

Analysis of Foundation Options for the marine segment of the Greater Port Harcourt Ring Road, in the Niger Delta

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Abstract

The greater PHC ring road was conceived as the remedy for the growing congestion of roads in Port Harcourt city, Nigeria the proposed road traverses some 40km of marine section over which a decision is needed for a suitable pavement foundation design. The sub-soils, which are diurnally inundated by up to 2.5m of water, comprise a top very soft to soft silty and peaty clay (5 to 30m thick) overlying a predominantly medium dense sandy formation. The foundation options included the placement of 6m of sand fill, the removal of 3m of top soft-soil and replacement with sand, supplemented with vertical sand drains and combinations of micro-piles. Settlement analysis based on a surcharge of roughly 120kN/m² representing maximum expected axle road, indicated values of up to 3m, reducing only to 1.2m after removal of 3m of the top soft soil. The option maximizes the benefits from improved bearing capacity of top layers, settlement minimization, partial improvement in navigation through a thoughtful dredging layout, and the potential for development of new coastal settlements. Although the cost of implementing the micro-piles option was considered exorbitant, the option exerted minimum impact on the environment with a capacity to conserve the hydro ecology. The balance of functionality, cost and the environment were critical in the final choice of the option for implementation.

Keywords: Niger delta, Foundations, embankments, marine sediments, consolidation

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1 Introduction

Port Harcourt city has grown in population from less than 350, 000 in 1967 when it was created capital of Rivers State (RS Dev Plan 1975), to over 7million in 2015. This rapid growth, which is driven largely by the presence of multi-national oil/gas related activities comes with associated increase in vehicular traffic (NDES 1999). The growing nuisance of heavy traffic is already having a significant impact on human health through gaseous emissions (NDES 1999) and the economy of the state through lost time. The conceptualization of a greater Port Harcourt Road, as a ring around the city, is the state's response to a deteriorating traffic situation in the capital.

The proposed road which traverses some 40km of marine section of the Bonny River estuary (Fig. 1), running essentially perpendicular to the dominant drainage direction and over mangrove swamp terrain and ecology would inevitably be faced with difficult soil and ecological conditions.

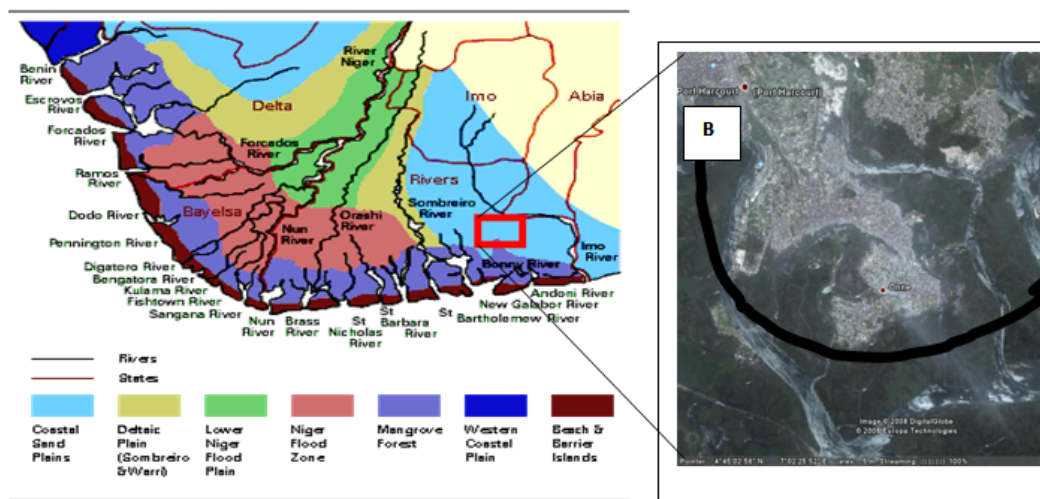


Fig. 1: Ecological zones of the Niger delta (after SPDC 1997) showing typical terrain of project

The Mangrove ecology which comprises very soft to soft sometimes thick sequences of organic clay is also considered by many as sensitive (NDES, 1999) and subject to diurnal inundation by up to 2.5m of tidal water, with unstable banks (Abam, 1993). The presence of thick clay sequences suggest the necessity for some form of ground improvement (Ratuv, 2010) or a choice of foundation options in which cost may be matched with effectiveness, while instability of the river banks imply that bridge abutment are likely to face challenges of stability.

2 Methods of Investigation

The investigation involved the drilling of seventeen (17) geotechnical boreholes to 30m depth, 12 no. Cone Penetration tests along the proposed alignment of the road (Fig 1), using the conventional barge mounted light shell and auger percussion rig described by George and Abam (1992) and a 10 Ton Geomil type CPT respectively. The layout of test points and sequence is shown in Fig. 2.

A: Okrika

B: Borokiri

BH	1	2	3	4			5	6	6	7			8	9	10			11	12	13			14	15	16	
									A																	
CP	1				2	3	4				5	6	7			8	9	10				11	12			
T																										

Fig. 2: Boring and CPT sounding layout

Undisturbed cohesive soils samples were retrieved from the borehole and subjected to a series of geotechnical tests, including quick undrained triaxial and oedometer consolidation tests. The quick undrained shear tests responded to the critical loading conditions that prevail during the placement of sandfill on the soft topsoils. In combination with the oedometer results, the quick undrained strength values were used to effectively determine the rates of sand fill placement needed to avoid shear failures in the top clay soils. Total settlement in preloaded sections was predicted based on oedometer results and the in-situ CPT tests results using established procedures and relationships (Bowles 2005).

For calculation of foundation settlement, it is required that we estimate the vertical stress increase in the soil mass due to the net load induced by the placement of a 6m high sand fill surcharge. This scenario has been schematized in Fig. 3. Assuming a two-dimensional loading condition of a typical cross-section of an embankment as illustrated, the vertical stress increase may be expressed as:

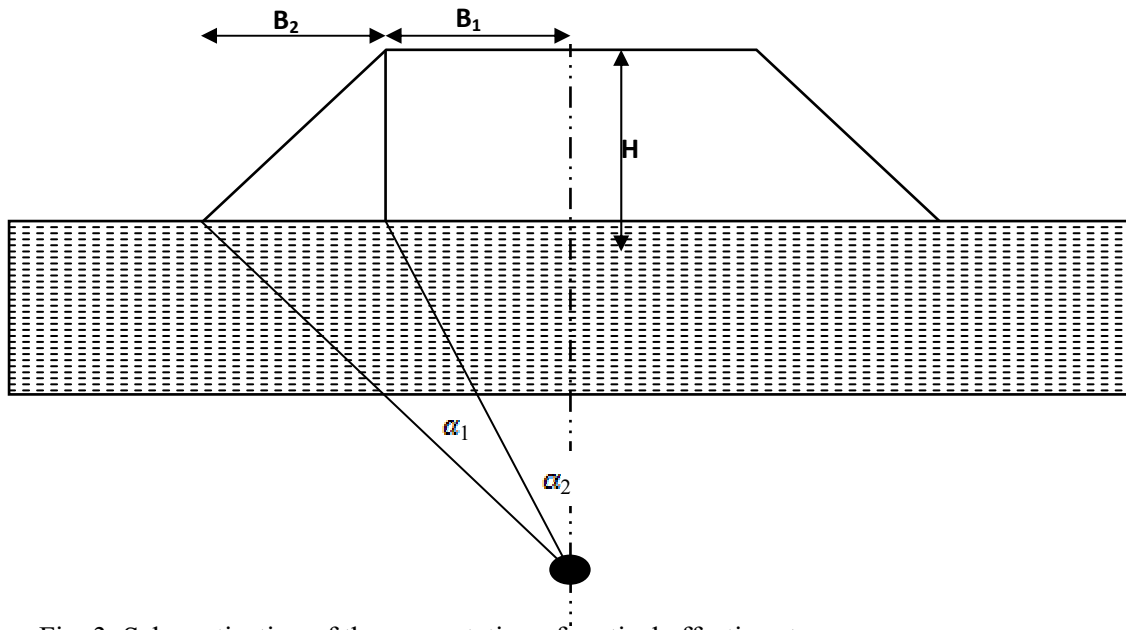


Fig. 3: Schematization of the computation of vertical effective stress

$$\Delta_p = \frac{q_0}{3.142} \left[\frac{B_1 + B_2}{B_2(a_1 + a_2) - \frac{B_1 a_2}{B_2}} \right] \quad (1)$$

Where $\Delta_p = \gamma H$

γ = unit weight of the embankment soil, which in this case is sand

H = height of the embankment

$$\alpha_1 \text{ (radians)} = \tan^{-1} \left(\frac{B_1 + B_2}{2z} \right) - \tan^{-1} \left(\frac{B_1}{z} \right) \quad (2)$$

$$\alpha_2 = \tan^{-1} \left(\frac{B_1}{z} \right) \quad (3)$$

Using the vertical effective stress profile generated from the above relationship, total settlement caused by the caused by the placement of a 6m sandfill surcharge was predicted assuming a unit weight of sand of 19KN/m³. Similar settlement computations were made for the case where 3m of top soft sediments were removed and replaced with sand.

Axial pile capacities were also computed for each river crossing for driven, single, straight-shafted, close-ended, tubular steel piles using the method summarized by the following equations (Bowles 2005):

$$\text{Ultimate carrying capacity, } Q_{\text{ult}} = Q_b + Q_s \quad (4)$$

Where:

$$Q_{\text{bs}} (\text{Ultimate base resistance in clay}) = 9.C_u.A_b$$

$$Q_{\text{bs}} (\text{Ultimate base resistance in sand}) = P_0^1.N_q.A_b$$

$$Q_{\text{sc}} (\text{Ultimate shaft resistance in clay}) = \alpha C_u.A_s$$

$$Q_{\text{ss}} (\text{Ultimate shaft resistance in sand}) = K_s.P_0.\tan \delta.A_s$$

The parameters in the above equations are defined further as follows:

C_u = average undrained cohesion at the pile base

A_b = base pile of the pile

P_0 = effective overburden pressure at the pile base

N_q = bearing capacity factor

A_s = exposed area of shaft

K_s = coefficient of lateral earth pressure ($K_s / K_0 = 1$ to 2). For small displacement, pile ratio varies from 0.75 to 1.75, $K_0 = 0.6$

P_0 = average effective overburden pressure over soil layer

α = pile wall adhesion

δ = effective soil/pile friction angle (smooth surface = 0.5 to 0.7)

Undrained strength to which a factor of safety of 1.8 was applied as recommended by (Eurocode 7 EN 1997), $C_{\text{ub}} = \frac{cu}{f_s = 1.5 - 1.8}$ in the computation of pile capacity

within the clay formations. To obtain the safe pile capacity, the relationship in equation 5 was used.

$$\text{Safe Pile capacity, } Q_{\text{allowable}} = (Q_b + Q_s)/3 ; (Q_b /3 + Q_s /2.5) \quad (5)$$

3 Results and Discussions

The lithologs of the borings have been juxtaposed (Fig. 4) to provide the local stratigraphy underlying the proposed road. The borings reveal an underlying sandy formation, believed to be a sub-marine extension of the Benin Formation. This is overlain by fine Quaternary and Pleistocene sediments of soft consistency, varying in thickness from 5m to 30m across the Bonny River basin, with the thickest section occurring beneath the main drainage channel. The Atterberg limits of the top fine sediments (Fig.5) indicate a wide range of plasticity (from low to very high plasticity), suggestive of diverse sources of sediments. Since this clay is very soft and highly compressible, it could easily fail in shear upon loading and or exhibit exceptionally high consolidation settlement which would occur over a considerable length of time because of large thickness. Therefore it was perceived that sand would improve the bearing characteristics and at the same induce settlement.

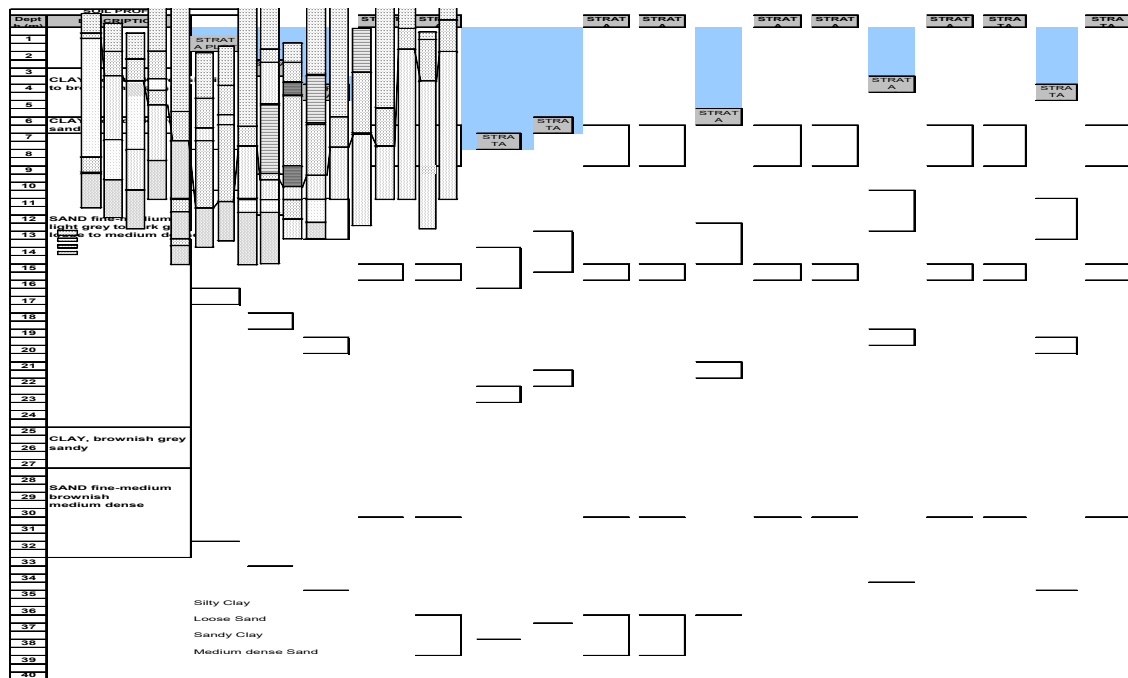


Fig 4. Sub-Soil stratification along proposed alignment

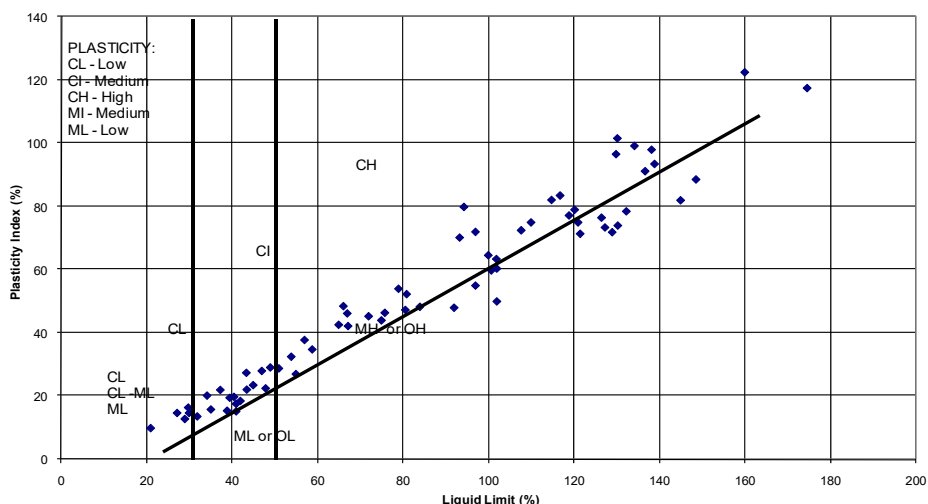


Fig 5. Soil classification by Casagrande Plasticity chart

Settlement computations from oedometer and CPT data consolidation indicated total Settlement values varying from 1m to 4m (Table 1) depending on the thickness and compressibility parameters of the sediments along the alignment. The influence of thickness of the highly compressible sediment on settlement is evident in Fig. 6, in which higher total settlements were always associated with thicker clay layers.

Table 1: Summary of Settlement Computations

BH No.	Settlement (m)	CPT No.	Settlement (m)
4	4.366	1	1.23
5	3.434	2	1.291
7	4.069	3	1.911
8	2.603	4	2.55
10	3.407	5	2.754
11	3.55	6	2.918
13	3.85	7	3.398
14	1.333	8	3.114
16	1.787	9	3.03
		10	3.474
		11	2.651
		12	1.32

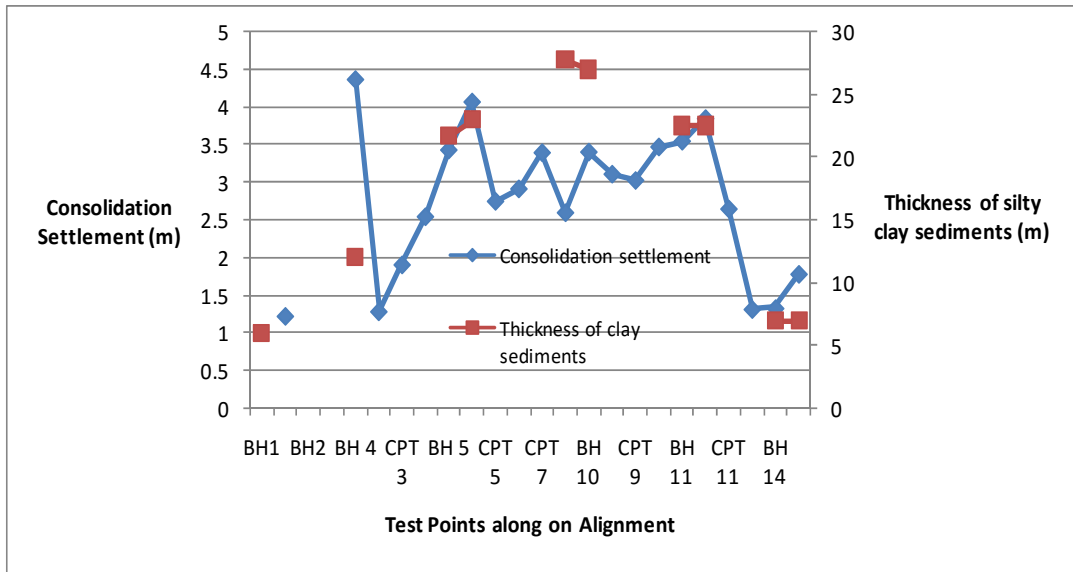


Fig.6 Variation of settlement along alignment in relation to thickness of top silty clay

Settlement computations were also undertaken for the alternative option of removal of 3m of soft top clay before the placement of 6m of sand. As expected, this scenario gave significantly reduced total settlement estimates. Table (2) and Fig. 7 provides a summary of the settlement estimates of the two scenarios.

Table (2): Comparative Total Settlement for the scenarios of where 3m of weak top soil is removed

CPT No.	Settlement from placement of 6m sandfill over swamp	Settlement from placement of 6m sandfill over swamp after removal of top 3m
1	1.229	0.668
2	1.291	0.586
3	1.911	1.202
4	2.55	1.98
5	2.754	2.088
6	2.918	2.326
7	3.398	2.898
8	3.114	2.406
9	3.03	2.184
10	3.474	2.581
11	2.651	1.927

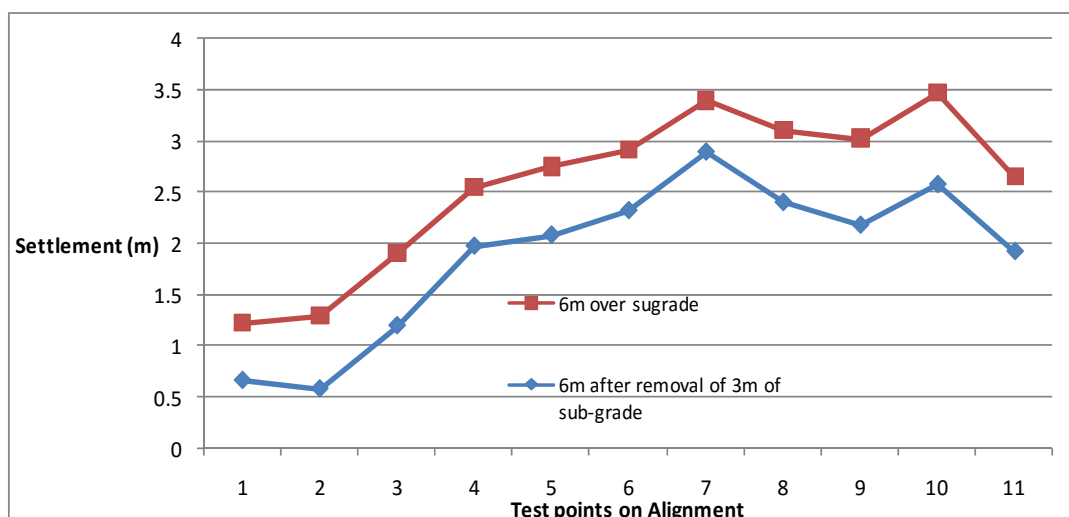


Fig. 7: Comparison of Total settlement for two ground improvement scenarios

Although attainment of lower total settlement was attractive, the time over which at least 97% of settlement was to take place was of crucial importance. Since the permeability of the overlying clay layer was exceptionally low, a process was needed to accelerate it. This was achieved by the incorporation of sand drains into the design. The sand drains effectively reduced the drainage path and accelerated the consolidation process. Settlement Analysis for the scenario where 3m of weak top soil is removed before placement of 6m thick sand surcharge is shown in Table (2). This clearly shows that comparatively large settlement $>2\text{m}$ occurring between BH4 to BH13 and between CPT 4 to CPT 11 along the proposed alignment.

Results of a typical incremental settlement analysis is presented graphically (Fig 8) to show the vertical distribution of total settlement and its cummulation to derive total Settlement in the boring and CPT. This figure shows that settlement distribution is concentrated within the top 8m indicating also that the impact of the stress induced by the 6m thick sand pre-load will be limited to 9m.

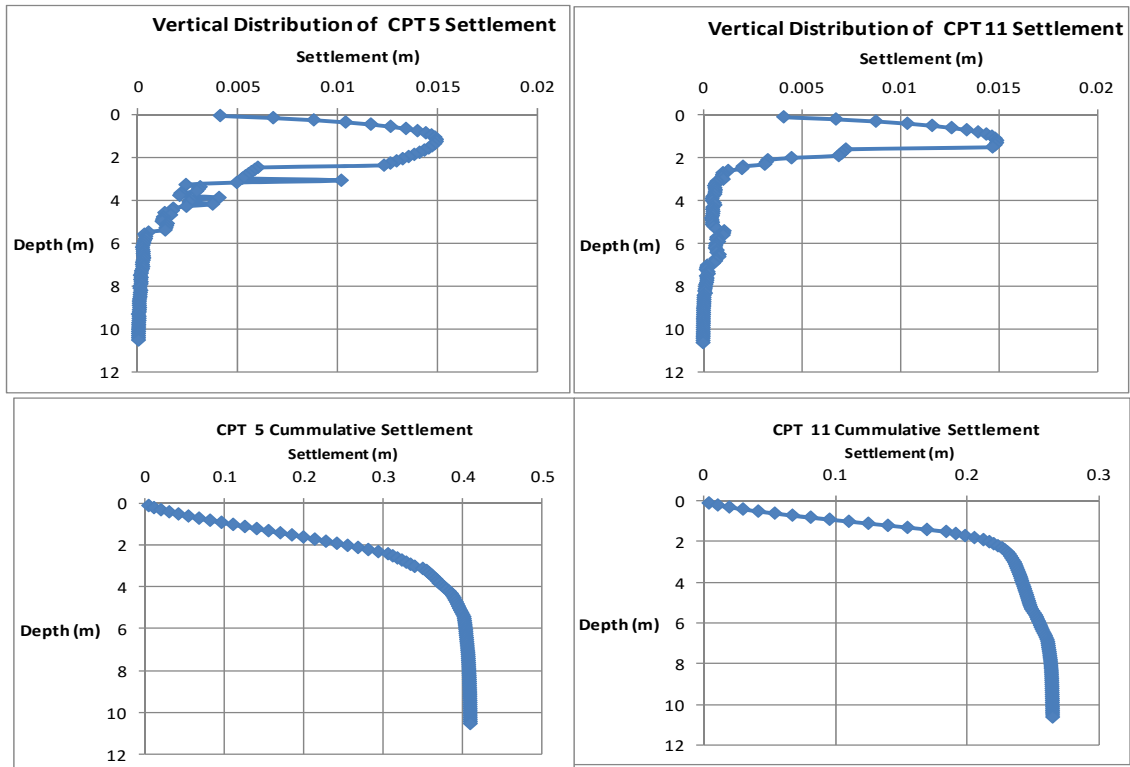


Fig. 8: Vertical settlement distribution and cummulation at two points on the alignment

In sections where the total settlement was large as indicated earlier, the micro-pile option was suggested. The type of pile and the depth of embedment were dependent on the soil characteristics. An assessment of the axial pile capacity was however made for 406mm, 900mm and 1500mm diameter (Tomlinson 1999; Das, 2006). The smaller diameter 406mm pile was to be closed ended tubular driven steel piles while the larger diameters (900mm and 1500mm) were to be essentially end bearing. This assessment indicated the expected Allowable driven as well as end bearing pile capacities (Fig. 9) at each boring location. The high cost of piles is widely recognized and any measure to minimize their use should result in lower project cost.

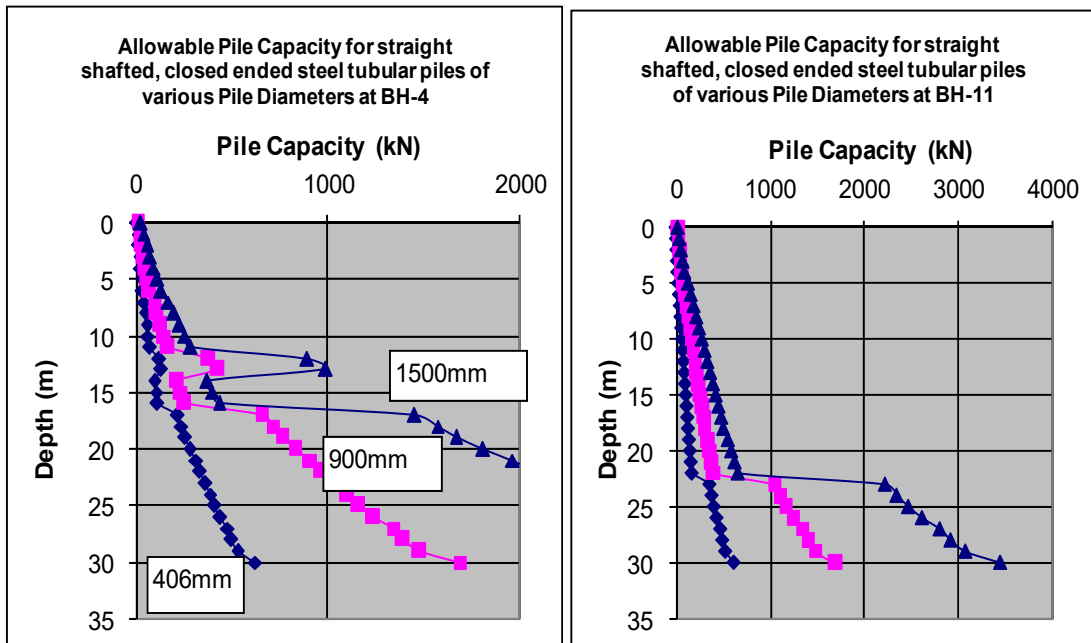


Fig. 9: Axial Pile capacities for driven piles in typical marine segment locations.

By being aligned perpendicular to the drainage direction, the sand filling of the proposed road, will inadvertently alter surface water flow rates, leading to increased sedimentation upstream, and promoting the creation of new settlement in the area. At the same time, the discharge through the main river channels will be increased, thereby increasing the prospects of bank erosion in ways that have already been described by an earlier work (Abam 1993).

4 Conclusion

The following conclusions are drawn from the study:

The greater Port Harcourt ring road was conceived as the remedy for the growing congestion of roads in Port Harcourt city. However, the proposed alignment of the marine section is over soft silty clay sub-soils that are likely to present some geotechnical challenges. Among several foundation options, the removal of 3m of top soft-soil followed by the placement of 6m of sand fill, supplemented with vertical sand drains was considered the most satisfactory. The option maximizes the benefits from improved bearing capacity of top layers, settlement minimization, partial improvement in navigation and the potential for development of new coastal settlements. This option highlights the necessity to balance functionality, cost and the environment.

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