An Evaluation of the Geotechnical Characteristics of the Abutments of a Proposed Bridge Across a 400-Meter River Channel in the Lower Niger Delta, Nigeria

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ABSTRACT

The Niger Delta is situated in the southern-most section of Nigeria and forms the major crude oil reservoir of Nigeria. However, it is in most parts devoid of transportation routes. A proposed Trans-Kalabari Highway is expected to connect some of the communities located within the Mangrove ("Transition") hydro-meteorological zone of the delta that is characterized by a network of rivers, creeks and rivulets. The left abutment of one of the bridges across a 400-meter wide river indicates that the sub-surface down to a depth of 30.00 meters at a distance of about *40.00 meters* from the edge of the river channel has *six (6) different soil layers as against four (4) at a comparative distance on the right abutment.* These soil layers are basically *dark-gray organic silty clays (OH)* underlain by *grayish silty clayey sands (SC)* which are further underlain by *poorly graded silty sands (SP)*. A *dark, highly plastic, grayish silty clay layer (SC-SM)* underlies the above strata at a depth of *between 12 to 18 meters*. *Well-graded sands and gravel (SW)* layer further underlies the above and extends to depths in excess of 30.00 meters. Borings situated between *40.00 meters* and the edge of the shoreline of the river channel all have *five layers* with *poorly graded sands (SP)* and *well-graded sands and gravels (SW)* underlying the organic silty clays and silty sands. Steel piles for the bridge support are expected to be borne at depths of between *20 and 25 meters* corresponding to the well-graded sands and gravels (SW) layer. This paper describes the detailed geotechnical engineering properties of the sub-soils at both abutments, gives a bathymetric profile of the river bed at the bridge crossing and recommends the design parameters for the piles such as the *end-bearing-capacities* for the piles to be used for the bridge support.

INTRODUCTION

The project is situated within the Tropical Zone and in the southern-most section of the Nigerian Niger Delta sub-region (Figure 1). The Niger Delta is zoned into three, namely: Coastal, "Transition" or Mangrove and Freshwater zones (Teme, 1988).

The Coastal or Lower Delta Zone consists mainly of sand bars and ridges, saline water bodies which are subjected to diurnal ebb and flow tides. The sub-soils here consist of *sand, silts and highly plastic clays* in some inlet areas, while the vegetation is basically mangrove trees with a preponderance of nippa palms (a recent development in this zone). The climate of the zone is basically that of tropical monsoon with rainfall of over 4000mmm, occurring almost all through the year except the months of December, January and February which are not completely free from rainfall in some years. (*Institute of Geosciences and Space technology Meteorology division records 1988-2000)*

'Transition' Or Mangrove (Middle Delta) Zone coincides with the Mangrove brackish water zone with its numerous inter-tidal flats and mangrove vegetation. Sub-soils here are characterized by a typical *fibrous, pervious clayey mud (that exhibits large values of compressibility and consolidation),* underlain by *silty sands which most often grade into poorly-graded sands and further downwards into well-graded sands and gravels. R*ainfall within the zone reaches highs of over 600mm at Port Harcourt, Opobo and Warri during the peak of the wet seasons.

Freshwater or Upper Delta Zone comprises the remaining northern portion of the Niger Delta sub-region and is predominantly fresh water rivers, creeks and ephemeral depressions. Generally, soil profiles here comprise a *top*

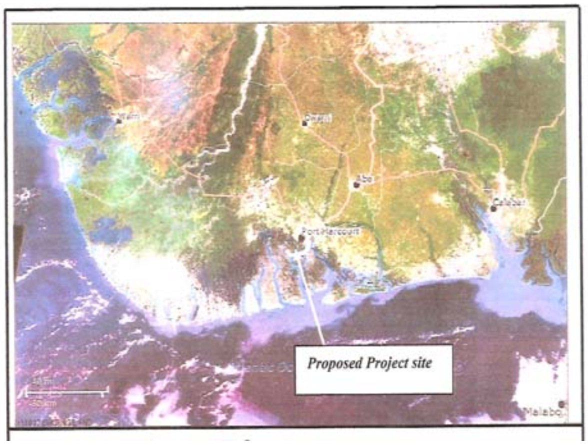

Fig. 1: A recent Satellite imagery covering the project area

lateritic clay layer usually underlain by silty clays and silty sands which are further underlain by poorly-graded sands and sands and gravels. The vegetation here comprises tall grasses, Palm trees, broad-leafed trees with very thick undergrowth characterized by creepers and climbing varieties. Rainfall occurs in over nine months of the year, especially during the annual flood periods of May through October and ranges in intensity between 200 and 600mm.

Fig. 2. Topography and Vegetation at the Left Abutment of the proposed bridge at Project site.

Description of the project area

The project is located within the Tropical Zone and in the southern-most section of the Niger Delta sub-region of Nigeria near Bakana in the Degema Local Government Area of Rivers State. Geographically, the project site is situated approximately on Latitude 04^0 44' North of the Equator and Longitude 06^0 57' East of the Greenwich Meridian.

Subsurface Conditions. The Subsurface conditions at the project site were studied by sounding in the form of Standard Penetration Testing (SPT), with the aid of Shell-Percussion Rig *(Fig.3)* while retrieving soil samples at specific depth intervals of 1.50 meters for purposes of visual examination of soil samples, laboratory testing and classifications, as the case may BE.

Fig. 3. Percussion Rig used at the Bridge Abutment Sites.

The bearing capabilities of the various soil horizons at the project site were assessed using the Standard Penetration Test data. This gave valuable information about the sub-surface characteristics at the project area.

Local Geology. The local geology of the project areas is basically that of the Coastal Plains Sands *(Qp)* of the lower Quaternary (Pliocene-Pleistocene) and Alluvium of upper Quaternary (Recent sediments). (Geological Map of Nigeria Series, 1984). The geological configuration of the project sites is given in *Figs.4 and 5 below*.

Water Table. The Water Table at the site was observed to be about *0.40 to 1.45 meters* above ground surface during the full tide at the right abutment. At ebb tides however, the groundwater table was a mere *0.80meter* below ground level.

Subsurface explorations. The subsurface exploration programme at the project site comprised Shell-and-Auger borings, Pressure-meter Testing using the Norwegian cone (CPT) and soil samplings. Standard Penetration Testing (SPT) was also carried out during the Shell-and-Auger boring exercise.

Borings. A total of Six (6) Shell-and-Auger borings each to a depth of 20.00 meters were made at each abutment of the bridge site.

Soundings. Standard Penetration Tests *(SPT)* were carried out during the subsurface exploration-sounding programmes at the project sites. The SPT-N values were used in evaluating the soil bearing capacities.

Standard Penetration Tests (SPT). These were carried out at the sampling depth where cohesion-less *(c)* materials or c - ϕ *soils* were encountered, during the boring exercise.

Samplings. In general, disturbed samples were obtained during the drilling programme using the *Shell-and-Auger* equipment. Within the zone of cohesive materials such as clays or sandy clays, undisturbed soil samples were obtained during the percussion drilling with the aid of *split-spoons and U4-tubes*.
Sampling intervals during the drilling were *1.50-meter*s apart down to the end of the boring. All the depths mentioned in this report are in relation to ground level at the time of investigations.

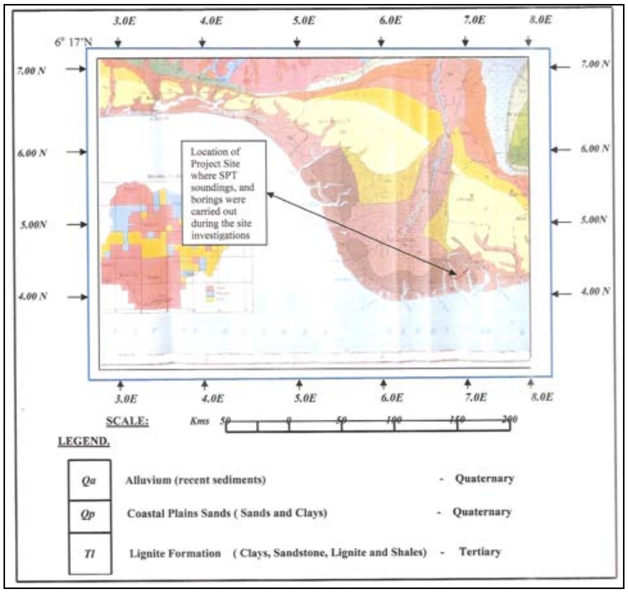

Fig. 4. The geological sequence at the project sites

Subsurface Profiles
The summary of the profiles of the soils at each abutment of the bridge across the New Calabar River are as given below.
Left Abutment, there are *Six (6)* basic types of soil profiles namely,
(i) Dark grayish Organic Silty Clay Layer (OH)
(ii) Grayish Clayey Sands Layer (SC)
(iii)Poorly graded Sands Layer (SP)
(iv) Grayish Clayey Sands Layer (SC)
(v) Plastic Dark grayish Silty Clays Layer (CH)
(vi) Well-graded Sands and Gravels Layer (SW)

At the *Right Abutment*, there are *Five (5)* basic types of soil profiles namely,
(i) Dark grayish Organic Silty Clay Layer (OH)
(ii) Grayish Clayey Sands Layer (SC)
(iii) Poorly graded Sands Layer (SP)
(iv)Plastic dark greyish Silty Clays Layer (CL)
(v) Well-graded Sands and Gravels Layer (SW)
The cross-sectional profiles between the two bridge abutments is shown in Fig. 5 below.

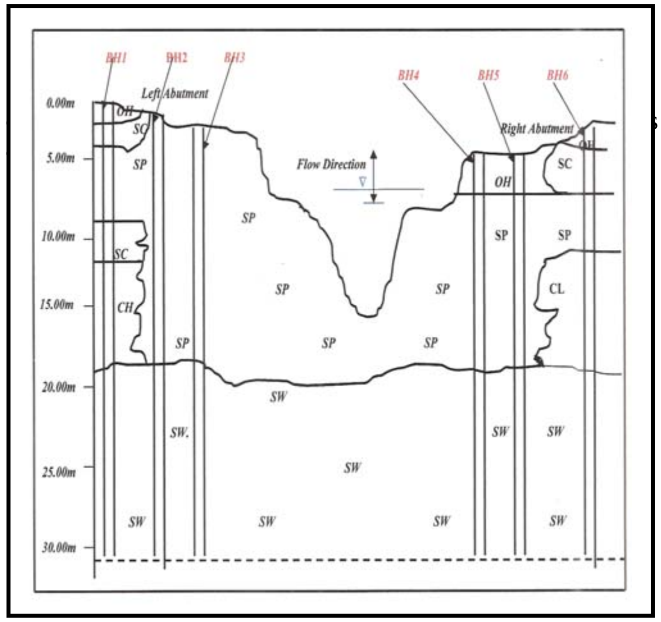

Fig. 5. Subsurface Stratigraphy across the bridge abutments at the New Calabar River

The following laboratory tests were carried out on selected soil samples recovered from the borings.
(a)Visual Classification of Soil Samples. (b) Grain Size Analysis, (c) Consistency Limits (Atterberg Limits); (d) Unit Weights determinations; (e) Unconsolidated-Undrained Tri-axial Tests and (f) Oedometer Consolidation Tests. The results are as shown in Table 1.

Soil Bearing Capacity . This was evaluated by means of determination of the coefficient of volume compressibility (Mv) and the coefficient of consolidation (Cv) through the Terzaghi One-dimensional Oedometer Tests and the field SPT-N values. The net soil bearing pressures obtained using the relationship qa = 0.22N (0.1073) MPa [modified from Peck, Hanson and Thornburn 1974] were:

(i) Grayish Clayey Sands Layer (SC)	=	0.0472MPa
(ii) Poorly graded Sands and gravels(SP)	=	0.1967MPa
(iii)Grayish Clayey Sands (SC)	=	0.0865MPa
(iv)Well-graded Sands and gravels	=	0.543 MPa

DISCUSSION OF RESULTS IN RELATION TO FOUNDATION SYSTEMS.

On the basis of the subsurface soil types encountered at the project site and bearing in mind the proposed project for the sites, it was recommended that only ***Deep Foundations*** should be used for the proposed Bridge abutment Foundation at the site.

Deep Foundation Options.

In using deep foundations, *Reinforced Steel Hollow Cylindrical Piles* were recommended because of their durability and relative ease of installation.

Design Considerations for the Reinforced, Steel Hollow cylindrical Pile Foundations. This took into consideration the following:- (a) Depth of embedment of pile *(D_f)*, (b) Cross-sectional area of reinforced steel hollow cylindrical piles, (c) ultimate carrying capacities of piles of different diameters,

Table 1. Summary of Some Geotechnical Properties of Sub-Soils at the Trans-Kalabari Bridge Crossing at Bakana-Bukuma

Soil Type	USC Class	U – U Triaxial Tests		Oedometer Consolidation		Soundings	Sat. Unit Wt.	Soil Consistency		
		ϕ_u (^{o})	C_u (kPa)	M_v (m^2/MN)	C_v (m^2/yr	SPT (N)		Wn %	LL %	PI %
Dark Brownish Organic Silty Clay	OH	4 - 6	28 - 36	0.20 – 0.43	1.15 – 1.95	-	0.98	28-34	34.5 - 38.6	17-18
Greyish Clayey Sands	SC	4 - 6	14 – 18	-	-	6 – 8	1.78	15-18	18.5 - 20.5	8-10
Poorly graded Sands	SP	30-32	0.00	-	-	>50	2.60	NP	NP	NP
Grayish Clayey Sands	SC	28-30	0 – 8	-	-	11	1.78	15-18	18.5 - 20.5	8-10
Plastic dark-grayish Silty Clays and Sands	CH	4 - 6	32.00	0.18 – 0.26	1.02-1.25	-	1.20	15-20	28-32	12-14
Well-graded Sands and Gravels	SW	32-34	0.00	-	-	>50	2.98	NP	NP	NP

(d) Base resistance of piles, (e) Shaft resistance {unit skin friction } of piles.

Depth of embedment of pile *(D_f).* From boring and sounding records obtained from the Six (6) borings at each abutment, the depths of pile embedment were determined to be 25.00 meters for the Left abutment and 20 meters for the Right abutment. These depths coincided with the well-graded sands and gravels (SW) soil horizon.

Cross-Sectional Area of Reinforced Steel Hollow Cylindrical Piles. The proposed cross-sectional area for each of the *Reinforced Steel Hollow Cylindrical Piles* was taken as πR^2 where R = radius of pile ~ $\pi \times (400/2)^2 m^2$ ~ *0.12506* m^2. This cross-sectional area serves for all the bridge abutments.

Ultimate Carrying Capacities Of Piles Of Different Diameters. The Ultimate Carrying Capacity of Piles is dependent on the sum of the *Ultimate Resistance of the Base of the pile and the Ultimate Skin Friction (Shaft Resistance) of the pile* considered.

$$Q_u = Q_b + Q_s \quad (1)$$

where: $\boldsymbol{Q_b}$ = base resistance of tip of pile, $\boldsymbol{Q_s}$ = Skin friction of pile

Base Resistance of Piles

Net unit base resistance $\boldsymbol{q_{ult}} = q_f = p = p_d (N_q - 1)$ (2)
where:
P_d = effective overburden pressure at pile base level (3)
For a pile depth of *25.00 meters*, we have:

Q_b = 6.41084 MN

Shaft Resistance {Unit Skin Friction } of Piles. is given as:

$$f = Ks \, . \, p_d \, . \, \tan \delta \qquad (4)$$

However, the failure load of the pile Q_u = load at failure applied to the pile Q'_u + Wt of the pile (W_p) ie:

$$Q_u' = Q_u - W_p = Q_b + Q_s = A_b P_d (N_q - 1) + Q_s$$

But weight of concrete in pile ≤ weight of soil displaced,

$$\therefore Q_s = P_d (A_b N_q + K_s \tan \delta A_s) \qquad (5)$$

$$= P_d\{(\pi \, . \, r^2)(18.40)\} + \{1.1 \times \tan(2/3 \, (30.00)) \, (\pi \, \mathbf{D} . 25.00)\}$$

$$\therefore Q_b + Q_s = 6.41084 \text{ MN} + \{2171.0225 r^2 + 1181.138 D\} \qquad (6)$$

where:

A_b = cross-sectional area of pile
A_s = embedded surface area of pile
P_d = average effective overburden pressure over embedded depth of pile

When D = 300mm, then we have,

$Q_b + Q_s$ = <u>90.693 MN</u>

Settlement and Rates Of settlements

If excessive loads are imposed on the pile foundation, settlement may occur as a result of loading on the individual piles or pile group, as the case may be. The solution proffered by Burland Butler and Duncan (1966) is suitable to be used in estimating the pile settlements that might occur after emplacement of the Bridge. The settlements arising from pile emplacements have been given by the mentioned authors as:

$$\rho_i = B . K \, (q / q_f) \qquad (7)$$

where:

B = base of pile tip
K = coefficient of earth pressure
$\mathbf{q}$ = imposed Load on the pile foundation = **T**
q_f = sum of resistance from the soil

For instance, if a single pile in the group is to settle in this proposed case, the settlement will be equivalent to the following:-

$$\rho_i = (0.30\text{m}) (1.00) (T / 6{,}408.4)[100] \text{ mm}$$
$$= 0.004681355 T \text{ mm} = 4.68 \times 10^{-3} \, T \text{ [mm]}$$

SUMMARY AND CONCLUSIONS

On the basis of field investigations and laboratory testing carried out on the soil samples obtained from the project site, it is observed that basically *five (5) to six (6)* identifiable soil horizons are present at both Left and Right Abutments of the bridge, respectively.

(a) A Deep Foundation System employing *Steel Hollow Cylindrical Piles* was proposed for purposes of bearing the proposed Bridge.

(b) At each Abutment, the Steel Hollow Cylindrical Piles should be driven to depths of 25.0m or at refusal at both sides

(c) The dimensions of the Steel Hollow Cylindrical Piles were about 28.00m; the internal diameter was 300.00mm; the wall thickness was 0.25cm; angle of wall friction, δ, was taken as equal to 2/3 ϕ of the soil and the Earth Pressure Coefficient K_s = 1.00 for loose soil conditions and 2.00 for relatively dense soil conditions.

(d) The Ultimate Carrying Capacity of the Steel Hollow Cylindrical Piles, $\boldsymbol{Q_u' \geq q_{net}}$ ($\boldsymbol{q_{net}}$ being the load imposed on the piles by the weight of the Bridge super structure

(e) Minimal Pile settlements are expected to occur since the proposed piles are to be anchored on the Well-graded Sands and gravels at depths of between 20.0 to 25.0m.

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