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and Symposium in Honor of Clyde Baker

ALIGNMENT AND DESIGN OF A 73-KM LONG COASTAL ROAD IN THE SOUTH-CENTRAL SEGMENT OF THE NIGER DELTA, NIGERIA

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ABSTRACT

A 73-km East-West Coastal Highway that traverses six major rivers within the Mangrove and Coastal Hydro-meteorological Zones of the Niger Delta is to be built. The total number of river crossings along the five intervening sections of this road is 36.The Niger Delta Sub-region lies at the southern-most portion of Nigeria.

Geotechnical investigations along the road profiles showed between 10-18 meters of thick Organic Clays (OH) underlain by 2.50-4.50m thick Silty-clays (OL) along the first three Sections (A,B,&C) of the road. These have saturated densities (γ_{sat}) of 10-15.40 kN/m^2; PI ~15.00-35.00%; cohesion (c) ≤24.50-68.50kPa, low strength ($q_{ult} \leq 12.00$ kPa) and relatively high settlement values of δ_{ult} ~ 0.056m-0.072m. Poorly-graded sands (SP) and well-graded sands with high bearing capacity values (482 – 4,250kPa) lie beneath these at depths of 20m and 30m, respectively. Most of the road alignments were submerged, with few points lying 0.30m above water level during the time of the investigations (December – March). Sections D &E of the road have relatively thinner soft layers (2.00 – 2.50m thick) underlain by sands (SP and SW) with relatively high bearing values of 582-4,250kPa.

The large thicknesses of compressible layers underlying most portions of the road alignment require special pavement construction techniques such as: (i) Excavation of 2.50m of the soft layer materials; (ii) Emplacement of vertical pre-fabricated Geo-drains; (iii) Emplacement of woven geotextiles atop the pre-fabricated Geo-drains, (iv) Emplacement of about 4.50m high sand-dump on top of the woven geotextiles, (v) Allow for settlement of the underlying soft layer corresponding to t_{50}, in this case *~1.14 years*. Settlement computations obtained prior to- and after pre-loading phases were *0.0608m* and *0.670m*, respectively. Geosynthetic reinforcements were to be used in the pavement construction of the highway in order to attain a four-fold pavement structure consisting of: ***(a) Bound layers*** made up of (i) Overlay, (ii) Surface layer and (iii) Binder layer course; ***(b)*** Either bound or Unbound made up of (i) Base; ***(c)*** Unbound layers made up of (i) Sub-base, (ii) capping and (iii) Protection layer; ***(d)*** Sub-grades made up of (i) Stabilized sub-grades and (ii) Sub-grade proper. For most portions of the remaining Sections D and E, where the thin upper soft layers are less than 1.25m these are to be scraped off before emplacement of the Bound layer directly on top of Sub-grades. This paper describes the geotechnical characteristics of the sub-soils along the entire 73-km of the road alignment and the pavement design considerations adopted.

INTRODUCTION

The Niger Delta sub-region of Nigeria is generally an un-accessible region due to its anastomosing network of creeks, rivulets, streams, rivers and extremely dense vegetations. There is an existing East-West Road passing through the northern segment of the delta thus leaving the largely un-inhabited and petroleum-prolific southern segment of the Niger Delta devoid of roads and highways. It is in order to solve this intractable and perennial problem of lack of all forms of transportation in this south-central segment, it became imperative to plan for an ***East – West Coastal Road*** from Calabar to Lagos (terminating at Lekki Lagos). This proposed Highway has been divided into ***ten (10) Segments***, for ease of implementation of its studies and constructions. The location of the ***East-West Coastal Highway*** in the Tropical setting is shown in figures 1a-b and 1c.

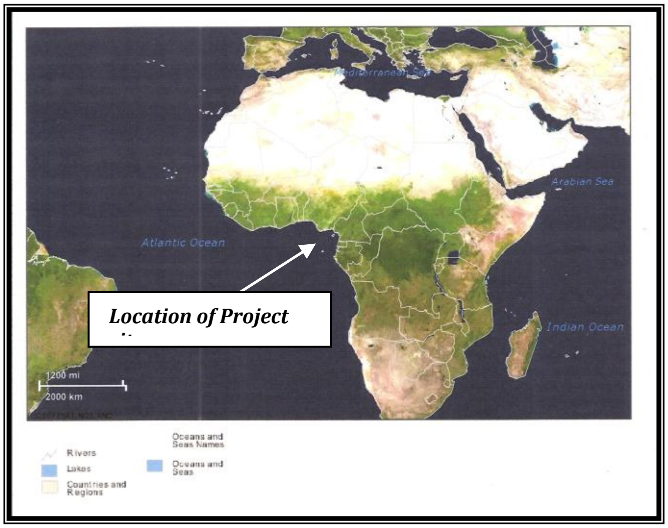

Fig. 1a: Location of Project Site within the Tropical zone.

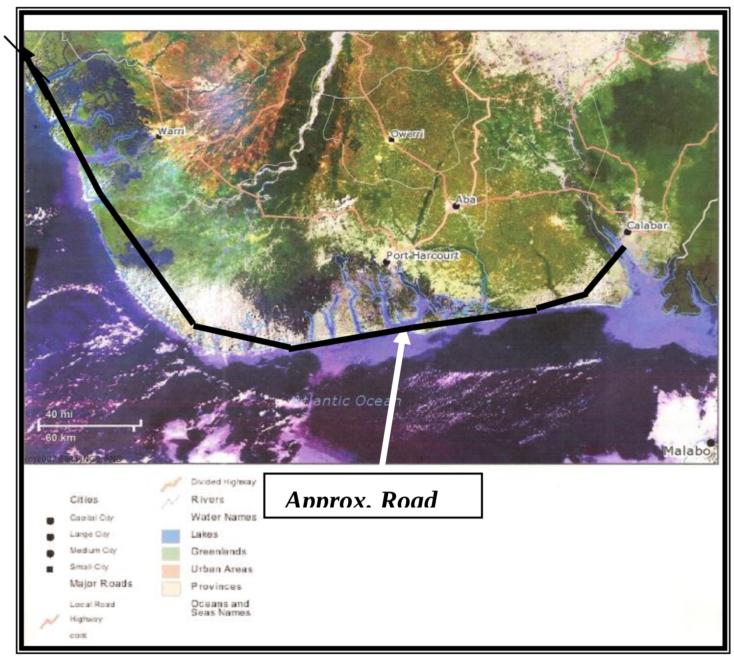

Fig. 1b.A recent Satellite Imagery covering the project area

For ease of carrying out of the studies, the ***Segment 3 of the East-West Coastal Road*** was sub-divided into ***five (5) Sections*** as stated below:

<u>Section A: River Andoni – Bonny River</u>. This section is characterized predominantly by very low-lying lands covered in most parts by mangrove trees ***(Fig. 2 a & b)***. Wild life such as shown in ***Fig. 2c*** are very common in this ***Section A.***

(a) *(b)*

Fig. 2: Vegetation (a) and Topography (b) of Section A:- Andoni River to Bonny River of Segment3 of the proposed East-West Coastal Road Project.

Fig. 2c: Wild Life Creature Encountered during Site

<u>Section B: Bonny River – New Calabar River</u> This section is characterized predominantly by very low-lying lands covered in most parts by mangrove trees and palm trees *(Figures 3 a & b)*.

(a) *(b)*

Fig. 3: Topography (a) and Vegetation (b) of Section B:- Bonny River to New Calabar River of Segment 3 of the proposed East-West Coastal Road Project.

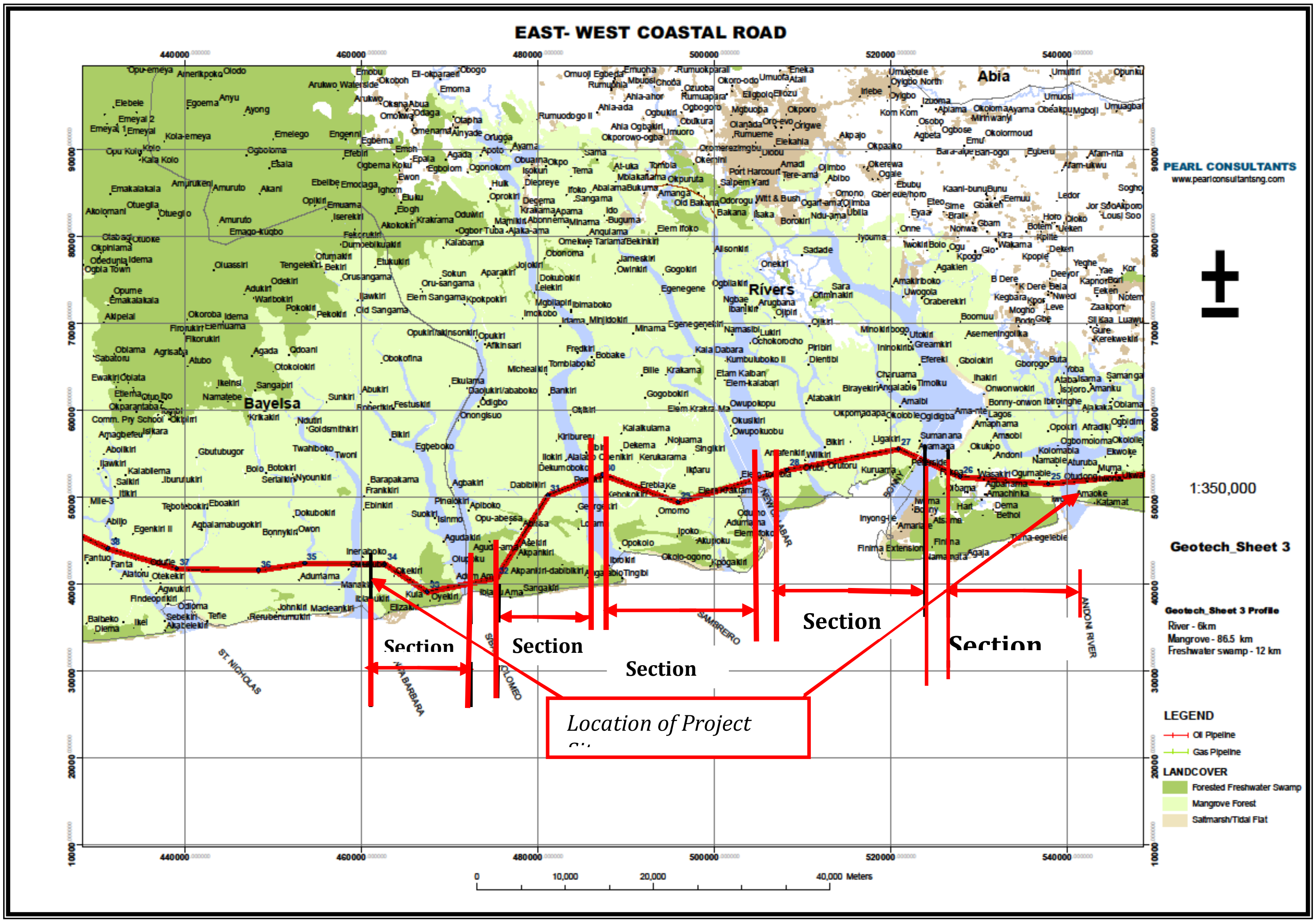

Figure 1c: Location of Segment 3 of the Project Site within the southern-most section of the Niger Delta sub-region, subdivided into Sections A-

<u>Section C: New Calabar River – Sombreiro River</u>. This section is characterized predominantly by low-lying lands covered in most parts by mangrove trees *(Figs.4 a & b)*. Wild life such as shown in *Fig. 4c* are very common in this *Section C.*

4(a)

4(b)

Fig. 4: Vegetation (a) and Topography (b) of Section C:- New Calabar River to Sombreiro River of Segment 3 of the East-West Coastal Road Project.

Fig. 4c: Wild Life Encountered in Section C during Site Investigation

Section D: Sombreiro River – Bartholomeo River. This section is characterized predominantly by low-lying lands covered in most parts by mangrove trees (Figs. 5 a & b).

(a)

(b)

Fig. 5: Vegetation (a) and Topography (b) of Section D:- Sombreiro River – Bartholomeo River of Segment 3 of the East-West Coastal Road Project.

Section E: St. Bartholomeo River – Sancta Barbara River. This section is characterized predominantly by low-lying lands covered in most parts by mangrove trees *(Figs. 6 a & b).*

MATERIALS AND METHODS

This study which took almost three months to accomplish owing to the difficult terrain, security and sundry problems had modes of transportation of boats and traversing in between creeks and rivers by foot.

Soil boring was accomplished by

(a)

(b)

Fig. 6: Vegetation (a) and Topography (b) of Section E:- St. Bartholomeo River to Sancta Barbara River of Segment 3 of the East-West Coastal Road Project.

(i)Deep borings with the aid of Percussion Boring Rigs to depths of 40 meters at the proposed bridge abutments at River crossings and

(ii) Shallow borings at one-kilometer intervals along the proposed Road Alignments

(iii) Cone Penetration Testing (CPT) – the CPT was carried out to refusal at both the River Abutments as well as at one-kilometer intervals along the proposed Road Alignment

For the *Deep Borings*, the following numbers of borings were carried at the respective Sections of Segment 3 of the proposed East-West Coastal Highway:

Table 1a: Deep Borings in Section 3, Segment 3 of the Proposed East-West Coastal Highway

S/No.	Section	No. of River Crossings	No. of Deep Borings	Length of Section (km)
1.	A: Andoni River – Bonny River	.x9 No.	.x 18 No.	12km
2.	B: Bonny River – New Calabar River	.x4 No.	.x 8 No.	16km
3.	C: New Calabar River – Sombreiro River	.x8 No.	.x 16 No.	18km
4.	D: Sombreiro river – St. Bartholomeo River	.x8 No.	.x 16 No.	16km
5	E: St. Bartholomeo River – Sancta Barbara River	.x7 No.	.x 14 No.	11km
	Sub-Total:	.x36No.	.x72No.	.x73km.

Table 1b: Shallow Borings in Section 3, Segment 3 of the Proposed East-West Coastal Highway

S/No.	Section	No. of Shallow 20m-deep Borings	Length of Section (km)
1.	A: Andoni River – Bonny River	.x12 No.	12km
2.	B: Bonny River – New Calabar River	.x16 No.	16km
3.	C: New Calabar River – Sombreiro River	.x18 No.	18km
4.	D: Sombreiro river – St. Bartholomeo River	.x16 No.	16km
5	E: St. Bartholomeo River – Sancta Barbara River	.x11 No.	11km
	Sub-Total:	.x73No.	.x73km.

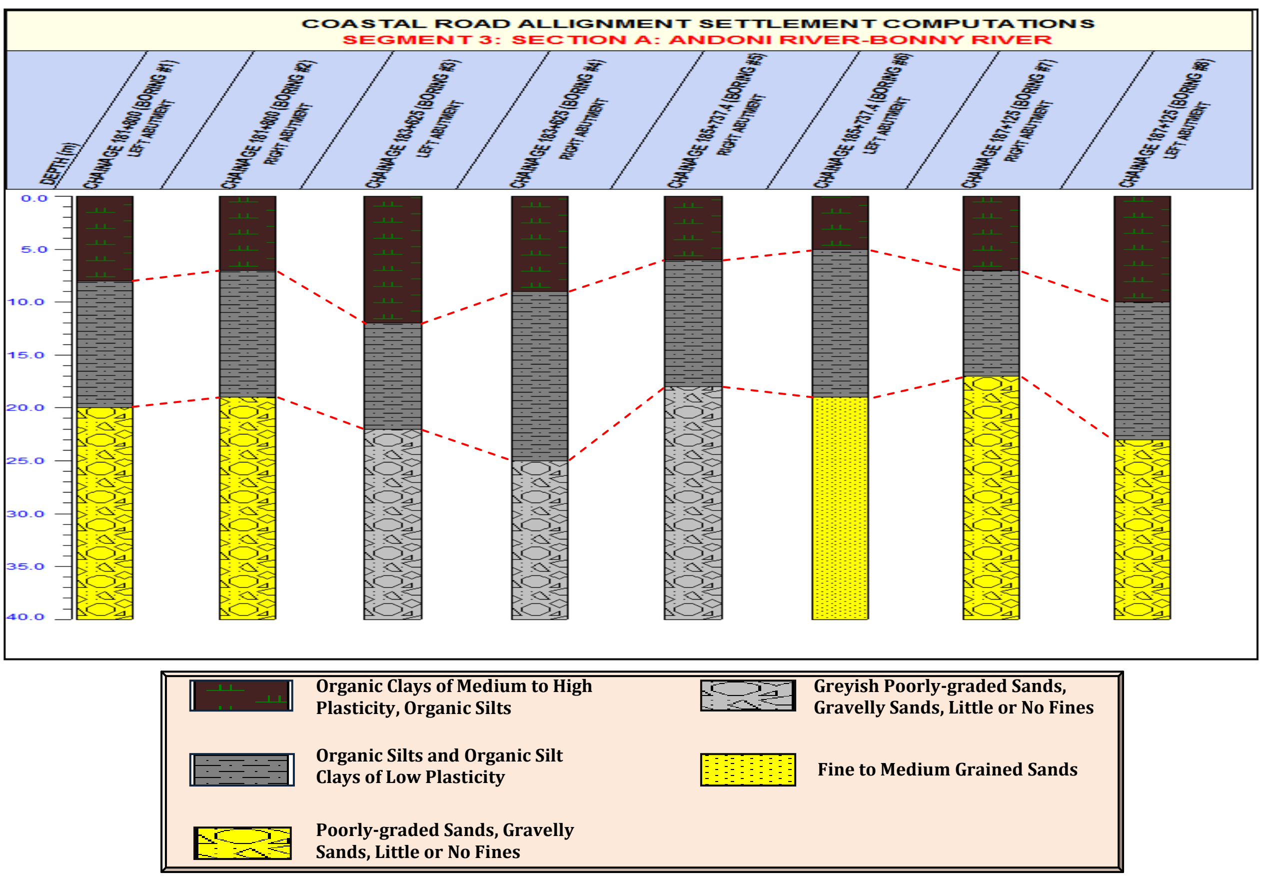

Fig. 7 . Fence diagram of deep borings along Section A (Andoni River to Bonny River) of the Road alignment.

For the *Shallow Borings*, the number of borings carried out along the respective Sections of Segment 3 of the proposed East-West Coastal Highway are as shown on Table 1b above

The fence diagram of the Shallow borings along Section A, for example is shown in Fig. 8.

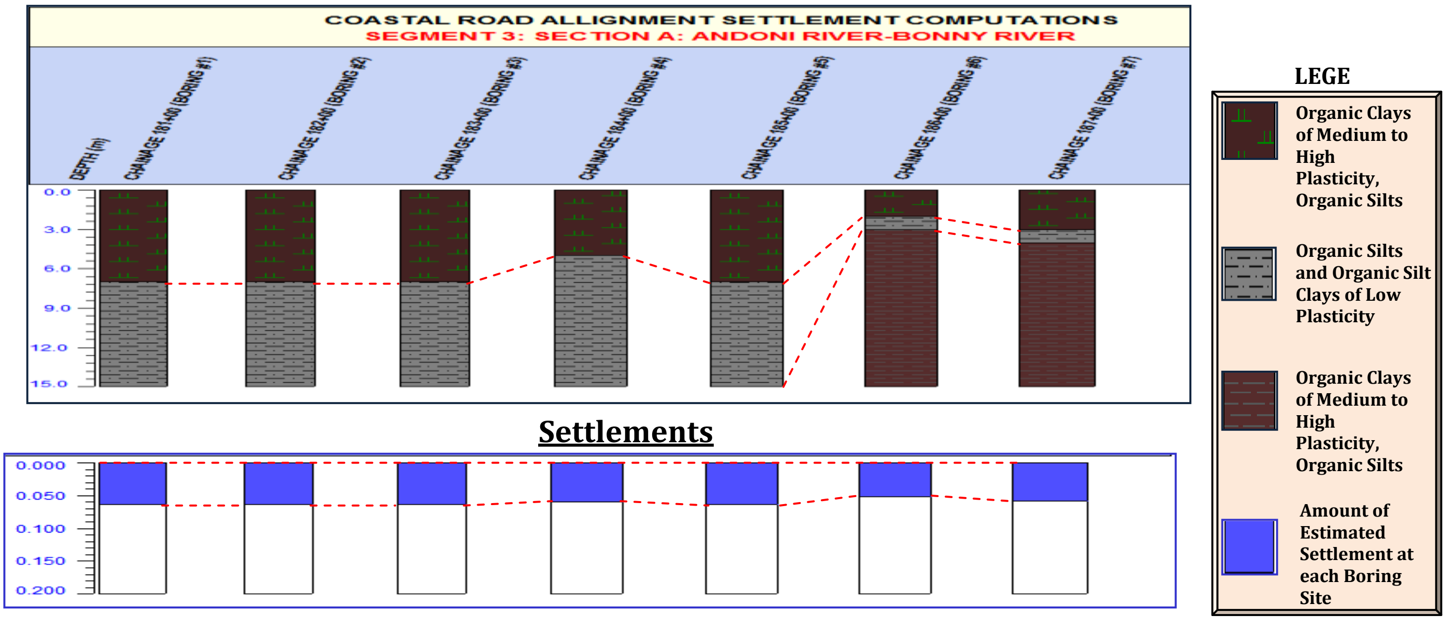

Fig. 8 . Fence diagram of shallow borings along Section A (Andoni River to Bonny River) of the Road alignment.

<u>Cone Penetration Testing (CPT)</u>. The *Dutch Cone Penetration Test* was carried out at abutments of River Crossings as well as along each kilometer length of the 73-km long Segment 3 of the proposed East-West Coastal Highway Project.
The process of carrying out the CPT is shown in *Fig. 9* below.

Fig. 9: The Cone Penetrometer Test being carried out along the Andoni River to Bonny River East-West Coastal Road Alignment.

GEOTECHNICAL CHARACTERISTICS ALONG THE ROAD ALIGNMENT BY SECTIONS.

The road passes through at least two hydro-meteorological zones namely, the Niger Delta Coastal zone and the "Transition" or Mangrove zone, so the geotechnical characteristics of the sub-soils are different in the different zones. The observed geotechnical characteristics of the five (5) Sections namely, Section A: Andoni River to Bonny River, Section B: Bonny River to New Calabar River, Section C: New Calabar River to Sombreiro River, Section D: Sombreiro River to Saint Bartholomeo River and Section E: Saint Bartholomeo River to Sancta Barbara River are given below.

The geotechnical characteristics of the sub-soil samples obtained from both the shallow borings along each kilometer of the road alignment as well as from the deep borings (40-meter depths) at each abutment of the rivers traversed along the alignment were determined. The following tests were conducted in the laboratory: Consistency Tests (Atterberg Limits); Undrained-Unconsolidated Triaxial Tests; Oedometer consolidation tests and Grain-size Distribution test. Field Tests carried out during the field investigations were: Standard Penetration Tests (SPT) and the Cone Penetration Tests. The results from these tests for the five (5) Sections are shown in Tables 2a, 2b, 2c, 2d and 2e, respectively.

From the field investigations, the different types of soils encountered ranged from a top-most Organic Clay with Peat (OH) [0.00 – 8.00m], underlain by Greyish Organic Silty Clay (OH) [8.00 – 20.00m]. This is further underlain by Poorly-graded Sand Layer (SP) [20.00 – 40.00m, which was the limit of the depth of exploration].

The water Contents (w) of the top-most Organic Clay with Peat (OH) [0.00 – 8.00m] varied from 26.50 to 32..00-%; the plasticity indices of same materials ranged from 15.20 to 17.80 %. The Saturated unit Weight (γ_{sat}) of these Organic Clays ranged from 11.00 to 12.00 kN/m^3. The un-drained friction angles (ϕ_u) and the Cohesion intercepts (c_u) for these top-most soils ranged from (2 - 4°) and (82.00 – 92.00 kPa) respectively. The coefficient of Volume Compressibility (m_v) of the Organic Clays with Peat (OH) vary from (0.22 – 0.36)m^2/MN for 50kPa surcharge to (0.25 – 0.50) m^2/MN for 400kPa surcharge. On the other hand, the Coefficient of Consolidation (c_v) for the same materials vary from (0.24 – 0.55)m^2/yr for 50kPa surcharge to (0.25 – 0.78) m^2/yr for 400kPa surcharge.

The water Contents (w) of the second layer Greyish Organic Silty Clay (OH) [8.00 – 20.00m] varied from 28.5 to 31.10%; the plasticity indices of same materials ranged from 12.40 to 25.40 %. The Saturated unit Weight (γ_{sat}) of these Organic Clays ranged from 16.50 to 16.80- kN/m^3. The un-drained friction angles (ϕ_u) and the Cohesion intercepts (c_u) for these top-most soils ranged from (4 -5°) and (8 – 10 kPa) respectively. The coefficient of Volume Compressibility (m_v) of the Organic Clays with Peat (OH) vary from (0.42 – 1.42)m^2/MN for 50kPa surcharge to (0.59 – 1.87) m^2/MN for 400kPa surcharge. On the other hand, the Coefficient of Consolidation (c_v) for the same materials vary from (0.64 – 1.76)m^2/yr for 50kPa surcharge to (0.89 – 2.14) m^2/yr for 400kPa surcharge.

For the third (Poorly-graded Sands) layer which occur at depths ranging from about 20.00 meters to about 32meters, in places,, the Water Contents (w) varied from 8.0 to 11.50%; they are Non-Plastic but their Saturated unit Weights (γ_{sat}) ranged from about 19.80 to 20.80- kN/m^3. The un-drained friction angles (ϕ_u) and the Cohesion intercepts (c_u) for these top-most soils ranged from (22 - 24°) and Non-cohesive (c = 0.00kPa) respectively. These Non-Plastic Poorly-graded soils are not compressible..

SETTLEMENTS ALONG THE PROPOSED HIGHWAY ALIGNMENT.

Settlement computations were carried out at each boring point along the 73-km Road Alignment, using conventional Soil Mechanics approach. In doing this it was assumed that a pressure of approximately 100kPa had been applied from a 4.5m well-graded Sand Dump for a period of $t_{50} \sim 1.85$yrs (as computed using the soil properties at site).

The following implicit Assumptions were made in the computations of the settlements of the soils along the proposed Road Alignment.:

$$\sigma'_w = \sum\gamma H + [\sum(\sigma_z)_{induced} - \mu\,]\ (kPa), \quad (1a)$$

$$\sigma' = 100kPa;\ \gamma_w = 9.8kN/m^3, \quad (1b)$$
$$\sigma' z_f = \sigma'_w + \gamma_{fill} H_{fill}; \quad (1c)$$

$$C_c = 0.009(LL\text{-}10); \quad (1d)$$

$$C_c = 1.15(e_o - 0.35) \quad (1e)$$

The Ultimate Settlements were computed using the basic equation (Holtz & Kovacs 1981) of:

$$(\delta_c)_{ult} = \sum Cc/1{+}e_o\ H \log(\ \sigma'_{zf}/\ \sigma'_{zo}\ ) \quad (2)$$

A summary of the Ultimate Settlements computed for each of the Five (5) Sections along Segment 3 of the proposed East-West Coastal Highway is given on Table 3 below.

The Settlement characteristics of the soils along the proposed Road Alignment determined the type of Pavement construction method to be adopted during the phase of development of this Highway.

Factors considered in the adoption of type of pavement construction include:
(i) Excavation of the Compressible soils,
(ii)Emplacement of 4.50m high Sand-fill
(iii)Soil improvement methods (eg. Pre-Loading) to be adopted in areas of deep compressible soils such as OH (Organic Clays of Medium to high Plasticity) and to an extent OL soils (Organic Silts and Organic Silty Clays)

Pavement improvement methods considered include:
(a)Application of Geotextiles /
(b)Application of Geosynthetics and or/
(c)Application of combinations thereof.

RESULTS AND DISCUSSIONS

The results of both ***Shallow and the Deep borings*** carried out at both the alignments and the River Crossings, respectively, in each of the five (5) sections of Segment 3 studied indicated the following sub-surface characteristics at the various project sites. For pavement design purposes, we shall consider ONLY the Shallow Borings (down to 20 meters) along the Alignment.

Table 2-a*:* Summary of Geotechnical Properties fo0r the Sub-soils along the proposed East-West Coastal Road Project, Rivers State (Andoni River to Bonny River Crossing): Chainages 181+800 – Chainage 187++975.39 [Latitude N04º 27' 57.8'' /Longitude E007º 19' 02.5'' to Latitude N04º 27' 58.8'' /Longitude E007º 17' 05.6'']

S/No	Section	Soil Layer	Depth (m)	W (%)	PI (%)	γ_{sat} (kN/m^3)	ϕ_u (°)	C_u (kPa)	m_v (m^2/MN)		c_v (m^2/yr)		SPT N-value
									50.00kPa	400kPa	50.00kPa	400kPa	
1.	SECTION A: Andoni River to Bonny River	OH	0-8.00	26.5 – 38.0	15.2-17.8	11.0 - 12.0	2 – 4	8.0 – 9.2	0.22-0.36	0.25-0.50	0.24-0.55	0.25-0.78	-
		OH	8-20	28.5 – 30.1	12.4-25.40	16.7-16.8	4 – 5	8.0-10.0	0.42-1.42	0.59-1.82	0.64-1.76	0.89-2.14	-
		SP	20-40	8.0 – 12.0	NP	19.0-20.80	27 – 28	0.00	-	-	-		32-46

Table 2-b*:* Summary of Geotechnical Properties for the Sub-soils along the proposed East-West Coastal Road Project, Rivers State (Bonny River to New Calabar River Crossing): Chainages 197+350 – Chainage 213+000 [Latitude N04º 28' 50.6'' /Longitude E007º 12' 55.9'' to Latitude N04º 29' 9.03'' /Longitude E007º 08' 26.3'']

S/No	Section	Soil Layer	Depth (m)	W (%)	PI (%)	γ_{sat} (kN/m^3)	ϕ_u (°)	C_u (kPa)	m_v (m^2/MN)		c_v (m^2/yr)		SPT N-value
									50.00kPa	400kPa	50.00kPa	400kPa	
2.	SECTION B: Bonny River to New Calabar River.	CH	0-8.00	26.5 – 32.0	15.2-17.50	11.0	2 – 4	8.0 – 9.2	0.20-0.36	0.20-0.50	0.24-0.55	0.24-0.78	-
		CH	8-20	28.5 – 30.4	12.2 -25.60	16.8	4 – 5	9.0-10.0	0.42-1.42	0.56-1.87	0.64-1.76	0.89-2.14	-
		SP	20-40	8.0 – 12.40	NP	19.8-20.80	22 – 22.6	0.00	-	-	-		38-56

Table 2-c*:* Summary of Geotechnical Properties for the Sub-soils along the proposed East-West Coastal Road Project, Rivers State (New Calabar River to River Sombreiro Crossing): Chainages 197+350 – Chainage 213+000 [Latitude N04º 28' 50.6'' /Longitude E007º 12' 55.9'' to Latitude N04º 29' 90.3'' /Longitude E007º 08' 26.3'']

S/No	Section	Soil Layer	Depth (m)	W (%)	PI (%)	γ_{sat} (kN/m^3)	ϕ_u (°)	C_u (kPa)	m_v (m^2/MN)		c_v (m^2/yr)		SPT N-value
									50.00kPa	400kPa	50.00kPa	400kPa	
3.	SECTION C: New Calabar River to Sombreiro River	OH	0-8.00	26. – 34.0	15.2-17.50	11.0	2 – 4	8.0 – 9.2	0.20-0.36	0.20-0.50	0.24-0.55	0.24-0.78	-
		CH	8-20	28.5 – 30.1	12.2 -25.60	19.8-20.8	4 – 5	9.0-10.0	0.42-1.42	0.56-1.87	0.64-1.76	0.89-2.14	-
		SP	20-32	8.0 – 11.50	NP	19.8-20.80	22 – 22.6	0.00	-	-	-		38-56
		SW	32-40	10.2-11.70	NP	20 - 20.4	27 - 28	0.00	-	-	-	-	42-49

Table 2-d*:* Summary of Geotechnical Properties for the Sub-soils along the proposed East-West Coastal Road Project, Rivers State (River Sombreiro to St. Bartholomeo River Crossing): [BH # 9] Chainages 218+800 – Chainage 235+050 [Latitude N04º 86' 00'' /Longitude E006º 59' 51.3'' to Latitude N04º 28' 29.4'' /Longitude E006º 50' 60.6'']

S/No	Section	Soil Layer	Depth (m)	W (%)	PI (%)	γ_{sat} (kN/m^3)	ϕ_u (°)	C_u (kPa)	m_v (m^2/MN)		c_v (m^2/yr)		SPT N-value
									50.00kPa	400kPa	50.00kPa	400kPa	
4.	SECTION D: Sombreiro River to St. Bartholomeo River.	CH	0-2.00	32.0	15.20	11.0	2	8.0	0.36	0.50	0.24	0.25	-
		SM	2 - 10	8.5 – 11.10	NP	19.8-20.8	28	0.00	-	-	-	-	28-48
		SP	10 –25	11.1–12.90	NP	19.8-20.70	28 – 30	0.00	-	-	-		32-57
		SW	25- 40	4.6-8.00	NP	15.9 - 21.0	28.00	0.00	-	-	-	-	38-56

Table 2-e: Summary of Geotechnical Properties for the Sub-soils along the proposed East-West Coastal Road Project, Rivers State (St. Bartholomeo River to Sancta Barbara River Crossing) [BH # 3]: Chainages 261+040 – Chainage 269+675 [Latitude N03^o 9$'$ 72.2$''$ /Longitude E004^o 70$'$ 28.0$''$ to Latitude N03^o 95$'$ 9.2$''$ /Longitude E004^o 69$'$ 76.4$''$]

S/No	Section	Soil Layer	Depth (m)	W (%)	PI (%)	γ_{sat} (kN/m^3)	ϕ_u (^{o})	C_u (kPa)	m_v (m^2/MN)		c_v (m^2/yr)		SPT N-value
									50.00kPa	400kPa	50.00kPa	400kPa	
5.	SECTION E: Sombreiro River to St. Bartholomeo River.	OH	0-2.00	27.0-32.0	15.00-17.4	11.0	2 -3	8.0-9.8	0.36	0.50	0.55	0.78	-
		SM	2 – 11	18 – 25.20	NP	19.8-20.1	18-20	0.00	-	-	-	-	14-18
		OH	11 – 27	26.5– 32.00	15.2-17.40	11.00	2 – 4	8-9.2	0.22-0.36	0.25-0.50	0.27-0.55	0.29-0.78	-
		SP	27-29	8.5 -11.00	NP	19.8 - 20.8	22.00-24.00	0.00	-	-	-	-	24-42
		SW	29 - 40	7.0- 10.0	NP	20. – 28.0	32-34	0.00	-	-	-	-	48->50

Table 3: Summary of Ultimate Settlements along Segment 3 of the Proposed East-West Coastal Highway

S/No.	Section	Average Ultimate Settlements [$\delta_{c\ (ult)}$] - (m)		Remarks
		Eastern	Western	
1.	A: Andoni River – Bonny River	0.62	0.0608	More settlement in the Eastern Sector
2.	B: Bonny River – New Calabar River	0.0475	0.00483	More settlement in the Eastern Sector
3.	C: New Calabar River – Sombreiro River	0.063	0.064	Fairly constant settlement in both Eastern & Western Sectors
4.	D: Sombreiro river – St. Bartholomeo River	0.063	0.0046	More settlement in the Eastern Sector
5	E: St. Bartholomeo River – Sancta Barbara River	0.054	0.2574	More settlement in the Western Sector

Table 4-a: Shallow Borings: Sub-surface Lithology.

S/No.	Section	Lithology	Thickness (m)		Remarks
			Eastern Sector	Western Sector	
1.	A: Andoni River – Bonny River	*OH = Top soil, compressible Clays*	2 - 6	1 – 4	*Thicker in the East than West*
		OL=Organic Silts and organic silty Clays	2 - 13	2 – 3	*Thicker in the East than West*
		SP=poorly graded Sands	1 - 2	1 – 3	*Minor occurrence due to depth of boring (15m)*

Table 4-b: Shallow Borings: Sub-surface Lithology.

S/No.	Section	Lithology	Thickness (m)		Remarks
			Eastern Sector	Western Sector	
2.	A: Bonny River – New Calabar River	*OH = Top soil, compressible Clays*	5 – 10	6 – 12	*Thicker in the West than East*
		OL=Organic Silts and organic silty Clays	10 - 16	7 – 12	*Thicker in the East than West*
		SP=poorly graded Sands	1 - 2	1 – 3	*Minor occurrence due to depth of boring (15m)*

Table 4-c: Shallow Borings: Sub-surface Lithology.

S/No.	Section	Lithology	Thickness (m)		Remarks
			Eastern Sector	Western Sector	
3.	A: New Calabar River – Sambreiro River	*OH = Top soil, compressible Clays*	7 – 13	6 – 10	*Thicker in the East than West*
		OL=Organic Silts and organic silty Clays	8 – 12	6 – 14	*Thicker in the West than East*
		SP=poorly graded Sands	1 - 3	1 – 4	*Minor occurrence due to depth of boring (15m)*

Table 4-d: Shallow Borings: Sub-surface Lithology.

S/No.	Section	Lithology	Thickness (m)		Remarks
			Eastern Sector	Western Sector	
4.	A: Sambreiro River – St. Bartholomeo River	*OH = Top soil, compressible Clays*	8 – 12	0 – 11	*Thicker in the East than West*
		OL=Organic Silts and organic silty Clays	8 – 14	0 – 7	*Thicker in the East than West*
		SP=poorly graded Sands	1 – 4	2 – 18	*Thicker in the West than East*

Table 4-e: Shallow Borings: Sub-surface Lithology.

S/No.	Section	Lithology	Thickness (m)		Remarks
			Eastern Sector	Western Sector	
5.	A: St. Bartholomeo River – Sancta Barbara River	*OH = Top soil, compressible Clays*	6 – 10	6 – 10	*Equal thickness in both East and Western Sectors*
		OL=Organic Silts and organic silty Clays	10 – 14	10 – 14	*Equal thickness in both East and Western Sectors*
		SP=poorly graded Sands	1 – 3	2 – 4	*Thicker in the West than East within the limit of boring (20m)*

DUTCH CONE PENETRATION TESTS

These were carried out along the entire stretch of the proposed Roadway *(73km)* in *Segment 3* of the proposed *East-West Coastal Highway*. An example of such soundings is shown in Fig. 8

SOIL IMPROVEMENT METHODS ADOPTED

<u>Excavation of Compressible soil layers</u>. From the field investigations carried out along the road alignment in ***S**ection C of Segment 3* of the East-West Coastal Road, the average thickness of the compressible soft layers (OH + OL) is *about 20.00meters*. It is proposed to excavate 2.00 meters of compressible soils

<u>Emplacement of 4.50m high Sand-fill</u>. Well-graded sands should be placed to a height of about 4.50 meters and pre-loaded for a period of t_{50} *~ 1.129 years.*

<u>Application of pre-fabricated Geo-synthetic Vertical Drains</u>. It is recommended that pre-fabricated Geo-synthetic vertical drains be used in the soft layers in order to accelerate the rate of drainage during the

surcharge application to induce both primary and secondary consolidation settlement.

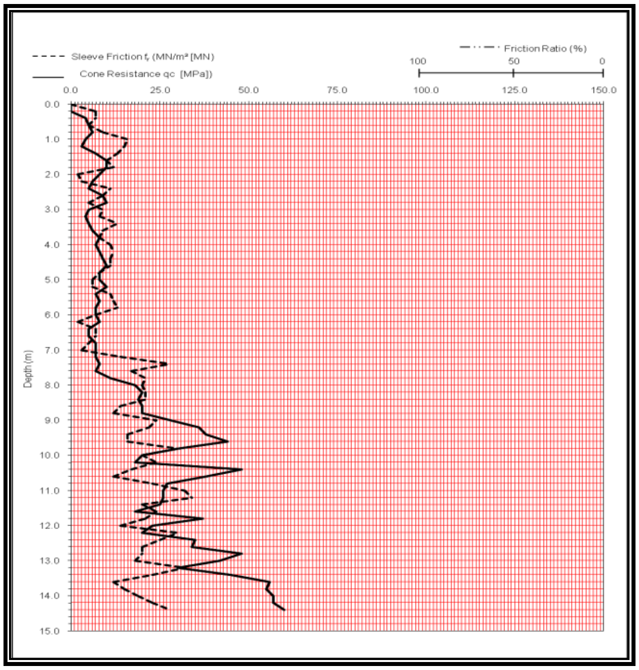

Fig. 10: Cone Penetrometer Test Plot at Chainage 218+925 Left Abutment.

<u>Dimensions of Prefabricated Geo-synthetic Vertical Drains</u>. The pre-fabricated Geo-synthetic Drains are *101.6mm (4-inch) in diameter* and about *20.00m* long in the vertical directions to extend the whole thickness of the compressible layer of (*20.00m)* as found in Section C, in the field as shown in *Figure 11a* below).

Emplacement of the *woven geotextiles* across the entire surface width of the road alignment in question prior to emplacement of the Sand-dump is shown schematically below in Figure 11b.

FLEXIBLE PAVEMENT CONSTRUCTION CONSIDERATIONS ALONG SEGMENT 3 OF THE PROPOSED EAST – WEST COASTAL HIGHWAY

The application of geosynthetic reinforcements in pavements has been practiced in Europe for over four decades (>40 years) while the use of steel meshes has spanned just a little over 20 years *(Rathmeyer, 2007)*. Utilization of reinforcing elements in road pavements is a multi-purpose solution to;-

(i) increase pavement fatigue life,
(ii) minimize differential and total settlements,
(iii) reduce rutting in surface and sub-grades,
(iv) limit reflective cracking,
(v) reduce natural material (mineral) usage,
(vi) reduce maintenance costs
(vii) increase bearing capacity of pavement layers,
(viii) enable bridging over voids,
(ix) enable economic construction of platforms

The use of reinforcement depends largely on the following:-
(a) local conditions
(b) foundation
(c) moisture regimes
(d) climatic and traffic conditions
(e) types of granular materials
(f) precipitations

The pavement structure, according to the *COST REIPAS (COST-348, 2005)* as shown in Figure 11 below has been adapted for the proposed *East-West Coastal Road* structure.

In essence, this consists of four (4) Layers, namely:

(1) Bound Layer comprising of the following:
(a)Overlay
(b)Surface Layer
(c)Binder Course

(2) Either Bound or Unbound Layer comprising of only
(a)Base Course

(3) Unbound Layer comprising of the following:
(a)Sub-base
(b)Capping
(c)Protection Layer

(4) Sub-grades comprising of
(a) Stabilized Sub-grade
(b)Sub-grade

Depending on the Section along the Segment 3 of the East-West Coastal Road, some or all of the above Four-fold Layers of the Pavement structure may be adapted. A summary of the recommended Pavement Structures for Sections along the Segment 3 of the East-West Coastal Highway is given in Table 5 below.

The types of Geosynthetics to be used as reinforcements in each of the Pavement Layers can be selected based on the results of soil tests carried out on the site soils. This is shown in Fig. 13.

However, in new roads such as the proposed east-west Coastal Road, the reinforcement is commonly placed directly on the Sub-grades to effectively increase the Bearing Capacity of the soft subsoil by distributing stresses induced by the wheel loads over a wider area and thus reducing pressures being applied to the soft subsoil and hence less deformation during the construction period and less deformation(differential settlements and rutting) during the service life of the road. In cases with very soft sub-soils, such as along the alignment of the proposed East-west Coastal Road, a multi-layer solution with reinforcement at the sub-grade combined with a second or third layer up in the road structure can be occasionally used.

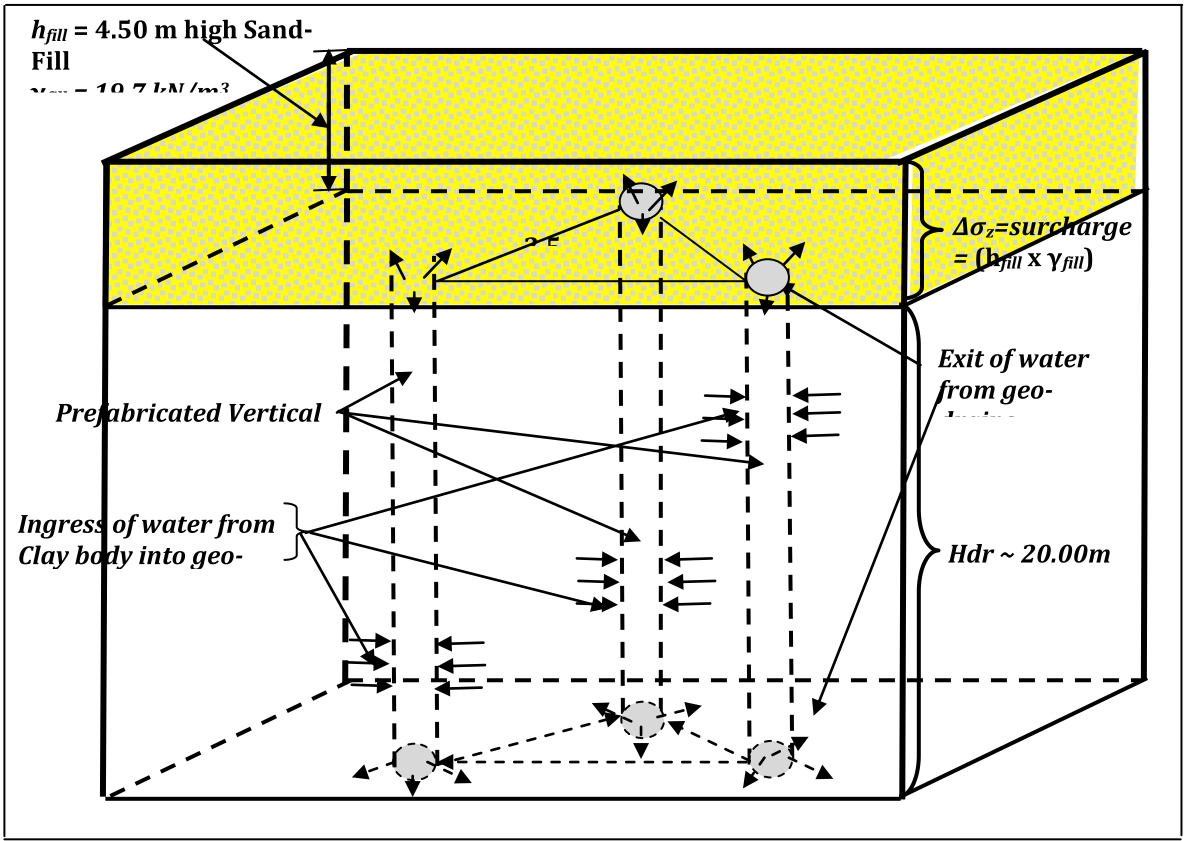

Fig. 11a. Principles adopted in emplacement of surcharge on the compressible layers

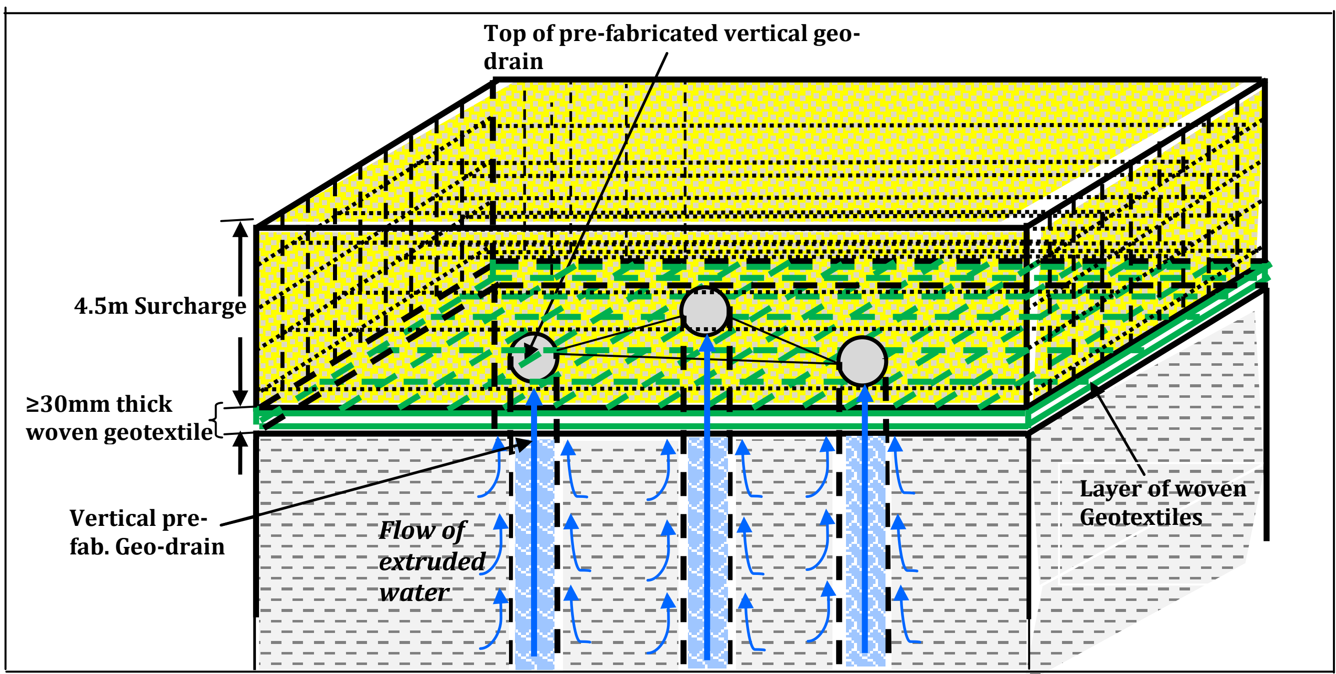

Fig. 11b: Emplacement of Woven Geotextiles before placement of Surcharge on the Road Alignment

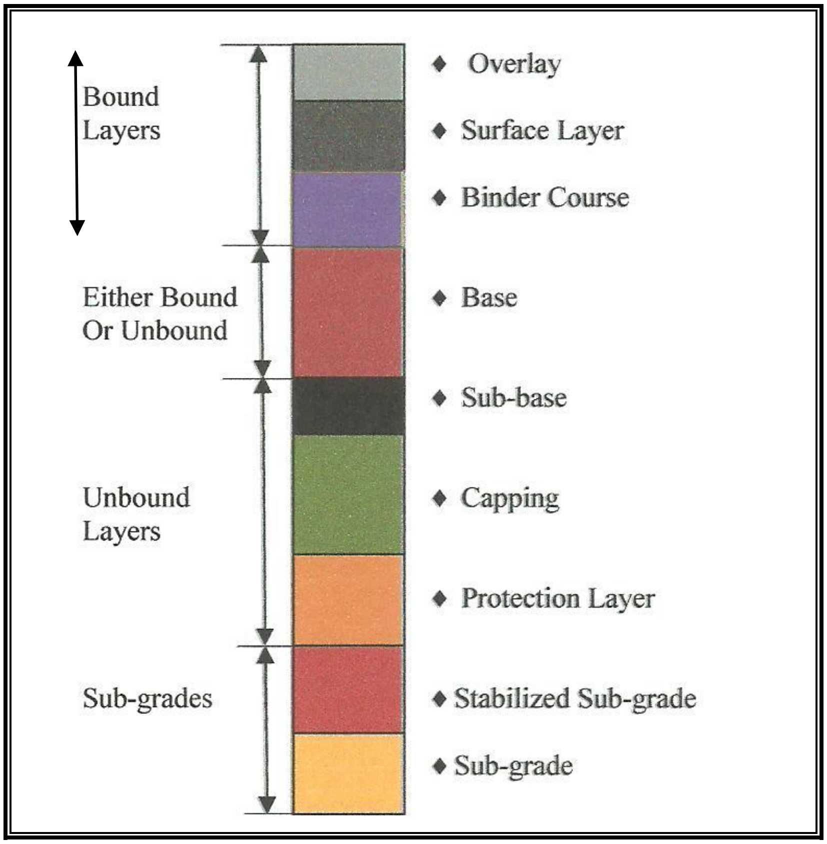

Fig. 12: Proposed Pavement Structure for the East-West Coastal Road, Segment 3: Section C. (adapted from the COST REIPAS Project, 2005)

Table 5: Recommended Flexible Pavement Structure in Segment 3 of the East-West Coastal Highway.

S/No.	Section	Recommended Pavement Structure		Remarks (if any)
		Eastern sector	Western Sector	
1.	A: Andoni River – Bonny River	Four-fold	Four-fold	All Four Layers are required
2.	B: Bonny River – New Calabar River	Four-fold	Four-fold	All Four Layers are required
3.	C: New Calabar River – Sombreiro River	Four-fold	Four-fold	All Four Layers are required
4.	D: Sombreiro river – St. Bartholomeo River	Four-fold	Three-fold	All Four Layers are required in the Eastern sector but ONLY three Layers are required within the Western Sector because of the Soil types in Western Sector
5	E: St. Bartholomeo River – Sancta Barbara River	Four-fold	Four-fold	All Four Layers are required

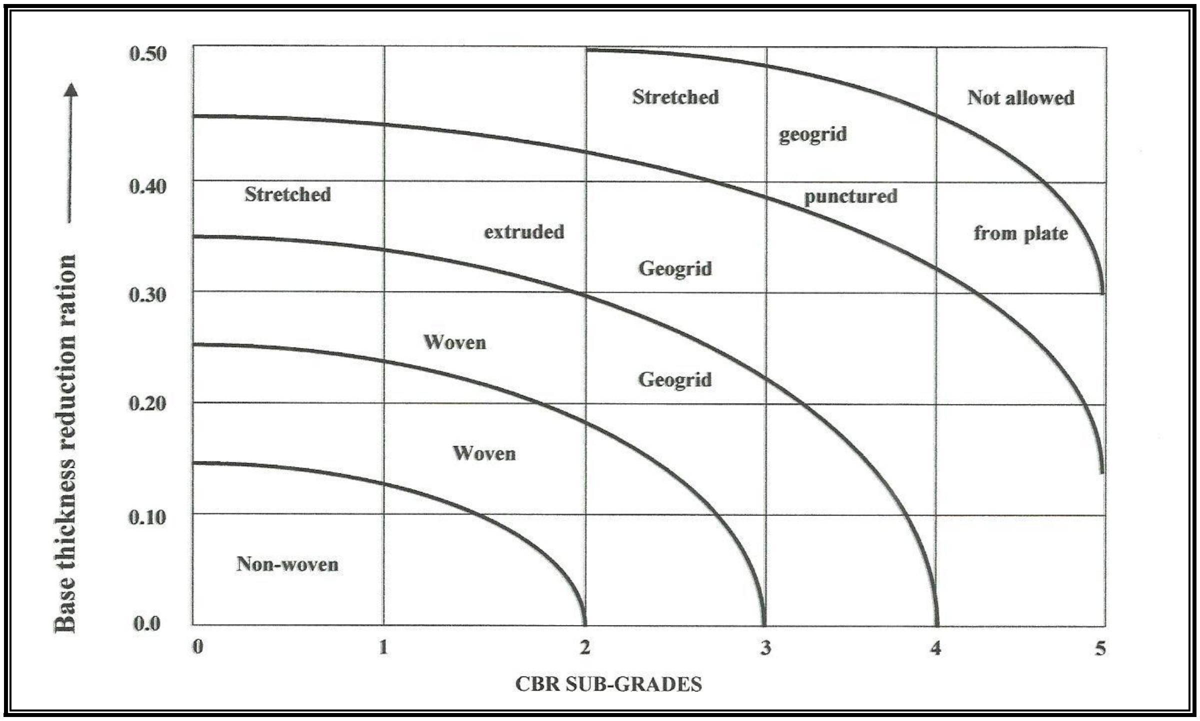

Fig. 13: Classification Chart for selection of Geosynthetic Reinforcement

CONCLUSIONS AND RECOMMENDATIONS

A series of geotechnical investigations including Deep borings at River crossings to depths of 40.00 meters using a 6-in (152.4mm) diameter casings; Shallow borings to depths of 15.00m along each kilometer length of the Roadway Alignment and Dutch Cone Penetrometer Tests carried out at both Bridge abutments and at 1000m along the length of the Roadway.
Soil samples retrieved from the field were subjected to a battery of tests including:

Atterberg limits
Grain Size Distribution Patterns,
Triaxial Tests
Oedometer Consolidation Tests,
California Bearing Ratio Tests (CBR)
Chemical Tests

Based on both the field and laboratory test results, appropriate types of Flexible Pavement Foundation designs were proffered for the different Sections of the Road passing through Segment 3 of the proposed East-West Coastal Highway which passes through Andoni River in Rivers State and Sancta Barbara River in Bayelsa State.

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