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Unethical Geotechnical Practice, Building Collapse and Failure of Infrastructures in Nigeria: *A Call for Separate Geotechnical Consultant on Infrastructural Projects*

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Abstract: All structures are founded either on or in soil or rock and design of all engineering structures is based on material properties. The alarming increase in the incidences of building collapse in Nigeria can be linked to the failure of foundation soils, apart from poor quality of construction materials in some cases. Under a structure, a foundation footing column can rest on a firm subgrade while another can be founded on a weak, highly compressible and collapsible soil. Hence, subsurface lithologic profile of the soils underlying a structure is important for safe design and sustainable infrastructure. In the Niger Delta region, correlation of the borehole logs revealed occurrence of peat and peaty clays from the ground surface to a depth ranging from 1.5 – 10m and can extend up to 35 – 42m. Under such geological condition, knowledge of the origin and implicitly the behaviour of the soil under different conditions of saturation; and seasonal wetting and drying cycles; and their implications on structural settlement, material composition of the structure and effects on corrosion etc. are required for safe and economic design. The designer of every project therefore expects minimum specified properties from the geotechnical investigation and interpretation of the results since design is fit to purpose and in-situ soil or rock cannot be changed except being improved upon. Therefore, in the wake of a number of reported cases of professional incompetence and unethical geotechnical practices, a good geotechnical investigation report should provide the soil lithologic profile, basic engineering geological properties and their interpretations with recommendations and design implications including ground control conditions during construction. This study highlights that *Geotechnical Consultant* should be assigned to all infrastructural development projects in the Nigerian construction industry.

Keywords: Profession, Engineering Geology, Geotechnics, Ethical Practices, Design Requirements, Geotechnical Consultant

1. Introduction

All structures are founded either on soil or rock for surface infrastructures or within the subsurface soil or rock for subsurface infrastructures like tunnels. Hence, the reasons why the designs of all engineering structures are generally based on material properties on or within which they are to be sited. The alarming increase in the incidences of building collapse in Nigeria especially in the coastal Niger Delta region and Lagos, the most recent being that of Woji Street, GRA, Port Harcourt with colossal loss of irreplaceable human life and properties is linked to the failure of foundation soils. Other parts of the country are not left out as a 2019 report by Punch Newspaper stated that 43 buildings collapsed during the year with Lagos accounting for 39.5%. Lagos also accounted for 134 cases between 1979 and 2013 [1].

The soils and rocks which constitute the foundation support below the superstructure serves for load bearing, transfer and distribution. These soils are complex aggregates of minerals whose behaviour depends strongly on the parent weathered rock composition and provenance. Soils can vary at very short distances under a structure due to varying hydrological and geomorphological dynamics, especially for marine deposition that gives rise to lateral facies changes at the close separation. The variation is worst in coastal deltas due to rapid deposition and incomplete decomposition of organic debris forming thick layers of weak and highly compressible peaty clay soils. Depth-wise lithological changes along the profile can also give rise to firm soil overlying weak ones. Foundations on rocks are not exempted from failures due to the discontinuous, inhomogeneous, anisotropic and non-linear elastic nature of the materials.

Abija et al noted that foundation engineering design is traditionally carried out against bearing capacity failure and excessive settlement which are directly related to the shear strength of the soil at the foundation [2]. It is concerned primarily with ensuring that movements of footings are within tolerable limits without adverse effect on the functionality and performance of the structure [3]. Geological and groundwater conditions and, more particularly, the various types of ground movement that can occur are fundamental for the sustainability of any infrastructure. Hence, these must be incorporated into the engineering design and also inform the choice of foundation types and construction methods. Therefore, failure to adequately investigate, characterize, predict and incorporate the soil profile under the entire structure, the material properties of the varying soil layers and their time dependent response to imposed structural loads into a design, is automatically planning for the structure to fail. In addition, according to the sustainable development goals (SDG), the development of infrastructures (SDG 9) and cities/communities (SDG 11) has to be both resilient and sustainable. To achieve the desired goals, it requires pre-design geotechnical investigations to properly and adequately characterize (1) the subgrade material at the foundation, (2) assess the thickness, depth of occurrence and type of foundation materials, and (3) predict structural settlement which could be differential and can cause redistribution of the structural load transfer mechanisms to the members founded on the weak substratum and resulting in failure. However, the roles of engineering geologists/geoscientists in geotechnical consultancy services and geo-environmental mapping in respect of infrastructural development has been under-estimated in Nigeria, as their full potentials are still far from been fully utilized. Based on the above background, this paper aim at outlining key principles of geological context in the engineering geological investigation of foundation soil/rock materials, for safety and sustainability of engineering structures in our construction industry in Nigeria. In addition, the intent is also to draw the attention of professional bodies in construction industry to unethical practice and professional incompetence in the construction sector vi-s-a-vis pre-construction engineering geological investigations and undermining of geological factors in the designs of structures and a call for separate Independent Geotechnical Consultants on infrastructural Projects in the Nigerian Construction Industry.

1.1. Soil Profile Variation, Eccentric Column Loads and Differential Settlement

Under a structure, one footing in the substructure can rest on a firm subgrade while another can be founded on a weak, highly compressible and collapsible soil as exemplified by the leaning tower of Pisa and most building collapse debris sites in the coastal cities of Nigeria. The failure and collapse can be attributed to soil profile variation within the foundation under the superstructure, eccentric loading against the design concentric column loads application and resulting differential settlement. Eccentricity is defined as the ratio of the moment to the vertical load. It is off-centre loading and the resultant load on the foundation moves away from the centre of gravity as against concentric or axial loading coincident with the centre of gravity [4]. Under such loading condition, the foundation of structures is subjected to moment forces in addition to the vertical loads leading to non-uniform pressure distribution in the foundation material [5, 6]. When the eccentricity is greater than B/6, the minimum pressure distribution becomes negative and tensional stresses are generated on the foundation. Geomaterials (soils and rocks) are especially weak under tension and cannot withstand tensional stresses, therefore leading to separation between the foundation substructure and the underlying subgrade. The weak, highly compressible and collapsible foundation subgrade and other clay horizons within the zone of the bulb of pressure can be subjected to fluid expulsion due to increased load from the structure, pore water pressure dissipation and consolidation settlement beneath the column on the weak strata. The settlement inevitably becomes differential due to the change in the line of distribution of loads from concentric to eccentric state. Therefore, the design factor of safety against bearing capacity failure for eccentric column loading is not a rule of thumb and must be evaluated.

Road pavement performance depend on subgrades that provides a uniform and sufficiently stiff, strong, and stable foundation for the overlying layers and adequate drainage that quickly remove water from the pavement structure before the water degrades the properties of the unbound layers and subgrade. The base and subbase courses must also provide additional strength and resistance to moisture induced deterioration including swelling and freeze/thaw and other degradation (*e.g.*, erodibility, intrusion of fines). Therefore, adequate characterization and interpretation of the in situ subgrade, subbase fills and unbound aggregates for the base courses including the depth of occurrence of the suitable subgrades are very essential at every 25m interval or less in swampy terrains.

1.2. Peat, Peaty and Organic Clays – The Underlying Geotechnical Problem

Incomplete, anaerobic microbial degradation of plant and animal remains in waterlogged areas under shallow water, alluvial, estuarine and deltaic environments result in formation of organic soils termed Peat and Peaty clays [7]. Peats have a spongy consistency, are fibrous, dark brown to black in colour and organic odour; and compositionally made of > 35% organic content [8] often interbedded with lenses of silts, sands and gravels. They also are termed variable deposits characterized by high compressibility and moisture content; low shear and compactive strengths and poor bearing capacity.

Geotechnically, peat is a problematic soil due to its properties [9] and is commonly recognized as a material unsuitable as foundation materials for any construction works [10]. Clays on the other hand consist of several hydrous aluminum silicate minerals. Magnesium or Iron can replace wholly or in parts Aluminum. Clays can be organic or inorganic in nature and are classified as Kaolinites, smectite, illites, halloysites while the most common group is the montmorillonites. Clay - water interaction gives rise to water absorption causing swelling and heave; water expulsion causing volume change, consolidation settlement and settlement of structures. The water also causes shear strength reduction, increase in consistency and moisture migration giving rise to shrinkage upon drying [11]. It is important to characterize the type of clay under a structure and determine its suitability as a foundation material.

1.3. The Role of Engineering Geological Practice in Sustainability of Infrastructures

The stability and performance of any infrastructural project depends on the subgrade strength, consolidation settlement, swelling and expansivity which are guides in the choice of foundation for the superstructure's load [12, 2]. Pre-design and construction engineering geological investigations aims to assure adequate consideration of all geological factors affecting the location, design, construction, operation and maintenance of engineering works and incorporate them into the design and construction [13, 14]. Engineering geological investigation considers the geological processes under which the soils and or rocks at the proposed project site were formed, assess these processes and the soil and or rock characteristics to form the basis for judging the suitability of a site for a proposed engineering project. The nature, physical and engineering characteristics of the foundation subgrades, their vertical and lateral distributions and variations; topography, excavations around the site, quarries, escarpments, evidence of erosion, geohydrologic, flood marks, drainage ditches, adjoin vegetation, underground workings, slope stability analysis and tectonic regimes in seismically active areas are all parts of the engineering geological assessment [15, 16]. In addition, soil stratigraphy, abandoned dump sites, shrinkage cracks, tension cracks and existence of cracks in walls (in existing structures) are all evaluated during the investigation.

In line with the sustainable development agenda, planning and development of the urban and smart cities should be preceded by slope instability and landslide susceptibility assessment which are covered under engineering geological investigation [17]. The scope of the investigation depends on the type of structure, site geology and topography. The intensity (drilling and sampling intervals) of the investigation depends on the type of structure, uniformity of materials on the site, the importance and cost of the proposed engineering works, relations between ground properties and geotechnical requirements of the proposed construction. This is important in order to arrive at a conclusive choice of the most feasible site, develop workable and satisfactory design, construct and operate engineering works with maximum economy and safety.

Nonetheless, if any significant variations in ground conditions occur, during the construction stage, modifications are introduced and incorporated into the design [5, 7, 18]. [1] noted that one of the causes of foundation failures and one of the greatest causes of building collapse is insufficient knowledge of the ground conditions making it imperative for detailed engineering geological exploration of ground conditions. Ground conditions encountered during construction can also be different from predicted and anticipated due to insufficient and poor knowledge of the subsoil and the incorrect interpretation of the test results thereby posing a major problem. [19] submitted that traditional discipline-based knowledge, methodologies and approaches are no longer sufficiently effective in addressing complex and interconnected global problems.

2. Unethical Practices and Professional Incompetence

According to [20], a profession is a learned calling with specialized knowledge applied with experienced judgement in the context of recognized social responsibilities. It renders services based upon advanced knowledge, skill and judgement, which the public takes on trust. A profession is charged with substantive public obligation and performs services to a greater or lesser degree in the general public interest and is bound by a distinctive ethical code in its relationships with the public, clients, employees and colleagues. A profession accepts responsibility to regulate professional members and professional services provided to clients and the public. Professions such as engineering, and geoscience are generally highly organized with definitive minimum standards of admission and regulate the activities of their members in terms of both skilled practice and ethical conduct. They promote the advancement of knowledge and encourage the formulation of standards. Professions granted self-governing status under statutory regulatory councils such as the Council of Nigerian Mining Engineers and Geoscientists (COMEG), Council for the Regulation of Engineering in Nigeria (COREN), Architects Registration Council of Nigeria (ARCON) etc. have the authority to discipline those members who fail to comply with proper standards of practice and ethical professional conduct. Professionals have a responsibility to lead by example and set the tone for the competent and ethical conducting of business.

Project design engineers in Nigeria are reportedly guilty parties in unethical professional practice by engaging in rule of thumb design without recourse to subsoil conditions and material properties. A case in question is a 1km road in Abua, Rivers State in which only two exploratory borings to a depth of 2m were conducted at chainages 0 +500 and 0 + 950 upon which design was based on unsoaked California Bearing Ratio test of just two samples. This was contrary to the recommendation of the [21] that sample soaking should be 96 hours to simulate in situ field groundwater conditions. Sampling distance of 25m interval may be inadequate in problematic coastal terrains that are dominated by a preponderance of lateral facies changes. Another report amongst so many others is the design of several infrastructural projects (buildings, roads, bridges and electrical installations) in Ogba, Egbema, Ndoni areas of Rivers and Bomadi area of Delta States commissioned by an International Oil Company in which design engineers failed to carry out any geotechnical investigation and substructure design was completely missing. The designs were also reportedly not endorsed by any qualified competent person. In most of the instances where geotechnical investigations were carried out, only one exploratory boring on a building site to a depth of 1.2m were undertaken, irrespective of the anticipated design loads. The examples listed here are not isolated cases and are just few of the numerous unethical practices in the infrastructure development sector in Nigeria.

Guided by the norms and ethics of professional practice, The Nigerian Association for Engineering Geology and the Environment (NAEGE) has received several reports of unethical professional practices and manifest incompetence regarding the conduct of colleagues in the other professions in the Infrastructure Development Sector in Nigeria. The situation is worrisome in spite of mass failure of roads and building collapse leading to loss of life and properties. Therefore, collaborative synergy between the professional bodies in the construction sector as observed by [19] with inclusive, holistic and interdisciplinary or multidisciplinary approach to problem solving is the much-needed action to achieve the goals of eliminating quackery and guarantee safe and sustainable infrastructures in Nigeria.

3. Elements of a Good Geotechnical Investigation Report

In his notes on practical rock engineering, [22] queried when is a rock engineering design acceptable? In consideration of the soil or rock as the foundation of a structure for which design is against bearing capacity failure and excessive settlement: hence, it is imperative to define minimum requirements of a geotechnical investigation report. The type of foundation design for any infrastructure is dependent on the shear strength of the soil or rock at the foundation level, soil moisture and its volume change behaviour; and depth of occurrence of suitable subgrade materials. Therefore, the designer of every project expects minimum specified properties from the geotechnical investigation and interpretation of the results since design is fit to purpose and in- situ soil or rock cannot be changed except being improved upon. A good geotechnical investigation report therefore should provide the soil lithologic profile, basic engineering properties and their interpretations with recommendations and design implications and possible ground control conditions during the construction phase.

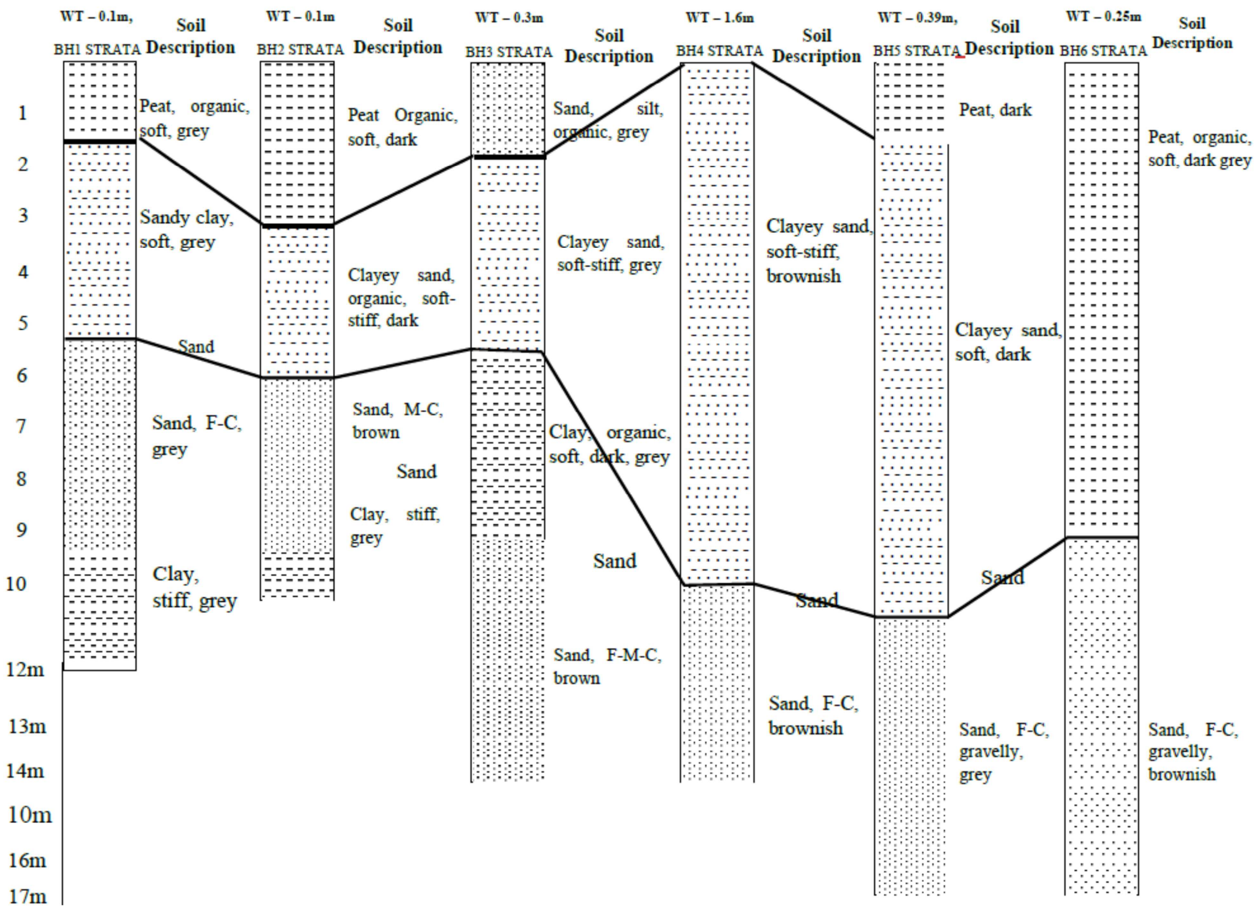

Figure 1. *Typical soils profiles from the Niger Delta Regions showing correlation of six boreholes at a site (modified after [24]).*

3.1. Subsoil Stratigraphy and or Profiles

A subsurface lithologic profile of the soils underlying a structure is important for design and construction. Figure 1 presents a typical subsurface stratigraphic profile beneath a site in Rivers State, Nigeria depicting variation of soil lithologies along the intervals. A correlation of the boreholes shows that peat occurs from the ground surface to a depth ranging from 1.5 – 10m across the boreholes. This depth-wise variation in peats have been reported to extend to 10 – 15m in places and in exceptional cases can extend up to 35 – 42m in the Niger Delta region [23].

Subsoil stratigraphic profile has serious design and construction implications for buildings, roads, and other infrastructures as the engineering properties of the underlying materials determine the characteristic bearing loads within tolerable limit of ground settlement.

Table 1. *Typical engineering properties of the foundation subgrades [after 24].*

SOIL LAYER	SOFT CLAY LAYER			HARDER CLAY LAYER		
Property	Minimum	Maximum	Average	Minimum	Maximum	Average
Moisture Content, W_n (%)	76.26	91.3	89.4	17.0	48.17	40.7
Wet Density (g/cm^3)	1.131	1.371	1.35	1.623	1.970	1.770
Wet Unit weight (KN/m^3)	11.095	13.449	12.77	15.922	19.34	17.03
Dry Density (g/cm^3)	0.701	0.821	0.802	0.972	1.551	1.39
Dry Unit weight (KN/m^3)	6.877	8.054	7.92	9.535	15.215	13.91
Saturated Unit weight (KN/m^3)	22.64	24.81	23.98	16.092	16.336	16.271
Specific Gravity (G_s)	2.42	2.51	2.49	2.46	2.92	2.89
Porosity (n)	0.63	0.649	0.638	0.56	0.65	0.62
Void ratio (e)	1.70	1.85	1.82	1.28	1.33	1.31
Initial void ratio	1.0727	1.3321	1.2991	2.1920	3.8461	3.1173
Compression index (C_C)	0.1291	0.1863	0.1784	0.7227	0.722	0.420
Swell Index (C_S)	0.44	0.57	0.49	0.12	0.15	0.14
Swell pressure (KPa)	4.776	4.840	4.803	3.979	4.216	4.19
Swell potential (%)	11.4	30.64	27.33	4.83	7.21	6.01
Undrained shear strength C_u (KN/m^2)	42.0	75.0	69.0	45	50	47.91
Friction angle $(\phi)^0$	0	3	2.91	4	8	7.0
LL (%)	83.6	90.3	89.02	49.2	61.2	59.7
PL (%)	40.0	50.0	48.71	21.4	28.0	26.9
PI	40.3	43.6	40.31	27.8	33.2	31.6
Activity (%)	7.0	11	10.37	4.0	7.0	5.1
USCS Classification	CH-OH, MH – OH			CH – OH, MH – OH		

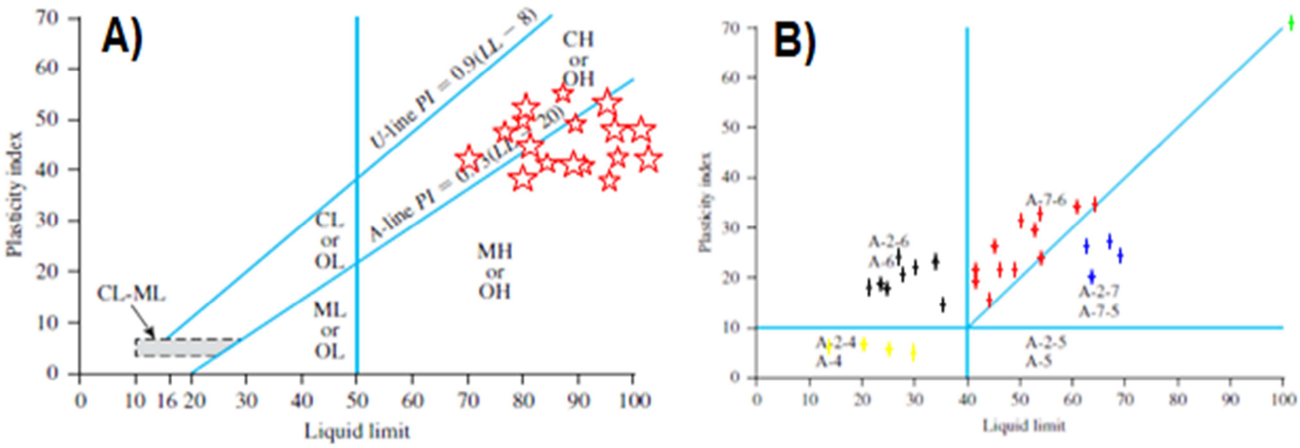

Figure 2. *(a) Typical USCS soil classification (b); Typical AASHTO soil classification for roads.*

3.2. Geotechnical Laboratory Results and Interpretations

Typical engineering properties of foundation subgrades are shown in Table 1. It is not enough for a geotechnical study on a project to list the soil's engineering properties as shown. Knowledge of the origin and implicitly the behaviour of the soil under different conditions of saturation; and seasonal wetting and drying cycles; and their implications on structural settlement, material composition of the structure and effects on corrosion etc. are also required. Results obtained from different tests and their interpretations have serious implications for the soil mechanics condition and therefore on the foundation soil's response to imposed load. Figures 2(a) and 2(b) are plasticity charts for soil classification. Figure 2(a) is the unified soils classification method for foundations and specifies the state of soil compressibility and or plasticity. Figure 2(b) on the other hand is based on the American Association of State Highway and Transportation Officials soil classification system developed for the quality of subgrades materials. Interpretation is therefore important in choosing the subgrade level for excavation and replacement. Soil moisture retention is a factor of the amount of clay, a low permeability or hydraulically non-conductive material in the foundation. The particle size distribution and its interpretation (Figures 3(a) and 3(b)) should indicate the clay content in a soil and recommendations on suitable foundation improvement. Figure 3(a) shows the clay content while Figure 3(b) has no information on clay even though both are particle size distribution curves and problems in foundations soils arise from the clay fraction. The difference lies in the method of sieve analysis and Figure 3(a) was carried out with the hydrometer method while Figure 3(b) was based on dry sieving. To properly characterize the clay fraction in a soil, the hydrometer and sedimentation test are inevitable.

Figures 4(a) and 4(b), presented plots of undrained triaxial shear strength test on foundation soil samples. Figure 4(a) indicates an unsaturated soil condition while figure 4(b) depicts a saturate soil condition. The application of soil saturation condition with corrections for water table imbedded foundations, is the hallmark of a good geotechnical investigations for structures under saturated condition. Examples of such results are shown in Tables 2 and 3 [24]. Furthermore, in-situ cone penetration test in addition to standard penetration test carried out inside the geotechnical boreholes are useful for deriving the undrain strength, elastic properties and pile unit resistance. Figures 5(a) and 5(b) depicts the undrained cohesion and pile unit resistance empirically derived from a cone penetration test data set.

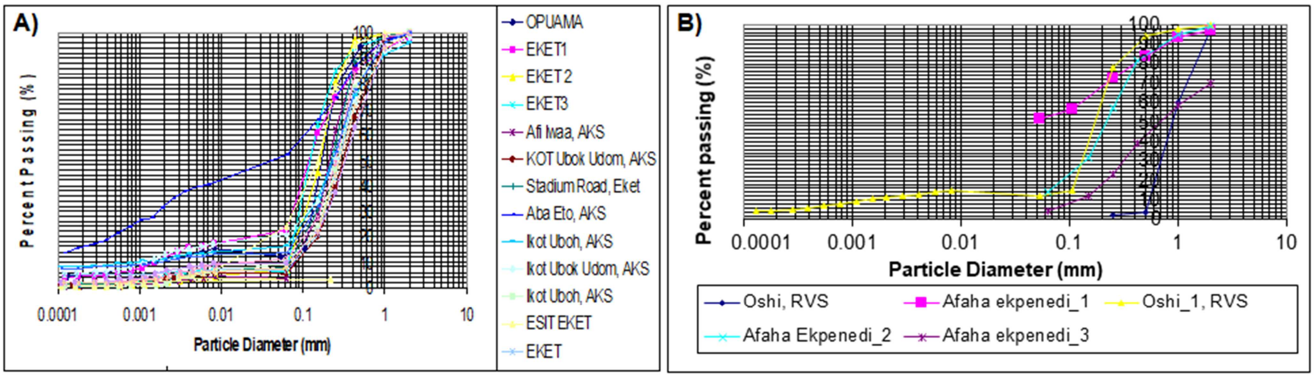

Figure 3. Typical Particle Size Distribution Curves based on hydrometer test (a) and based on wet or dry sieving test (b) for some Niger Delta soils.

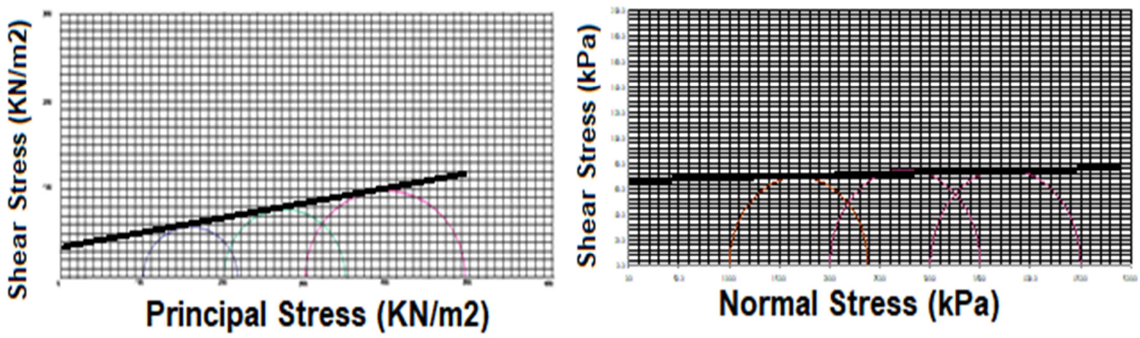

Figure 4. Typical undrained shear strength test for Niger Delta Soils (a) unsaturated soil condition (b) saturated soil condition.

Table 2. Typical bearing capacity of foundation subgrades [24].

Depth (m)	B/L = 1		B/L = 1.5	
	Ultimate Bearing Capacity (KN/m^2)	Allowable Bearing Capacity (KN/m^2)	Ultimate Bearing Capacity (KN/m^2)	Allowable Bearing Capacity (KN/m^2)
Cu = 75KN/m^2, $\phi = 0^0$				
1.2	491.63	163.88	523.69	174.56
2.0	580.56	193.52	644.69	214.90
Cu = 42 KN/m^2, $\phi = 3^0$				
1.2	213.78	71.26	171.97	57.32
2.0	226.0	75.34	184.2	61.40
Cu = 50 KN/m^2, $\phi = 8^0$				
1.2	493.35	164.45	684.40	228.13
2.0	603.97	201.33	668.47	222.82
Cu = 45 KN/m^2, $\phi = 4^0$				
1.2	435.35	145.12	482.18	160.72
2.0	429.43	143.14	477.22	159.07

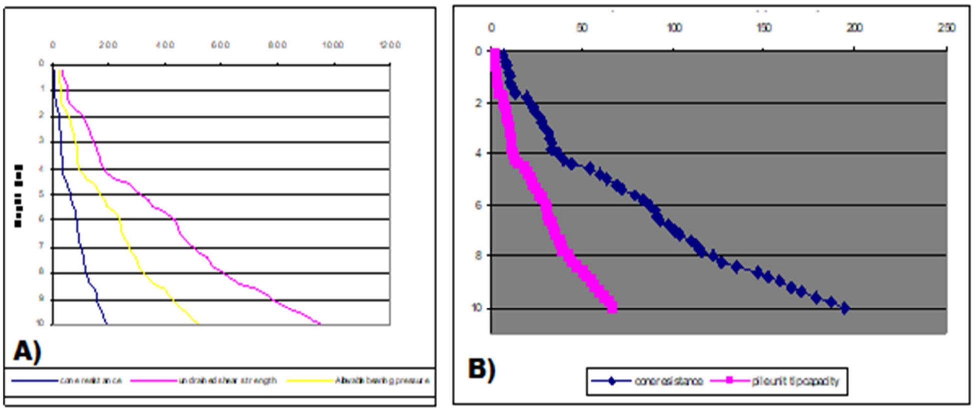

Figure 5. *Typical undrained cohesion from in situ cone penetration test (CPT) results (a) and Typical pile unit resistance from CPT test results (b).*

3.3. Predicting Foundation Settlement

The ground on which a structure is founded existed under in-situ geomechanical conditions which strive to attain equilibrium. Section 1.1 noted that differential settlement due to non-uniform rotation of the eccentrically loaded foundation footing; and redistribution and concentration of the of the loads to the member, are the causative mechanism of most foundation failures on weak soils. The prediction of settlement is usually based on the results of laboratory oedometer test (Figure 6). Note that the correct foundation settlement is usually estimated based on the state of consolidation of the natural soil, whether normally or over consolidated. This requires determination of the pre-consolidation pressure shown in Figure 6, appropriate design loads, swelling characteristics of the clays and drainage condition of the clay layers. Typical load calculations are shown in Table 3 while predicted structural settlement is shown in Table 4.

3.4. Foundations on Rocks

The dangerous misconception that foundations on rock don't fail and therefore structures built on and in rock do not require geotechnical investigations is an error that must be corrected. Buildings, dams, energy infrastructures, tunnels, open cast and underground mine excavations all require engineering geological and /or geotechnical investigations. All rocks have planar discontinuities and rock strength depends on the strength of the intact rock as well as that of the rock mass. Hoek, (2006) submitted that the corner-stone of any practical rock mechanics analysis and by implication rock engineering design is the geological model and the geological data base upon which the definition of rock types, structural discontinuities and material properties are based. He noted that even the most sophisticated analysis can become a meaningless exercise if the geological model upon which it is based is inadequate or inaccurate.

Therefore, a rock mass characterization is required for all rock engineering designs and must include geological, structural and rock mass modeling, intact and rock mass strength and kinematic stability analysis of the rock blocks. Limit equilibrium analysis may also be included. Rock permeability, effect of groundwater and groutability tests are also required for dam foundations and must be covered in the engineering geological and or geotechnical investigation.

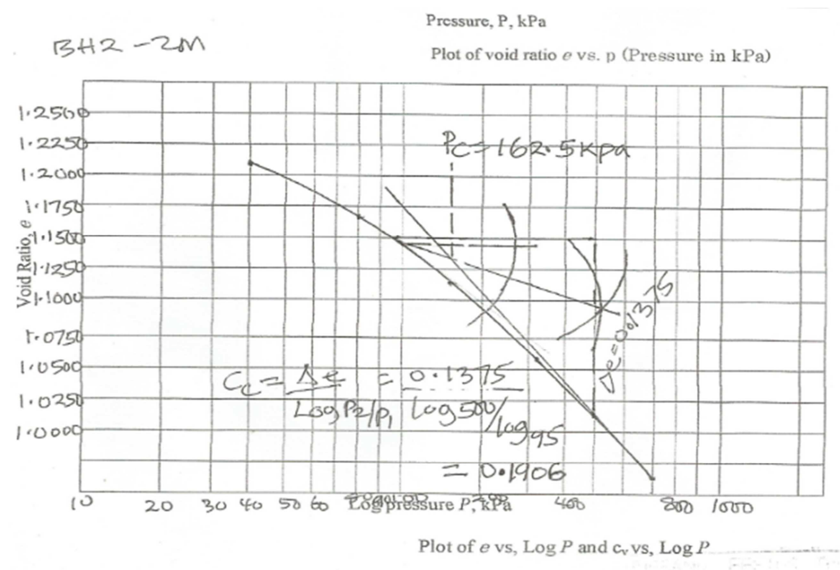

Figure 6. *Typical e log p curve showing the pre-consolidation pressure upon which settlement calculation [24].*

Table 3. Typical results of calculated load on the foundation [24].

Site section	Depth (m)	L (m)	B (m)	A (m^2)	1.5 Factored D+L' Load (tons)	Unfactored Dead + Live Load (tons)
HOSTEL COMPLEX						
Stream	1.2	39.7	33.7	1337.88	2700	1800
	2.0	39.7	33.7	1337.88	2700	1800
Land	1.2	39.7	33.7	1337.88	2700	1800
	2.0	39.7	33.7	1337.88	2700	1800
4 BEDROOM DUPLEX						
Stream	1.2	20.5	10.0	205	655	436.7
	2.0	20.5	10.0	205	655	436.7
Land	1.2	20.5	10.0	205	655	436.7
	2.0	20.5	10.0	205	655	436.7
2 BEDROOM BLOCK OF FLATS						
Stream	1.2	28.2	11.5	324.3	1270	846.7
	2.0	28.2	11.5	324.3	1270	846.7
Land	1.2	28.2	11.5	324.3	1270	846.7
	2.0	28.2	11.5	324.3	1270	846.7

Table 4. Typical result of building settlement prediction [24].

Site section	ΔPav KN/m^2	S_T (cm)	Coefficient of subgrade reaction	% Reduction in total settlement	t_{50} Years	t_{90} Years
HOSTEL COMPLEX						
Stream	4003.2	160.1	25	8.5	2,130.90	9,172.6.
	4003.2	146.5	27.3			
Land	4003.2	211.1	19	16.7	28.82	45.28
	4003.2	175.9	22.8			
4 BEDROOM DUPLEX						
Stream	924.53	111.9	8.3	9.3	492.12	2,118.37
	924.53	101.5	9.1			
Land	924.53	180.1	5.1	18.4	6.65	28.65
	924.53	146.9	6.3			
2 BEDROOM BLOCK OF FLATS						
Stream	1822.74	134.5	13.6	8	970.2	4,178.34
	1822.74	124	14.7			
Land	1822.74	190.5	9.6	17.4	13.12	56.48
	1822.74	157.3	11.6			

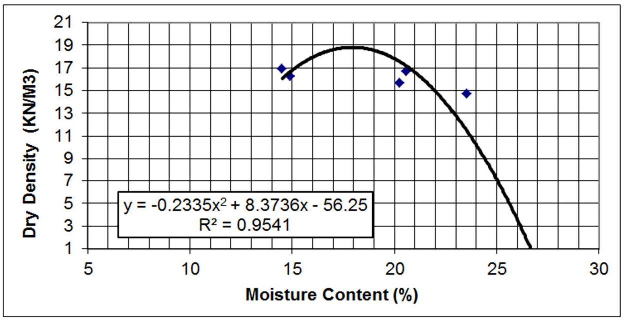

Figure 7. Typical subgrades moisture– density relationship.

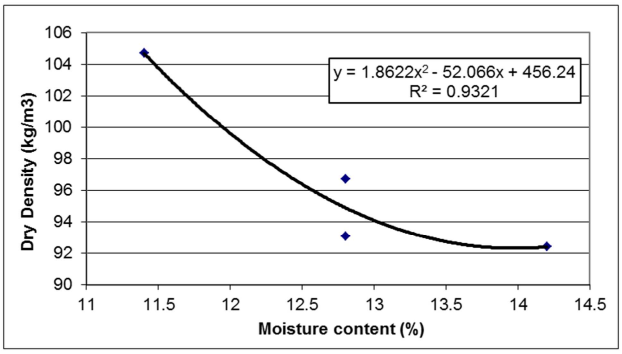

Figure 8. Plot of in situ maximum dry density against moisture content during earthworks construction.

3.5. Subsoil Characterization for Road Infrastructure

In Nigeria, road pavement infrastructures are designed based on California Bearing ration (CBR) strength index tests on soaked and unsoaked subgrades. The investigations conducted by the Department of Materials and Geotechnics and Quality Control of Nigeria's Ministry of Works (2011) revealed that most premature failures on Nigerian roads are caused by weak foundation subgrades. Consequently, the specification of the Federal Ministry of Works for subgrade materials that stipulates,

a) Percent passing sieve No. 200 should not exceed 35%,
b) Subgrade soaking period shall be 96 hours,
c) Minimum CBR shall be 15%,
d) Subgrade shall be modified whenever the CBR value is less than 15% and
e) The CBR to be used in pavement structural design shall be as determined on site irrespective of any improvement being carried out.

Results of CBR test informs the recommendation on the specification of the roadbed thickness, material and source to be used as fill in subgrade improvement or the quality of the subbase as fill materials. Furthermore, the moisture density relationship determined under compaction test (Figures 7 and 8) has a direct application in the choice of compactor and the compaction of the subgrade material. It guides in choosing the energy of the compactive effort and attainment of the desired maximum dry density in the quality control during earthworks. Typical application is the addition of water during densification of the subgrade and sub-base courses.

Report of the investigation for road infrastructure design and construction should include:

a) Classify subgrade based on AASHTO and group index,
b) Identify sections underlain by unsuitable materials & provide for removal and replacement or improvement,
c) Classify subbase (laterites and lateritic borrow pit materials) using CBR and grading modulus, elastic and resilient moduli,
d) Check for critical hydraulic gradient, piping and permeability ratios and,
e) Recommend design options including drainage.
f) Aggregates for use a bases or where applicable subbases.

4. Call for Actions: Separate Engineering-Geological / Geotechnical Consultants for All Infrastructural Projects in Nigeria

Akpokodje, E. G. (2017) [19] noted the rather unfortunate situation in which in spite of the importance of geological input in sustainability of infrastructures, the profession is still perceived as an ad-hoc service agent in construction industry in Nigeria. We to recommend that:

a) The current status quo in which Geotechnical Consultancy Services are hitherto subsumed in the Civil Engineers Consultancy services whereby the consultant has to hire often incompetent persons as geotechnical service provider be reversed in favour of a separate Geotechnical Consultant for the services,
b) All infrastructural Development projects in the Nigerian construction industry should be assigned a Geotechnical Consultant designate just as we have the Architect and Quantity Surveyor (on all building projects), Civil Engineer, Mechanical Engineer, Electrical Engineer on all infrastructural projects built on, in or within soil/rock/ground.
c) The construction of structures (buildings, dams, roads, highways etc.) in Nigeria should be preceded by comprehensive integrated engineering geological investigations which must be coordinated by COMEG certified Engineering Geologists/Geoscientists as is the case in developed countries.
d) The Engineering Geologists/Geoscientists and the regulatory certificate of the Council of Nigerian Mining Engineers and Geoscientists (COMEG) should become a prequalification document for all Geotechnical Consultancy Services requirements in all call for bids and or expression of interest (EOI) for such infrastructural projects in Nigeria.
e) Engineering Geologists/Geoscientists be actively involved in exploitation and evaluation of naturally occurring construction materials such as lateritic soils, sands, gravels, quarry products etc.
f) For the sustainability of relevant infrastructural projects in the Ministries of Mines and Steel Development, Works and Housing, Water Resources, Petroleum Resources and Environment, Engineering Geologists/Geoscientists should be engaged in pre-construction investigations and monitoring.
g) The need for partnership between Council of Nigerian Mining Engineers and Geoscientists (COMEG) and its affiliate society and associations (e.g. NMGS, NAEGE etc.), on one hand, government institutions, development partners and other professional bodies such as the Architect Registration Council of Nigeria (ARCON), Council for the regulation of Engineering in Nigeria (COREN) on the other hand in order to ensure sustainable infrastructural development and minimization of failures and environmental hazards.

5. Conclusion and Recommendations

Engineering Geologists / Geoscientists, as Geotechnical Consultants are required to provide information that will guide plans and decisions regarding the design, construction, operation, safety and maintenance infrastructural or development projects. Usually, Engineering Geologists / Geoscientists are to work in conjunction with engineers to ensure the safety of structures while most activities that require geological advice of geoscientists are closely connected directly, or indirectly to the safe design of the structures. As urban areas expand, the geologic sub-base upon which cities and catchments are built becomes ever more critical to human safety in the face of potential natural geological hazards. In addition, the emerging global environmental change (i.e. climate change) portends increasing risks to urban centers, located in coastal areas, on deltas, and in floodplains; thus putting the populations at the risks (i.e. floods, landslides, ground subsidence, and soil/coastal erosion). Hence, understanding location-based geological constraints and risks is the first step in designing, developing, and executing a successful urban infrastructural development project (Figure 9).

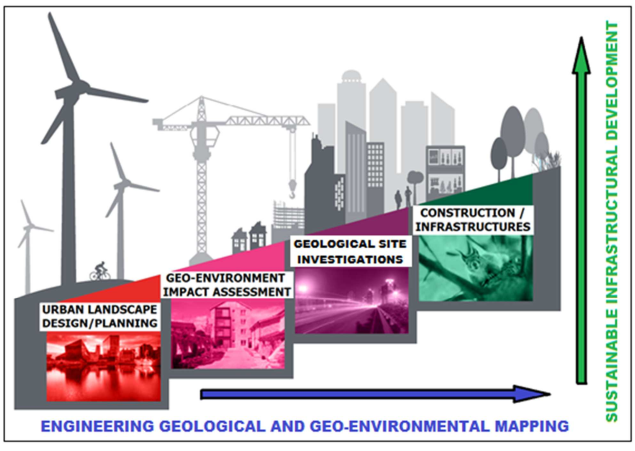

Figure 9. *Pictorial representation of types of projects requiring engineering geological and geo-environmental mapping for infrastructural sustainability.*

The level of geological details required is dependent on the nature of the infrastructural development, its potential impact and associated mitigation measures. As graphical presented in Figure 9, to achieve sustainable urban infrastructural development, there should a clear integration of geological information with engineering structural designs of infrastructural projects in Nigeria, in order to prevent geological hazards and avoidance of structural failure / damages. Hence, it is essential that the engineering geological investigations of foundations and associated data evaluation and interpretations provided by Engineering Geologists / Geoscientists, as Geotechnical Consultants, be of the highest scientific and technical standards. Therefore, it is recommended that:

a) Design should not apply any rule of thumb generalization in respect of engineering geological investigation of subsoil / rock in foundation studies.
b) Site specific details of subsoil exploratory boring and engineering characterization key to design and construction of sustainable infrastructures should be provided for.
c) Geotechnical consultant, separate from the civil engineer, is recommended on every project in order to ensure that details geological considerations are incorporated for sustainability of all infrastructures.

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