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SUBGRADE HYDRAULIC CHARACTERISTICS, SEEPAGE INDUCED ROAD FAILURES AND DESIGN IMPLICATIONS FOR SUSTAINABLE PAVEMENT INFRASTRUCTURE IN PARTS OF THE COASTAL SECTION OF AKWA IBOM STATE, EASTERN NIGER DELTA, NIGERIA

Fidelis A. Abija[1,4], Desmond E. Ewa[2], Edet A. Amah[3]

1. Centre for Geomechanics, Energy and Environmental Sustainability, Port Harcourt, Nigeria
2. Department of Civil Engineering, Cross River University of Technology, Calabar, Nigeria
3. Department of Geology, University of Calabar, Calabar, Nigeria.
4. Institute of Geosciences and Space Technology, Rivers State University, Port Harcourt, Nigeria

*Correspondence: Email: fidelabija@yahoo.co.uk.; +234-80389626222.

ABSTRACT: *Road pavements in the coastal Niger Delta are under perennial flooding and ingress of undrained water into the pavement layers through cracks, joints, voids, and embankments. Studies have shown that water in road bed leads to increased unit weight under saturated conditions, reduced shear strength, excess pore water pressures, increased seepage pressure and reduced effective stress constituting the major culprit in road failures. This study involved field boring and sampling of 18 holes to a depth of 2m, monitoring of climate induced detrimental environmental variables and geotechnical laboratory testing including identification, classification and soil grading tests and results analyzed using empirical relationships. Hydraulic conductivity was determined using the Kozeny - Carman equation and Hazens method for plastic and non-plastic subgrades respectively. Subgrades were classified as A3, A-7-5 and A-7-6 AASHTO soil groups and poorly graded CI – CL (USCS), Kaolinitic clayey silts. The hydraulic conductivities vary from 1.66 x 10^{-4} – 9.604 x 10^{1} cm/sec, degree of saturation from 36.1 – 121.1%, submerged unit weight from 5.77 – 14.49KN/m^3, critical hydraulic gradient from 0.59 – 1.48 and void ratios from 0.52 – 1.28. The effective stress under dry and submerged road conditions range from 1.731 – 4.347KN/m^2 and 1.554 – 3.903 KN/m^2 respectively indicating a % reduction >10% in all the samples under a seepage pressure of 1.02 – 6.43 KN/m^2. Subsurface drainage was considered based on piping ratio which range from 1.32 x 10^{-3} – 3.60 x 10^{-3} and permeability ratio which varies from 0.00947 – 0.90 indicating that subgrades are unsuitable filter materials in the road bed foundation. Recommended design options for pavement sustainability include increasing pavement elevation above the historical average flood level and raising the road bed thickness by filling with free draining materials such as graded sand, provision of subsurface drains and geosynthetic or geotextile materials to aid water egress.*

KEYWORDS: Subgrade, hydraulic characteristics, pavement, effective stress, subsurface drainage, Eastern Niger Delta.

INTRODUCTION

The engineering response of a soil to load depends on several interacting and inters related factors which are compositional and environmental and pavement sustainability is significantly controlled by the effective stress in the road bed which is a factor of the pore water pressure. Road infrastructures which form important component of societal growth and development are expected to be resilient, durable and able to perform satisfactorily throughout their service life [1]. The ingress of undrained water into the pavement foundation and saturation of the road bed is the major culprit in highway pavements failure [2]. It is important to keep moisture out of the sub-soil during construction and during the design life of the pavement as it affects the soils mechanical properties. Submerged subgrades and sub-bases are subjected to increased unit weight, reduced effective stress and shear strength due to excess pore water pressure [3]. The state of consistency of a subgrade which is controlled by its moisture content controls its engineering behavior and response to transient stresses of vehicular traffic. Ponding of the road surface causes infiltration by gravity drainage and saturation of the road bed where there is no egress routes initiating particle disaggregation creating instability and enhancing siltation of drains. This phenomenon is controlled by the hydraulic conductivity of the subgrade and sub-base layers which provide ingress and egress routes [4]. Water may infiltrate into the subgrade from many sources such as rainfall, capillary action, seasonal movement of the groundwater table [5]. Climatic change variability factors require mechanistic design approach for sustainability of the pavement infrastructure especially in coastal microclimatic environments [1]. Road bed drainage depends on ingress and egress routes which are controlled by the hydraulic conductivity of the subgrade and sub-base layers. [4] observed that variability in hydraulic conductivity can occur laterally and vertically within the sub-base and subgrade due to the natural permeability of the material layer and effects of densification. Post-depositional compaction and consolidation process may also induce spatial variations in the subgrade permeability. The hydraulic conductivity of a soil is a property of the medium which gives it the capacity to transmit fluids through it without causing a change in the structure of the medium and intrinsic permeability is the inherent hydraulic conductivity character that is independent of the fluid's characteristics [6, 7, 8]. A soil's lateral and vertical variation in hydraulic conductivity is a function of the soil type, textural composition, structure, void ratio, particle size, stratification, and even temperature. The smaller the particle sizes, the smaller the void ratio leading to reduced size of flow channels and low hydraulic conductivity [3].

Storm water effects and ponding on roads is climate and weather dependent varying with the seasons. Roads in coastal environments are most susceptible to climate induced pavement deterioration due to high amount of precipitation that occurs all year round. Climate change induced rise in sea level combined with storm surges and increased intensity of precipitation leading to flooding of low lying roadways is a critical consideration as these variables introduce drastic deformation in pavement [1].

[4] observed that changes in sub-base strength due to saturation affect the total strength of a pavement which needs to be mobilized to maintain the stresses on the subgrade. The absence of drainage leaves the roads in submerged conditions enhancing pavement deterioration. On the contrary, effective drainage aids longevity of the pavement infrastructure. This was recognized by the likes of Metcalf, Telford and Macadam in their early pavement designs which considered cross slopes, side ditches and sub-surface drainage for removing excess water before the sub-grade can be affected [2, 4]. McAdam is reported to have stated that "if water passes through a

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road and fills the native soil, the road whatever its thickness losses its support and goes into pieces" thus stressing the negative effect of saturation of the subgrade and the need for efficient drainage of the road bed [2].

Road bed deterioration occurs when excess and undrained water permeate into the layers changing the state of consistency and causing grain agitation, loss of cohesion and particle disaggregation. Water induced reduction in the shear strength of the subbase and foundation subgrades alter the mechanical properties and causes instability and failures. The shear strength of a subgrade which is offered by the frictional resistance of particle contacts is lost to displacement of finer materials that provide stability and grain disaggregation causing weakness and structural problems. The displaced water in supersaturated conditions can transport these fines forming in a slurry layer within and at the top of the subbase course and further reducing the effective permeability [4]. Effective stress which is the grain to grain contact pressure in the roadbed is responsible for increase in void ratio or decrease in the frictional resistance of a soil/rock mass. Pore water pressure increases a subgrade's volume and decreases its frictional resistance. This pressure reduces to zero when the subgrade's hydraulic gradient attains its maximum value which is the critical hydraulic gradient under which a soil will be in quick condition and at which there is effectively no grain to grain contact pressure. The soil will be at the threshold of being lifted up by the seepage force. Under this condition, a subgrade loses cohesion and all of its shear strength and bearing capacity thus initiating the onset of grain agitation, disaggregation and lifting. This phenomenon is termed boiling or quick condition.

Pavement sustainability depends on Environmental factors which exert significant impact on the layers strength. [1] held that climatic indicators are linked to the type and extent of climate induced pavement deterioration a highway is subjected to and [9,10] stated that all pavement types are susceptible to deterioration under potential changes in climate. Mechanistic empirical design of pavement infrastructure should be based on historic climatic patterns reflective of local climate incorporating reasonable range and levels of temperature, wind speed and precipitation which influences the groundwater table depth. The United States [11] concluded that regional and global changes in climatic factors impacts heavily on transportation infrastructure and transportation professionals should incorporate them in the design, construction, operation and maintenance.

Good drainage in a road equates to higher effective stress implying more frictional strength and yielding a road that last longer, more economic in term of construction and maintenance. For optimal performance, a roadbed's effective stress must be kept high thus necessitating efficient drainage. Road design under soaked pavement conditions such as the study area requires expedient drainage more than a cost effective pavement system with the worst conditions. Good drainage keeps water away from the road bed by draining off as quickly as possible to prevent infiltration and saturation of the subgrade and subbase layers.

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MECHANISM OF INGRESS INDUCED PAVEMENT FAILURES

Undrained water in submerged pavement infiltrates into the pavement layers through surface cracks, voids and joints. The water is entrapped in surfaces of successive lifts of bituminous layers creating a bathtub condition and causing uplift pressures and reduction in support efficiency. It also causes bitumen stripping from aggregate materials and lowering the binding strength of the pavement inducing pumping phenomenon in rigid pavements or pot holes in in bituminized pavements as a result of water ingress. Subsurface runoff infiltrates into the subgrade increases its buoyancy by a rise in the submerged unit weight. Grain contact and support power are lost creating lifting and erosive piping channels.

Flat terrains such as the Niger Delta which are perennially inundated suffer from infiltration and erosion of subgrades, subbase and base courses leading to washouts, increase heave, pumping and piping failures [1]. Clayey subgrades amenable to high volume change in response to wetting and drying cycles of seasons, swell and shrink creating cracks which eventually become ingress pathways on pavement surfaces into subgrades and increasing the pore water pressures. Under load, subgrades undergo elastic compression at grain contacts and relative sliding of particles. When there is no flow of water in the subgrade mass due to low hydraulic conductivity, the inter-granular pressure remains constant at any level but decrease or increases depending on the direction of flow as a result of variable permeability [12].

Subgrades in the coastal Niger Delta have been reported to be weak bearing [13, 4]. [15] reported the dominating occurrence of extra-sensitive, quick and expansive clayey silty subgrades in the area with over 58% of them rated as poor AASHTO materials for pavement. [16] also reported the existence of high compressibility kaoliitic clays with swelling potential up to 30% and swell index varying from 0.44 - 0.57 which are under inundation of perennial coastal flooding in the study area.

STUDY LOCATION

The study area is within the Eket, Esit Eket and Ibeno areas within the coastal stretch of Akwa Ibom State, Eastern Niger Delta, Nigeria georeferenced N and E (Fig. 1.0). It is a tropical rainforest area with seasons; the wet season spanning through April – November and the dry season that last from December - March with occasional rains during the dry season. The mean rainfall varies from 2000mm to over 4000mm at the coast with about 85% occurring in wet season. Temperatures range, on average, between 26 and 27^0C during the dry months of February to March and about 24^0C during wet months of June and September. Daily temperatures oscillate between 31. 7^0C and 23^0C in dry season highest average values of humidity reach 90 in August as against an average minimum of 74% in February [17]. Wind and wave conditions along the Nigerian coast can be distinguished into three by [18] namely calm (November - January), transition (February - April) and storm (May - October). Prevailing onshore (mostly southwesterly) winds have a modal velocity of 6 - 9 m/s with a marked increase in frequency during the storm season [18].

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Geomorphologically, it is a flat land topography ruined by rivers and rivulets, tributaries, creeks and creeklets in a coastal plain setting (< 3m above mean sea level). [19] subdivide the Niger Delta into three hydro-meteorological zones as coastal zone consisting mainly of sand bars and ridges with saline water bodies under diurnal tides which deposit sands, silts, and highly plastic clays. The transition or mangrove zone coincides with the brackish water zone immediately north of the coastal zone an made of fibrous, pervious clayey muds that exhibit large values of compressibility and or consolidation underlain by poorly graded silty sands and freshwater zones which is the upper reaches of the region. The subsoils of this zone are composed of cohesionless subgrades with occurrence of lateritic soils in places.

Fig. 1: Map of Nigeria showing study location and climatological zones.

BRIEF GEOLOGY OF THE NIGER DELTA

The area is a sedimentary structure of clastic fills varying in thickness from 9000-12000m. It is within the Niger Delta basin, one of the largest regressive deltas estimated to cover an area of 300,000 km^2 with a sediment volume of 500,000 km^3 [20] and over 10 km thickness in the basin depocenter [21]. The stratigraphic sequences of the basin is composed of three units namely Akata shale Formation which forms the basal unit, the middle Agbada Formation made of intervening layers of sandstone and shales and the upper Benin sandstone Formation [22]. The onshore portion of the Niger Delta Province is delineated by the geology of southern Nigeria and southwestern Cameroon. The Benin flank, an East-North East trending hinge line south of the West Africa basement massif marks the boundary north-westward while Cretaceous outcrops of the Abakaliki High form the northeastern boundary. The Calabar flank, a hinge line bordering the adjacent Precambrian basement, forms the East – South - East limit of the basin.
Most civil engineering structures and are founded within the coastal plains sands made up of quaternary sands and clays deposits and construction is faced with serious physical challenges due to the poor soil conditions which have escalated projects [23].

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METHODS OF STUDY

Geotechnical Investigations

Geotechnical programme involved site identification and location using GPS (coordinates in table 1) the boring of 18 number boreholes to a depth of 2m using hand auger, sampling at 1m intervals and laboratory analysis. Subgrade samples were roughly observed, classified and labeled in the field. Laboratory tests on samples include identification and classification tests which include Moisture content, Particle size distribution, Atterberg limits (liquid and plastic limits), Specific gravity and density all performed in accordance with the specifications of [24]. Due to the significance of the clay and silt fractions in clay plasticity, potential for swell and or shrinkage, compressibility, hydraulic conductivity, true cohesion and frictional strength, their proportions was quantified by soaking the sample overnight in potable water, oven drying and then washing through B.S. sieve number 200 (0.074mm sieve size) before

Borehole Number	Northing	Easting	Elevation (m)
BH1	N04^{0}47’.401’’	E008^{0}03’.348’’	-
BH2	N04^{0}47’.111’’	E008^{0}03’.908’’	-
BH3	N04^{0}47’.178’’	E008^{0}03’.765’’	-
BH4	N04^{0}45’.340’’	E008^{0}02’.863’’	38.8
BH5	N04^{0}45’.022’’	E008^{0}02’.606’’	32.7
BH6	N04^{0}44’.991’’	E008^{0}02’590’’	33.9
BH7	N04^{0}44’.444’’	E008^{0}02’.133’’	40.4
BH 8	N04^{0}46’.264’’	E008^{0}02’.979’’	49.6
BH9	N04^{0}39’.264’’	E008^{0}04’.014’’	33.6
BH10	N04^{0}39’.053’’	E008^{0}04’.034’’	27.9
BH11	N04^{0}39’.144’’	E008^{0}03’.884’’	31.7
BH12	N04^{0}36’.730’’	E007^{0}56’.941’’	15.9
BH13	N04^{0}36’.958’’	E007^{0}56’.914’’	16.2
BH14	N04^{0}35’.632’’	E007^{0}’39’.067’’	5.6
BH15	N04^{0}35’.769’’	EE007^{0}33’.981’’	19.4
BH16	N04^{0}35’.841’’	E007^{0}38’.935’’	23.7
BH17	N04^{0}36’.285’’	E007^{0}’39.084’’	24.7
BH18	N04^{0}36’.373’’	E007^{0}39’.014’’	18.5

dry sieving.

MONITORING OF CLIMATE VARIABILITY PARAMETERS

Climatic parameters were randomly measured at 6 locations using Testo 350XL multimeter during the field sampling campaign and results have been presented in table (5).

METHODS OF GEOTECHNICAL DATA ANALYSIS

DETERMINATION OF SUBGRADE HYDRAULIC CONDUCTIVITY

The hydraulic conductivity of plastic subgrades was determined using the empirical method of [25]. Equation (1) defines hydraulic conductivity as

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$$K = \frac{\phi^3}{CS^2(1-\phi^2)} \quad \text{………………………} (1)$$

where ϕ = Porosity, C = constant = 5, S = clay specific surface.

In plastic soils, clay interaction with water is due to its high specific surface area, structure of the clay minerals and the polar nature of the water molecules [26] and the potential swell, shrinkage and expansion of clay is controlled by its plasticity. [27] derived an empirical equation for estimating the specific surface of a plastic soil based on its Liquid Limit (LL) obtained using the Cassagrande method. This method yields predicted results within ± 25% of the measured LL when 1/LL > 0.167 i.e. LL > 60%. This equation (2) has been applied in in this study since hydraulic conductivity depends on the specific surface of plastic soils.

$$1/S = 1.3513(1/LL) - 0.00089 \quad \text{………………………………..} (2)$$

where S is in m^2/g, of solids. For the non-plastic soils, [28] equation (3) was applied in the determination of the hydraulic conductivity.

$$K = Cd^2_{10} \quad \text{…………………………………} (3)$$

where K = hydraulic conductivity, d_{10} = effective particle size, and C = 100 for all practical purposes [4].

The degree of saturation (S_R) of the soils was determined from eqn. (4) while the submerged unit weight (γ_{sub}) was derived using equation (7). Equation 8 was employed in determination of the dry unit weight (γ_d) while the critical hydraulic gradient (I_c) to cause lifting and boiling under quick condition was predicted using equation (9).

$$S_R = \frac{wG_s}{e} \quad \text{…………………………………} (4)$$

Where

$$e = \frac{\phi}{1-\phi} \quad \text{…………………………………} (5)$$

$$\text{and} \quad \phi = \frac{e}{1+e} \quad \text{…………………………………} (6)$$

G_s = grain specific gravity

$$\gamma_{sub} = \frac{\gamma_w (G_s - 1)}{1+e} \quad \text{…………………………………} (7)$$

$$\gamma_d = \frac{\gamma_w (G_s)}{1+e} \quad \text{…………………………………} (8)$$

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$$I_c = \frac{\gamma_{sub}}{\gamma_w} = \frac{G_s - 1}{1 + e} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

The effective stresses (σ') under dry and submerged road conditions were evaluated using equations (10) and (11) respectively while the seepage pressure (P_s) acting upward at any depth was determined using equation (12)

$$\sigma'z_1 = Z_1\, \gamma_{sub} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

$$\sigma'z_1 = Z_1\, \gamma_{sub} - i_c\, Z\, \gamma_w \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

$$P_s = i_c\, Z\, \gamma_{sub} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

where, Z1 = depth, γ_{sub} = submerged unit weight, γ_w = unit weight of water

Evaluation of Filtration Capacity of the Subgrades

Coastal roads fail by heave starting from the downstream section of the highway with higher uplift forces. The availability of egress paths in a subgrade and subbase to evacuate water and prevent ponding can be assured through the provision of a properly graded filter media at the roadbed foundation (subgrade and/or subbase) to prevent erosion of soil in contact with it due to seepage pressures. Mechanism of prevention particle movement into or out of the filter material is to provide small pore spaces between the filter to hold some of the protected materials in place. If filter materials are small enough to hold 85% (D_{85}) particle size distribution of the subgrade, the finer particles will also be held in place. Filter material suitability is tested using the filter media criteria developed by [29]. The gradation requirements for the filter capacity of the roadbed media are provided by ratios of grain diameter's for the materials as defined by the piping and permeability ratios [29]. The piping ratio (P_R) is defined in equation (13) while the permeability ratio (K_R) in equation (14) where D_{15}, D_{85} are grain diameters determined from the particle size distribution curve of the material.

$$P_R = \frac{D_{15}\text{ (filter)}}{D_{85}\text{ (soil)}} < 5 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (13)$$

$$K_R = \frac{D_{15}\text{(filter)}}{D_{15}\text{(soil)}} > 5 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

RESULTS AND DISCUSSION

The profile of the soil depicts a soft, black humus top inorganic clay layer from surface to an average depth of 0.55m, a poorly graded silty sand layer to about 1m and a poorly graded sand layer to 2.0m. These subgrades were classified as A3, A-7-5 and A-7-6 AASHTO soil groups (figure 3b and tables 1 and 2) and Kaolinitic clayey silts (CL – CI and ML - MH) figure 3b.

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Kaolin clays are the 1:1 group of clays generally with plasticity index < 40% distinguishing them from halloysites [26].

The hydraulic conductivities vary from 1.66 x 10^{-4} – 9.604 x 10^{1} cm/sec (table 1) in places indicating variable (high to low) permeability conditions with the non-plastic materials possessing higher permeability. The kaolinitic clayey silts which occur within the zone of transient vehicular axle pressures at 1m are characteristically the lower permeability subgrades, the clays acting as fills and reducing the permeability. Kaolinites and Kaolinitic clays are formed from weathering products of hydrothermal kaolin deposits (Orthoclase) where the clays are both coarse and crystallized.

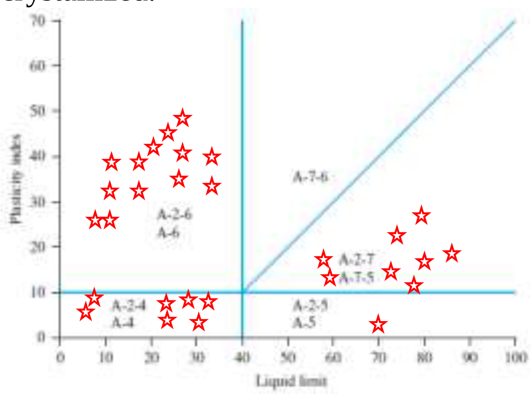
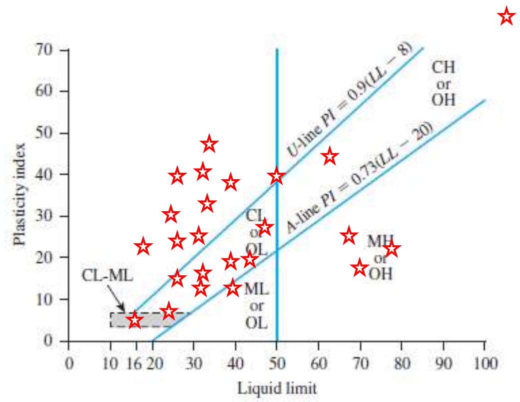


Figure 3a: AASHTO classification



(b) Figure 3b. USCS classification

[26] reports that these clays are capable of reversal or reduction in plasticity indices when brought in contact with water upon consolidation and partial cementation during burial diagenesis. Kaolinitic clay adds to fill the soil pores and reduce permeability thereby inhibiting drainage. The hydraulic conductivity was found to vary directly with the degree of saturation (figure 4) and inversely with the critical hydraulic gradient (figure 5) and effective stress (figure 6). Porosity does not show any definite relationship with the hydraulic conductivity (figure 7) suggesting no direct influence on the permeability of the subgrades.

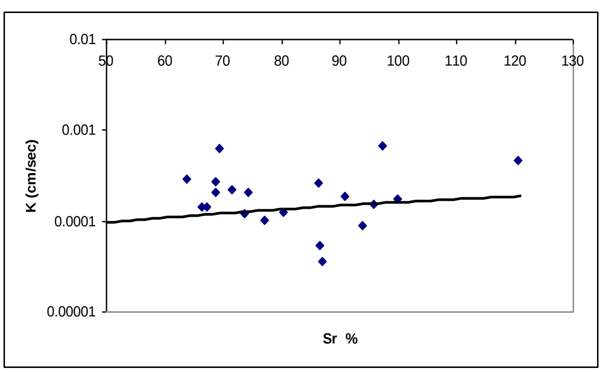


Figure 4: Variation of critical hydraulic gradient with hydraulic conductivity

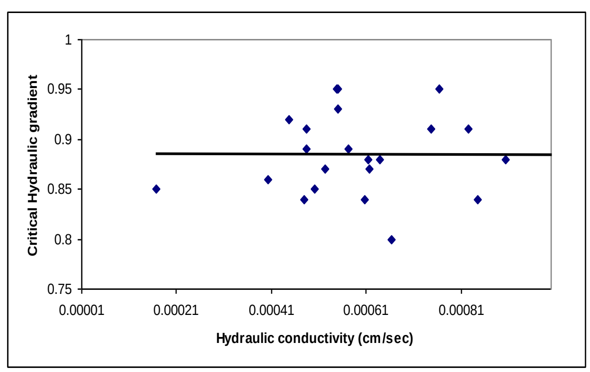


Figure 5: Variation of critical hydraulic gradient with hydraulic conductivity

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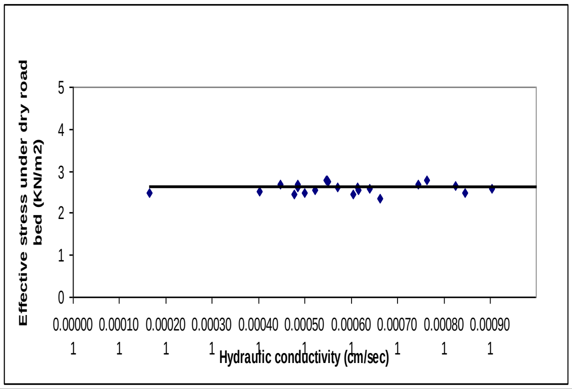

Figure 6: Variation of effective stress with hydraulic conductivity

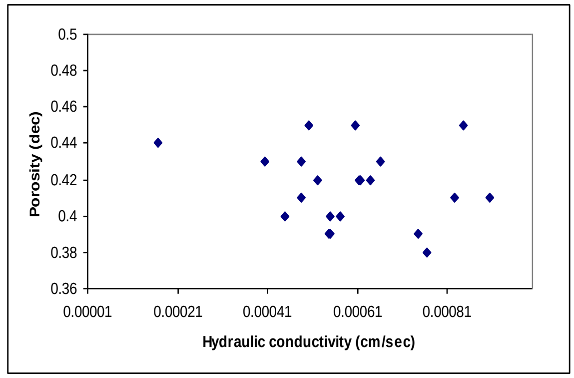

Figure 7: Variation of porosity with hydraulic conductivity

The degree of saturation of the subgrades ranges from 36.1 – 121.1%, (table 1) the non-plastic silty materials possessing high saturation. The degree of saturation was found to decrease with the void ratio which was found to range from 0.52 – 1.28 (table 1 and figure 8) and increase with the submerged unit weight until a maximum level and decreases when soil is fully saturated and all the voids have been filled (figure 9).

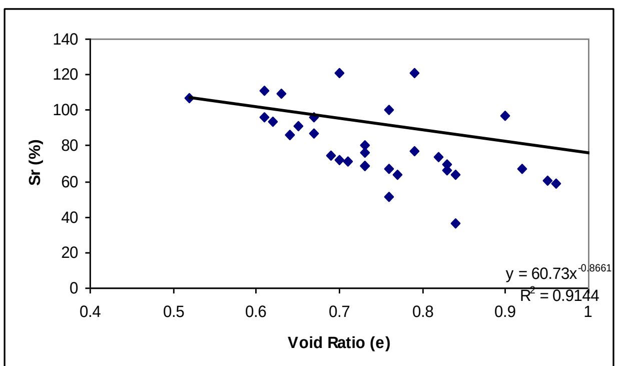

Figure 8: Variation of degree of saturation with void ratio

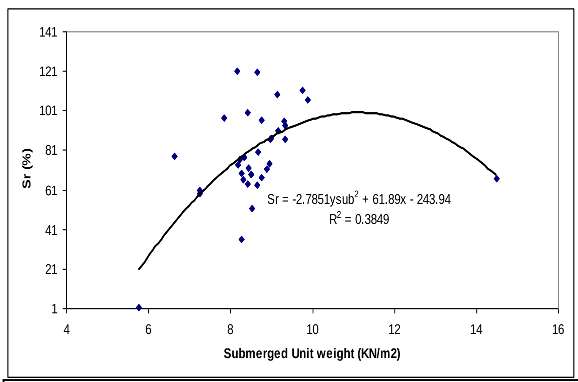

Figure 9: Variation of degree of saturation with submerged unit weight

The critical hydraulic gradient of the subgrades vary from 0.59 – 1.48 (table 1); the non-plastic silty subgrades indicating higher degree of boiling, lifting and buoyancy. Th critical hydraulic gradient varies increases with the submerged unit weight (figure 10), effective stress under dry and submerged road bed conditions ((figures 11 and 12 respectively) and the seepage force acting to induce boiling (figure 13). The submerged unit weight varies from 5.77 KN/m^2 – 14.49KN/m^2 while the effective stress under dry and submerged road conditions range from 1.731 – 4.347KN/m^2 and 1.554 – 3.903

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KN/m^2 respectively. Submerged subgrade conditions depict a reduction in effective stress greater than 10% in all the samples was observed. Suitability of subgrades as free draining materials using piping and permeability ratios depicts that piping ratio varies from 1.32 x 10^{-3} – 3.60 x 10^{-3} while the permeability ratio ranges from 0.00947 – 0.90 indicating that subgrades are unsuitable filter materials in the road bed foundation. [30] has stated that well drained roadbed conditions prevents pore pressure increase keeping the effective stress high, accelerating consolidation of the low permeability subgrades leading to enhanced stability.

Climate variability parameters depicts the mean daily temperatures indicated ranges of 25.55 to 27.11^{o}C with an average of 26.4^{o}C, mean daily relative humidity from 38% - 61% averaging 44.50% while wind speed varies from 1.00 – 1.20 with a mean value of 1.12 m/sec (table 4).

Table 1: Geotechnical properties of the subgrades

Sample ID	Depth (m)	S_R (%)	W_n (%)	Void ratio	Φ	LL	PL	I_p	SS (m^2/g,)	Grading
1A	1	64.0	21.3	0.84	0.45	NP	NP	NP	NP	Poorly graded
1B	2	73.6	24.16	0.82	0.45	NP	NP	NP	NP	Poorly graded
2A	1	77.2	24.69	0.79	0.45	49.3	31.389	28.4	37.71	Poorly graded
2B	2	95.9	23.97	0.61	0.44	50.8	32.484	27.3	38.90	Poorly graded
3A	1	99.9	29.4	0.76	0.38	38.2	23.286	17.9	29.54	Poorly graded
3B	2	80.4	23.79	0.73	0.43	41.7	25.841	18.3	31.73	Poorly graded
4A	1	66.4	22.10	0.83	0.42	45.5	28.615	24.8	34.71	Poorly graded
4B	2	120.6	31.42	0.70	0.45	47	29.71	21.7	35.89	Poorly graded
5A	1	111.2	27.15	0.61	0.41	27.9	15.767	8.5	25.29	Poorly graded
5B	2	97.3	35.31	0.90	0.38	NP	NP	NP	NP	Poorly graded
6B	1	71.9	-	0.70	0.48	25.7	14.161	6.4	19.35	Poorly graded
7A	2	67.1	32.1	0.76	0.41	NP	NP	NP	NP	Poorly graded
7B	1	93.8	20.1	0.62	0.43	44.8	28.104	21.3	34.16	Poorly graded
8A	2	86.4	23.57	0.64	0.39	46.6	29.418	18.9	35.58	Poorly graded
8B	1	90.8	21.38	0.65	0.40	33.6	19.928	12.4	25.43	Poorly graded
9A	2	68.8	23.19	0.73	0.39	36.5	22.045	16.5	27.68	Poorly graded
9B	1	68.7	20.13	0.73	0.42	35.3	21.169	17.8	26.75	Poorly graded
1A	2	69.3	21.10	0.83	0.42	38.4	23.432	15.2	29.15	Poorly graded
10B	1	71.4	23.36	0.71	0.45	28.2	15.986	5.3	21.26	Poorly graded
11A	2	63.7	20.13	0.77	0.41	36.5	22.045	17	27.68	Poorly graded
11B	1	74.3	19.41	0.69	0.42	34.2	20.366	14.2	25.89	Poorly graded
12A	2	106.5	20.00	0.52	0.41	37.7	22.6	15.1	37.12	Poorly graded
12B	1	36.1	21.49	0.84	0.34	NP	NP	NP	NP	Poorly graded
13A	2	51.4	11.79	0.76	0.46	NP	NP	NP	NP	Poorly graded
13B	1	78.2	15.04	1.13	0.43	NP	NP	NP	NP	Poorly graded
14A	2	85.3	36.50	1.28	0.99	NP	NP	NP	NP	Poorly graded
14B	1	96.2	50.93	0.67	0.56	NP	NP	NP	NP	Poorly graded
15A	2	121.1	29.84	0.79	0.40	111.9	32.7	79.2	89.40	Poorly graded
15B	1	86.9	48.40	0.67	0.44	NP	NP	NP	NP	Poorly graded
16A	2	109.5	23.98	0.63	0.40	61.2	28	33.2	47.19	Poorly graded

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16B	1	58.9		0.96	0.39	NP	NP	NP	NP	Poorly graded
17A	1	60.6		0.95	0.49	NP	NP	NP	NP	Poorly graded
17B	2	86.5		0.64	0.49	NP	NP	NP	NP	Poorly graded
18A	1	76.5		0.73	0.39	54.1	23.6	23.6	54.1	Poorly graded
18B	2	-		1.0	0.42	NP	NP	NP	NP	Poorly graded
Range				0.52 – 1.28	0.38 – 0.99	25.7 - 111.9	14.161 - 32.7	5.3 - 33.2	19.35 - 89.40	

Table 2: Summary of other geotechnical properties of subgrades in the study area

Engineering Property	Sampling Depth (m)		Results		
	Minimum	Maximum	Minimum	Maximum	Average
Specific Gravity	1.0	2.0	2.34	2.61	2.52
Bulk Density (g/cm^3)	1.0	2.0	1.507	2.035	1.779
Bulk Unit Weight (KN/m^2)	1.0	2.0	14.784	19.963	17.452
Dry Density (g/cm^3)	1.0	2.0	1.029	1.665	1.434
Dry Unit Weight (KN/m^2)	1.0	2.0	10.094	16.333	14.055
Optimum Moisture content %	1.0	2.0	15.77	18.0	17.14
Maximum Dry Density (KN/m^3)	1.0	2.0	18.07	18.75	18.39
CBR % (48 hours Soaked)	1.0	2.0	7	9	7.47
% Clay	1.0	2.0	0.4	8.0	2.89
% Finer than sieve No 200	1.0	2.0	3.5	19.5	8.68
% Silt	1.0	2.0	1.6	13.5	5.7
% Sand	1.0	2.0	8.0	96.4	84.02
% Gravel	1.0	2.0	0.1	87.5	7.32
Clay activity	1/0	2.0	0.8	41.25	11.79
Expansivity	1.0	2.0	4.83	68.90	19.447

Table 3: Subgrades hydraulic characteristics

Sample ID	Depth (m)	I_c	γ_{sub} (KN/m^3)	σ'_{dry} (KN/m^2)	σ'_{sub} (KN/m^2)	P_S ((KN/m^2)	σ'_z (red)	%Red in σ'_z	K (cm/sec)	$P_{\_ratio}$	$K_{\_ratio}$
1A	1	1.48	14.49	4.35	3.90	6.43	0.444	10.21	0.9604	2.22×10^{-3}	0.019
1B	2	0.86	8.42	2.53	2.27	2.17	0.258	10.21	0.8145	1.40×10^{-3}	9.47×10^{-3}
2A	1	0.84	8.19	2.46	2.20	2.06	0.252	10.26	6.06×10^{-4}	-	-
2B	2	0.85	8.33	2.50	2.24	2.12	0.255	10.20	1.66×10^{-4}	1.50×10^{-3}	9.8×10^{-3}
3A	1	0.95	9.32	2.80	2.51	2.66	0.285	10.19	7.65×10^{-4}	1.5×10^{-3}	0.014
3B	2	0.86	8.42	2.53	2.27	2.17	0.258	10.21	4.04×10^{-4}	1.39×10^{-3}	0.024
4A	1	0.88	8.68	2.60	2.34	2.29	0.264	10.14	6.15×10^{-4}	-	-
4B	2	0.85	8.31	2.49	2.24	2.12	0.255	10.23	5.01×10^{-4}	3.6×10^{-3}	0.036
5A	1	0.88	8.66	2.60	2.33	2.29	0.264	10.16	9.04×10^{-4}	-	-
5B	2	0.99	9.75	2.93	2.63	2.90	0.297	10.15	3.60×10^{-1}	1.32×10^{-3}	0.013
6B	1	0.8	7.85	2.36	2.12	1.88	0.240	10.19	6.63×10^{-4}	1.39×10^{-3}	0.016
7A	2	0.86	8.43	2.53	2.27	2.18	0.258	10.20	9.11×10^{-3}	-	-
7B	1	0.89	8.75	2.63	2.36	2.34	0.267	10.17	4.85×10^{-4}	-	-

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8A	2	0.95	9.33	2.80	2.51	2.66	0.285	10.18	5.48×10^{-4}	1.73×10^{-3}	0.069
8B	1	0.95	9.33	2.80	2.51	2.65	0.285	10.18	5.50×10^{-4}	1.84×10^{-3}	9.78×10^{-3}
9A	2	0.93	9.16	2.75	2.47	2.56	0.279	10.15	5.51×10^{-4}	-	-
9B	1	0.87	8.51	2.55	2.29	2.22	0.261	10.22	5.23×10^{-4}	3.0×10^{-3}	0.015
10A	2	0.87	8.51	2.55	2.29	2.22	0.261	10.22	6.17×10^{-4}	-	-
10B	1	0.84	8.26	2.50	2.23	2.08	0.252	10.17	8.46×10^{-4}	2.3×10^{-3}	0.011
11A	2	0.91	8.89	2.67	2.40	2.43	0.273	10.24	8.26×10^{-4}	-	-
11B	1	0.88	8.65	2.60	2.33	2.28	0.264	10.17	6.40×10^{-4}	-	-
12A	2	0.91	8.94	2.68	2.41	2.44	0.273	10.18	4.85×10^{-4}	2.32×10^{-3}	0.015
12B	1	1	9.88	2.96	2.66	2.96	0.3	10.12	9.29×10^{-1}	2.26×10^{-3}	0.014
13A	2	0.84	8.26	2.48	2.23	2.08	0.252	10.17	8.91×10^{-1}	2.29×10^{-3}	0.013
13B	1	0.87	8.53	2.56	2.30	2.23	0.261	10.20	8.12×10^{-1}	2.25×10^{-3}	7.50×10^{-3}
14A	2	0.68	6.63	1.99	1.79	1.35	0.204	10.26	0.7921	2.30×10^{-3}	0.80
14B	1	0.59	5.77	1.73	1.55	1.02	0.177	10.23	8.37×10^{-1}	2.31×10^{-3}	0.90
15A	2	0.89	8.75	2.63	2.36	2.34	0.267	10.17	5.72×10^{-4}	3.57×10^{-3}	0.01
15B	1	0.83	8.17	2.45	2.20	2.03	0.249	10.16	0.5625	2.16×10^{-3}	0.026
16A	2	0.92	8.99	2.70	2.42	2.48	0.276	10.23	4.48×10^{-4}	2.33×10^{-3}	0.031
16B	1	0.93	9.13	2.74	2.46	2.55	0.279	10.19	8.10×10^{-1}	3.46×10^{-3}	0.01
17A	2	0.74	7.26	2.18	1.96	1.61	0.222	10.19	6.08×10^{-1}	2.90×10^{-3}	0.081
17B	1	0.74	7.24	2.17	1.95	1.61	0.222	10.22	8.00×10^{-1}	2.10×10^{-3}	0.01
18A	2	0.91	8.97	2.69	2.42	2.45	0.273	10.15	7.46×10^{-4}	2.20×10^{-3}	0.012
18B	1	0.84	8.22	2.47	2.21	2.07	0.252	10.29	8.01×10^{-1}	2.17×10^{-3}	0.082
Range	1 – 2	0.59 – 1.48	5.77 – 14.49	1.73 – 4.35	1.55 – 3.90	1.02 – 6.43	0.177 – 0.444	10.12 – 10.29	9.04×10^{-4} - 0.9604	0.0036 – 0.00132	0.0075 – 0.9

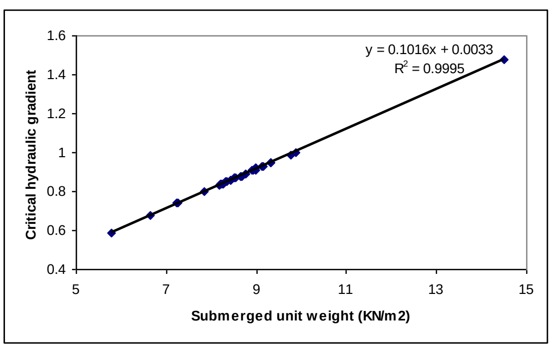

Figure 10: Variation of critical hydraulic gradient with submerged unit weight

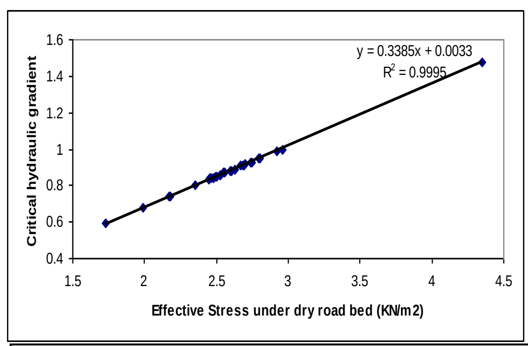

Figure 11: Variation of critical hydraulic effective stress under dry

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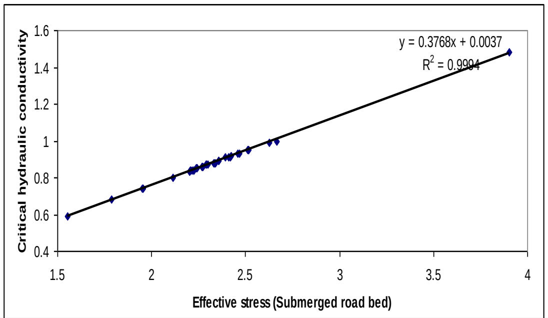

Figure 12: Variation of critical hydraulic effective stress under submerged roadbed condition.

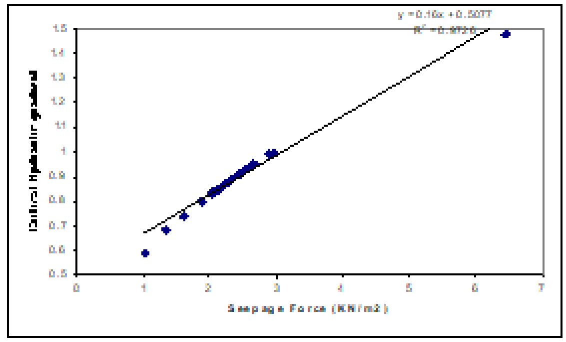

Figure 13: Variation of critical hydraulic gradient with seepage force.

Table 4: Climatic Data from the Study Area

Sample Code	Season	Temperature ^oC	Relative Humidity (%)	Wind speed (m/s)	Wind Direction
CM1	Wet	26.43	43	1.05	SE
CM2	Wet	26.16	43	1.00	SE
CM3	Wet	25.55	39	1.19	SE
CM4	Wet	27.11	45	1.20	SE
CM5	Wet	26.10	44	1.12	SE
CM6	Wet	26.81	38	1.20	SE
CM7	Wet	26.21	43	1.09	SE
CM8	Wet	27.01	61	1.14	SE
Mean		26.42	44.50	1.12	
Range		25.55 – 27.1	38 – 61	1.00 – 1.20	

IMPLICATIONS FOR DESIGN AND CONSTRUCTION

The critical hydraulic gradient of all the subgrades under varies from 0.59 – 1.48. The common construction practice is to excavate and cart to spoil 300mm of the topsoil and fill with lateritic fill materials as subbase and compact to 100% WASC. For a design road thickness based on CBR a strength parameter of 7% and using]311 design charts yields a pavement thickness of 300mm and excavation depth of 300mm. Under submerged condition, the hydraulic head is 600mm at the subgrade level. The prevailing hydraulic gradient is 2m which is well over the critical hydraulic gradient of 1.48 depicting that all subgrades will be under quick condition when acted upon by an upward seepage pressure of varying from 1.02 – 6.43KN/m^2. The subgrade's permeability ratio of 0.0075 – 0.9 range well below the threshold and recommended value of 5 indicates that under submerged conditions, subgrades do not satisfy filter media requirements to be able to provide egress routes for drainage and provision of the high effective stress required. It is necessary to consider the climate variability results recorded during the sampling campaign in relationship to historical data against global climate change induced variations in mechanistic

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design and construction of earthworks, pavement and drainage. Specific considerations for drainage and improvement of effective stress include (1) raising the pavement elevation above the historical average flood level and increasing the road bed thickness by filling with free draining materials graded sand. (2) Geosynthetic or geotextile subdrainage layers are also advantageous for their high retention capacity of fine particles, excellent permeability, flow properties and inhibition of piping. They possess high tensile strength and are easy to install during construction due to layer uniformity; and (3) provision of heavy walled polyvinyl chloride or no fines concrete subsurface pipe drains with a minimum 100mm filter material bed above the subgrade level.

The use of sheepsfoot and vibratory roller compactors for all earthworks during construction to achieve the maximum dry density which can b verified from quality control test is a fundamental necessity for the roads to be sustainable and serve the design lifespan.

CONCLUSION

Flooding and submergence of road pavement infrastructures in the coastal Niger Delta has been adduced as the major culprit together with the poor geotechnical properties of the subgrades prevalent in the substratum of the area.. This research have shown that water in road bed submerged roads have a high hydraulic gradient which exceeds the critical hydraulic conductivity thus inducing quick conditions, roadbed buoyancy and lifting. Therefore for sustainability, subsurface drainage, raising pavement elevation above the historical average flood level and increasing the road bed thickness by filling with free draining materials such as graded sand, provision of subsurface drains and the use of geosynthetic or geotextile materials have been recommended.

References

[1] Li, Q, Mills, L. and McNeil, S. (2011). The implications of climate change on pavement performance and design. A report submitted to the University of Delaware University Transportation Center. UDUTC, Final Report. 54pages

[2] Kadyali, L. R. and Lal, N. B. (2008). Principles and practices of Highway engineering. New Delhi: Khanna Publishers. 848 pages.

[3] Murthy, V. N. S. (2012). Textbook of Soil Mechanics and Foundation Engineering: Geotechnical Engineering Series. New Delhi: CBS Publishers and Distributors Pvt. Ltd.1043pages.

[4] Apul, D.S., Gardener, K, Eighmy, T, Benoit, J. and Brannaka, L. (2002). A review of water movement through highway environment. Implications for recycled materials use. Recycled Materials Resource Center, University of New Hampshire, Durham Report NH 03824.

[5] Drumm, E.C., Rainwater, N.R., Andrew, J., Jackson, N.M., Yoder, R.E., Wilson, G.V. Pavement response due to seasonal changes in subgrade moisture conditions. 2nd International Conference on Unsaturated Soils, Beijing, 1998, pp. 196-201

[6] Todd, D.K. (959). Groundwater hydrology. New York: John Wiley and Sons, Inc.
[7] Sanders, J.E. and Friedman, G.M. (1978). Principles of Sedimentology. New York: John Wiley and Sons, Inc.
[8] North, F. K. (1985). Petroleum Geology. London: McGraw Hill Book Co. Ltd.
[9] Meyer, M. Amekudzi, A., and O'Har, J. P. (2010). Transportation assest management systems and climate change. In Transportation research Records. J. of the Transportation Research Board. No. 2160 pp. 12 – 20.
[10] Meyer, M. and Wiegel, B. (2011). Climate change and transportation engineering. Preparing for s sustainable future. J. of Transportation engineering Vol. 137, pp. 393 – 403.
[11] Transportation Research Board (2008). Potential impacts of climate change on US transportation. Transportation research Board Special Report 290, Washington D.C. 2008.
[12] Fetter, C. W. (1990). Applied Hydrogeology, 2nd edn. New Delhi: CBS Publishers and
[13] Teme, S. C., Adu, A., Olise, C. (2015).Design considerations in the construction of a basement in a 7-storey hospital complex in the marginal lands of the Niger Delta sub-region. 51st NMGS Conference book of abstract, Pp. 57.
[14] Akpokodje, E. G. (1987). The Engineering Geological characteristics and classification of major superficial soils of the Niger Delta. Engineering Geology, Vol. 23, pp. 193 – 211.
[15] Abija, F. A. (2019). Geotechnical assessment of subgrade and sub-base quality for the design and construction of road pavements in parts of the coastal section of Akwa Ibom State, Eastern Niger Delta, Nigeria. International J. of Scientific and Engineering Research, Vol. 10, issue 7, pp. 1864 – 1877.
[16] Abija, F. A., Teme, S. C and Oborie, E. (2018). Geotechnical considerations for the design and construction of foundation in a marshy stream channel of Iwochang-Ibeno, Eastern Niger Delta, Nigeria. J. of Civil, Construction and Environmental Engineering Vol. 3(6), pp. 154 -170.
[17] Adefolalu, D. O (1981). The weather and climate of Calabar: a study of coastal microclimatology in equatorial tropics. Senate Research Project, University of. Calabar.
[18] Antia, E. E. (1989). A short term study of the effects of changing coastal conditions on some geomorphological elements on Nigerian beaches. Zeitscrhift F. Geomorphologie, 73, 1 – 16.
[19] Fubara, D. M. J., teme, S. C., Mgbeke, T., and Abam, T. K. S. (1988). Hydro-meteorological zones of the Niger Delta. Technical Bulletin No. 1, Institute of Flood, Erosion and Transportation, Rivers State University of Science and Technology, Port Harcourt.
[20] Hospers, J., 1965, Gravity field and structure of the Niger Delta, Nigeria, West Africa: Geological Society of American Bulletin, Vol. 76, p. 407-422.
[21] Kaplan, A., Lusser, C.U., Norton, I.O. 1994. Tectonic map of the world, panel 10: Tulsa, American Association of Petroleum Geologists, scale 1:10,000,000.
[22] Short, K. C., and Stäuble, A.J., 1965, Outline of geology of Niger Delta: American Association of Petroleum Geologists Bulletin, Vol. 51, Pp. 761-779.
[23] Abam, T. K. S. (2016). Engineering Geology of the Niger delta. J. of earth Sciences and Geotechnical Engineering. Vol. 6 No. 3. Pp. 65 – 89.

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[24] British Standards Institute (1990).Methods for testing of soils for Civil engineering Purposes, BS 1377, part 4 (1990).

[25] Kozeny, J. (1933). Theorie and Berechnung der Brunnen, Wasserkr. Waasseruritsch; Vol. 28, pp. 104

[26] Gillott, J. E. (1986). Some clay related problems in Engineering Geology in the North America. Clay Minerals, 21, pp. 61 – 278.

[27] Chapius, R.P. and Aubertin, M. (2003). On the use of Kozeny Carman equation to predict the hydraulic conductivity of soils. Canadian Geotechnical Journal 40(3) pp. 616 – 628.

[28] Hazen, A. (1911). Discussion of dams on san foundations by A. C. Koenig. Trans. Of Am. Soc. of Civil Engineers, 73, pp. 199.

[29] Betram, G. E, (1940). An experimental investigation of protective filters. Soil Mechanics Series No. 7, Publication no. 267, Graduate School of Engineering Harvard University.

[30] AASHTO (1986). Standard specifications for transportation materials and methods of sampling and testing, 14th edn. American Association of State Highway and Transportation Officials, Washington, DC.

[31]Steele, D. J. (1945). Application of classification and group index in estimating desirable subbase and total pavement thickness. Proceedings, Highway Research Board, Pp. 388 – 392.

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