Assessment of some geo-environmental problems associated with road construction in the Eastern Niger Delta

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Abstract: A detailed assessment of some geo-environmental problems associated with the Gbaran-Tombia Access Road, Eastern Niger Delta, was carried out. Four (4) water wells were drilled along the access road to obtain baseline data on water level monitoring, water quality and subsoil analysis for infiltration characteristics. The boreholes were drilled with the use of a light cable percussion rig to a depth of 10m in each borehole. The static water levels recorded in the boreholes were 0.55m, 1.58m, 2.50 and 3.68m for boreholes 1, 2, 3 and 4, respectively. Laboratory tests carried out were grain size distribution analysis, permeability (using the constant and falling head permeameters) and Atterberg (consistency) limits. Borehole 1 (BH 1) shows a 1.25m thick deposit of light brown, fine grained, stiff consistency, highly plastic silty clay overlying a silty sand layer that extends to a depth of 3m. Borehole 2 (BH 2) displays a light brown, coarse sand of 1.5m thickness as its overburden. The stratigraphy of Borehole 3 (BH 3) and Borehole 4 (BH 4) are uniform, both displaying light brown, fine grained, loose, plain sands. Grain size analysis shows that the predominantly silty clay soils are poorly graded with high fines (87.73-89.71%). Atterberg limits show a moderate to high plasticity range (24.7-34.0%) for the silty clay, while the sandy soils are non-plastic. Permeability tests (constant and falling head) results reveal a low range of 2.06 x 10⁻³ to 2.22 x 10⁻³ cm/sec for the silty clay soils, while the sandy clay soils display a high range of 7.50 x 10⁻¹ cm/sec. Groundwater occurs under confined conditions in the area on account of the clayey soil overlying the aquifers of boreholes (BH 1), (BH 3) and (BH 4), while borehole 2 (BH 2) being overlain by coarse sand is unconfined (Phreatic) in its uppermost aquifer. The absence of a confining overburden layer in (BH 2) as well as the high water table of (BH 1) clearly indicate that the first (upper) aquifer is susceptibility to groundwater contamination through infiltration, hence there is the need to ensure good drainage and properly compact the sub-grade/sub-base materials to ensure dense soils which will reduce water infiltration and percolation.

Key Words: Road Construction, Geo-environmental assessment, Niger Delta, Nigeria

Introduction

Integrated study on the hydro-geotechnical aspects of road construction are very important in providing detailed guidance for effective environmental assessment as well as minimize the cost outlay and potential environmental effects (Bowles, 2005). Geotechnical information are useful in ensuring that the effects of projects on the environment, natural resources and associated communities are properly evaluated and mitigated where necessary (Nwankwoala, et al., 2009).

This study aims to provide geo-environmental assessment of the Gbaran-Tombia access road in Bayelsa State, eastern Niger Delta. The geo-environmental monitoring plan can help in flood and erosion monitoring, especially in relation to the access road, as well as determine whether or not groundwater contaminants introduced into the soil will reach the aquifer or not. This paper presents an integrated environmental management plan and also provides geotechnical data and reviews sustainable road design.
scenarios with potential for considerable cost minimization as well as quality hydro-geotechnical aspects, for better understanding of their importance for road construction in the area.

**Data collection and analyses**

**Description of the Local Geology**

The study area is characterized by the freshwater ecology of the upper reaches of the River Nun within the Niger Delta. It lies within the outcropping Benin Formation made up of continental deposits of Miocene to Recent sediments. It is associated with freshwater swamps, backswamps and meander belts of flat to sub-horizontal elevation. There are severe drainage problems with seasonal and temporary flooding due to heavy rainfall and rise in groundwater table. This results in almost total submergence during the wet season with the exception of the natural levees. The major soil types are light brown to dark grey, fine sand to silty clay.

**Regional Geology**

The area is located within the Niger Delta, which was formed during the Tertiary period as a result of the interplay between subsidence and deposition arising from a succession of transgressions and regressions of the sea. These phenomena evolved the three lithostratigraphic units of Akata, Agbada and Benin Formations, with an overall approximate thickness of over 5,000m of sediment body.

The Akata Formation (outcropping as the Imo Shale Group) is made up of marine clay, shale and limestone and is estimated to be about 1,000m in thickness. The Agbada, which outcrops as the Ameki Formation overlies the Akata Formation and comprises various alternations of marine shales and sandstones. It has an estimated thickness of 1,700m. The youngest of these formations is the Benin Formation. The Benin Formation is about 2,100m thick at the basin centre and consists of coarse-medium grained sandstones, thin shales and gravels. The upper section of Benin Formation consists of Quaternary deposits which is about 40 – 150m thick (Table 1) and comprises rapidly alternating sequences of sand and silt/clay with the latter becoming increasingly more prominent seawards (Etu-Efeotor and Akpokodje, 1990).

**Table 1: Quaternary deposits of the Niger Delta (after Etu-Efeotor & Akpokodje, 1990)**

<table>
<thead>
<tr>
<th>Geologic Unit</th>
<th>Lithology</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alluvium</td>
<td>Gravels, sand, clay, silt</td>
<td>Quaternary</td>
</tr>
<tr>
<td>Freshwater, back swamps</td>
<td>Sand, clay, some silt, gravel</td>
<td></td>
</tr>
<tr>
<td>Mangrove and some saltwater/Back swamps</td>
<td>Medium-fine sands, clay and some silt</td>
<td></td>
</tr>
<tr>
<td>Active/abandoned beach ridges</td>
<td>Sand, clay and some silt</td>
<td></td>
</tr>
<tr>
<td>Sombreiro-Warri deltaic plain</td>
<td>Sand, clay and some silt</td>
<td></td>
</tr>
</tbody>
</table>

**Borehole Drilling (Monitoring Wells)**

Four (4) water wells were drilled in the area to obtain baseline water quality data, water level monitoring and sub-soil analysis for infiltration characteristics. The boreholes were drilled with the use of a light cable percussion rig to a depth of 10m in each borehole. The drill type permits more accurate determination of groundwater levels and sampling of groundwater for quality analysis. The wells were logged on site with soil samples recovered at intervals where distinct changes in soil type occur, for laboratory analysis. Water samples were also collected into appropriately labeled containers for physico-chemical analysis. The static water levels recorded in the boreholes were 0.5m, 1.58m, 2.50m and 3.68m for boreholes 1, 2, 3 and 4, respectively. The water levels in the boreholes are subject to seasonal fluctuations. These values were observed during the late dry season.
Laboratory Analysis

The physical properties of the soil samples recovered from the boreholes were examined to obtain parameters used as indices of the infiltration capacity of the soils in the area. Laboratory tests were carried out on representative soil samples in accordance with the British Standards (B.S) 1377, which are equivalent to the American Society for Testing and Materials Standards (ASTM) Standards. The tests were grain size distribution analysis, permeability (using the constant and falling head permeameters) and Atterberg (consistency) limits. These tests were conducted for proper assessment and evaluation of the gradation, hydraulic conductivity (coefficient of permeability) and consistency (water absorbing and adsorbing ability) properties of the soil samples, as well as their classification.

Results and Discussion

Soil Stratigraphy and Index Properties

Lithologic profiles of the soils from each of the four (4) boreholes drilled are detailed in the borehole logs (Figures 1, 2, 3 & 4). In borehole (BH 1) (Table 2), a 1.25m thick deposit of light brown, fine grained, stiff consistency, highly plastic silty clay overlies a silty sand layer that extends to a depth of 3m. Another layer of the silty clay soil of about 3m in thickness succeeds this layer.

Table 2: Summary of laboratory test results

<table>
<thead>
<tr>
<th>BORE-HOLE NUMBER</th>
<th>SAMPLE NUMBER</th>
<th>DEPTH (m)</th>
<th>SOIL NOMENCLATURE</th>
<th>GRAIN SIZE DISTRIBUTION (PERCENT PASSING SIEVES)</th>
<th>CONSISTENCY LIMITS</th>
<th>permeability (cm/sec.)</th>
<th>UNIFIED SOIL CLASSIFICATION SYSTEM (U.S.C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BH 1</td>
<td>BH1(Om)</td>
<td>0.0</td>
<td>SILTY CLAY</td>
<td>NO.4 (4.75mm) 100</td>
<td>NO.10 (2.00mm) 100</td>
<td>NO.40 (0.42mm) 100</td>
<td>NO.200 (0.75mm) 87.76</td>
</tr>
<tr>
<td>BH1 (1.25m)</td>
<td>BH1(Om)</td>
<td>0.0</td>
<td>SILTY SAND</td>
<td>NO.4 (4.75mm) 100</td>
<td>NO.10 (2.00mm) 100</td>
<td>NO.40 (0.42mm) 100</td>
<td>NO.200 (0.75mm) 15.37</td>
</tr>
<tr>
<td>BH 2</td>
<td>BH2 (Om)</td>
<td>0.0</td>
<td>SAND</td>
<td>NO.4 (4.75mm) 100</td>
<td>NO.10 (2.00mm) 99.21</td>
<td>NO.40 (0.42mm) 84.11</td>
<td>NO.200 (0.75mm) 0.01</td>
</tr>
<tr>
<td>BH2 (2.5m)</td>
<td>BH2 (Om)</td>
<td>0.0</td>
<td>CLAYEY SAND</td>
<td>NO.4 (4.75mm) 100</td>
<td>NO.10 (2.00mm) 100</td>
<td>NO.40 (0.42mm) 98.1</td>
<td>NO.200 (0.75mm) 21.42</td>
</tr>
<tr>
<td>BH 3</td>
<td>BH3 (Om)</td>
<td>0.0</td>
<td>SILTY CLAY</td>
<td>NO.4 (4.75mm) 100</td>
<td>NO.10 (2.00mm) 100</td>
<td>NO.40 (0.42mm) 100</td>
<td>NO.200 (0.75mm) 87.73</td>
</tr>
<tr>
<td>BH3 (8m)</td>
<td>BH3 (Om)</td>
<td>0.0</td>
<td>SAND</td>
<td>NO.4 (4.75mm) 100</td>
<td>NO.10 (2.00mm) 100</td>
<td>NO.40 (0.42mm) 95.78</td>
<td>NO.200 (0.75mm) 0.01</td>
</tr>
<tr>
<td>BH 4</td>
<td>BH4 (Om)</td>
<td>0.0</td>
<td>SILTY CLAY</td>
<td>NO.4 (4.75mm) 100</td>
<td>NO.10 (2.00mm) 100</td>
<td>NO.40 (0.42mm) 100</td>
<td>NO.200 (0.75mm) 89.71</td>
</tr>
<tr>
<td>BH4 (10m)</td>
<td>BH4 (Om)</td>
<td>0.0</td>
<td>SAND</td>
<td>NO.4 (4.75mm) 100</td>
<td>NO.10 (2.00mm) 100</td>
<td>NO.40 (0.42mm) 100</td>
<td>NO.200 (0.75mm) 97.1</td>
</tr>
</tbody>
</table>

Below this layer is light brown, fine-grained, loosely dense friable sand to the bored depth of 10m. Borehole 2 (BH 2) shows a light brown, coarse sand of 1.5m thickness as its overburden. Underlying this layer is light brown mottled grey, fine-grained, stiff silty clay to a depth of 2.5m. This is underlain by a 2.7m thickness of medium grained clayey sand. The aquiferous stratum of coarse-grained sand follows another deposit of 2.8m of silty clay to the maximum-drilled depth of 10m. The stratigraphy of BH 3 and BH 4 are uniform, displaying light
brown, fine-grained, loose, plain sands. BH 3 shows the silty clay to be about 2m thick, while they occur in depths to about 7.30m in BH 4.

Grain size analysis results show that the predominantly silty clay soils from all four boreholes possess very high fines (silty/clay fractions) ranging from 87.73 to 89.71%. The plain sands and sandy soils are uniformly graded and with lower silt/clay fractions of 0.01 to 21.4%. The fine grained nature of the silty clays mean that fluid flow through them will be restricted and slow, as the number of particles per unit area is relatively small and void spaces are fewer.

Atterberg limits (also known as consistency limits) expresses the water absorbing and adsorbing ability of fine-grained, cohesive soil, with the plasticity index indicating the range of water content, through which the soil remains plastic. The results show a moderate to high plasticity range (24.7 to 34.0%) for the silty clay, while the sandy soils are non-plastic. Atterberg limit tests are applicable only to fine-grained, cohesive soils. The moderately high values of plasticity indices of the plastic soils are an indication of their high water retaining capacities.

The soils were classified under the Unified Soil Classification System (USCS) as SM, SC, CP, CL and CH, indicating silty sands, clayey sands, poorly graded sands, medium and high plasticity inorganic clays. The permeability test (constant and falling head) results reveal a low range of 2.06 x 10^-3 to 2.22 x 10^-3 cm/sec for the silty soils, while the sandy soils display a range of 7.50 x 10^-1 to 8.05 x 10^-1 cm/sec. The ability of these sediments to hold and transmit water is determined by their porosity and permeability. Coefficient of permeability increases with increase in size of voids, which in turn increases with increasing grain size. The larger grains permit more fluid motion as a result of high permeability than the finer ones. Permeability depends on soil density, degree of saturation, viscosity of fluid and soil particle size. Infiltration capacity of soil depends on the permeability, degree of saturation, vegetation and amount and duration of rainfall (Todd, 1980).

Geo-Environmental Impact Assessment

The hydrology of the study area is influenced by its high precipitation rate with a mean annual rainfall of over 2,500mm, the overburden lithologic strata that overlie the aquifer, the flat topography and neighbouring rivers and creeks. Surface waters are received from non-tidal seasonal freshwater flows. Recharge of the aquifer is usually by rainwater that eventually moves through the overburden into the aquifer. Recharge depends on rainfall intensity and distribution and amount of surface runoff. Groundwater occurs under confined conditions in the area on account of the clayey soil overlying the aquifer in the area of boreholes 1, 3 and 4, while borehole 2 being overlain by coarse sand is unconfined (phreatic) in its uppermost aquifer.

The absence of a confining overburden layer implies the susceptibility of the first or upper aquifer to groundwater contaminant in the area of borehole 2. The high water table of the borehole 1 is an indication that infiltration of pollutants into the groundwater will be restricted in that area. This is because infiltration decreases as the soil becomes saturated due to the filling of the soil pores by water (Davies & DeWeist, 1966). The existence of these overburden layers at the study area will determine whether or not groundwater contaminants introduced into the soil will reach the aquifer.
<table>
<thead>
<tr>
<th>BOREHOLE REF.</th>
<th>SAMPLES</th>
<th>LEGEND</th>
<th>HORIZON DEPTH</th>
<th>LITHOLOGICAL DESCRIPTION</th>
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</thead>
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<tr>
<td></td>
<td>TYPE</td>
<td>THICKNESS</td>
<td>NO. OF LAYERS</td>
<td>FROM (m)</td>
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<td>4.0</td>
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Figure 1: Log of Borehole 1.

<table>
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<tr>
<th>BOREHOLE REF.</th>
<th>SAMPLES</th>
<th>LEGEND</th>
<th>HORIZON DEPTH</th>
<th>LITHOLOGICAL DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TYPE</td>
<td>THICKNESS</td>
<td>NO. OF LAYERS</td>
<td>FROM (m)</td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>2.0</td>
</tr>
</tbody>
</table>

Figure 2: Log of borehole 2

END OF BOREHOLE

END OF BOREHOLE
### Figure 3: Log of borehole 3

<table>
<thead>
<tr>
<th>BOREHOLE REF.</th>
<th>SAMPLES</th>
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<th>HORIZON DEPTH</th>
<th>LITHOLOGICAL DESCRIPTION</th>
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</thead>
<tbody>
<tr>
<td>DATE: 29/02/07</td>
<td>TYPE</td>
<td>THICKNESS (m)</td>
<td>NO. OF LAYERS</td>
<td>FROM (m)</td>
</tr>
<tr>
<td>SILTY CLAY</td>
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<td>1</td>
<td>0.0</td>
<td>2.0</td>
</tr>
<tr>
<td>METHOD OF DRILING:</td>
<td>PERCUSSION</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DRILLER:</td>
<td>UD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOGGED BY:</td>
<td>YPO</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>BOREHOLE DIAMETER</td>
<td>152.4mm</td>
<td>101.6mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BOREHOLE DEPTH</td>
<td>10m</td>
<td>2mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>STATIC WATER LEVEL</td>
<td>0.55m</td>
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<tr>
<td>GROUND LEVEL</td>
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<td></td>
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</tr>
<tr>
<td>APPENDIX</td>
<td>1</td>
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<tr>
<td>SAND</td>
<td>8.0</td>
<td>1</td>
<td>2.0</td>
<td>10.0</td>
</tr>
</tbody>
</table>

**Figure 4: Log of borehole 4**

<table>
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<tr>
<th>BOREHOLE REF.</th>
<th>SAMPLES</th>
<th>LEGEND</th>
<th>HORIZON DEPTH</th>
<th>LITHOLOGICAL DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>DATE: 29/02/07</td>
<td>TYPE</td>
<td>THICKNESS (m)</td>
<td>NO. OF LAYERS</td>
<td>FROM (m)</td>
</tr>
<tr>
<td>SILTY CLAY</td>
<td>7.30</td>
<td>1</td>
<td>0.0</td>
<td>7.30</td>
</tr>
<tr>
<td>METHOD OF DRILING:</td>
<td>PERCUSSION</td>
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<td></td>
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</tr>
<tr>
<td>DRILLER:</td>
<td>UD</td>
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</tr>
<tr>
<td>LOGGED BY:</td>
<td>YPO</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>BOREHOLE DIAMETER</td>
<td>152.4mm</td>
<td>101.6mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BOREHOLE DEPTH</td>
<td>10m</td>
<td>8mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>STATIC WATER LEVEL</td>
<td>3.68m</td>
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<tr>
<td>GROUND LEVEL</td>
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<tr>
<td>APPENDIX</td>
<td>1</td>
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<td></td>
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</tr>
<tr>
<td>SAND</td>
<td>2.70</td>
<td>1</td>
<td>7.30</td>
<td>10.0</td>
</tr>
</tbody>
</table>

END OF BOREHOLE
Conclusion

The eastern Niger Delta experiences severe drainage problems with seasonal and temporary flooding due to high precipitation rate, and rise in groundwater table. In the light of the above, the following geo-environmental management plans are recommended for the area:

(i) River improvement work such as riverbed dredging, straightening and re-aligning the channel (re-adjustment of rivers and creeks) and eliminating bed and bank irregularities. By this exercise, the intercepted rivers and creeks will follow other free flow paths, thereby mitigating the flood episodes.

(ii) Bank protection of the modified and improved river channel if still prone to flooding with flood/erosion control schemes such as standard revetments (synthetic mattress, sand-cement and sand-gravel bags, rip-rap, gabions, etc.)

(iii) Ensuring that the road has good drainage and paved shoulders. This will properly define/dedicate the flow path of surface waters.

(iv) Ensure that appropriately thick base course and bituminous surface are utilized as fill and sub-base materials on the road. More importantly, the stabilization and compaction of the sub-grade/sub-base materials to ensure dense soils and reduction of water infiltration/percolation is vital for sustainability.

References


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