tests were used to determine the settlement rate of the soil. These parameters include compressive index (C_C) and coefficient of volume compressibility (M_V). The relationship between changes in void and imposed load with corresponding consolidation characteristics are presented in Tables 2 and 4.

J. Soil Stratigraphy and Characterization

Soil Stratification is characterized by abrupt porosity changes at various depths of soil formation. These changes in dimensions of the spaces between soil particles affect water and air movement within the pore spaces. Soil stratifications are caused by abrupt texture changes and compaction. The most common textural change is caused by the role of water in soil formation. The major soil formations of interest in this investigation are the grayish coarse sand, the light brown medium dense sand at the shallow and deep soil formations. Some engineering properties of these soil materials as extracted from field and laboratory analysis are presented in Table 2, Table 3 and Table 4.

TABLE 2: Engineering Characteristics of Ababa Soils

BH No.	Depth (m)	Friction Angle (Degree)	Cohesion (KN/m^2)	Compressive Index	Coeff. Vol. Comp. (m^2/KN)	SPT N-Values	Corresp. Friction Angle For SPT N-Values	Bulk Unit Weight (KN/m^3)
1	7.5	-	-	-	-	18	31	18.1
	12	-	-	-	-	20	33	18.8
	15	-	-	-	-	22	33	19.2
	21	-	-	-	-	30	35	20.3
	24	-	-	-	-	34	36	20.8
2	6	-	-	-	-	12	25	17.2
	9	-	-	-	-	10	25	19.9
	15	-	-	-	-	20	32	19.7
	18	-	-	-	-	21	33	19.1
	22.5	-	-	-	-	22	33	19.2
3	4.5	-	-	-	-	18	31	18.1
	7.5	2	52	0.13	1.55×10^{-4}	-	-	18.9
	12	-	-	-	-	22	33	19.2
	15	-	-	-	-	28	34	19.7
	21	-	-	-	-	36	38	21
4	6	-	-	-	-	18	31	18.1
	9	-	-	-	-	20	32	18.7
	12	-	-	-	-	22	33	19.2
	18	-	-	-	-	24	33	19.4
	24	-	-	-	-	32	35	20.6

TABLE 3: Ababa Soil Classification

BH NO	Depth (m)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index	% Passing #200	USCS
1.	6	-	-	-	89	SW
2.	15	-	-	-	87	SW
3	7.5	56	34	22	28	CH
4	21	-	-	-	90	SW

TABLE 3: Ababa Soil Classification

Properties		Mean Value
Liquid limit (%)		56
Plastic limit (%)		34
Plasticity Index (%)		22
Undrained shear strength	C_u (KN/m^2)	52
	Ø (degree)	2
SPT N-Value from depth of 10m and above		20
Corresponding shear strength from SPT N-Value on sand	Ø (degree)	32
	C_u (KN/m^2)	-
Initial void ratio (e^o)		0.77
Bulk unit weight (KN/m^3)		18.9
Coefficient of volume compressibility Mv (m^2/KN)		1.55×10^{-4}
Compressive index (Cc)		0.13

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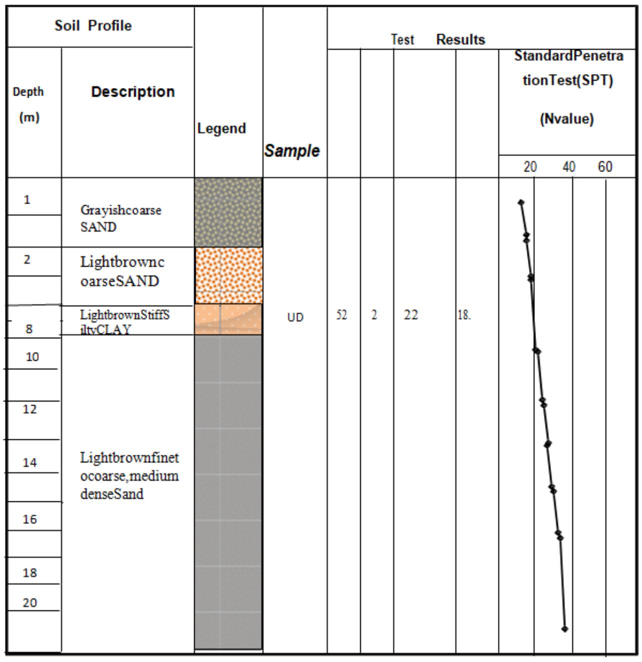


Figure (2): Borehole Characterization

III. DEFINITION OF EXPRESSIONS AND ABBREVIATIONS

Qu = Qp + Qs

Qa = Qu/3

Qp = PpAb,

Pp = qNq+0. 4BγNγ

= 1.3CNc+15BNqγ+0.4γNγQs

= ∝CuAs + γhckltanδ

Where

Qu = ultimate pile capacity,

Qa = allowable pile capacity

Qp = ultimate point (tip) resistance of the pile

Pp = ultimate base resistance of pile

C = Cu = cohesion (kN/m^2) = 0

Qs = ultimate shaft resistance of pile

Ab = base area of pile

Q = effective overburden pressure at the pile base

Nq, Nγ = bearing capacity factor

As = exposed area of shaft

K = coefficient of lateral earth pressure

= 1-sinϕ

∝ = pile wall adhesion

δ = pile wall friction angle = 17^o

hc = critical depth = 15B

B = diameter of pile (m)

l = length of pile (m)

A. Design Computations

The normal (usual) loading conditions with basic allowable stresses and safety factors will be utilized in the computation. A minimum factor of safety of 3 is considered adequate for both compression and tension members. The critical depth hc is taken as 15B within the medium dense sand formation. The minimum angle of friction between the soil and pile is taken as δ = $17^o$and the bulk unit weight of soil material is y=19.1 KN/m^3. Concrete pile diameters (D) ranging from 0.306m, 0.356m, 0.406m, 0.456m, 0.600m for circular piles and square piles with width (B) ranging from 0.300m, 0.360m, 0.400m,0.480m, 0.600m will be utilized in computation. The Static Method of Terzaghi's pile capacity design expressions will aid in determining the pile carrying capacity (KN) as a function of embedment depth. The detailed software design computations are presented in figures 3 to 12.

STATIC METHOD FOR DRIVEN CIRCULAR PILES IN COHESIONLESS SOIL
PROPOSED BRIDGE PROJECT, NSIT IBOM L.G.A., AKWA IBOM STATE.

Sand,Ø=32, C=0, y=19.1kN/m^3

QU=QP+QS — **Qp**=PpAb, **Pp**=1.3cNc+15BNqy_1+0.4By_1Ny, q=y(hc) and hc=15B (Terzaghi)

Qs=αCuAs+$y_1$hckltanD where Cu=0, **Qs**=$y_1$hckltanD, k=1,D=wall friction of concrete=17^0 ,tanD=0.30

Average SPT N Value= 20 which corresponds to Ø of 32^o for Ø=32 Nc=44,Ny=27,Nq=29,(Terzaghi)

Qu=Ultimate pile capacity,**Qa**=Allowable pile capacity Qa=Qu/3 y_1=y-yw, yw=9.8kN/m^3 y_1=9.3kN/m^3

For diameter(D)=0.306m Ab=3.142D^2/4,As=3.142DL

ULT(kN)	Allowable(kN)	l=Depth(m)	B(m)	Ab(m^2)	Pp	Qp	Qs	Qu	Qa
253.39	84.46	12.5	0.306	0.07	1268.6576	93.311137	160.07625	253.39	84.46
285.40	95.13	15	0.306	0.07	1268.6576	93.311137	192.0915	285.40	95.13
317.42	105.81	17.5	0.306	0.07	1268.6576	93.311137	224.10675	317.42	105.81
349.43	116.48	20	0.306	0.07	1268.6576	93.311137	256.122	349.43	116.48
413.46	137.82	25	0.306	0.07	1268.6576	93.311137	320.1525	413.46	137.82

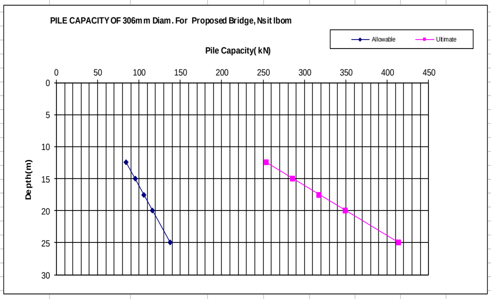


Figure (3): Pile Capacity (kN) of 0.306m Diameter Vs. Depth of Embedment (m)

STATIC METHOD FOR DRIVEN CIRCULAR PILES IN COHESIONLESS SOIL
PROPOSED BRIDGE PROJECT, NSIT IBOM L.G.A., AKWA IBOM STATE.

Sand,Ø=32, C=0, y=19.1kN/m^3

QU=QP+QS **Qp**=PpAb, **Pp**=1.3cNc+15BNqy_1+0.4By_1Ny, q=y(hc) and hc=15B (Terzaghi)

Qs=αCuAs+$y_1$hckltan$_D$ where Cu=0, **Qs**=$y_1$hckltan$_D$, k=1,$_D$=wall friction of concrete=17^0 ,tan$_D$=0.30

Average SPT N Value= 20 which corresponds to Ø of 32^0 for Ø=32 Nc=44,Ny=27,Nq=29,(Terzaghi)

Qu=Ultimate pile capacity,**Qa**=Allowable pile capacity Qa=Qu/3 y_1=y-yw, yw=9.8kN/m^3 y_1=9.3kN/m^3

For diameter(D)=0.356m Ab=3.142D^2/4,As=3.142DL

Qa=Qu/3

ULT(kN)	Allowable(kN)	l=Depth(m)	B(m)	Ab(m^2)	Pp	Qp	Qs	Qu	Qa
333.17	111.06	12.5	0.356	0.10	1475.9546	146.93295	186.2325	333.17	111.06
370.41	123.47	15	0.356	0.10	1475.9546	146.93295	223.479	370.41	123.47
407.66	135.89	17.5	0.356	0.10	1475.9546	146.93295	260.7255	407.66	135.89
444.90	148.30	20	0.356	0.10	1475.9546	146.93295	297.972	444.90	148.30
519.40	173.13	25	0.356	0.10	1475.9546	146.93295	372.465	519.40	173.13

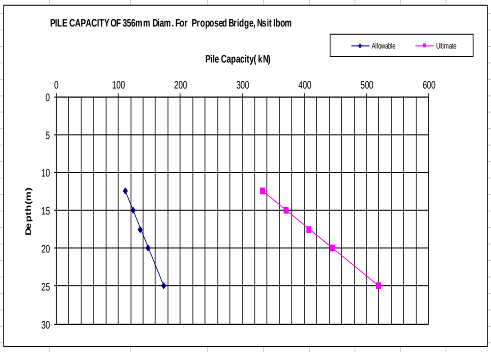


Figure 4: Pile Capacity (kN) of 0.356m Diameter Vs. Depth of Embedment (m)

STATIC METHOD FOR DRIVEN CIRCULAR PILES IN COHESIONLESS SOIL
PROPOSED BRIDGE PROJECT, NSIT IBOM L.G.A., AKWA IBOM STATE.

Sand,Ø=32, C=0, y=19.1kN/m^3

QU=QP+QS **Qp**=PpAb, **Pp**=1.3cNc+15BNqy_1+0.4By_1Ny, q=y(hc) and hc=15B (Terzaghi)

Qs=αCuAs+$y_1$hckltan$_D$ where Cu=0, **Qs**=$y_1$hckltan$_D$, k=1,$_D$=wall friction of concrete=17^0 ,tan$_D$=0.30

Average SPT N Value= 20 which corresponds to Ø of 32^0 for Ø=32 Nc=44,Ny=27,Nq=29,(Terzaghi)

Qu=Ultimate pile capacity,**Qa**=Allowable pile capacity Qa=Qu/3 y_1=y-yw, yw=9.8kN/m^3 y_1=9.3kN/m^3

For diameter(D)=0.406m Ab=3.142D^2/4,As=3.142DL

Qa=Qu/3

ULT(kN)	Allowable(kN)	l=Depth(m)	B(m)	Ab(m^2)	Pp	Qp	Qs	Qu	Qa
430.33	143.44	12.5	0.406	0.13	1683.2516	217.9452	212.38875	430.33	143.44
472.81	157.60	15	0.406	0.13	1683.2516	217.9452	254.8665	472.81	157.60
515.29	171.76	17.5	0.406	0.13	1683.2516	217.9452	297.34425	515.29	171.76
557.77	185.92	20	0.406	0.13	1683.2516	217.9452	339.822	557.77	185.92
642.72	214.24	25	0.406	0.13	1683.2516	217.9452	424.7775	642.72	214.24

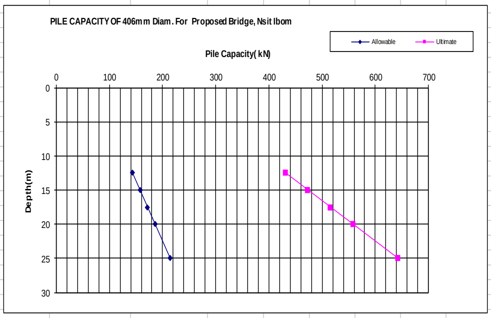


Figure (5): Pile Capacity (kN) of 0.406m Diameter Vs. Depth of Embedment (m)

STATIC METHOD FOR DRIVEN CIRCULAR PILES IN COHESIONLESS SOIL
PROPOSED BRIDGE PROJECT, NSIT IBOM L.G.A., AKWA IBOM STATE.

Sand,Ø=32, C=0, y=19.1kN/m^3

QU=QP+QS **Qp**=PpAb, **Pp**=1.3cNc+15BNqy_1+0.4By_1Ny, q=y(hc) and hc=15B (Terzaghi)

Qs=αCuAs+$y_1$hckltan$_D$ where Cu=0, **Qs**=$y_1$hckltan$_D$, k=1,$_D$=wall friction of concrete=17^0 ,tan$_D$=0.30

Average SPT N Value= 20 which corresponds to Ø of 32^0 for Ø=32 Nc=44,Ny=27,Nq=29,(Terzaghi)

Qu=Ultimate pile capacity,**Qa**=Allowable pile capacity Qa=Qu/3 y_1=y-yw, yw=9.8kN/m^3 y_1=9.3kN/m^3

For diameter(D)=0.456m Ab=3.142D^2/4,As=3.142DL

Qa=Qu/3

ULT(kN)	Allowable(kN)	l=Depth(m)	B(m)	Ab(m^2)	Pp	Qp	Qs	Qu	Qa
451.92	150.64	7.5	0.456	0.16	1890.5486	308.79036	143.127	451.92	150.64
499.63	166.54	10	0.456	0.16	1890.5486	308.79036	190.836	499.63	166.54
547.34	182.45	12.5	0.456	0.16	1890.5486	308.79036	238.545	547.34	182.45
595.04	198.35	15	0.456	0.16	1890.5486	308.79036	286.254	595.04	198.35
690.46	230.15	20	0.456	0.16	1890.5486	308.79036	381.672	690.46	230.15

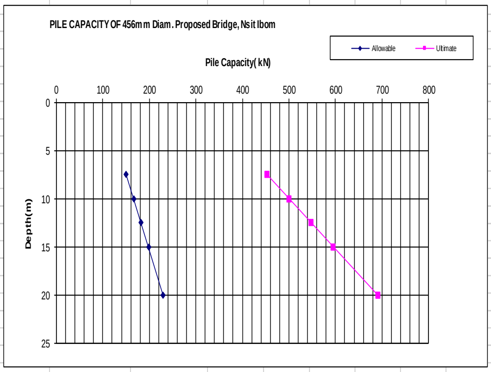


Figure (6): Pile Capacity (kN) of 0.456m Diameter Vs. Depth of Embedment (m)

STATIC METHOD FOR DRIVEN CIRCULAR PILES IN COHESIONLESS SOIL
PROPOSED BRIDGE PROJECT, NSIT IBOM L.G.A., AKWA IBOM STATE.

Sand,Ø=32, C=0, y=19.1kN/m^3

QU=QP+QS **Qp**=PpAb, **Pp**=1.3cNc+15BNqy_1+0.4By_1Ny, q=y(hc) and hc=15B (Terzaghi)

Qs=αCuAs+$y_1$hckltan$_D$ where Cu=0, **Qs**=$y_1$hckltan$_D$, k=1,$_D$=wall friction of concrete=17^0 ,tan$_D$=0.30

Average SPT N Value= 20 which corresponds to Ø of 32^0 for Ø=32 Nc=44,Ny=27,Nq=29,(Terzaghi)

Qu=Ultimate pile capacity,**Qa**=Allowable pile capacity Qa=Qu/3 y_1=y-yw, yw=9.8kN/m^3 y_1=9.3kN/m^3

For diameter(D)=0.61m Ab=3.142D^2/4,As=3.142DL

Qa=Qu/3

ULT(kN)	Allowable(kN)	l=Depth(m)	B(m)	Ab(m^2)	Pp	Qp	Qs	Qu	Qa
930.66	310.22	7.5	0.61	0.29	2529.0234	739.19447	191.46375	930.66	310.22
994.48	331.49	10	0.61	0.29	2529.0234	739.19447	255.285	994.48	331.49
1058.30	352.77	12.5	0.61	0.29	2529.0234	739.19447	319.10625	1058.30	352.77
1122.12	374.04	15	0.61	0.29	2529.0234	739.19447	382.9275	1122.12	374.04
1249.76	416.59	20	0.61	0.29	2529.0234	739.19447	510.57	1249.76	416.59

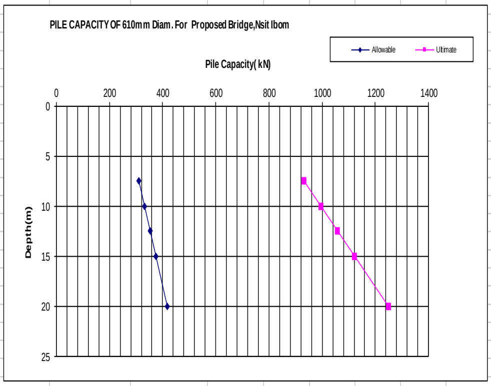


Figure (7): Pile Capacity (kN) of 0.610m Diameter Vs. Depth of Embedment (m)

STATIC METHOD FOR DRIVEN SQUARE PILES IN COHESIONLESS SOIL
PROPOSED BRIDGE PROJECT, NSIT IBOM L.G.A., AKWA IBOM STATE.

Sand,Ø=32, C=0, y=19.1kN/m^3

QU=QP+QS **Qp**=PpAb, **Pp**=1.3cNc+15BNqy_1+0.4By_1Ny, q=y(hc) and hc=15B (Terzaghi)

Qs=αCuAs+$y_1$hckltan$_D$ where Cu=0, **Qs**=$y_1$hckltan$_D$, k=1,$_D$=wall friction of concrete=17^0 ,tan$_D$=0.30

Average SPT N Value= 20 which corresponds to Ø of 32^0 for Ø=32 Nc=44,Ny=27,Nq=29,(Terzaghi)

Qu=Ultimate pile capacity,**Qa**=Allowable pile capacity Qa=Qu/3 y_1=y-yw, yw=9.8kN/m^3 y_1=9.3kN/m^3

B=0.3m,Qc=Pile base perimeter=4B, As=Qcl

Qa=Qu/3

ULT(kN)	Allowable(kN)	l=Depth(m)	B(m)	Ab(m^2)	Pp	Qp	Qs	Qu	Qa
268.88	89.63	12.5	0.3	0.09	1243.782	111.94038	156.9375	268.88	89.63
300.27	100.09	15	0.3	0.09	1243.782	111.94038	188.325	300.27	100.09
331.65	110.55	17.5	0.3	0.09	1243.782	111.94038	219.7125	331.65	110.55
363.04	121.01	20	0.3	0.09	1243.782	111.94038	251.1	363.04	121.01
425.82	141.94	25	0.3	0.09	1243.782	111.94038	313.875	425.82	141.94

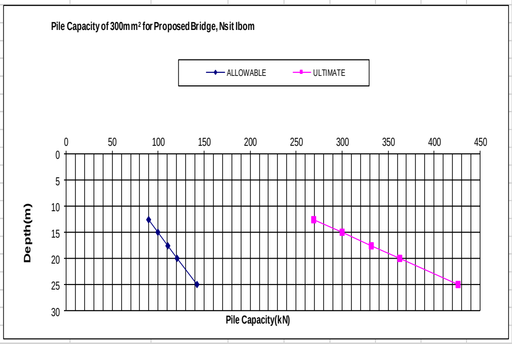


Figure (8): Pile Capacity (kN) of 0.300m Square Vs. Depth of Embedment (m)

STATIC METHOD FOR DRIVEN SQUARE PILES IN COHESIONLESS SOIL
PROPOSED BRIDGE PROJECT, NSIT IBOM L.G.A., AKWA IBOM STATE.

Sand,Ø=32, C=0, y=19.1kN/m^3

QU=QP+QS **Qp**=PpAb, **Pp**=1.3cNc+15BNqy_1+0.4By_1Ny, q=y(hc) and hc=15B (Terzaghi)

Qs=αCuAs+$y_1$hckltan$_D$ where Cu=0, **Qs**=$y_1$hckltan$_D$, k=1,$_D$=wall friction of concrete=17^0 ,tan$_D$=0.30

Average SPT N Value= 20 which corresponds to Ø of 32^0 for Ø=32 Nc=44,Ny=27,Nq=29,(Terzaghi)

Qu=Ultimate pile capacity,**Qa**=Allowable pile capacity Qa=Qu/3 y_1=y-yw, yw=9.8kN/m^3 y_1=9.3kN/m^3

B=0.36m,Qc=Pile base perimeter=4B, As=Qcl

Qa=Qu/3

ULT(kN)	Allowable(kN)	l=Depth(m)	B(m)	Ab(m^2)	Pp	Qp	Qs	Qu	Qa
381.76	127.25	12.5	0.36	0.13	1492.5384	193.43298	188.325	381.76	127.25
419.42	139.81	15	0.36	0.13	1492.5384	193.43298	225.99	419.42	139.81
457.09	152.36	17.5	0.36	0.13	1492.5384	193.43298	263.655	457.09	152.36
494.75	164.92	20	0.36	0.13	1492.5384	193.43298	301.32	494.75	164.92
570.08	190.03	25	0.36	0.13	1492.5384	193.43298	376.65	570.08	190.03

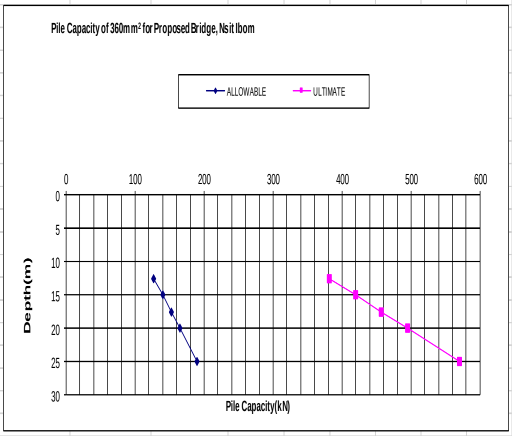


Figure (9): Pile Capacity (kN) of 0.360m Square Vs. Depth of Embedment (m)

STATIC METHOD FOR DRIVEN SQUARE PILES IN COHESIONLESS SOIL
PROPOSED BRIDGE PROJECT, NSIT IBOM L.G.A., AKWA IBOM STATE.

Sand,Ø=32, C=0, y=19.1kN/m^3

QU=QP+QS **Qp**=PpAb, **Pp**=1.3cNc+15BNqy_1+0.4By_1Ny, q=y(hc) and hc=15B (Terzaghi)

Qs=αCuAs+$y_1$hckltan$_D$ where Cu=0, **Qs**=$y_1$hckltan$_D$, k=1,$_D$=wall friction of concrete=17^0 ,tan$_D$=0.30

Average SPT N Value= 20 which corresponds to Ø of 32^0 for Ø=32 Nc=44,Ny=27,Nq=29,(Terzaghi)

Qu=Ultimate pile capacity,**Qa**=Allowable pile capacity Qa=Qu/3 y_1=y-yw, yw=9.8kN/m^3 y_1=9.3kN/m^3

B=0.4m,Qc=Pile base perimeter=4B, As=Qcl

Qa=Qu/3

ULT(kN)	Allowable(kN)	l=Depth(m)	B(m)	Ab(m^2)	Pp	Qp	Qs	Qu	Qa
474.59	158.20	12.5	0.4	0.16	1658.376	265.34016	209.25	474.59	158.20
516.44	172.15	15	0.4	0.16	1658.376	265.34016	251.1	516.44	172.15
558.29	186.10	17.5	0.4	0.16	1658.376	265.34016	292.95	558.29	186.10
600.14	200.05	20	0.4	0.16	1658.376	265.34016	334.8	600.14	200.05
683.84	227.95	25	0.4	0.16	1658.376	265.34016	418.5	683.84	227.95

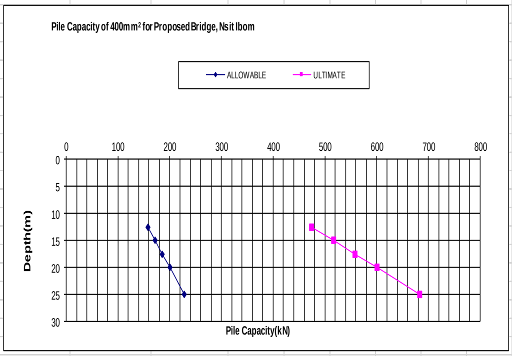


Figure (10): Pile Capacity (kN) of 0.400m Square Vs. Depth of Embedment (m)

STATIC METHOD FOR DRIVEN SQUARE PILES IN COHESIONLESS SOIL
PROPOSED BRIDGE PROJECT, NSIT IBOM L.G.A., AKWA IBOM STATE.

Sand,Ø=32, C=0, y=19.1kN/m^3

QU=QP+QS **Qp**=PpAb, **Pp**=1.3cNc+15BNqy_1+0.4By_1Ny, q=y(hc) and hc=15B (Terzaghi)

Qs=αCuAs+$y_1$hckltan$_D$ where Cu=0, **Qs**=$y_1$hckltan$_D$, k=1,$_D$=wall friction of concrete=17^0 ,tan$_D$=0.30

Average SPT N Value= 20 which corresponds to Ø of 32^0 for Ø=32 Nc=44,Ny=27,Nq=29,(Terzaghi)

Qu=Ultimate pile capacity,**Qa**=Allowable pile capacity Qa=Qu/3 y_1=y-yw, yw=9.8kN/m^3 y_1=9.3kN/m^3

B=0.48m,Qc=Pile base perimeter=4B, As=Qcl

Qa=Qu/3

ULT(kN)	Allowable(kN)	l=Depth(m)	B(m)	Ab(m^2)	Pp	Qp	Qs	Qu	Qa
709.61	236.54	12.5	0.48	0.23	1990.0512	458.5078	251.1	709.61	236.54
759.83	253.28	15	0.48	0.23	1990.0512	458.5078	301.32	759.83	253.28
810.05	270.02	17.5	0.48	0.23	1990.0512	458.5078	351.54	810.05	270.02
860.27	286.76	20	0.48	0.23	1990.0512	458.5078	401.76	860.27	286.76
960.71	320.24	25	0.48	0.23	1990.0512	458.5078	502.2	960.71	320.24

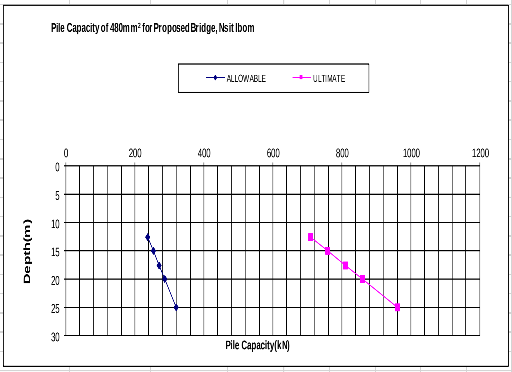
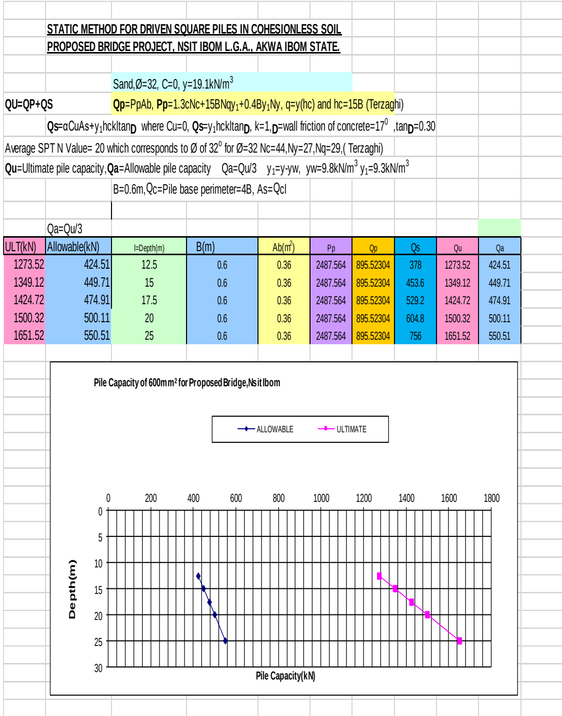


Figure (11): Pile Capacity (kN) of 0.480m Square Vs. Depth of Embedment (m)



STATIC METHOD FOR DRIVEN SQUARE PILES IN COHESIONLESS SOIL
PROPOSED BRIDGE PROJECT, NSIT IBOM L.G.A., AKWA IBOM STATE.

Sand,Ø=32, C=0, y=19.1kN/m^3

QU=QP+QS — **Qp**=PpAb, **Pp**=1.3cNc+15BNqy$_1$+0.4By$_1$Ny, q=y(hc) and hc=15B (Terzaghi)

Qs=αCuAs+y$_1$hckltan$_D$ where Cu=0, **Qs**=y$_1$hckltan$_D$, k=1,$_D$=wall friction of concrete=17^0 ,tan$_D$=0.30

Average SPT N Value= 20 which corresponds to Ø of 32^0 for Ø=32 Nc=44,Ny=27,Nq=29,(Terzaghi)

Qu=Ultimate pile capacity,**Qa**=Allowable pile capacity Qa=Qu/3 y$_1$=y-yw, yw=9.8kN/m^3 y$_1$=9.3kN/m^3

B=0.6m,Qc=Pile base perimeter=4B, As=Qcl

Qa=Qu/3

ULT(kN)	Allowable(kN)	l=Depth(m)	B(m)	Ab(m^2)	Pp	Qp	Qs	Qu	Qa
1273.52	424.51	12.5	0.6	0.36	2487.564	895.52304	378	1273.52	424.51
1349.12	449.71	15	0.6	0.36	2487.564	895.52304	453.6	1349.12	449.71
1424.72	474.91	17.5	0.6	0.36	2487.564	895.52304	529.2	1424.72	474.91
1500.32	500.11	20	0.6	0.36	2487.564	895.52304	604.8	1500.32	500.11
1651.52	550.51	25	0.6	0.36	2487.564	895.52304	756	1651.52	550.51

Figure (12): Pile Capacity (kN) of 0.600m Square Vs. Depth of Embedment (m)

IV. DISCUSSION OF RESULTS

Figures 3 to 7 present the results of both the ultimate and allowable pile bearing capacity values for various sizes of circular piles. The pile diameter ranged from 306mm, 356mm, 406mm, 456mm to 610mm. Figures 8 to 12 present results derived from square piles. The width of square piles varied from 300mm, 360mm, 400mm, 480mm to 600mm. These are all reinforced concrete piles.

Tables 5 and 6 present the summary of the bearing capacity of the various pile sizes as a function of depth of embedment using a factor of safety = 3.

TABLE 5: Bearing Capacities of Driven Piles at Different Depths

Depth (m)	Circular Pile Carrying Capacity (KN)				
	306ø	356ø	406ø	456ø	610ø
12.5	84	111	143	151	310
15	95	123	157	166	331
17.5	106	136	171	182	353
20	116	148	186	198	374
25	138	173	214	230	417

TABLE 6: Bearing Capacities of Driven Piles at Different Depths

Depth (m)	Square Pile Carrying Capacity (KN)				
	300	360	400	480	600
12.5	89	127	158	237	425
15	100	140	172	253	449
17.5	110	152	186	270	475
20	121	165	200	287	500
25	142	190	320	320	551

Where it is anticipated that negative skin friction (which could contribute to uneven settlement) would impose undesirable large downward drag on pile, the negative skin friction could be eliminated by providing a protective sleeve or surrounding them with a soft asphalt coating. Where it is anticipated that negative skin friction (which could contribute to uneven settlement) would impose undesirable large downward drag on pile, the negative skin friction could be eliminated by providing a protective sleeve or surrounding them Generally, it is observed that the carrying capacity of circular piles varies with depth of embedment and with slight lower values compared to square piles. For instance, it is observed that at 15 meters depth, the bearing capacity for the various sizes of circular piles vary from 95KN to 331KN. Pile diameter varied from 306mm to 610mm. At a depth of 20 meters, the values ranged from 116KN to 374KN. Inference is that, the working load and the depth of embedment have a linear relationship aided by soil friction as well as the soil bearing resistance.

The square piles seem to exhibit comparatively larger bearing capacity. At a depth of 15 meters the bearing capacity values for the various sizes of square piles vary from 100KN to 449KN. The pile width varied from 300mm to 600mm. At a depth of 20 meters the carrying capacity values appreciated from 121KN to 500KN.

A. Limitations

The investigations were carried out in accordance with acceptable geotechnical engineering practice. It is not expected that the soil conditions will vary significantly from those described but where such occurs during construction, special investigation may be conducted to ascertain the actual soil bearing conditions.

V. CONCLUSION

From this investigation and as extracted from the borehole formation the foundation bearing soil of interest at this site is the light-brown, medium dense sand for the proposed bridge. Within the depths explored, the subsoil stratigraphy consists mainly of sand which becomes denser with depth with the exception of borehole 3 with a thin layer of stiff silty clay at a depth of 7.5 meters. The thickness of the clay layer is insignificant compared to depth drilled and hence was not considered in evaluating the entire project area. The medium dense sand encountered from 10m down to final drill depth is a good foundation engineering material where pile can be rested. Both circular and square piles are considered functional for this project. However, the square piles exhibit tendency to absorb higher carrying capacity per depth of embedment compared to the circular piles. Arising from the above discussions, driven pile is recommended as main foundation for the proposed bridge. The recommended pile depths for various working load and sizes are presented in Tables 5 and 6.

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