UNIVERSITY OF PORT HARCOURT

"GEOTECHNICAL ENGINEERING – THE CORNERSTONE IN INFRASTRUCTURE DEVELOPMENT IN DIFFICULT GROUND ENVIRONMENTS"

By

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SEPTEMBER 29th, 2015

INAUGURAL LECTURE SERIES

NO. 125

ACKNOWLEDGEMENTS

Vice-Chancellor Sir, I wish to humbly submit that I was not begotten as a Geotechnical Engineer by my parents. Rather, I was made a Geotechnical Engineer by a combination of circumstances and events in my life as well as the positive influence and contributions by well-meaning individuals that crossed my path. I am grateful to you for affording me the opportunity to give account of myself through this Inaugural lecture.

Firstly, my gratitude goes to the Almighty God, the author of all knowledge, who graciously revealed Geotechnical Engineering as a discipline for mankind to explore. He ordained me a Geotechnical Engineer from the beginning and even coordinated my academic history to suit that purpose.

Next are my parents, John and Stella Ejezie of blessed memory who laboured and toiled under extenuating conditions to ensure that I went to “college” (as secondary school used to be known), which was the cradle of higher education in those good old days! My father went the extra mile of vowing that because education eluded him (owing to circumstances of his noble birth) he would do all he could to enable his children make up the deficit. I am glad his sacrifice was not in vain.

I wish to thank my primary school teachers who, at my tender age, were able to use their “Teacher’s sense” to identify me as a budding academic potential and accorded me maximum encouragement. Among these, I would like to single out my primary school Headmaster and Standard Six teacher, Mr Jonas Ejeagwu (now Sir Jonas Ejeagwu, KSM). He was my academic adviser and played a major role in the choice of the schools I attended. Most importantly, he enthusiastically encouraged my father to ensure that I was sent to secondary school against all odds. I deeply appreciate his goodness to me and remain very grateful.

My academic history will not be complete without a special tribute to my alma mater, the famous Government Secondary School, Afikpo, for giving me quality education that eventually blossomed into my present academic and professional status. Topping my class in this prestigious institution in my first year automatically earned me the highly-valued School Scholarship that saw me through my entire secondary and higher school education – from class one to upper six. In the same vein, I want to thank the University of Ibadan for planting the seed of my Geotechnical Engineering education, Cornell University for fertilising and watering it and Carnegie-Mellon University for nurturing it to maturity. I acknowledge, with fondness, the roles played in my academic career by my Professors in the United States of America, especially my major supervisors, Professors Thomas D. O'Rourke (Cornell University) and Kingsley Harrop-Williams (Carnegie-Mellon University). Tom O'Rourke, along with two other colleagues of his at Cornell – Professors Dwight Sangrey and Fred Kulhawy – inducted me fully into the Geotechnical Engineering profession. I remain indebted to them for the knowledge they transferred to me. Professor Harrop-Williams supervised my PhD research work at Carnegie-Mellon University. We had very cordial working relationship and this impacted positively on my work progress and output. I heartily thank him and my other Professors in the then Department of Civil Engineering at Carnegie-Mellon – D. A. Sangrey (then Head of Department), Jacobo Bielak, Paul Christiano (of blessed memory) and William (Red) Withaker – for their roles in raising my competence level in Civil and Geotechnical Engineering to that of a globally recognised expert.

I owe an abundant measure of gratitude to my employer, the University of Port Harcourt, for having the foresight to put in place the original Academic Staff Development Policy that lured brilliant young men and women away from the emerging and attractive oil and gas industry to pursue a career in academics. I happened to be one of them and that opportunity enabled me to attend Cornell University (an Ivy League institution) and the equally world-renowned Carnegie-Mellon University, both in the United States of America. I appreciate the wise council of the Dean of Physical Sciences and Engineering at the time, Prof. Andrew Evwaraye who advised me to accept Cornell in preference to other top class universities that offered me admission to their graduate programmes. He really knew the potential benefits.

I am grateful to members of my family – both immediate and extended – for their love, patience and understanding all these years of my academic expedition. In particular, I want to thank my junior brother, Ezinna Paul Ejezie (Abiaogwu); my senior brother, Sir Isaac Ejezie (KSM); my sisters, Barr (Mrs) Kate Izuehie and Mrs Esther Obiakor; and my nephew, Mr Innocent Mmuoh for their unflinching support and encouragement. In a special way, I appreciate my children – Ijeoma, Francis, John, Chinenye and Chinwendu – for being there for me. The demands of my academic pursuits occasionally denied them pleasure and comfort, yet they did not mind. I am immensely happy with them for taking me as I am, and also for following my footsteps to develop their talents.

Finally, let me acknowledge my colleagues in the Department of Civil Engineering and in the Faculty of Engineering as a whole for their wonderful comradeship and healthy academic interaction. My students, current and former, undergraduate and post-graduate, have been a source of tremendous joy and encouragement to me. Their eagerness to listen to me and learn from me has always boosted my morale on the job. I am equally grateful to the National Federation of Catholic Students (NFCS), the Association of Catholic Engineering Students (ACES) and the Catholic Graduate Students’ Fellowship (CGSF) of the Chapel of Annunciation Catholic Chaplaincy, University of Port Harcourt for their solidarity and prayers. I wish them resounding success in their life endeavours.

PREAMBLE

My foray into the field of Civil and Geotechnical Engineering was ordained by God. Yes, I call it Divine intervention because, as can be inferred from my academic and professional history, I was first exposed to other areas of specialisation which may be considered relatively more lucrative at the time; yet I jettisoned them and patiently went through the rigours of multi-disciplinary and broad-based educational training required for the geotechnical engineering profession.

As a young high school lad at the famous Government Secondary School, Afikpo, with outstanding proficiency in mathematics and the sciences, my fantasy was to explore the outer space and the underground space as potential regions that would receive possible future population overflow from the earth's surface. The outer space fantasy took me to the Nigerian Civil Aviation Training Centre in Zaria for a pupil Pilot pre-training selection interview in 1972. This unfortunately coincided with my HSC examination period. I was therefore left to choose between the pilot training and my HSC final examination. As it pleased God, I was able to find my way back from Zaria, arriving Enugu just on the eve of commencement of my HSC practical examination.

By the time the HSC examinations were over, my interest in the outer space weaned, while the underground space took upper hand and dominated my fantasy. This influenced my choice of discipline of study in the university. The closest discipline to ground engineering in the then new faculty of Technology at the University of Ibadan was Petroleum Engineering. There was also the older, well-known earth science discipline with undergraduate specialisation in geology /geophysics. Driven by my quest for better knowledge of the subsurface, I found myself taking full advantage of the Course System operating in the university and combining courses in Geology, Geophysics and Petroleum Engineering. However, my area of study specialisation was eventually determined by the SPDC when, in my second year, I was retroactively awarded the company's highly competitive and relatively well-funded undergraduate scholarship for Geology and Geophysics specialisation.

Vice-Chancellor Sir, my studies at the University of Ibadan provided me with qualitative knowledge of the nature of the subsurface and fuelled my desire for in-depth probe with a view to acquiring specialist skill and technical competence in ground engineering. This was further given a boost by my one year stint at Sokoto-Rima River Basin Development Authority where I was deployed for my NYSC primary assignment. Here I was exposed to design and construction of dams, embankments and substructures. In fact, this period marked the beginning of my migration to soil mechanics and geotechnical engineering. Because this is a specialisation in civil engineering practice, it immediately dawned on me that a degree programme in civil engineering was "sine-qua-non" and an imperative for anyone venturing into this area. The opportunity for this was soon placed within my reach by my later employer, the University of Port Harcourt that sponsored me to Cornell and Carnegie-Mellon Universities in the United States of America for my studies in Civil and Geotechnical Engineering. These world-class institutions provided the facilities and conducive learning environment where I was adequately groomed to acquire high level proficiency and expertise in Geotechnical Engineering. This is attested to by my numerous contributions in the education and training of geotechnical engineers both in Nigeria and outside Nigeria, as well as the several outstanding solutions proffered by me to effectively mitigate ground stability problems.

My successful transformation into a Geotechnical Engineer, Mr Vice-Chancellor was as a result of extreme perseverance and consistency in hard work which enabled me to acquire the necessary analytical problem-solving skill and computational ability. These required a lot of patience particularly in view of the prolonged duration of study. By God's Grace I subjected myself to this rigour and, today, I have every reason to be happy with my decision. My professional history has demonstrated that truly, "A patient, focused, well-calculating dog really gets a fat bone".

OUTLINE: **PAGE**

1.0 INTRODUCTION

This Inaugural Lecture, strictly speaking, ought to have come much earlier in my career in this University but for exigencies occasioned by excessive excess workload and official/administrative responsibilities which hardly allowed me a breathing space all these years. I am not sure I vividly remember when last I took an annual or sabbatical leave which would have afforded me ample time to prepare for the lecture. Be that as it may, Mr Vice-Chancellor, here I come. An obvious advantage of coming up this late though is that the lecture will not only cover the academic activities for which I was elevated to the rank of a Professor, but will also include some of my achievements since then in the field I profess – Civil and Geotechnical Engineering. However, to ensure that I comply as closely as possible with the stipulations in the new guidelines for Inaugural Lectures, particularly the time limits, I have concentrated largely on my area of specialisation – Soil Mechanics and Geotechnical Engineering – sometimes simply referred to as “Geotechnical Engineering” for short.

This is the branch of Civil Engineering hidden from general view yet having the overall control on the stability of structures and facilities that constitute the constructed environment. This is the area of Civil Engineering variously regarded as the “Unsung Hero of the Built Environment”, the “Hidden “Facilitator of construction in difficult ground”, or, as I have chosen for this lecture, the “Conner stone in the development of Engineering Infrastructure in difficult ground conditions”.

Vice-Chancellor Sir, these appellations point to one fundamental fact which I believe arouses the organs of wonder and credulity in many of those who hear it, namely: “It is possible to build structures of your choice on any type of ground anywhere on earth”. In other words, that your parcel of land is categorised as “weak or poor ground” cannot debar you from building your choice homes and facilities on it. This is a heart-warming, re-assuring statement particularly to those of us whose lands of inheritance fall within regions classified as difficult terrains. This unique assurance of hope is provided by the equally unique area of Civil Engineering – Geotechnical Engineering. And this is the area of study I have chosen for a career to enable me contribute in restoring hope and putting smiles on the faces of people who are often compelled to vacate or abandon their lands and migrate to other areas where they may not even be welcome. Indeed, Geotechnical Engineering really touches on the lives of human beings and impacts positively on society. This lecture particularly highlights its role in converting difficult terrains into habitable lands, and in arresting the presently rampaging phenomenon of building collapse experienced in different parts of the country.

1.1 What is Geotechnical Engineering?

From the fore-going it is readily deduced that Geotechnical Engineering is the branch of Civil Engineering that clearly defines the roles of earth materials – soils and rocks of the subsurface – in the development of the constructed environment. It is also the discipline that provides the highly needed explanation for the mechanics of soils and rocks, their behaviour in nature and interaction with structures built by man. In fact, the term "Geotechnical Engineering" was introduced, following the rapid expansion of soil mechanics as a subject, to describe the application of soil mechanics principles to the analysis, design and construction of civil engineering structures which are in some way related to the earth (Powrie, W. 2004 2nd Edition).

As noted earlier, the achievements of Geotechnical Engineering are like hidden treasures because most of what Geotechnical Engineers do cannot be seen by the naked eye (Ballouz, 2012). Their work is either underground or below water. The earth materials they deal with exhibit a high degree of variability because they are associated with physical, index and engineering properties that are very often dependent on natural geologic processes of their formation as well as time and environmental factors which induce post-formation alterations on them. In fact, soils can exhibit extreme consistencies ranging from liquid state to very hard solid state. Natural soil deposits can exhibit a high degree of heterogeneity. The environmental factors to which a soil mass is exposed, such as temperature, rainfall, and gravitational forces are beyond human control and can greatly affect soil properties.

All these render the tasks of Geotechnical Engineers extremely difficult. Their primary function in virtually all engineering activities involving earth materials is to predict, with a high degree of accuracy, the behaviour and performance of soils and rocks, in terms of their load-deformation characteristics, both as construction materials and as supports for engineered works. They use fundamental principles of soil mechanics and rock mechanics to probe the nature of the sub-surface, including soil and rock layers, in order to determine the parameters needed for analysis and design of geotechnical works that are directly interacting with the subsoil, both in the onshore and offshore environments. Typical of these include natural and artificial slopes, earthworks, foundations for structures, earth structures and retaining walls, and tunnels. These predictions usually require them to obtain physical, index and engineering properties from tests conducted on representative soil and rock samples and in-situ field tests following standardised testing procedures. The outputs of these tests, overtime, enable the engineers to rapidly gain experience and obtain a “feel” for the behaviour of earth materials. Hence, Geotechnical Engineering is commonly described as being considerably more “state-of-the-art” or judgement-dependent than other engineering disciplines.

The economic significance of the role of Geotechnical Engineers is predicated on the obvious fact that soil is the most abundant and readily available construction material at any site. As a result, a good understanding of its nature, as afforded by Geotechnical Engineering, adds great value to Engineering practice.

1.2 Historical Background

The practice of Geotechnical Engineering in past centuries was largely by trial and error and, sometimes, based on experience gained from observation and empirical experimentation. It remained so till the first quarter of the twentieth century. Major Geotechnical projects were executed, some without hitches, others after surmounting serious challenges. Typical of these were the pyramids, the temples and the canals of old. Later in the middle ages, the post-construction tilting of the famous Tower of Pisa raised serious concerns and prompted a revolutionary scientific approach to subsurface probing.


Fig. 1: Leaning Tower of Pisa

The Tower was started in 1174 and completed in 1370. This fell within the period of wars when structures were generally very heavy as exemplified by castles and cathedrals of that era which were built with very thick walls. Objectionable settlements and severe instabilities were common as typified by the leaning Tower.

As recounted in Briaud, (2013), after the Renaissance which lasted from 1400 to 1650, significant development in engineering occurred between 1650 and 1900, with the most striking being a major shift from Military engineering to Civil engineering. Geotechnical Engineering was also being developed though still not well understood as it is today. Prominent efforts include the works of Charles Coulomb (1776) – Earth Pressure theory, Henry Darcy (1855) – Seepage theory, William Rankine (1857) – Earth pressure theory, Carl Culman (1858) – Graphical Earth Pressure solution, Otto Mohr (1882) – Stress theory and the famous Mohr Circle, Joseph Boussinesq (1885) – Solution to elasticity problem for soils.

The twentieth century (1900 – 2000) ushered in the development of modern Geotechnical Engineering. The trigger was pulled by Karl Terzaghi with the publication in 1925 of his famous book, "Erdbaumechanik" (Soil Mechanics). New edition of this book was coauthored with Ralph Peck in 1948 – Soil Mechanics in Engineering Practice.

Fig. 2: Major players in the Development of Geotechnical Engineering

Fig. 3: ISSMGE Board members (2009 -2013)

Terzaghi is considered to be the "Father" of modern Geotechnical Engineering. In 1936, he founded the International Society for Soil Mechanics and Foundation Engineering along with colleagues from about 20 countries around the world and became its first President. Later in 1986, this body metamorphosed into the present day International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE), the umbrella professional body of all geotechnical engineers around the world.

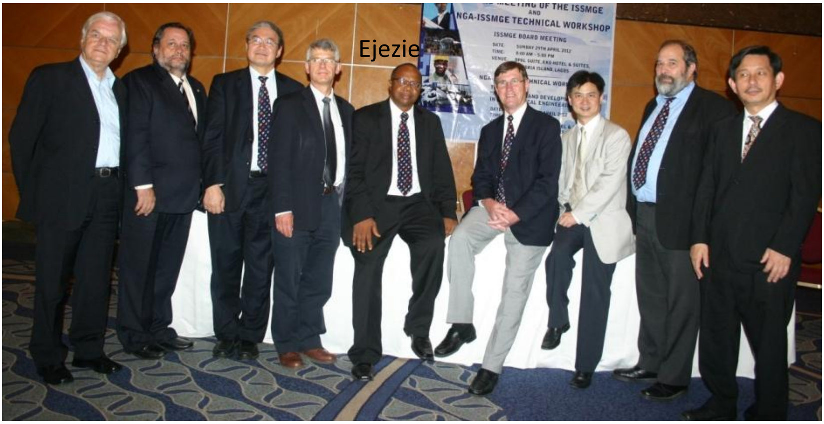


Fig. 4: ISSMGE Board members (2009 -2013) in Lagos, April 2012

Vice-Chancellor Sir, please permit me to recall with humility my cherished link in the "Geotechnical Engineering Professional Family" which clearly reveals that my geotechnical knowledge has been highly influenced by the works of the father of modern Geotechnical Engineering, Karl Terzaghi himself. How?

- **My supervisor for the Master's degree programme in Geotechnical Engineering was himself supervised by a former student and later, colleague of Karl Terzaghi.**

I am indeed delighted and find it exciting to belong to the Family Tree of modern Geotechnical Engineering.

2.0 FOUNDATIONS FOR STRUCTURES IN DIFFICULT GROUND

Our Lord Jesus Christ is the greatest Geotechnical Engineer ever known to mankind. This is attested to by His teachings as recorded in the Holy Bible, specifically in the Gospel of Saint Luke, Chapter 6, verses 47 to 49, thus:

"Everyone who comes to me and hears my words and does them, I will show you what he is like: he is like a man building a house, who dug deep, and laid the foundation upon rock; and when a flood arose,

the stream broke against that house, and could not shake it, because it had been well built".
"But he who hears and does not do them is like a man who built a house on the ground without a foundation; against which the stream broke, and immediately it fell, and ruin of that house was great".

In 1951 Karl Terzaghi, in his paper titled: "The influence of modern Soil studies on the design and construction of Foundations", opined as follows:
"……….If a building is to be constructed on an outcrop of sound rock, no foundation is required. Hence, in contrast to the building itself, which satisfies specific needs, appeals to the aesthetic sense, and fills its owners with pride, the foundations merely serve as a remedy for the deficiencies of whatever whimsical nature has provided for the support of the structure at the site which has been selected. On account of the fact that there is no glory attached to the foundations, and that the sources of success or failures are hidden deep in the ground, building foundations have always been treated as step children; and their acts of revenge for the lack of attention can be very embarrassing".

No wonder each time a building failure occurs, the foundation is presumed guilty until proved innocent, most times reluctantly though, by failure investigators!

The above remarks of Terzaghi apparently derive validity from the teachings of Christ Himself and therefore should be taken seriously by all Engineers. They need to make use of the growing knowledge of foundation design to render true service to their profession. Parts of structures underground (Substructures) should be treated as important as visible parts above surface (superstructures); hence, only well-qualified personnel should always be consulted and engaged in their design.

2.1 Features of Difficult Ground

When a structure is proposed at a site, the foundation engineer or, more appropriately, the geotechnical engineer is called in at the initial stage to evaluate the characteristics of the site. This activity generally entails

obtaining information on the properties of the subsurface materials with a view to evaluating their engineering behaviour. In the process, the likely geologic problems in the site which may result in unsatisfactory post –construction performance of the structure would be identified. When established, these serve as critical conditions whose mitigation constitutes the main focus of the design process involved in the project.
In addition, the nature of the subsurface in terms of the soil and rock types, their vertical and areal distribution, as well as their relative suitability for the envisaged engineering use will ultimately be revealed. The results will, in turn, serve as a guide in the choice, design, and construction of the appropriate foundation type for the structure.

In undertaking this important task the Geotechnical Engineer essentially seeks an answer to the basic question:
"How well does a soil stratum at the site serve a designated function?"

To obtain a satisfactory answer, he may have to look for answers to some more specific questions categorized into two groups, namely:

(A) How well will the strata at the site serve under in-situ condition? For example,
   (i) Does a stratum possess sufficient bearing capacity to support a given load;
   (ii) Would it permit excessive seepage if it were part of a dam design; and
   (iii) Will it undergo excessive settlement under certain loads?

(B) Is the soil subject to significant alterations from imposed conditions? For example,
   (i) Will a large sustained load consolidate the soil layer, as is the case with soft clay?
   (ii) Will dynamic loads transform a loose stratum of the soil into a dense state, as is the case with sand; and
   (iii) Will fluctuations of the water table affect the shear strength of the soil, as in clay?

The answers to these questions provide first-hand indicators of "P**oor or difficult Ground"** condition. They are normally obtained by combining the study of physical and index properties of the soil with sound judgment and relevant experience of the geotechnical engineer.

In poor grounds, the soils at any designated site for the construction of a given structure are often not ideal for the intended purpose. Our own dear Niger Delta is replete with similar ground conditions. The soils may be weak, highly compressible, or have a higher permeability than desirable from an engineering or economic point of view. In such instances, an attractive option is usually to simply relocate the structure or facility. However, certain important considerations may have influenced the choice of the location of the structure, in which case, the engineers are compelled to design for the site as it is. In other words, the structural foundation has to be adapted to the geotechnical conditions at the site. This is the view favoured by Geotechnical Engineers, of course! People should not abandon their land because ground condition is unfavourable. Rather, engineering solutions should be found.

The above discussion forms part of the fundamental activity usually undertaken by Geotechnical Engineers at the inception of every project namely, **SITE INVESTIGATION.**

The methods commonly adopted for site investigation are varied, ranging from simple conventional techniques to highly sophisticated methods. The choice generally is determined by the nature of the project and the applicability of the method under the prevailing site conditions. Figs. 5 and 6 respectively show onshore and offshore site investigation operations, while Fig. 7 is a soil lab. Time will not permit me to go into details of the procedures. Nevertheless, I am consoled because the Town Planning Authority these days will not grant approval to your building drawings without a Geotechnical Investigation Report. In other words, the Authority has created an avenue for everybody to become "Literate" in basic Geotechnical Engineering. Let me therefore skip that portion in the hope that you would insist that your "Geotechnical" Consultant conducts the foundation investigation on your actual plot of land before preparing a report for you.

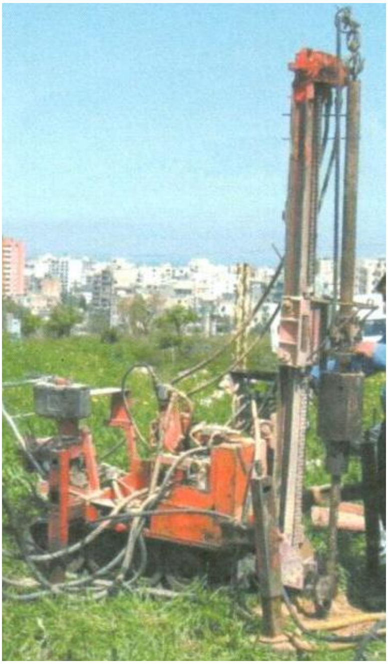


Fig. 5a: Typical Drilling For Onshore Geotechnical Investigation

Fig. 5b: Typical Drilling For Onshore Geotechnical Investigation

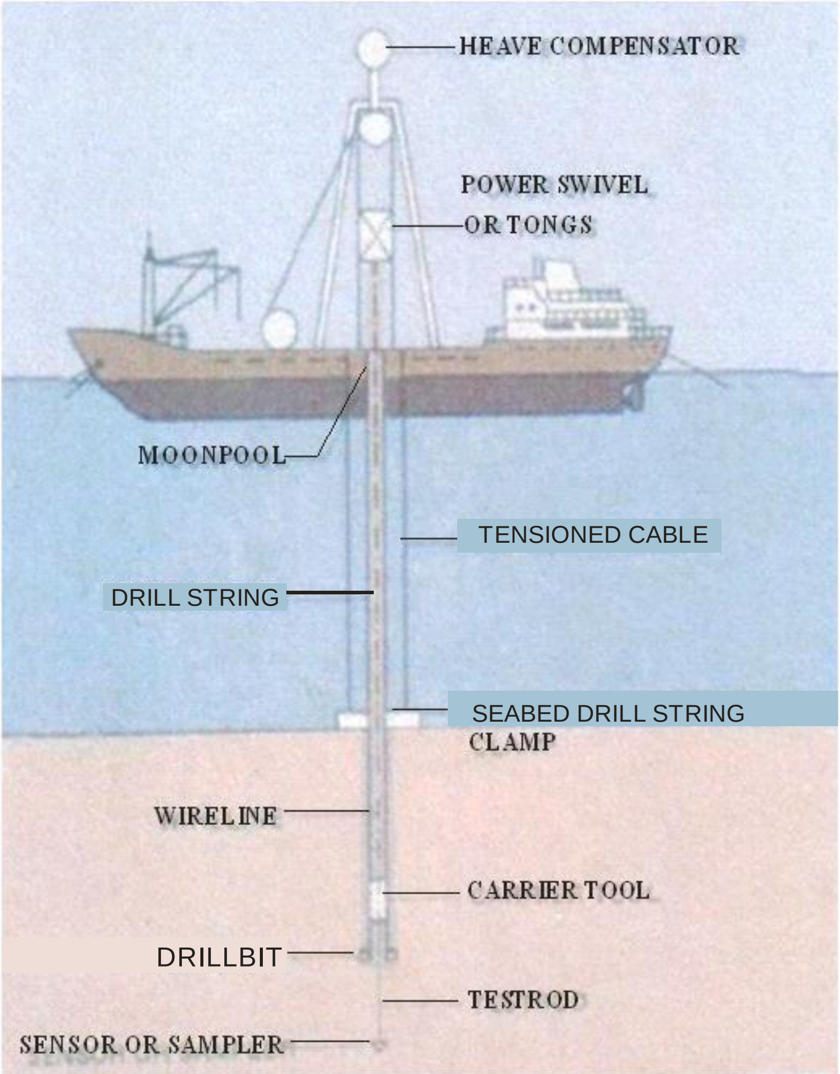


Fig. 6: Typical Drilling For Offshore Geotechnical Investigation

Fig.7: Typical Geotechnical Engineering Laboratory

2.2 Conventional Engineering Solutions for Poor Ground-related Problems

Typical examples of ground problems which can be unravelled by geotechnical probing of the subsurface together with suggested engineering solutions include the following:

- Soft ground and potential settlement: The usual engineering solution adopted is to design the foundation to reduce or redistribute the loading.

- Weak ground and potential failure: A popular solution is to embark upon appropriate ground improvement measures.

- Unstable slopes and potential sliding: This is commonly tackled by slope stabilisation and support works.

- Severe river or coastal erosion: The normal engineering solution for this problem consists of coastal protection works and barriers.

Aside from these, unforeseen ground conditions can still nevertheless occur, because materials of the subsurface exhibit a high degree of variability. However, it is pertinent to note that the conditions are often unforeseen largely due to inadequate site investigation.

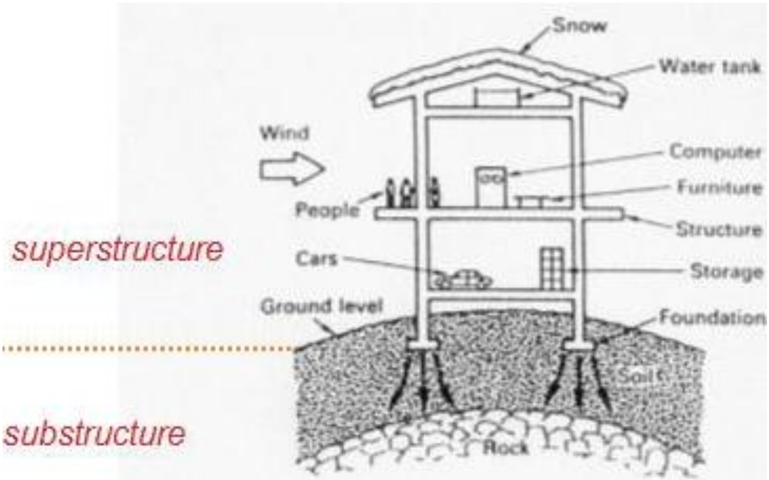
As stated earlier, the design of a foundation typically, is intended to incorporate solution strategies for any detected potential ground stability problem. The procedure, as in the case of the superstructure, is a process of optimisation. It generally involves examining all alternatives and selecting the one best suited for the structure in terms of functionality, ground behaviour and construction ease.

The major criteria commonly used to evaluate foundations are: safety from failure and freedom from objectionable deformation.

Failure can originate from the soil (or rock), the foundation elements of the facility, or the superstructure. However, when soil fails (i.e. bearing capacity failure), the entire structure is likely to fail also; but on the contrary structural elements can be damaged or “fail” without being preceded or accompanied by soil failure. Hence the concept of freedom of the structure from failure is best evaluated by focusing on the soil or rock underlying the site and supporting the foundation of the structure.

The objectionable deformation could be in the form of foundation settlement accompanying soil consolidation; heave; tilting; and distortion. These generally are promoted by ingress of water; and may result in structural damage, functional damage, or architectural damage of the constructed facility.

For clarity and avoidance of ambiguity, a “Foundation” can be defined as a system of structural elements designed to transmit load from superstructure to underlying soils and rocks. In other words, a foundation refers to that part of structure in direct contact with the ground and which transmits the load of the structure to the ground as depicted in Fig. 8.



Fig, 8: Typical model for Superstructure and Substructure

The different types of foundation in common use are grouped into two categories namely,

- Shallow foundations and
- Deep foundations.

Shallow Foundations are those that can be constructed from the surface of the ground by excavating trenches or isolated ditches or pits. The location of the foundation (below ground surface) is accessible to those constructing it, as schematically illustrated in Fig. 9.

Usual Depth range is ≅ 1 - 3m, the actual depth for a particular structure being determined by the site specific conditions of the subsurface.


Fig. 9a: Shallow Foundation (From Shah, A.)

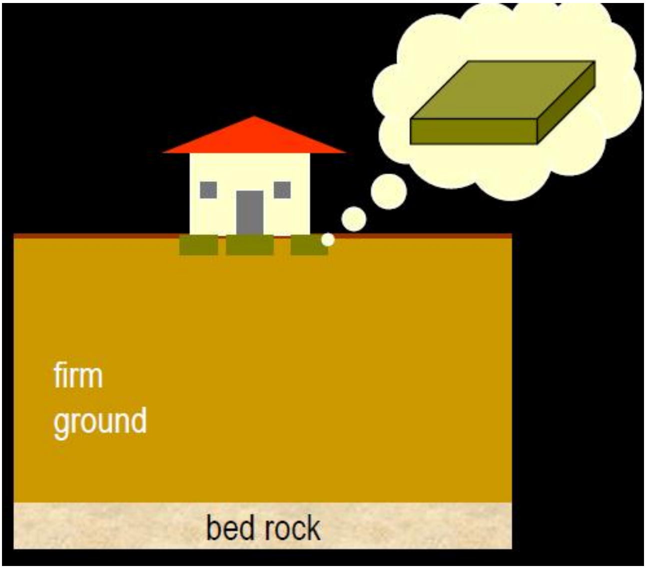


Fig. 9b: Shallow Foundation

Deep foundations are defined as those substructure elements that have a depth of penetration to width ratio equal to or greater than 5.0, (NAVFAC, DM 7.2, 1982). They are used for the purpose of transferring superstructure loads down through unsuitable soils to underlying firm bearing strata. They obtain support at some depth below the base of the structure which is not accessible from the ground surface as depicted in Fig. 10.

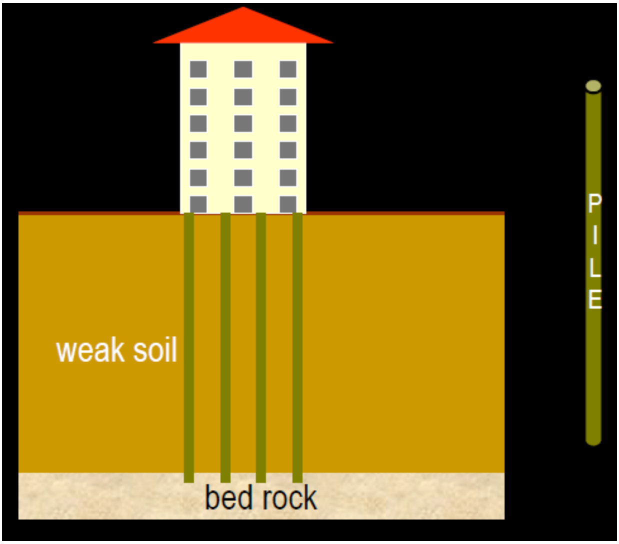


Fig. 10a: Deep Foundation

Fig. 10b: Deep Foundation (From Shah, A.)

The occasions for use of these foundations are determined by:

- Type of Structure (Indicative of expected load) and
- Condition of Bearing Stratum (whether weak and compressible, or firm and competent).

Shallow foundations, in general, are the most commonly used for conventional structures, such as one- or two-storey residential domiciles and light industrial houses, in sites where subsurface investigation has not revealed any cause for serious concern.

On the other hand, Deep foundations are used when the soil beneath the level at which a shallow foundation would normally be placed is too weak or too compressible to provide adequate support. They are also the option to resort to where shallow foundations are impractical, such as underwater, in close proximity to existing structures, and where there is need to provide uplift resistance and lateral load capacity.

The above foundation categories consist of different types. The appropriate choice for a given structure is the responsibility of the Geotechnical Engineer, relying heavily on the results of site investigation as well as professional experience.

To illustrate this, consider a hypothetical situation where spread footing (a type of shallow foundation) has been chosen for the foundation of a structure somewhere in the Niger Delta Region and a trial design reveals that this choice will result in excessive differential settlement (a typical objectionable deformation). The task of rectifying this anomaly can be accomplished by any of the following alternatives, namely:

> Changing the foundation, or changing the structure, or changing the soil, or changing the site.

- The foundation can be changed by altering the size – in this case increasing it or adopting a raft foundation. This will have the effect of appreciably decreasing the bearing pressures on the soil. Alternatively, the alteration can be effected by changing the depth of the foundation. In the sense used here, increasing the depth implies going closer to a more competent stratum. However, this may not always be true since it is possible to encounter sites where stiff crust overlies weaker material.

A change in the foundation that can potentially permanently control the settlement problem is the adoption of a deep foundation. This option usually is preferred for sensitive structures or facilities where the extra cost arising from conservative design is tolerable because this would offset uncertainties and appreciably minimise the probability of failure. Typical among these are oil and gas installations, high-rise buildings, and nuclear plant facilities.

- Changing the structure is an option commonly suggested by the geotechnical engineer. This is however generally unattractive to the architect and the structural engineer. Some of the possible changes include reducing the column loads, using lighter weight material such as substituting pre-fabricated metal panels for masonry walls; floating the foundation by constructing deep basement; making the structure flexible to take differential settlement; or making the structure very rigid.

- The change in the foundation soil entails the use of some practical measures to improve its engineering behaviour. This is an alternative frequently used in solving foundation problems by Geotechnical Engineers and is considered very feasible in the Niger Delta. Some of the measures include:

  Drainage, pre-loading, compaction, staging construction, and chemical stabilisation of soil

➢ Drainage of the soil can be improved by using sand drains to facilitate expulsion of water and dissipation of excess pore pressures.

➢ Pre-loading increases the strength of the soil and its resistance to shear and compression by facilitating consolidation process and ensuring that the soil achieves 100% primary consolidation before construction begins.

- ➢ Compaction of the soil is aimed at bringing the soil to its optimum water content, hence ensuring that its maximum mobilisable strength has been achieved.

- ➢ Staging of construction improves the strength and load-carrying capacity of the soil. The staging is similar to a very slow loading rate in which an imposed load increment is allowed to sit for a long time before further additions are made to it. The time is usually long enough to ensure the attainment of an equilibrium state of stress within the soil. In other words, the excess pore pressure generated by an imposed load is allowed to completely dissipate before new increments are added, and this ensures that the soil at each loading stage attains 100% primary consolidation before further loading proceeds.

- ➢ Chemical stabilisation of soil is a common method of improving soil strength and its resistance to shear and compression. It is usually carried out by injection of grouts into voids and cavities within the soil or by using any of the various types of soil reinforcement.

- The last alternative, changing the site, is normally opted for when all the others prove to be non-feasible. This may be from the point of view of economy or general amenability of the soils at the site to improvement using the various geotechnical engineering measures available. In this case, the simple line of action is total abandonment of the site in search of a new, albeit more favourable one.

3.0 GEOTECHNICAL ENGINEERING FRONTIERS

3.1 New Developments and Innovations

Cutting-edge research endeavours in Geotechnical Engineering are on-going at an accelerated rate in different academic institutions as well as in companies and corporate establishments around the world. The last 25 to 30 years have been particularly remarkable. Breakthroughs are regularly recorded in design, Finite Element Modelling, Centrifuge Testing and Analytical Mathematical Solutions.

Advances in Numerical Modelling have surpassed 3D Finite Element capabilities as Fig. 11 illustrates. Complex problems such as subsidence arising from tunnelling operations underneath mega cities have been successfully solved.

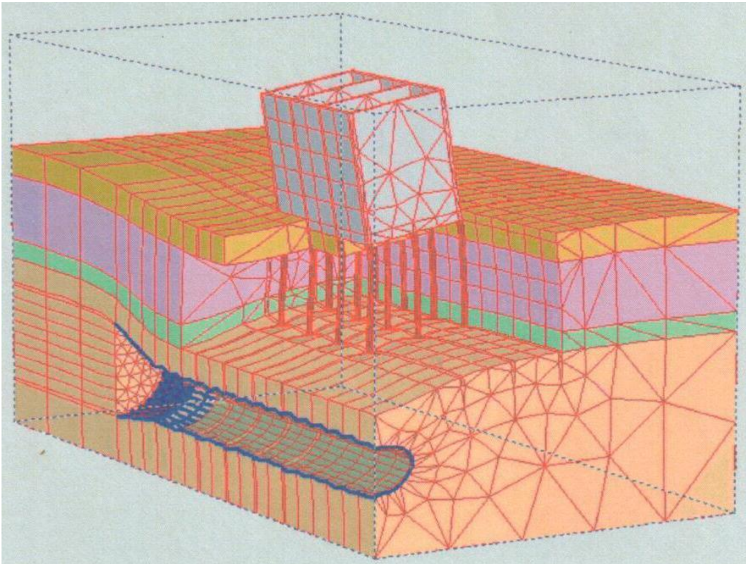


Fig. 11: 3-D Finite Element Modelling of Deep Foundation
(From Ballouz, 2012)

Non-destructive testing techniques used for structural integrity tests have been standardised and are regularly utilised to test the integrity of deep foundations and also for quality control. Geotechnical Testing facilities in some universities and research centres around the world have reached sophistication level relative to other sciences. A glaring example is the Centrifuge, shown in Fig. 12. It has been reported that a version of this equipment currently exists which is capable of accelerating an 1815 Kg payload to a maximum of 200 g in 14 minutes (Ballouz, 2013).

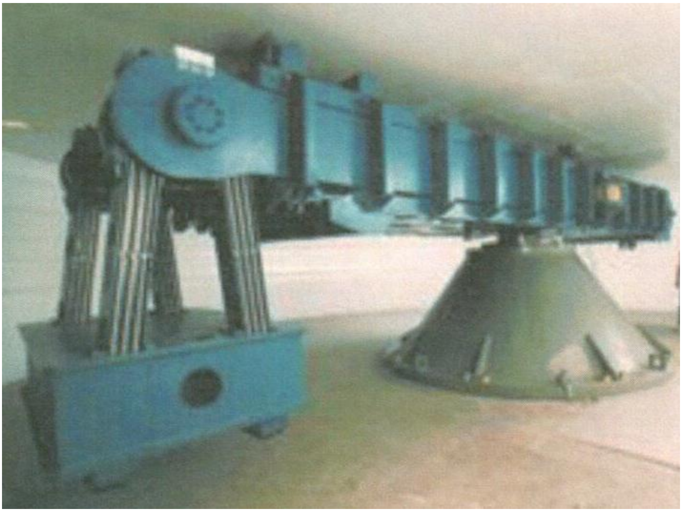


Fig. 12a: Large Centrifuge for Geotechnical Physical Modelling
(From Ballouz, 2012)

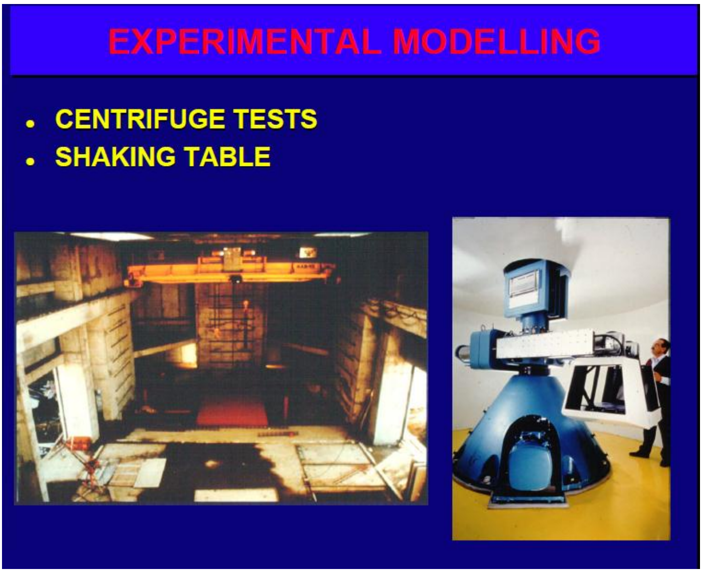


Fig. 12b: Centrifuge for Experimental Modelling (After Pinto, 2009)

Remote Sensing technology has also been applied in Geotechnical Engineering. It enables engineers to continuously monitor and evaluate their work particularly on critical projects which are subjected to extreme loading conditions, during construction as well as post construction.

Geo-thermal Energy research has also become very popular. This has found wide-spread application in deep foundation design particularly where there is need for heat exchange with deep soil layers to control the temperature of a building. In the same vein, the challenges initially posed by offshore wind turbine foundations capable of withstanding hurricanes, have been successfully solved.

Geotechnical design and construction works have been taken to an all-time high level. Previously unimaginable feats have been accomplished. Typical examples include the Kansai International Airport constructed in the artificial "Airport Island" right in the Pacific Ocean off the coast of Osaka, Japan (regarded as the Civil Engineering Millennium Project of the world in year 2000), the massive reclamation project in Incheon, South Korea (Incheon free economic zone), the 800m high Burj Khalifa in Dubai, United Arab Emirate, shown in Fig. 13 (currently the tallest building in the world and acclaimed as a triumph of geotechnical engineering due to the complex nature of the foundation), and so many others.


Fig. 13a: Burj Khalifa, Dubai (Tallest building in the world)

Fig. 13b: Burj Khalifa, Dubai

The restoration of the famous leaning Tower of Pisa, completed in 2001, deserves special mention. A 14-member multi-disciplinary committee of experts, set up by the Italian Prime Minister in 1990 and spear-headed by Geotechnical Engineers, accomplished this marvellous and memorable feat. Today the Tower is open to the world and is in conditions of largely improved safety margin. It was reopened to visitors since 2001.

Fig. 14a: Tower of Pisa Restoration - Geotechnical Team (Extracted from Jamiolkowski, 2009)

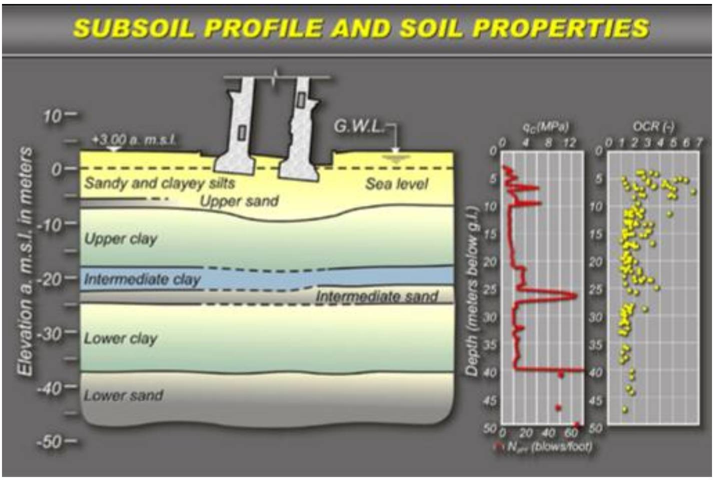


Fig. 14b: Tower of Pisa Restoration – Soil profile (Extracted from Jamiolkowski, 2009)

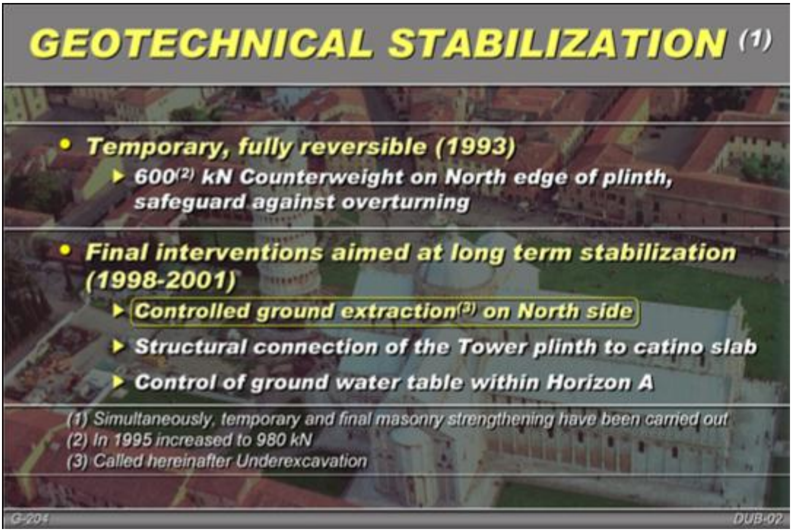


Fig. 14c: Tower of Pisa Restoration Procedure (Extracted from Jamiolkowski, 2009)

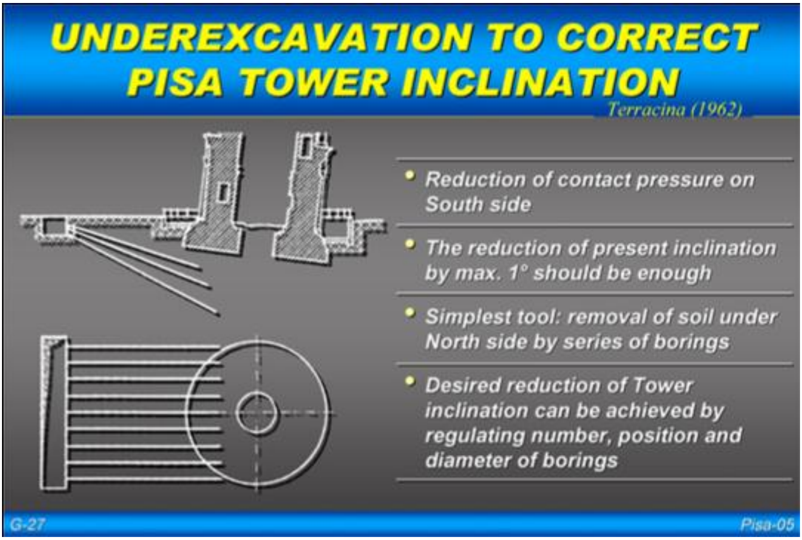


Fig. 14d: Tower of Pisa Restoration Outcome (Extracted from Jamiolkowski, 2009)

3.2 Ground Improvement Techniques

3.2.1 Geosynthetics

The use of geosynthetics (also commonly referred to as Geotextiles or Geo-membranes) for reinforcing soils enables Civil and Geotechnical Engineers to design and construct embankments and other structures more economically and with increased safety than is possible with traditional design and construction methods. They are relatively new and non-traditional civil engineering materials and are regarded as an invaluable asset in today's modern construction techniques. They are used in numerous groundwork projects where filtration, drainage, protection, separation, soil stabilization, reinforcement and durability are required. The three main areas of application of these geosynthetics for soil reinforcement include: embankments on soft foundations, steep slopes, and retaining walls and abutments. Fig. 15a shows a typical geo-membrane.

Fig. 15a: Typical Geotextile material and its application

Types of Geo-membrane

There are two basic types of geotextile membranes, **woven** & **non-woven** (shown in Figs. 15b and 15c respectively).

- **WOVEN** are tapes of polypropylene, multi-woven together to create a high mechanical strength and low porosity material. It is ideal for use in road construction. Typically, it possesses both excellent puncture resistance and water flow restriction characteristics.

Fig. 15b: Woven Geotextile (From Heerten, 2009)

- **NON-WOVEN** are fibres of polypropylene bonded together and needle punched to allow water flow and have good filtration properties. This type is of particular benefit for sand slope protection. The needle punching also retains the fine particles of sand whilst allowing the seepage of water, thus reducing the wash out of fines and down slope sand migration.

Application Requirements

The application of geotextile membrane as a protective cover for soil masses and earth structures must satisfy piping, filtration and mechanical strength requirements because the potential critical

Fig. 15c: Nonwoven Geotextile (From Heerten, 2009)

conditions include seepage flow due to likely rise and fall of pressure heads and tensile stresses developed during and after construction.

Piping criteria: Piping requirement prevents fine erosion without clogging of geo-filter's pores. Table 1 below is the proposal on the piping requirements of geo-filters put forward by different researchers.

Table 1: Piping Requirement of Geo-filters

Criteria for indicative pore size	Remarks	Indicative pore size, O_i	Proposer
$O_i < D_{85}$ (base soil)	-	O_{95}	U.S. Waterways Experimental Station
$O_i < D_{90}$ (base soil)	Non-woven	O_{90}	Delft Hydraulic Laboratory

Permeability criteria: Generally, the effective performance of a filter demands that its permeability be more than that of the base soil. In granular filters, a permeability value that is far greater than that of the base soil is usually specified and it is expressed by the grading relationship of D_{15} of the filter being kept at least 4 times greater than D_{15}size of the base soil.

Geotextiles are prone to clogging which may be permanent or temporary due to reverse flow. This affects permeability depending on the soil condition. The permeability of geo-filters which is expressed in $m^3/m^2/sec$ after clogging under small head should be more than the flow through the soil.

Mechanical Criteria: When used as filters Geo-membrane are exposed to both punching and tearing and these must be resisted. The punching and tearing requirements for non-woven fabric is given by:

Punching: $U = 1050H^{0.5}D_{85}\,(g/m^2)$ – - *mass of geotextile* (1)

Tearing: $F = 750(D_{50})^{0.45}$ for $D_{85} < 0.1$m and (2)

$F = 1500(D_{85})^{0.75}$ for $D_{85} > 0.1$m, (3)

where F is the tear strength of the fabric in Newton, H is the height from where the rock is placed in m. Based on the above discussion the specification of the geotextile membrane should be TYPE 4 as applicable to water resources and embankment projects.

Table 2: Specifications for Geo-filter

Test	**Type 4**
Nominal mass, g/m^2	280
Multidirectional tensile strength, (ASTM D4595), kN/m	18
Minimum tensile elongation at break	40
Minimum required resistance to construction stress, kN/m	7.2
CBR puncture strength, N	3000
Maximum effective opening size, O_{90}, *(mm)*	0.10
Permeability under 100mm head, m^3m^2/sec	0.18

4.0 MY MAJOR CONTRIBUTIONS TO GEOTECHNICAL ENGINEERING

Vice-Chancellor Sir, in presenting my contributions to knowledge in general and engineering profession in particular, I have deemed it ample to adopt a template typical of major projects. Firstly, an executive summary is given to sufficiently enkindle the interest and enthusiasm of the reader. This is then followed by details of my various accomplishments. The presentation is, of course, skewed to geotechnical engineering.

4.1 Summary of Academic and Professional Accomplishments

I have put in about 30 active, unbroken years of service in teaching and research as an academic staff in the university system. My research efforts and my outstanding role as an efficient facilitator of learning in tertiary institutions blended harmoniously and enhanced my productivity. Many of my research findings, including theoretically or empirically formulated methodologies and frameworks, have found useful applications in various phases of Civil and Geotechnical engineering practice – including analysis, design, construction, inspection and monitoring. In fact, I have successfully and convincingly demonstrated my high level technical proficiency in Civil and Geotechnical engineering by fully developing the ability to apply my theoretical knowledge to solving a wide range of practical problems.

My most outstanding contributions can be grouped as follows:

- Modelling the engineering behaviour of soils and prediction of soil responses to dynamic (cyclic or repeated) loading (Ejezie, 1984, 1987, 1988; Ejezie and Harrop-Williams, 1984, 1985);
- Solution of soil – structure interaction problems resulting from induced ground vibrations, including dynamic load response of humid tropical soils (Ejezie, 1986, 1987, 2003, 2004, 2006, 2012, 2013);
- Development of a framework (or tool) for predicting the engineering behaviour of humid tropical soils, including laterites and problem soils in Southern Nigeria (Ejezie, 1982, 1983, 1986, 1987, 2005, 2007, 2013);

- Solution of foundation engineering problems in parts of the Niger Delta (Ejezie and George, 1986, Ejezie, 1998, 2007);
- Failure Analysis of geotechnical structures (including foundations and coastal slopes) and design of mitigation and protection works in various parts of the Niger Delta (Ejezie, 2007, Ejezie et al, 2012);
- Geotechnical Engineering Education and Manpower Development.

Probabilistic Modelling and Soil Response Prediction

My work on the probabilistic modelling and prediction of soil responses to dynamic loading commenced during my Doctorate degree programme at Carnegie-Mellon University in the U.S.A. and continued until recently. It was necessitated by the increased significance of this mode of loading in Civil and Geotechnical Engineering. In the offshore environment, the problem is from wave loading of coastal and offshore structures which, in turn, transmit the loads to soil. In the onshore environment, the problem may result from earthquakes, traffic loading of soils, installation (driving) of deep foundations in soil, vibrating machine foundations and heavy machine operations. My contribution here focused on accurate modelling of the responses of soils under these loads with a view to minimising or forestalling the catastrophes associated with soil failure that could result from these phenomena.

I was able to achieve this by assessing the existing deterministic models (which have hitherto been used to predict the soil responses) based on the principles of reliability and probability theory. Through this assessment, I was able to establish the actual predictive capabilities of the models, hence exposing their relative weaknesses and inaccuracies occasioned by their susceptibility to the systematic errors associated with methods of testing and measurement bias. Subsequent upon this, I was able to formulate alternative probabilistic models for the soils responses by incorporating the variability of all the random parameters. These models allow for more rational cost – risk design of structures in soils susceptible to dynamic loading phenomena.

Damage Potential of Induced Ground Vibration

My works on induced ground vibrations represent significant contributions in solving the soil-structure interaction problems encountered by oil prospecting and drilling crews. Hitherto, many of the companies carried on with these activities without adequate monitoring and control of the structural damage potential (and likely disturbance to human beings) of their activities. The result was incessant complaints from host communities and frequent disruptions of the activities of the companies.

My contribution here focussed on two aspects of the problem. The first was the establishment of structural and human response criteria to vibrations emanating from drilling and pilling operations. These criteria were based on particle velocity since this is well – known to correlate more closely with damage potential than any other parameter. The response criteria so established were correlated with soil profile so that the results can always apply to other areas of similar subsurface conditions. These criteria serve as thresholds for assessing the degree of damage expected from a given operation.

The second part was the formulation of a pattern for vibration transmission and attenuation in soils. This specifically enabled me to assess and standardise the potential environmental impact of dynamite shooting and other activities involving the detonation of explosives frequently commissioned by oil companies in different parts of the Niger Delta. My key contribution here was that I succeeded in determining the "minimum safe shooting distances" for various combinations of charge weight and depth of shooting to be observed by crews working in different areas but of similar subsurface conditions. This "safe shooting distance" guarantees safety from vibration-induced damage for structures in the area.

Prediction of Humid Tropical Soil Performance

My work on the engineering behaviour of humid tropical soils was based on soils in Southern Nigeria as typical. I was able to establish and standardise the level of influence of the degree of laterisation on the soil characteristics – as evidenced by the big contrast between the engineering performance of laterised and non-laterised soil groups. Furthermore, I was able to provide acceptable explanation for the relatively high in-situ shear strength, excavation and pile driving difficulties usually posed by highly laterised soil groups (these are as a result of sesquioxide and hydroxide cementation). In like manner, the pseudo-granular texture associated with lateritic soils is responsible for their suitability as base course materials for roads and general susceptibility to treatment with stabilizers, such as lime. My contribution here has been widely used as a form of framework for the engineering characterisation of the soils. It serves as a reference guide to all practicing engineers wishing to embark on civil engineering projects, particularly those related to foundation engineering, in any part of Southern Nigeria or any other area of the humid tropical region with similar environmental conditions.

Foundation Solutions for Niger Delta

My work in the Niger Delta is an on-going exercise. Earlier, I proposed a methodology for characterizing offshore sites in the area for civil and Geotechnical engineering purposes based on seismic profiling. In addition, I have successfully executed numerous research and consultancy works related to foundations for structures in many parts of the delta despite the generally poor and frequently unpredictable subsurface conditions. The results of my work have enabled me to put together a system to serve as a preliminary knowledge base to guide all foundation engineering activities in the region. The research work is still continuing and there are plans for expansion. It is hoped that the final output would eventually be in the form of an expert system for geotechnical characterisation and design in the area.

In **Geotechnical Engineering Education**, my role (still on-going) is unprecedented. Apart from the undergraduate and post-graduate university programmes which I developed, I am currently actively championing Continuing Education and Professional Development programmes in Geotechnical Engineering. These are aimed at providing opportunities for continued growth in performance efficiency to those already practising the profession. Under the umbrella of Nigerian Geotechnical Association, I have carried the campaign to all nooks and crannies of the country, particularly the oil and gas companies, Government Agencies and Parastatals, and major engineering companies. It is worthy of note that my effort in this regard has yielded the desired fruit.

4.2 Detailed Description of selected Contributions

4.2.1 Soils of Nigeria, including Laterites and Problem Soils

I have studied Nigerian soils extensively and made major contributions through my research output particularly on the Humid Tropical and "Problem Soils" of Southern Nigeria. The soils are varied and exhibit a high degree of anisotropy. They range from residual to sedimentary both in nature and origin. My work yielded a widely adopted Engineering Classification Scheme for the soils and a useful engineering construction guide – a Framework for predicting the engineering behaviour of Humid Tropical Soils (Ejezie, 1982; Ejezie et al, 1983; Ejezie, 1986, 1987, 2005, 2007, 2013). Furthermore, I successfully tackled "Laterite" and unravelled the "mystery" behind the so-called "inconsistency with conventional expectations" in its engineering behaviour which was a major challenge to Civil and Geotechnical Engineers for many years. Highlights of some of my major contributions are presented subsequently.

i) Engineering Classification Scheme for Soils of Southern Nigeria

My work revealed that the different types of soil encountered in Southern Nigeria and their pattern of areal distribution are largely controlled by lithological features and changes that occur in their different locations. For example, soils found in the basement areas generally exhibit good textural gradation (Well-Graded) – from clay to gravel – and contain both stable and weatherable minerals. In the sedimentary areas the soils frequently exhibit poor gradation (well-sorted) resulting from the depositional processes associated with their formation. The predominant minerals here are relatively stable and resistant to weathering. The overall effect of these conditions is that laterisation is very pronounced and at a relatively more advanced stage in the residual soils of the basement complex zone than in the sedimentary basins, where the stable and resistant minerals are less susceptible to chemical decay.

Major Soil Groups

The classification scheme was developed as a generalised grouping of the soils in Southern Nigeria (Ejezie, 1982). This was achieved in part by combining previous works in the area (notably Ackroyd, 1967 and Madu, 1975) and some unpublished but reliable geotechnical investigation reports. This scheme consists of identified major soil groups superimposed on a map of Eastern Nigeria. The grouping involves considerable overlap, but at the same time essentially recognises approximate limits of areas where soils of similar characteristics, and which constitute specific major soil groups, are predominant and have a controlling influence on the overall engineering behaviour of soil. In fact, these groups depict areal zoning of the soils and can be used to examine the engineering properties and behaviour of the soils. They include:

i) Recent deposits;
ii) Non-concretionary acid sands and clays;
iii) Cretaceous sandy Clays and clayey Sands;
iv) Ferruginous soils.

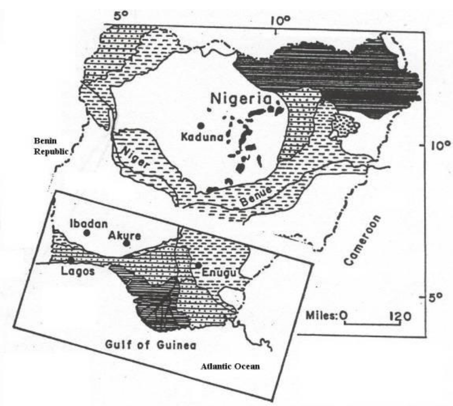


Fig16a: Humid Tropical Region of Nigeria

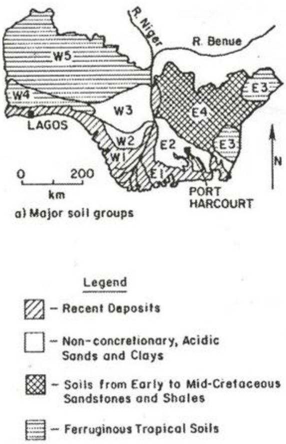


Fig. 16b: Soil Groups of the Humid Tropical Region of Nigeria (Ejezie 1982)

The **"Recent Deposits"** occurs in various forms mainly along the coastal areas and river channels. The soils of this group are mainly products of primary weathering as well as fragments of resistant minerals. Most common distinct types include: pale brown loamy alluvial silts and clays; dark grey mangrove soils (organic silty clays and clayey silts); and brownish yellow, fine sand derived from beach deposits.

The **"Non-concretionary Acid sands and Clays"** includes the various types of reddish brown soils, texturally porous, and derived from unconsolidated sandy deposits, sandstones, and shales. Typical examples are the red Benin Sands and the uniformly graded silty Delta Sands. This group occurs extensively over the sedimentary areas, extending from parts of the west to the extreme east, and limited in the south and along river valleys by the occurrence of the Recent Deposits along the coast and creeks.

The **"Cretaceous sandy Clays and clayey Sands"** is the group comprising the reddish-brown, gravely, clayey Sands and sandy Clays derived from sandstones and shales. They are generally referred to as laterised soils, and are confined to the areas of the Southeast underlain by Early to Mid-Cretaceous sedimentary rocks. **"Ferruginous Soils"** is the group consisting of laterites which occur extensively over the Basement Complex in the Southwest and part of the adjoining sedimentary area. They are also found in the extreme south-east boarder with the Cameroon Republic – also a region of Basement complex rocks.

Fig. 17 and Fig. 18 show the trend in the plasticity of these soil groups in relation to the A-Line of the conventional plasticity chart. These are similar to results from other humid tropical areas (Ejezie, 1982, 1983).

ii) Framework for Engineering Performance Prediction

Subsequent upon the successful development of a generalised soil classification scheme, I proceeded to use it as basis for formulating a framework for predicting the engineering performance of the soils in Southern Nigeria (Ejezie, 1982, 2005) as presented in Table 3 below. This is intended to serve as a preliminary guide or expert system for unveiling the likely nature of subsurface materials at any site in the region.

The formulation was anchored on certain soil characteristics, which are considered to have a controlling influence on soil performance. Correspondingly, the framework specifically focuses on some identified engineering performance indices of relevance in Tropical soil engineering, namely: in-situ permeability, time-dependent consolidation, collapsibility of soil structure, in-situ shear strength, excavation ease, pile driving, suitability as road construction material, reaction on exposure, suitability for low cost housing, and amenability to stabilisation. These are evaluated as having a high, moderate or low likelihood of occurrence within a given soil group. Hence, the scheme can conveniently be used to develop a preliminary estimate of engineering behaviour of the soils in the area.

The framework developed here is particularly helpful for predicting the engineering performance of the soils prior to any civil engineering project take-off. Though customized for soils of Southern Nigeria, it can equally be applied to other parts of Nigeria as well as other areas of the humid tropical region. Such extended application will, however, require additional confirmatory in-situ field tests, representative sampling and laboratory tests.

Table 3: Engineering Performance of Major Soil Groups in Southern Nigeria (Ejezie, 1982, 2005)

Engineering Performance Index	**Soil Group**			
	Recent Deposits	Acidic Soils	Cretaceous Soils	Ferruginous Soils
Low in-situ Permeability	●	○	◑	◑
Time-dependent Consolidation	●	○	○	○
Collapsible Soil Structure	○	◑	○	○
Low in-situ Shear Strength	●	◑	○	○
Difficulties with Excavation	○	◑	●	●
Difficulties with Driven Piles	○	○	◑	●
Suitable for Base Course	○	○	◑	●
Hardening upon Exposure	○	◑	◑	◑
Suitable for Low Cost Housing	○	◑	●	●
Amenable to Stabilisation	○	◑	●	●

Legend:

● High Likelihood

◑ Moderate Likelihood

○ Little or no Likelihood

It is evident from table 3 that the degree of laterisation has a strong influence on the soil characteristics. The process aggregates fine-grained particles into coarser grains, yielding a pseudo-granular texture.

The Ferruginous and Cretaceous soils, which are at advanced stage of laterisation, are characterised by a high degree of sesquioxide and hydroxide cementation, which develops a relatively low permeability as well as high in-situ shear strength and bearing capacity, generally enhanced stability even on steep slopes, and may lead to difficulties in excavation and pile driving. Also, the granular texture associated with these highly laterised soils makes them suitable as a base course for roads and generally susceptible to treatment with soil stabilisers, such as lime.

On the other hand, the granular texture and low to moderate degree of laterisation associated with the acidic soils generally give them high in-situ permeability and other related performance ratings as shown in table 3. The permeability of the Recent Deposits varies widely because of the variability of the soil group.

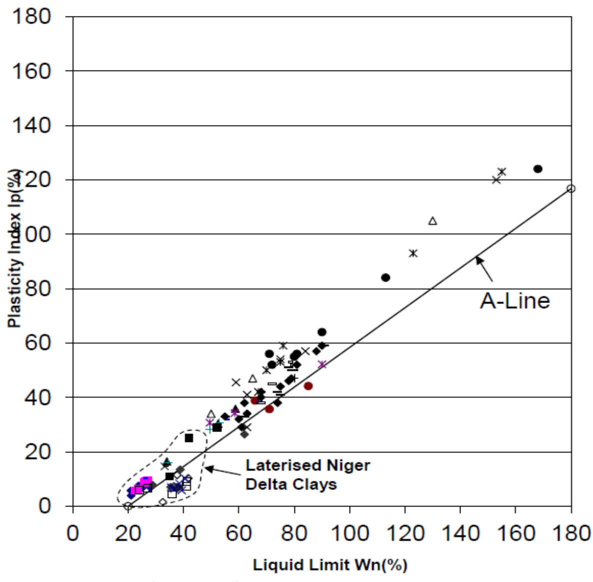


Fig17: Plasticity of Soils from Recent Deposits (Ejezie, 2005)

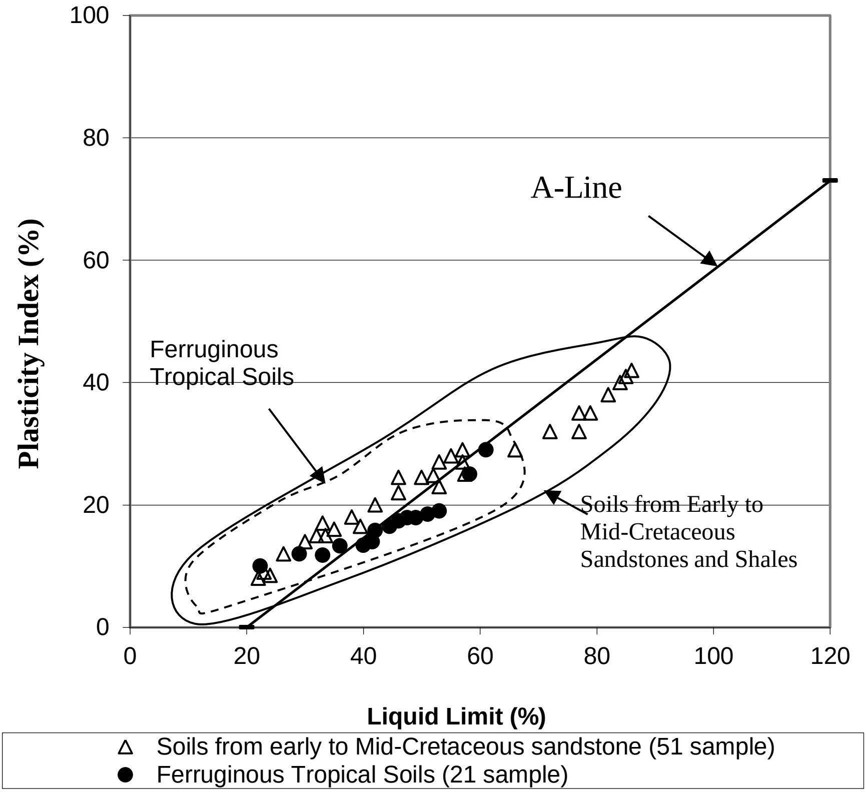


Fig. 18: Plasticity of Humid Tropical Soils (Ejezie, 1982)

NOTE:
The inconsistency in behaviour exhibited by lateritic soils vis-à-vis conventional expectations is manifested principally by the index tests in which sample preparation has substantially different consequences on results than that predicted by traditional soil mechanics theory. For example, a wet sieve analysis often yields a high proportion of fine-grained particles because the water and the mechanical sieving action disrupt the cement bonds and disaggregate the soil particles. Similarly the remoulding and the addition of water that precede liquid limit test increase the clay fraction thereby increasing the plasticity index of soil.

iii) Evaluation of In-Situ Shear Strength of Niger Delta Soils

A substantial part of my work on soils of Nigeria was concentrated in the Niger Delta Region. The soils here, as my research revealed, exhibit remarkable variability with both space and time. This is attributable to the manner of deposition of the sediments conveyed by the river system. These sediments are laid down in sets of coarse-, medium-, and fine-grained materials corresponding to decreasing energy of deposition typical of the three distinct environments identifiable in the region, namely continental, mixed and marine (Ejezie, 1986). This trend in deposition results in the superimposition of the sediments of the three environments and this partly accounts for the variability observed in the soils of the subsurface of the Niger Delta.

The humid tropical climate also plays a role in the variability of the soils. The intense weathering and the associated post formation alteration processes, particularly laterisation, transform the soils and confer on them unique properties that are not easily predictable using conventional soil mechanics theory. Most times predictions based on laboratory test results differ from actual field observations. The result of these observations is that conventional soil laboratory tests yield results which do not always reflect actual field performance of the soils. In fact, the reliability of laboratory tests in the prediction of the engineering behaviour of Niger Delta soils is generally low.

Conversely, my research has shown that in-situ tests generally have a high likelihood of accurately predicting the engineering behaviour of these soils and I therefore strongly recommend them for use in geotechnical data acquisition in the Niger Delta. As shown in Table 4 below, the tests include:

> Pressuremeter Test, Plate Loading Test, Cone Penetration Test, Standard Penetration Test, Flat Dilatometer Test, Vane Shear Test, Cone Pressuremeter, Seismic Cone, Resistivity Cone, and Seismic Dilatometer.

Figure 19 shows a schematic illustration of some of these in-situ test techniques.

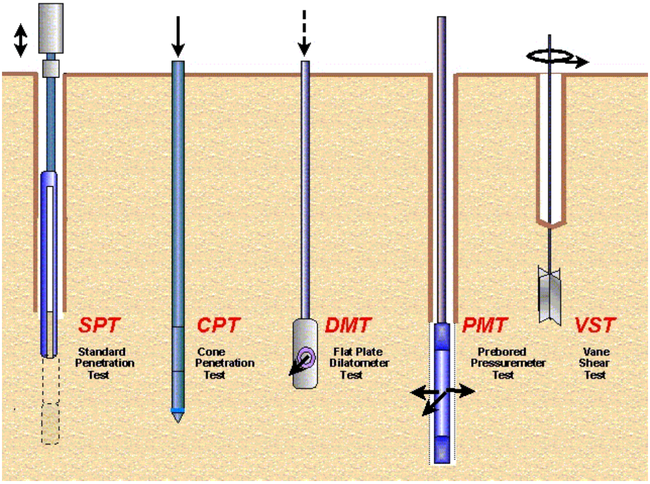


Fig. 19: Some Common In-Situ Testing Techniques

These tests yield reliable values of soil strength as well as information on the nature of the subsurface which can be interpreted to provide average properties of soil profiles and other common geotechnical design parameters as indicated in the Table 4. The versatility of these in-situ tests is due primarily to the relatively undisturbed state of the soils at the time of testing. The in-situ state of stress remains largely unaltered and the test result reflects the in-situ field conditions of the soils. Some provide 3-D or 2-D representation of the subsurface while others are designed to reveal 1-D information by direct measurement. The results, on analysis, reveal the target physical property – shear strength – based on simplifying assumptions.

This contrasts sharply with laboratory tests which involve appreciable disturbance of the soil test specimen. Furthermore, laboratory test specimens are obtained from samples collected from specific points in soil deposits. The accuracy of the results is therefore directly related to the homogeneity and isotropy of the parent deposit. Since soils in the Niger Delta are known to exhibit high degree of variability due to the effect of climate, laboratory test results are generally inconsistent and irreproducible. As a result, the reliability rating of laboratory tests in the determination of soil strength in the Niger Delta, as stated earlier is "Low".

Table 4: Commonly used In-situ Test Methods (Modified from Schnaid, 2005)

Test Group	Test Type/Technique	Designation/ Symbol	Test Parameters (measured)	Common Geotechnical Applications	Suitability Ranking for Soil Strength Determination in the Niger Delta
Non-Destructive Tests	Geophysical: Seismic Refraction	SR	P – Wave Velocity	Ground Characterisation and Small Strain Stiffness, G_0	Low
	Geophysical: Surface waves	SASW	R – Wave Velocity		
	Geophysical: Cross Hole Test	CHT	P – and S – Wave Velocities		
	Geophysical: Down Hole Test	DHT			
	Pressuremeter Tests: Pre-Bored Self-Boring	PMT SBPM	G_s, (ψ, ε) Curve	Shear Modulus, Shear Strength, In-situ Horizontal Stress, Consolidation Properties.	High
	Plate Loading Test	PLT	(L, δ) Curve	Stiffness and Strength	Very High
Invasive Penetration Tests	Cone Penetration Test: Electric Piezocone	CPT CPTU	q_c, f_S q_c, f_S, u	Soil Profiling, Shear Strength, Relative Density, Consolidation properties.	Very High
	Standard Penetration Test	SPT	Penetration Resistance (N-Value)	Soil Profile, Relative Density, Internal Friction Angle (ϕ).	Very High
	Flat Dilatometer Test	DMT	P_0, P_1	Stiffness, Shear Strength	High
	Vane Shear Test	VST	Torque	Undrained Shear Strength	Very High

Combined Invasive and non-Destructive Tests	Cone Pressuremeter	CPMT	q_c, f_S, +u, G_s, (ψ, ε).	Soil Profile, Shear Modulus, Shear strength, Consolidation Parameters.	High
	Seismic Cone	SCPT	q_c, f_S V_p, V_s, +u	Soil Profile, Shear Modulus, Shear strength, Consolidation Parameters.	High
	Resistivity Cone	RCPT	q_c, f_S, ρ	Soil Profile, Shear strength, Soil Porosity.	High
	Seismic Dilatometer		P_0, P_1, V_p, V_S	Stiffness (G, G_0), Shear Strength	High

4.2.2 Solutions for Typical Foundation Problems in the Niger Delta

A large part of the Niger Delta is water-logged and swampy, and this renders geotechnical work difficult as is the case in similar water environments. In particular, subsurface characterisation is an arduous and expensive task here and calls for special expertise of the Geotechnical Engineer with a wealth of practical experience in this or similar environments.

Based on existing soil classification system for southern Nigeria (Ejezie et al., 1983), the soils in the area can be categorised into two broad groups namely, “Recent deposits” and “Non-concretionary acid sands and clays”. The former occurs mainly in the coastal, low-lying areas and along river channels while the later occurs extensively in the upland areas and is only limited in the southern boundary by the occurrence of the Recent Deposits. The soils are highly variable, with the variability marked by erratic horizontal and vertical distribution patterns as revealed by borehole logs. The subsoil profile typically shows a sequence of very compressible clay to the top, underlain by silty and sandy strata which may become gravely with depth. Based on this, it is deduced that conventional shallow foundations bear on the compressible clay while deep foundations may either “embed” in the clay or bear on the more competent sand and gravel strata, depending on the thickness of the clay at the particular project location.

A variety of foundation problems are encountered in different parts of the delta ranging from those associated with high ground-water table to those posed by the deformation of highly compressible organic clays and peat. In general, the properties of the clay constitute the critical factors which affect the stability of foundations and hence determine their suitability. Furthermore, this area has been subjected to a continuous release of subsurface pressure through the extraction of oil and gas, an activity which may promote regional subsidence. These conditions call for development of new design solutions and construction techniques for structural foundations in the area, and this constitutes the focus of my contribution.

Types/Features of Foundation Solutions

In the course of my work I proposed several solutions, which include compensated foundations and different special modifications to the conventional foundation types – spread footing, shell raft foundation and pile foundation. The predicted performance of these foundations in parts of the Niger Delta, serves as a useful guide for future foundation construction activities in the area. The experience here and the adopted solutions are not unique to the Niger Delta. They have been successfully used in other areas of similar environmental conditions particularly in Mexico City (Rosenblueth, 1984).

Generally all the modifications are designed to suite the poor site conditions and geared towards increasing the capability of the compressible clay stratum to carry imposed structural loads because it poses the most critical field condition.

Spread Footing

The suggested modification is for the footing to take the shape of a **truncated cone shell** as shown in Fig. 20. This modification ensures that the bearing pressure is within tolerable limits and that the excessive volume and weight of concrete which would have resulted from enlargement of the footing are avoided.

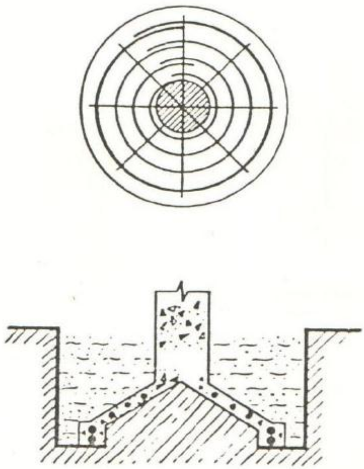


Fig. 20: truncated cone shell (Rosenblueth, 1984; Ejezie and George, 1987)

Hollow Footing with cylindrical shells or Bottom Slabs

These are illustrated in Figs. 21 and 22. The modifications have the potential of ensuring partial compensation to reduce settlement. Soft ground is prevalent in the Niger Delta and this is usually associated with intolerably large settlements. The footings therefore have a high likelihood of satisfactory performance in this area.

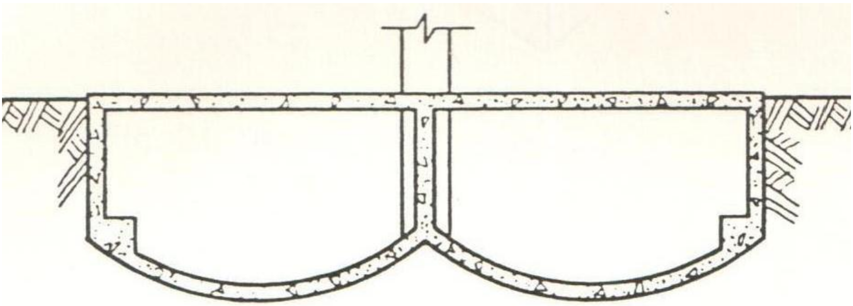


Fig. 21: Hollow Footing with cylindrical shells (Rosenblueth, 1984; Ejezie and George, 1987)

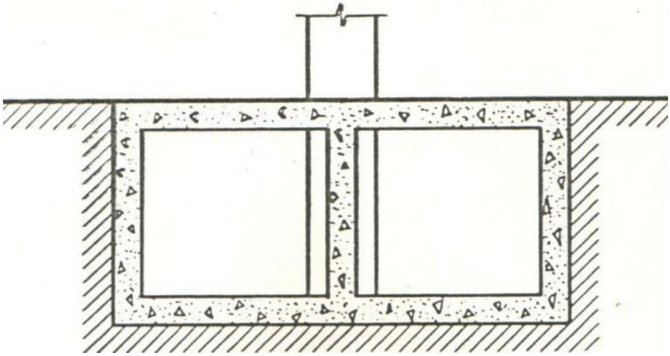


Fig. 22: Hollow Footing with Bottom Slab (Rosenblueth, 1984; Ejezie and George, 1987)

Raft

Conventional raft foundations are usually very large and require a large volume of concrete and reinforcement. As a result, they occasionally have stability problems in the form of excessive total and differential settlements in the soft and compressible clay zones of the Niger Delta. To reduce the weight of the raft and minimise settlements (and of course save cost), the foundation could be modified by replacing the slab with shells, mainly cylindrical shells as shown in Fig. 23. The modified raft is referred to as shell raft foundation.

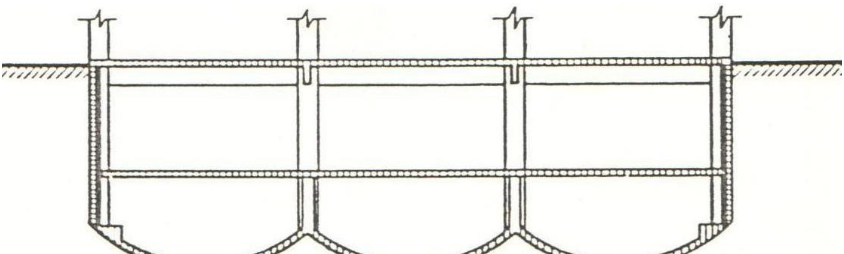


Fig. 23: Shell raft foundation (Rosenblueth, 1984; Ejezie and George, 1987)

Pile

Modifications that could be adopted for piles include:

a) Leaving a space between the pile tip and the bearing layer for end-bearing piles (about 15% of the distance from foundation base to top of bearing stratum) as shown in Fig. 24. This ensures that tip capacity is not mobilised to an extent that would give rise to differential settlement.

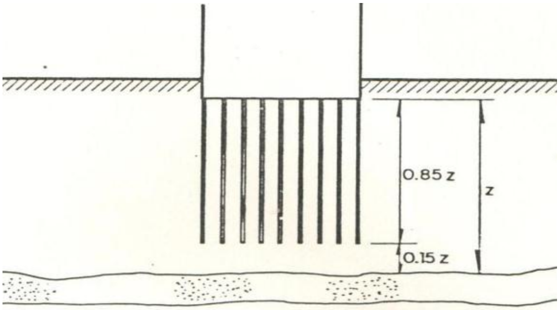


Fig. 24: Space between the pile tip and the bearing layer (Rosenblueth, 1984; Ejezie and George, 1987)

b) Enhancement of pile friction for Friction Piles, is achieved by:
   i. Creating deformations on the pile (concrete pile) and adding gravel as the pile is being driven (Fig. 25).
   ii. Using helical widening (steel pipe pile) as in Fig. 26.

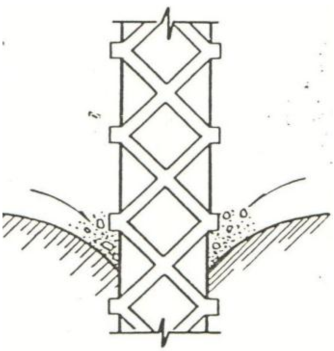


Fig. 25: Concrete pile with Deformations and added (Rosenblueth, 1984; Ejezie, 1987)

Fig. 26: Pipe Pile with helical widening (Rosenblueth, 1984; Ejezie, and George, 1987)

4.2.3 Dynamic Load Response of Humid Tropical Soils/Soil-Structure Interaction Problems resulting from Induced Ground Vibrations

My contributions in this important special problem area of Geotechnical Engineering are demonstrated here using two successfully executed research works. The first involves modelling deep foundation construction hazards while the second deals with modelling and simulation of environmental impacts of typical ground tremors arising from the use of explosives in construction and oil and gas exploration.

i. *Deep Foundation Construction Hazards*

The thrust of my work here was to develop a framework for assessing the impact of deep foundation construction hazards on the environment especially in parts of the Niger Delta. To achieve this, I focussed on the damage potential of piling-induced vibrations (prototype earth tremors) in the humid tropical soils of the Region with a view to establishing a threshold level for the accompanying ground movements. This would in turn be used to develop a model for predicting likely soil responses and structural vibration levels that may be encountered during piling activities in view of the growing interest in the environment and the need to forestall damage to third party property.

Pile foundation, at present, is the most popular and most widely used of all known types of deep foundation, particularly in poor ground conditions. The methods of construction are, in general, relatively sophisticated. The choice of a specific method for a particular project is a function of the general site conditions and, in particular, the engineering behaviour of the soils underlying the site. In some cases the adopted method may turn out to be a source of unpleasant environmental nuisance and a hazard with appreciable damage potential.

Of the known methods of construction, driving and drilling (boring) are the most commonly employed, and this is particularly the case in the Niger Delta Region. Their relative ease of application is a major factor that influences their choice. Another important factor is the soil response to loading because they depend more on the nature and characteristics of soil. Therefore, depending on the method of installation, Piles may be either “Driven piles” or “Drilled piles”. The choice between these two, for a particular site, could reliably be based on soil stress history, with pile driving restricted to contractive soils while boring could be adopted for either contractive of dilative soils.

However, “ease of construction” appears to have a controlling influence in the choice. In areas of high groundwater table such as offshore and water-logged environments, bored pile construction is relatively difficult. As a result, pile driving has somehow become the most widely used method.

Associated with it though is the problem of ground vibration, which has, in recent years, become a topical environmental hazard. In the Niger Delta there is proliferation of piling activities occasioned by the boom in oil exploitation and infrastructure development. This has been largely responsible for several cases of vibration-related structural damage and disturbance to humans. These problems actually motivated me to delve into this work to contribute towards the development of environmental impact assessment framework suitable for managing those activities that generate transient-type vibrations (Ejezie, 2004, 2015).

Features of Loading from Pile Driving

Pile driving is a form of repeated loading (or dynamic loading). The source of the load is the piling hammer falling freely through a height and dropping on the pile head. This episode represents a typical impact loading, similar to blasting. It generates transient-type ground motions which propagate radially outwards from the piling point and are transmitted away through the overburden soil and surrounding earth materials. The propagation and attenuation of these motions were monitored by directly measuring ground motion amplitudes in terms of particle velocity and displacement. By so doing, their probable effects on structures and human beings across property line were ascertained. The choice of velocity and displacement amplitudes as parameters for quantifying the ground motion was based on the fact that maximum particle velocity is an accepted criterion for evaluating the potential for structural damage induced by vibrations and can be approximately correlated with the Modified Mercalli Intensity in strong ground motion problems. The ground displacement, on the other hand, is known to be directly related to the strains to which structures might be subjected.

Damage Potential of Pile Driving in the Niger Delta

I have been able to quantify this through my work by focussing on the response of structures and human beings in the area to piling-induced vibrations based on vibration response criteria that are accepted internationally for assessing the potential for structural damage induced by vibrations (Ejezie, 2004, 2015). Usually, these criteria are essentially probabilistic. Hence, a safe criterion is usually a vibration level which, if exceeded by any of the components, would indicate that there is a reasonable probability that damage would occur.Two very widely used damage criteria developed by the Bureau of Mines of the US Department of the Interior and the US Department of the Navy are presented in figures 27 and 28 below. Superimposing these on the data from my Niger Delta study reveals the likely reactions of structures and human beings in the vicinity of the piling to the resulting vibrations.

Both the Bureau of Mines and the Department of the Navy criteria stipulate a velocity amplitude of 50.8 mm/sec as the threshold vibration level below which structures are considered safe and above which structural damage is likely.

Additionally, the Navy criteria incorporate specifications for predicting human response to vibrations, summarized as follows:

<0.5 mm/sec: Not easily noticeable to persons;

0.5-5.0 mm/sec: Noticeable to persons, and complaints possible,

05.0-30mm/sec: Disturbing, and complaints likely

30 -50.8 mm/sec: severe.

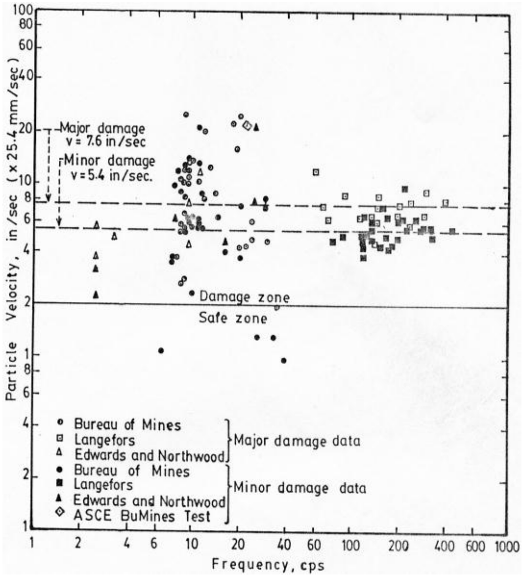


Fig. 27: Bureau of Mines Recommended Vibration Criteria

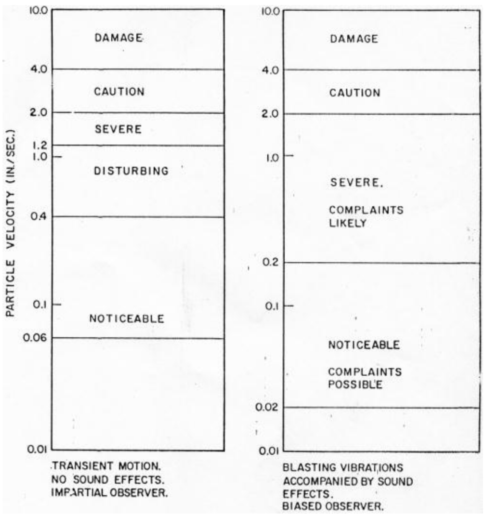


Fig. 28: Guide for Predicting Human Response to Vibrations
(US Department of the Navy, 1982)

The limits in the above criteria can shift up or down depending on various factors. For example, if there are no sound effects and the observer is impartial, velocity amplitude of up to 1.5 mm/sec is needed for the vibration to be noticeable. On the other hand, with a biased observer of vertical vibrations accompanied by sound effects, particle velocity amplitude as low as 0.3mm/sec may be enough to consider the vibration noticeable. Furthermore, the velocity amplitude required for a particular human response to a given vibration decreases appreciably with increase in frequency.

It is pertinent to point out at this juncture that human tolerance of vibrations is highly subjective and this introduces appreciable flexibility in establishing human response criteria. For example, some people may consider vibrations that are completely safe for structures annoying and very uncomfortable. Consequently, the subjective response of the human body to vibrations is generally categorized into three levels namely, “perceptible”, “unpleasant”, and “intolerable” corresponding respectively to “low”, “medium high”, and “high” velocity amplitudes. This scheme has found application in a wide range of vibration problems and I have therefore adopted it in my work in the Niger Delta.

Vibration monitoring

Data on the piling-induced vibration was obtained by directly measuring the ground motion amplitudes at various points around the case study site. The measurements were extended across property lines and expanded radially outwards with respect to the source and along the four cardinal axes - East, West, North and South. The monitoring stations were located at 50m intervals along these axes. The parameters measured were the maximum values of particle velocity and displacement as explained earlier regardless of where they occurred during the measurement. At each monitoring station the measurements were generally taken in three mutually perpendicular directions - vertical, radial to source projected on a horizontal plane, and transverse to source also projected on a horizontal plane. The maximum velocity readings at each station were vectorially added to obtain the peak particle velocity. Frequencies were computed from the velocity and displacement readings by assuming that the motion was simple harmonic.

This assumption allowed the use of the following relationship in the calculations,

$$u = v/2\pi f \quad (4)$$

or $$v = 2\pi fv, \quad (5)$$

$$\Rightarrow \quad f = v/2\pi u \quad (6)$$

In these expressions, u = displacement, v = velocity, and f = frequency.

The measured velocity amplitudes have been plotted against frequency and presented in Fig. 29 below. The plots disclose that the bulk of the observed frequencies generally ranged from 5 to 30 cps (excepting few values that fall below or above these limits). This is in close agreement with the findings of the Bureau of Mines (1971) that predominant frequencies generated by vibrations from impact loading are commonly in the range from 6 to 40 cps (Nicholls et al., 1971).

The figure actually represents the safe vibration criterion which has been developed from log-log plots of individual velocity components (vertical, radial and transverse) versus the corresponding frequencies because seismic motion is a vector quantity.

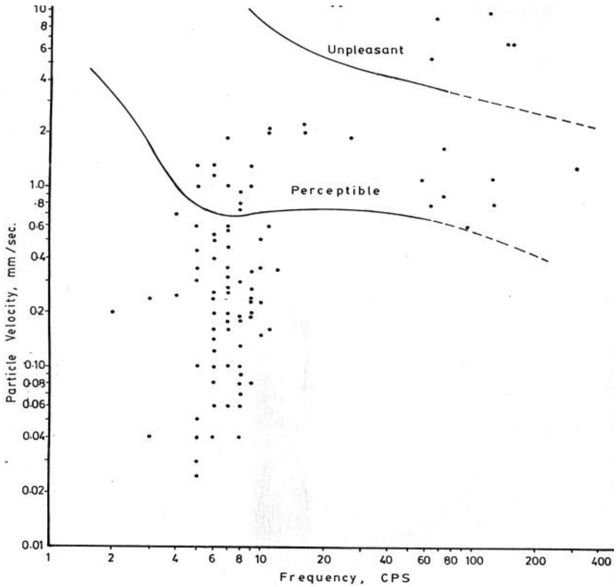


Fig. 29: Relationship between Velocity Amplitude and Frequency

Vibration Propagation and Attenuation in Soil

The data from vibration measurements were further analysed in terms of ground motion – the nature of its propagation and attenuation in the surrounding soils and its effects on structures and human beings.

The variation of velocity with distance away from the piling point was ascertained by plotting the velocity readings against the corresponding distances as shown in Figs. 30a and 30b. The plots were made on log-log coordinates based on the vibration propagation law:

$V = K D^n$ (Bureau of Mines, 1971), (7)

where: V = particle velocity,

D = distance (monitor station to source, in hundreds),

K = intercept, velocity at D = 1.0 (in hundreds of meters)

n = exponent.

The data were grouped into vertical, radial and transverse components along the East, West, North and South monitoring axes and plotted.

The vertical velocity components along the four axes were combined and plotted, and so also were the radial and transverse components.

Finally the peak velocities computed by taking the vector sum of the maximum velocities at each monitor station were combined and plotted.

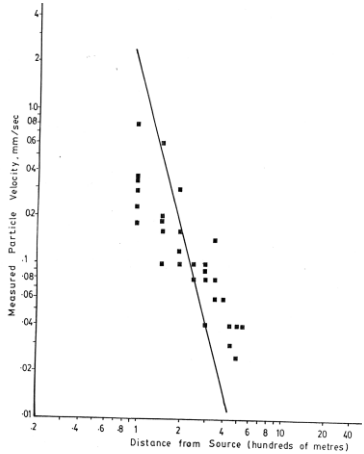


Fig. 30a: Vertical Component of Particle Velocity versus Distance from Source (Ejezie, 2004)

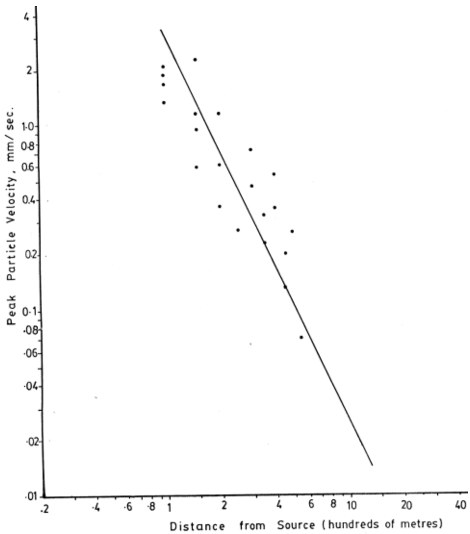


Fig. 30b: Peak Particle Velocity versus Distance from Source (Ejezie, 2004)

The values of K and n were determined for each set of plotted data by statistical analysis using the method of least squares. The values for K (presented in Table 5) represent the average velocity amplitudes along the property lines (D=1.0), while n approximates the rate of attenuation of the velocity with distance from the source.

Table 5: Computed values of the particle velocity intercept, K at D = 1.0 (property line, 100m from source) for the various sets of velocity data (Ejezie, 2004, 2015).

Velocity Component	**Velocity Intercept, k**
Vertical	2.16
Radial	3.07
Transverse	2.60
Peak	3.15

Contours have been developed for velocity amplitudes with increasing distance from the source as shown in Figs. 31a and 31b. This gave a clear picture of the zonation of damage probabilities around the project site. **The graphs and the contours reveal that the vibration died out rapidly with increasing distance away from the piling point**. This implied that the effect on structures and human beings across property lines in the case study site could not spread over an extensive area.

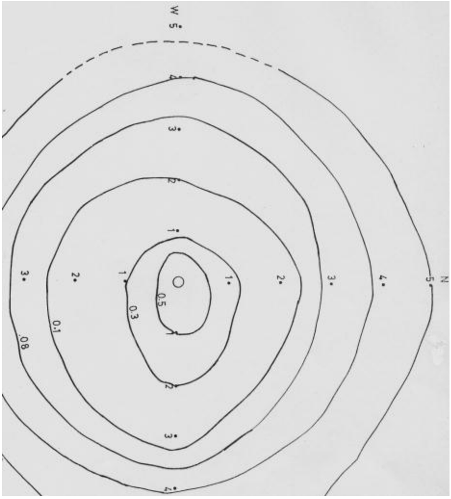


Fig. 31a: Contours of Vertical components of velocity, in mm/sec, measured around the Site during Piling. (Whole Numbers along Monitor Axes indicate Distances in hundreds of metres from Source) (Ejezie, 2004, 2015)

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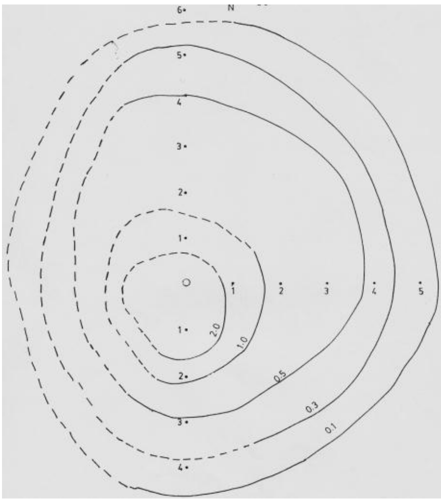

Fig. 31b: Contours of Peak velocity, in mm/sec, measured around the Site during Piling. (Whole Numbers along Monitor Axes indicate Distances in hundreds of metres from Source) (Ejezie, 2004, 2015)

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Deductions:
The analysis results show that, for the case illustrated, the zone of highest damage probability did not extend across property lines. Nevertheless, there is a high probability of complaints against inconvenience from occupants of residential structures located at less than 200m from the piling point. This is primarily due to sound effects and bias, which are likely to be prominent factors in their reaction to the vibrations. A greater percentage of these complaints are likely to come from residents of non-rigid buildings such as those of bamboo-reinforced earth.

Although Pile Foundations constitute a reliable solution to stability problems of structures in areas of soft ground conditions, their construction (Pile driving) brings mixed fortunes as it sometimes constitutes an environmental hazard. It frequently triggers off ground vibrations which are transmitted through the overburden soil to adjoining areas where they may adversely affect buildings and constructed facilities and can even lead to collapse of structures.

Extrapolation of vibration response data from one area to another should be discouraged, except where adequate correlation has been established among the controlling factors based on thorough subsurface material characterization and dynamic load response analysis for the soils.

ii. Environmental impacts of explosives used in construction and in oil and gas exploration.

The output of my work here was the formulation of a framework for on-site assessment of the seismic behaviour of lateritic soils as well as the potential environmental impact of dynamite shooting activities embarked upon by seismic crews engaged in oil and gas exploration in different parts of the Niger Delta (Ejezie, 2003, 2013). The highlight was the determination of safe shooting distances for various sizes of dynamite based on internationally accepted engineering standards for human tolerance and structural safety. The same model is applicable to the case of explosive charges used in construction (e.g. Blasting, demolition, tunneling, rock excavation, etc.). The findings can be adopted for other areas of similar geologic and environmental conditions.

As usual, the explosions generated typical impact loads, which triggered off transient-type ground motions that were transmitted away from the shot points via the thick, lateritic, overburden soil. My analysis revealed an attenuation pattern for the vibrations that is largely determined by soil characteristics. In other words, the recorded variation of peak particle velocity with depth, (typified by velocity contrasts at depths coinciding approximately with strata boundaries), as shown in Fig. 32; and the fairly high attenuation coefficient, as reflected in the rapid decrease of velocity amplitude with distance from source as clearly evident from Figs. 33a-33d (only barely perceptible beyond 500 metres), are attributable to the lateritic nature of the soil profile.

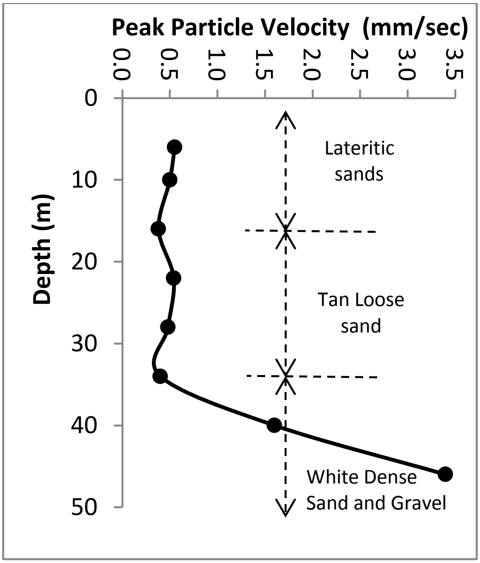

Figure 32: Arithmetic plot of Peak particle velocity vs. Depth for the constant charge wt., single-hole shots (Ejezie, 2003, 2013).

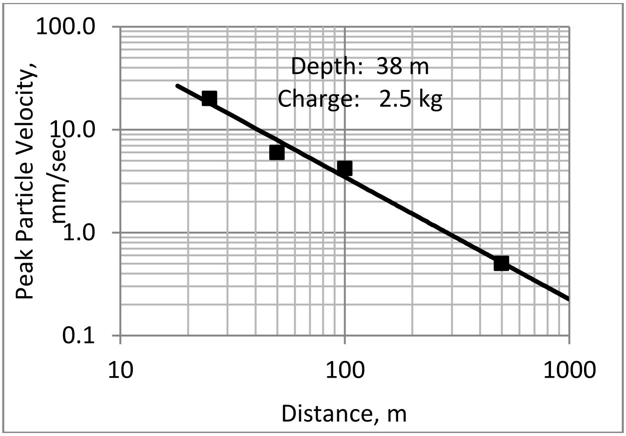

Figure 33a: Peak particle velocity vs. Distance for a constant charge wt. of 2.5 kg and shot (Ejezie, 2003, 2013)

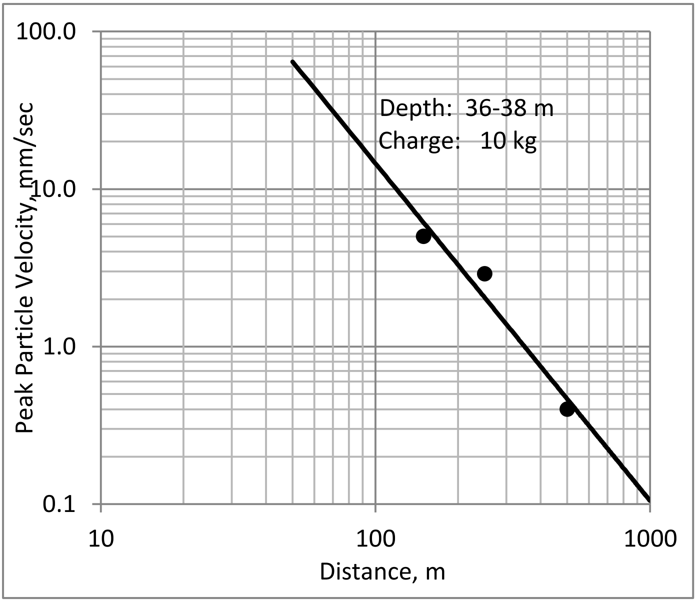

Figure 33b: Peak particle velocity vs. Distance for a constant charge wt. of 10.0 kg and depth 36-38m (Ejezie, 2003, 2013)

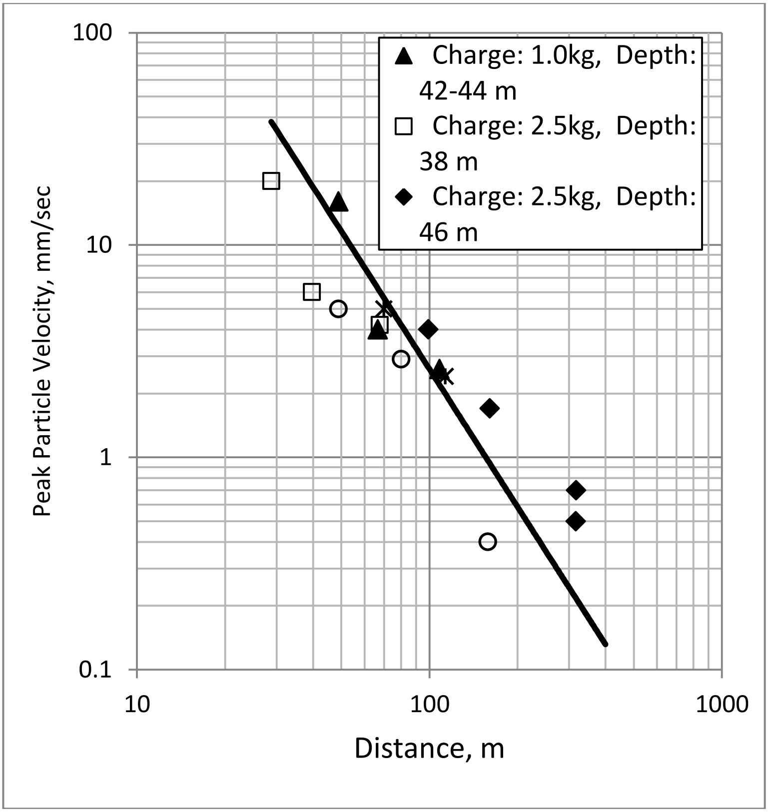

Figure 33c: Peak particle velocity vs. Scaled Distance (Ejezie, 2003, 2013)

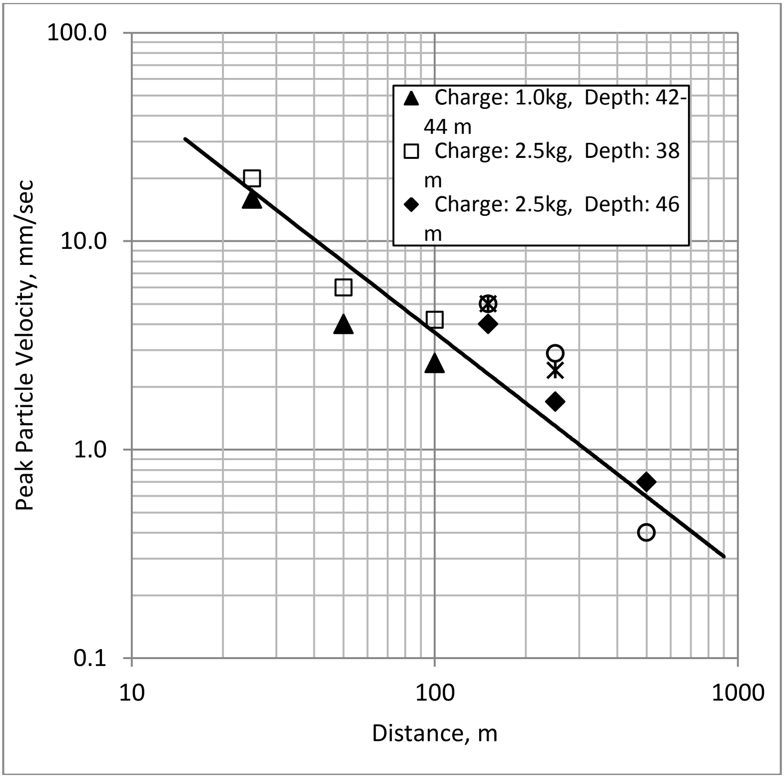

Figure 33d: Peak particle velocity vs. Distance:
Pooled plot for single-hole blasts with variable offset
(Ejezie, 2003, 2013)

The bulk of the peak particle velocity values fell within the zone of structural safety when compared with internationally accepted damage criteria for vibrations. In terms of human response however, the values indicate that the vibration level has a high probability of attracting complaints from owners of property within 500 m from the shot point, particularly if the shooting were carried out in a built up area. This inference is based on the fact that human response to vibrations is usually subjective and aggravated by bias and sound effects, both of which were assumed present in this study.

Minimum safe shooting distances

The biased human response has been taken as critical in the evaluation of minimum safe shooting distances because most dynamite shooting operations in oil and gas exploration deliberately avoid built-up areas. In this process, a particle velocity limit of 5.0 mm/sec is used. This value, in the Standard Criteria, corresponds to a vibration level above which human beings feel disturbed and are likely to raise complaints. By interpolating this value on the various velocity versus distance curves the corresponding minimum safe shooting distances are obtained as shown in Table 6 below.

The values obtained disclose that for a given amount of explosive, the safe shooting distance generally increased with depth (Ejezie, 2013). In other words, it may be safer to shoot a given weight of charge at a smaller than at a greater depth.

Table 6: Minimum Safe Shooting Distances for various Charge Weight and Depth Combinations studied (Ejezie, 2003, 2013).

Charge Weight (Kg)	Shot Depth (m)	Derived Minimum Safe Shooting Distance (m)	Remarks
1.0	43	120	
2.5	38	190	
2.5	46	270	
2.5	9	40	Five-hole pattern shot, 0.5 Kg per hole
5.0	44	300	Approximated; Graph inexact
10.0	37	280	

4.2.4 Coastal Protection/Slope Failure Mitigation in Niger Delta

The Niger Delta is adorned with a network of meandering rivers and creeks discharging into the adjoining Atlantic Ocean. The river banks are often unstable owing to excessive scouring at the river bed and the toe of the slope. This occasionally poses serious threats to constructed facilities in parts of the region. I have undertaken detailed studies of this problem in different parts of the region and contributed to lasting solutions. A typical illustration of my contribution is presented here using a site in the Meander Belt zone of the Niger Delta where sensitive facilities and installations have been sited on the convex side of a river bend whose bank is receding at an appreciable rate as revealed by studies carried out pre- and post-construction (Ejezie, 2011). Figs. 34a and 34b show the actual location.

The site, like in most parts of the Delta, is subject to seasonal inundation due to cyclic rise and fall in water level. This phenomenon usually occurs at a rapid rate especially during peak and low rainfalls. My investigation revealed that during these rapid fluctuations in water level the bank material experiences loss of weight due to buoyancy effect of submergence, strength degradation caused by excess pore pressure build-up, seepage forces resulting from relatively large head difference during sudden drop in water level in the river, and low shear strength of the soil underlying the slope. The combination of these factors subjects the project site to pronounced slope instability as exhibited by the features shown in Figs. 35a and 35b.

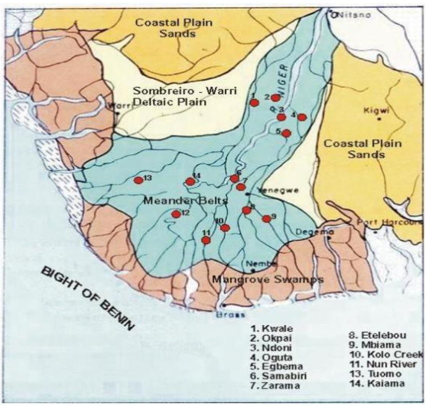

Fig. 34a: Meander Belt of Niger Delta

Fig. 34b: Site location (satellite view)

Figure 35a: A view of the failed bank with temporary sand bags

Figure: 35b Cracks observed on the ground at the onset of failure

My contribution focused on providing expert engineering solution to the stability problem which included modelling of the failure mechanism, as illustrated in Figs. 36 and 37, to determine the likely cause(s) and formulation of robust designs for failure mitigation and bank protection works (Ejezie et al, 2012).

This is synonymous to the application of new trends and developments in geotechnical engineering and is considered apt because trial conventional analysis and design yielded results which indicate that river banks in the area can only be stable on very low slope angles. The implication is that most of the river channels will pose navigation problems if conventional solution is adopted.

My work therefore involved devising a workable innovative solution which combined the conventional slope design with toe-stabilising anchored sheet pile wall as shown in Fig. 38. It is expected that this solution would equally perform satisfactorily in other areas of similar geological and environmental settings as the case study site.

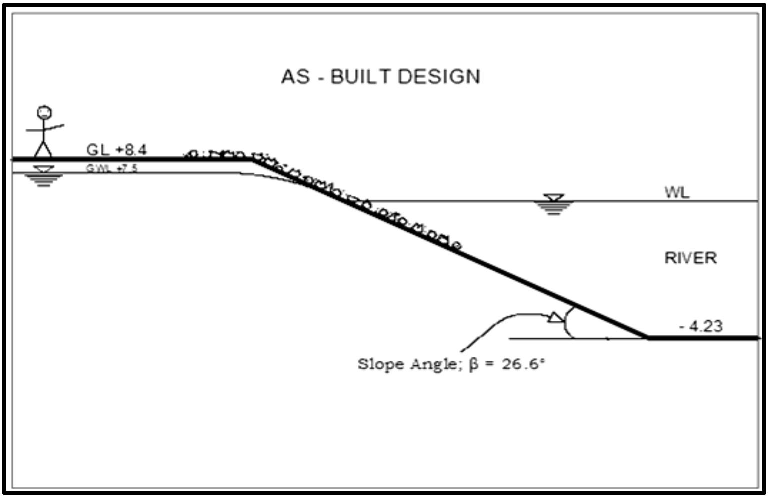

Fig. 36: Existing slope profile Model

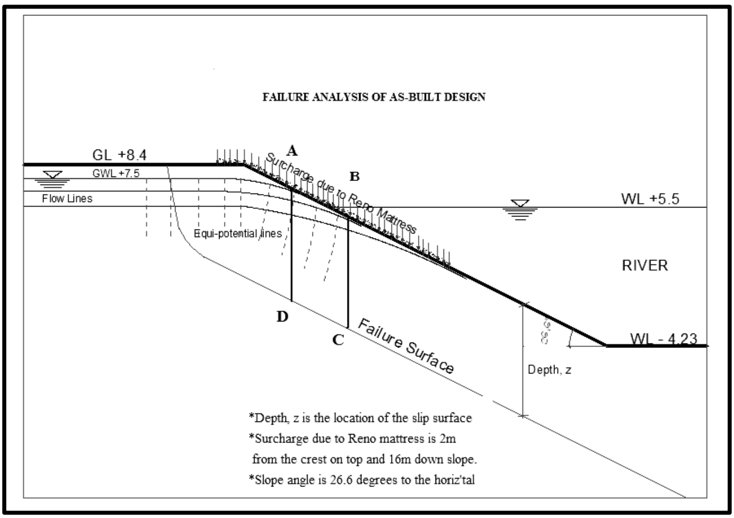

Fig. 37: Failure Analysis Model

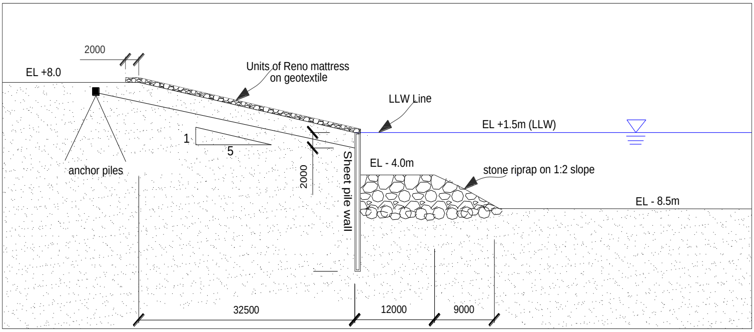

Fig. 38: Design for effective bank protection and failure mitigation

Design Justification

The river bank protection work is in a location which experiences several destabilizing forces amongst which are high water current and the associated eddying which result in scouring of the river bed within the vicinity of the river bank. The development of the scour hole continues to erode and undermine the bank slope thereby rendering the slope unstable. To forestall any possible occurrence of undercutting or undermining of the river bank, additional support systems in the form of steel sheet pile wall supplemented by stone rip rap on the river side, has been introduced. The sheet pile is located at a convenient distance away from the crest and driven to optimum safe depth to prevent the undermining of the slope. An additional advantage offered by the wall is the stability imparted on the slope by serving as a retaining wall. It also serves as a measure to mitigate the construction challenges experienced during the period of construction in sections of the protection work below water level. The most convenient position of the sheet pile wall was considered to be the LLW line. This was to ensure that the top of the wall levelled with the LLW elevation. As shown in Fig. 38, Stone riprap has been placed directly in front of the sheet pile wall to prevent scouring at the base of the wall.

Designed Slope versus Existing Transverse Profiles

Superimposing the designed slope on the transverse profiles obtained by means of bathymetric surveys of the site as shown in Fig. 39 reveals that the design has appreciable advantage in terms of the volume of construction material and ease of construction compared to the original/existing slope. Fill material required is substantially less. Also, a reduced thickness of rock fill is only needed along the river side of the sheet pile to prevent the occurrence of scouring. Furthermore, the installation of the sheet pile along the LLW level eliminates the difficulty and hence the uncertainties associated with constructing soil slopes under water.

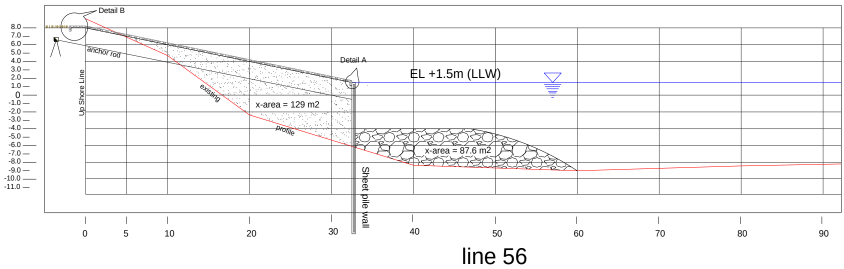

Figure 39a: Designed Slope vs. Typical Existing Transverse Profiles

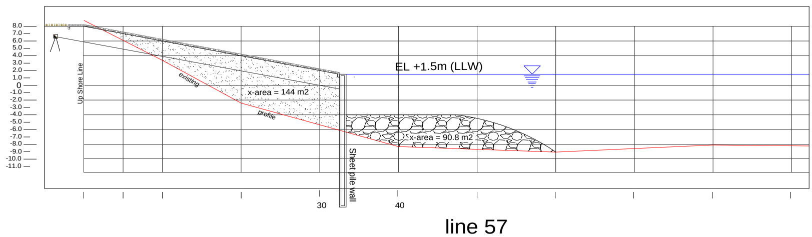

Figure 39b: Designed Slope vs. Typical Existing Transverse Profiles

4.2.5 **Modelling and Prediction of Dynamic Load Behaviour of Soils/Summaries of Key Outputs in Selected Published Works**

I have made very significant contributions to knowledge through my research in this subject area which centred on the "Application of Probability and Reliability Concepts in the Prediction of Soil Behaviour under Dynamic Loading Conditions". My major accomplishments included the development of probabilistic and reliability models for cyclic load soil strength, cyclic load soil deformation (strain), and cyclic load pore pressure (Ejezie and Harrop-Williams, 1985; Ejezie, 1987, 1988). In addition, I successfully developed and implemented a reliability assessment programme for evaluating the levels of accuracy of existing deterministic cyclic load pore pressure response models. Summaries of these are presented subsequently, as well as synopses of key outputs of selected published works.

a) Reliability assessment of cyclic load pore pressure response models for cohesive soil

The deterministic models of cyclic load pore pressure response of cohesive soils were subjected to detailed reliability analysis aimed at assessing their predictability of the pore pressure. The second-moment method of reliability analysis was adopted with comparison between measured and predicted pore pressures as the underlying principle.

The results from case studies revealed that the deterministic models are associated with perceptible error as shown Figs. 40 and 41. They predict mean pore pressures that are appreciably less than those actually measured and display a wide spread in most cases. This implies that the models give very conservative predictions of cyclic load pore pressures with a high degree of uncertainty.

Furthermore, it was determined that the models gave relative accuracies of 25%-30% for the case studies considered. Therefore it was concluded that the models, in their present deterministic forms, are not suitable for general application. As a result, they are only weakly recommended for use in predicting pore pressures generated in cohesive soils under cyclic loading. Details of this work are published in the International Journal of soil Dynamics and Earthquake Engineering (Ejezie, 1988),

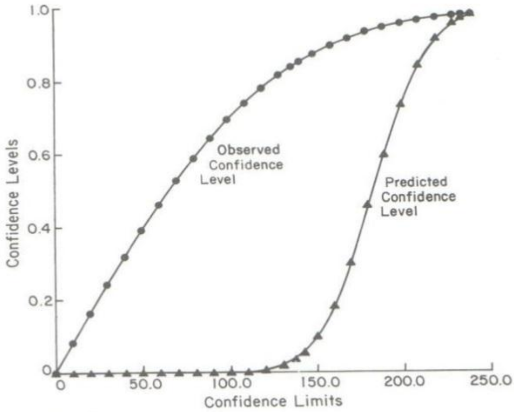

Fig. 40: Prediction variation of critical state limiting pore pressure models based on data from ISO-NC Dramen Clay under cyclic simple shear loading (Ejezie, 1988).

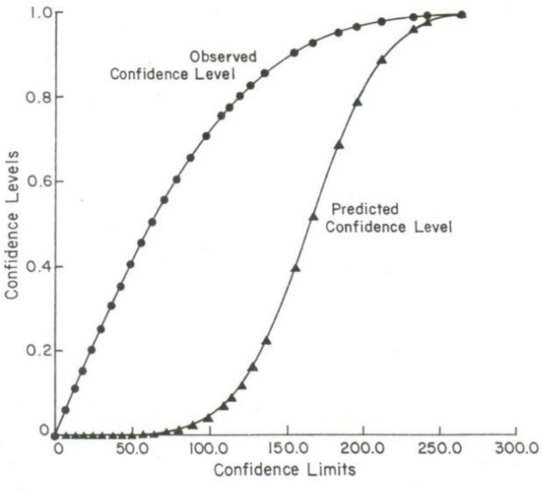

Fig. 41: Prediction variation of critical state limiting pore pressure models based on data from ISO-NC Dramen Clay under cyclic Triaxial loading (Ejezie, 1988).

b) Theoretical Development of Pore Pressure Response Model for Cohesive Soil Under Dynamic Loading

A model was formulated for pore pressures developed in contractive cohesive soil under undrained cyclic loading. The derivation was based on the framework of the particulate theory and emphasized a simultaneous transmission of stresses to the pore water and the solid particles of a saturated soil from cyclically applied loads.

The model expression shows that there is a linear relationship among pore pressure, soil compressibility, and the total strain energy absorbed in the soil during cyclic loading. The model accuracy was evaluated by comparing the model prediction with real case history data on measured cyclic load pore pressures. The best fit line through the observed and predicted pore pressure is a 45° line as shown in Fig. 42, implying that the model is suitable for the cyclic load pore pressure response of normally consolidated and lightly over-consolidated clays. Details of this work are presented in Ejezie (1987).

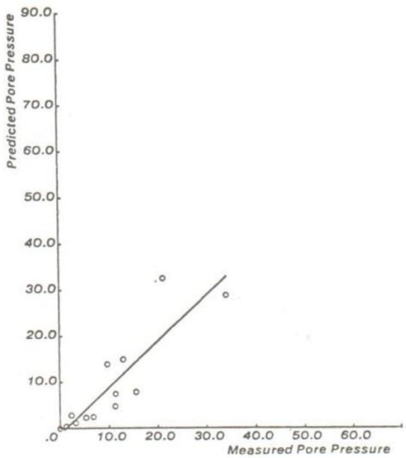

Fig. 42: Evaluation of the pore pressure model: - Predicted versus Measured pore pressures (Ejezie, 1987).

c) Reliability of Cyclic Load Deformation Models for Cohesive Soil

The concepts of probability and structural reliability theories have been employed to assess the predictive capabilities of existing deterministic models for soil deformation under dynamic loads. The results reveal that the models are associated with appreciable error attributed to the assumptions involved in their original formulations. The results also clearly distinguish the investigated models into three categories defined by their relative degrees of conservatism in predicting failure strain. The anisotropic residual deformation model is very conservative; the hyperbolic and Romberg-Osgood models are moderately conservative, while the cyclic stress-strain performance model is non-conservative. Hence the reliability analysis has enabled an in-depth perception of the relative effectiveness and limitations of the models as descriptors of dynamic stress-strain soil behaviour. Details of this work are presented in Ejezie (1987).

d) Probabilistic Nature of Cyclic Load Pore Pressure in Cohesive Soil

The probability distribution of cyclic load-induced pore pressure in contractive cohesive soil was derived based on its dependence on the compressibility of voids. The gamma distribution was established to be the most appropriate by summing exponential changes in the soil compressibility resulting from changes in the condition of the voids. However, since the pore pressure in this soil type is bounded, the upper limit being equal to the undrained strength of the soil and the lower limit near zero, the distribution can also be approximated by beta for specified limits.

It was established also that the normal distribution can be adopted for the cyclic load pore pressure without loss of accuracy because the gamma distribution approaches the unit normal distribution as the gamma parameter becomes very large. Besides, the gamma distribution has been derived by considering contributions from an infinite number of voids. Therefore the normal distribution, which is generally known as the probability model for sums of random variables when the number of variables is infinitely large, is a fairly reliable approximation of the pore pressure distribution for purposes of practical application. Details of this work are presented in Ejezie, (1987).

e) Probabilistic Distribution of Cyclic Load Strain in Cohesive Soil

A probabilistic model was derived for the variability of strain induced in contractive clays by dynamic loads. This was realised by using the concept of the mechanics of particulate media. In this approach the relationship between strain and soil compressibility was applied and it was established that the distribution of strain is identical to that of compressibility. The gamma distribution is determined to be the actual model although it is found that this can be approximated by the normal probability distribution without loss of accuracy. The approximation is warranted by the relative simplicity, easy applicability and the readily obtainable parameters of the normal distribution.
Details of this work are presented in Ejezie, (1987).

f) Entropy Analysis of Liquefaction Prediction Accuracy

Entropy is a general measure of uncertainty. Like the variance it can be used to measure the variability of quantitative random variables. Unlike the variance however, it can also measure the variability of qualitative random variables. Common uses of entropy can be found in thermodynamics, where it is employed to qualify the randomness in systems; and in information theory, where it serves as a measure of information.

In liquefaction prediction, if a model predicts that a site will liquefy with a probability, P, one will be more surprised if it liquefies when P = 0.01 than if it liquefies when P =0.99. Also it would be less surprising to hear later that liquefaction did indeed occur if liquefaction was predicted than if no prediction was made. It follows then that a liquefaction predicting model, depending on its accuracy, will reduce the surprise associated with liquefaction. This reduction of surprise is quantified as the entropy between prediction and observation.

In this work entropy was used to evaluate the accuracies of the different models formulated for the prediction of soil liquefaction resulting from seismic and dynamic forces. Dynamic loading on saturated sand under

undrained conditions such as during an earthquake, results in a progressive increase in pore water pressure. Liquefaction occurs when the pore pressure becomes equal to the confining pressure. In this case the effective stress reduces to zero and the sand has lost its strength.
Using an extensive and updated list of earthquake case histories, where liquefaction did and did not occur, the entropy in the prediction of nine of the most common models were evaluated. The models were then ranked as to their entropy (reduction in surprise). The entropy also gives a measure of the total randomness of each model as it is compared with the maximum possible entropy (when all the predictions are correct). Finally, correction factors were found for these models that maximize the entropy of each model prediction subject to the constraints imposed by the model formulation and the case histories. The entropy analysis shows that the models were generally approximate and none particularly proved to be more reliable than others.

More details of this work are presented in Harrop-Williams, K. and Ejezie, (1984).

g) Risk and Reliability Assessment Programme for Civil Engineering Construction

A model for assessing risk and reliability in conventional civil engineering construction practice was formulated in this work. The framework for the model recognizes three phases of activities namely, pre-construction, construction, and post construction. Based on this framework, a standard risk and reliability-assessment programme, (CERRAP) has been developed for general application in civil engineering works. The efficacy of the programme has also been demonstrated using a case study that involves structural integrity check of a building. This application was found to be successful because it enabled the determination of the actual state of the structure, the origin and cause of failure, and the appropriate remedial or renovation work.
Details are presented in Ejezie, (2003).

h) Geotechnical Potentials of Seismic Profiling in the Niger Delta

A framework has been formulated for identifying soil and rock materials and other geologic structures in the Niger Delta based on seismic reflection profiling. This approach is potentially capable of simplifying and reducing the cost of geotechnical work in the area. The sedimentary sequence of the delta is characterized by alternating high- and low-energy deposits, corresponding to sands and clays respectively, while the structure is dominated by synde positional growth faults and rollover anticlines. The proposed framework has a high potential of applicability in detecting these features and can therefore ensure accurate selection of drilling sites, as well as construction sites for offshore structures so as to prevent failure related to unfavourable seafloor topography in the area. The complete work is presented in Ejezie, (1986).

i) Work with my PhD Students

- **Lateral Response of Suction Caissons in Deep Water Floating Structures off Niger Delta Coast**

- (Ejezie, S. U. and B. Kabari (2009))

The lateral response of suction caissons used as anchors for floating structures in the offshore Niger Delta, shown in Fig. 43, was investigated using the "Lumped Parameter Systems" model. This involves computing dynamic soil parameters such as dynamic shear modulus, spring constant for soil, damping ratio, and natural frequency of soil-foundation system. Information regarding sinusoidal wave loading of floating structures is also required. Accurate determination of the maximum constant force amplitude of sinusoidal wave forces is necessary considering its effect on the amplitude of vibration.

In this process, the dynamic stability (horizontal vibration) of suction caissons used to anchor floating production facilities located deep offshore of the Niger Delta was examined (Figs. 44 and 45). Geotechnical conditions prevalent at Niger Delta Deep offshore were used to determine dynamic soil parameters needed for analyses. Also, dynamic wave properties of the offshore environment which correspond to 100 years return period served as inputs into the analyses.

Results of analyses show that for a given wave condition, an increase in the mass of caisson whose height to diameter ratio is 2:1 causes a decrease in the horizontal amplitudes of vibration of the caissons. Results also reveal that continuous increase in the mass of caisson beyond certain limits does not significantly reduce vibrating amplitude (Fig. 46). This is important because it provides information on the limiting mass and hence the size of caisson required in any particular situation.

Another important observation made was the fact that for a given wave steepness, the amplitude of vibration of the caisson can be greatly reduced if several smaller units of suction caissons are used instead of a single massive unit whose weight equals the combined weight of the smaller units. Cases considered showed that an increase in the number of caissons from 1(single massive unit) to 2, 4, 6, 10 and 20 (smaller units) reduced the amplitude of vibration by 23, 59, 68, 77 and 77% respectively. Selection of an appropriate number of caissons which represents optimum condition can therefore be made bearing in mind the maximum allowable vibration amplitude as well as the cost implications.

Fig. 43: Niger Delta Offshore

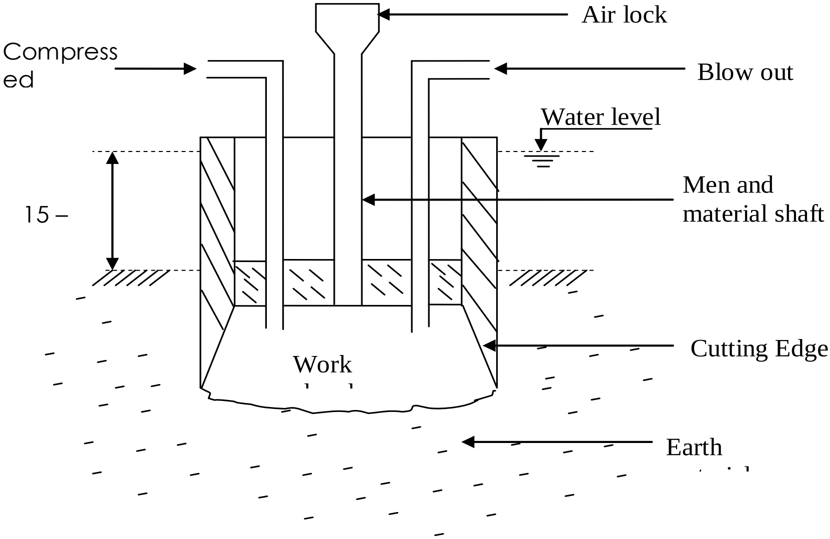

Fig. 44: Pneumatic caisson

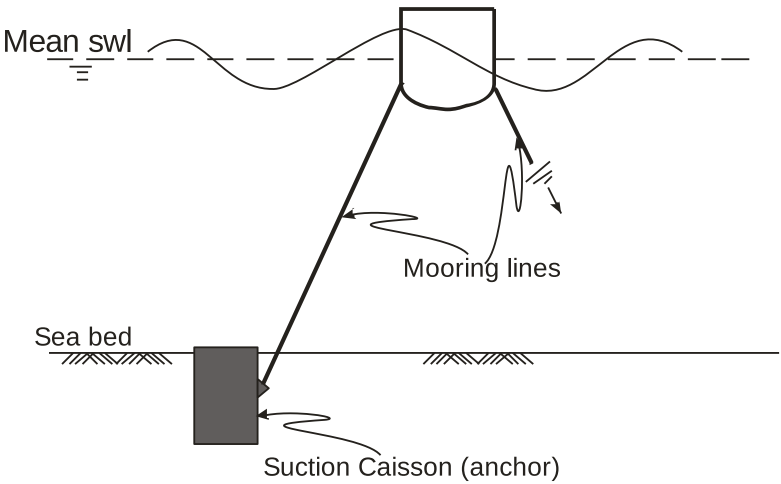

Fig.45: Suction Caisson as Anchor for Deepwater Floating Structures

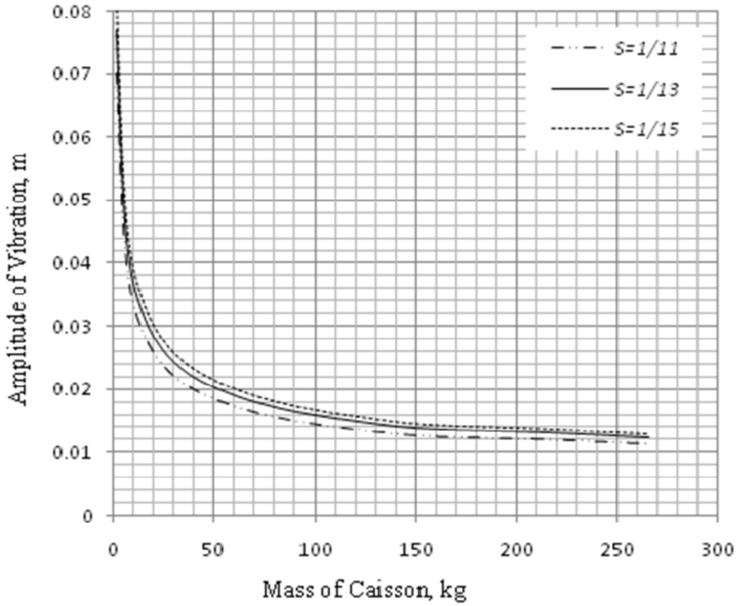

Fig. 46: Amplitude of Horizontal Vibration versus Mass of Caisson

- **Vertical vibration of suction caissons in floating structures offshore Niger Delta**
    - (Ejezie, S. U. and B. Kabari (2011))

The vertical vibration and dynamic stability of suction caissons used as anchors for deepwater floating structures were investigated using the same approach as for the lateral vibration discussed earlier. Load conditions corresponding to variable wave steepness were examined, while geotechnical characteristics typical of the Niger Delta offshore were again considered for different caisson geometry (sizes). The *Diffraction theory,* which is normally applicable for computation of wave forces on large floating structures, was used here to determine the forces. Results obtained from analyses (Figs. 47-49) showed again that with increasing mass of caisson the amplitude of vibration decreases while the induced dynamic force on the surrounding soil increases. From the point of view of economy this observation is important because it establishes the maximum size of caisson to be used in any particular situation.

Beyond a certain magnitude of caisson mass however, it is observed again that there was no further significant decrease in the amplitude of vibration.

Another important observation was that there is appreciable reduction in the amplitude of vibration when several smaller units of suction caissons are used instead of a single massive unit as observed for lateral vibration. Amplitudes of vibration of groups of 2, 4, 6, 10 and 20 caissons units are respectively observed to be of the order of 67, 41, 32, 23 and 23% of the amplitudes of vibration of the corresponding single massive units. Beyond a certain maximum equivalent number of caissons, there is no further reduction in the amplitudes of vibration of the units.

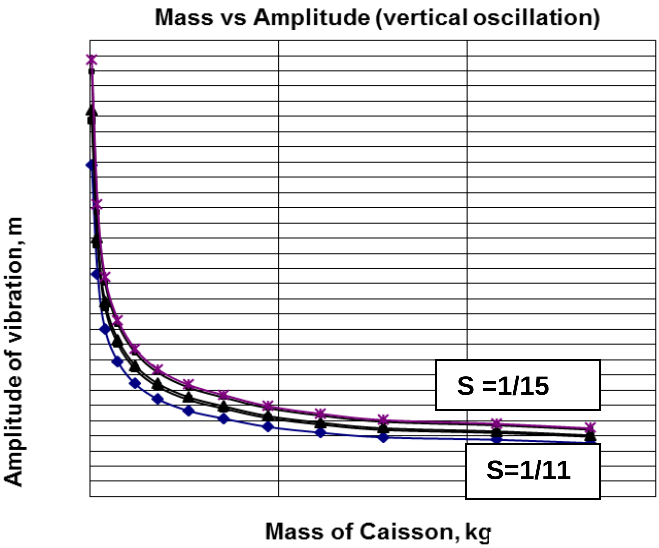

Fig.47: Mass vs. Amplitude of Vibration

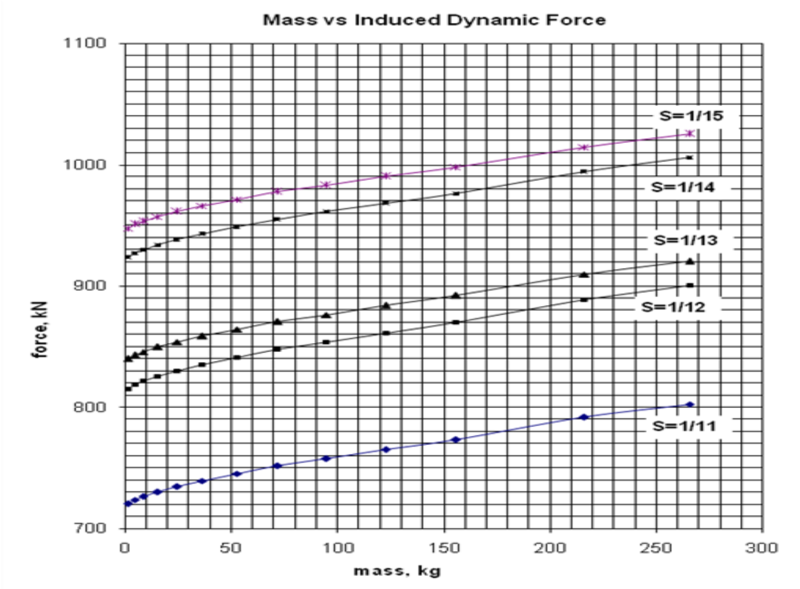

Fig. 48: Mass vs. Induced Dynamic Force

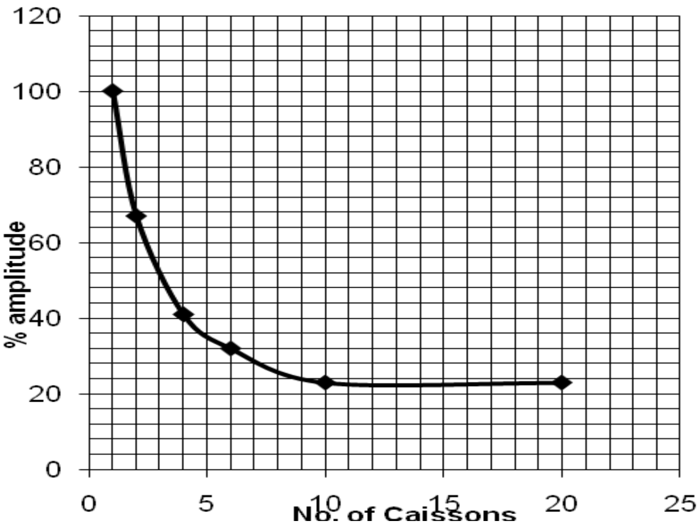

Fig. 49: Number of Caissons vs. Amplitude of Vibration (%)

- **Moment- Induced Displacement of Offshore Foundation in the Niger Delta**

– Ejezie, S. U. and S. Akpila (2011)

The rotational displacement of offshore shallow foundations on clay due to moment loading was studied in the Niger Delta Environment. Wave characteristics were deduced from available meteorological and oceanographic data while moments were evaluated from horizontal forces which impact on circular piles of 1.0-2.0 m diameter. The rotational displacement on an equivalent square foundation breadth B ranging from 9.9 m to 17.73 m, typical of circular foundation diameters of 10-20 m, was subsequently evaluated. Undrained shear strength s_u, of the sub-seabed (Fig. 50) was obtained from both field and laboratory tests.

It was observed, as shown in Figs. 51-53, that rotational displacement $\theta_{m1,}$ reduces with increase in foundation breadth B, and Poisson ratio for a given applied moment M. It also reduces as M/B ratio reduces with increasing μ. A dimensionless plot of the ratio of moments to undrained shear strength, foundation breadth and rotational displacement gave values of 18.66 and 37.33 at $\mu = 0$ and 0.5 respectively.
The generated graphs can be used as preliminary predictive tools in assessing the performance of offshore foundations on clays under wave loading in the Niger Delta.

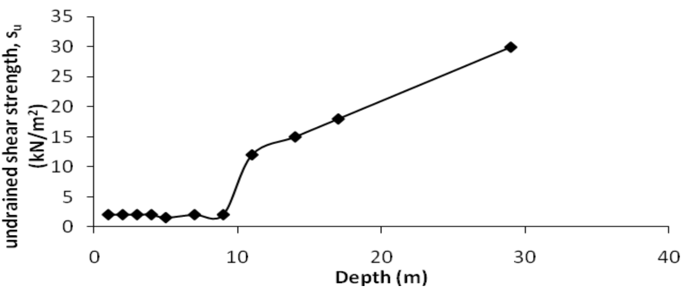

Fig. 50: Variation of undrained shear strength, s_u with Depth

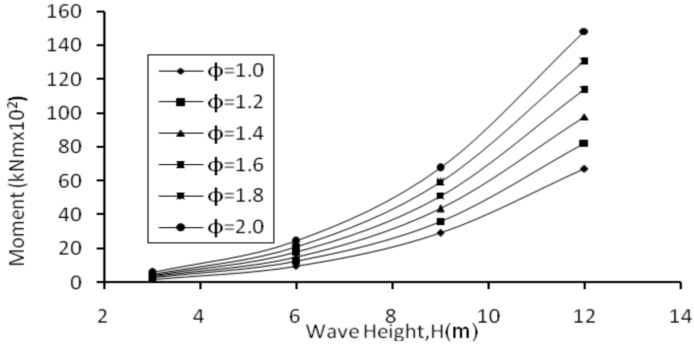

Fig. 51: Variation of moment, wave height and pile diameter.

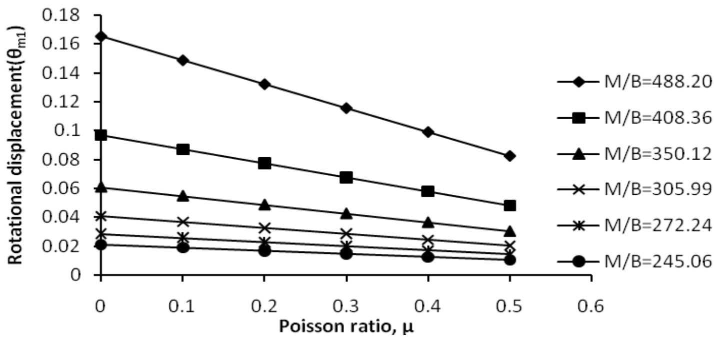

Fig. 52: Typical moment load and rotational displacement.

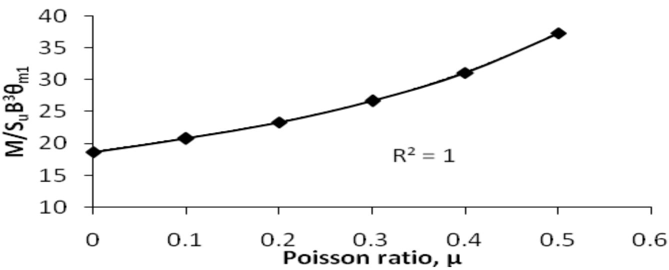

Fig. 53 : Moment loading of Foundation

- **Probabilistic Methods in the Stability Analysis of Earth Retaining Structures**

– Ejezie, S. U. and T. Njoku (2010)

The uncertainty and variability associated with soil parameters are conventionally accounted for in practice by the adoption of point estimates of parameters, with the estimated values reflecting the engineer's confidence level in the observed data. This approach is rather simplistic and falls short of providing enough information on the bulk of available data. The statistical and probabilistic method of analysis is a rational and systematic approach that recognizes the variability of soil properties and provides reliable estimates of soil parameters for design purposes. For homogeneous and slightly heterogeneous soils, the mean value of the parameters from probabilistic analysis compares favorably with single value estimates obtained from conventional soil analysis.

Reliability assessment of the stability of a retaining wall located in a project area of slightly heterogeneous soils in the Niger Delta region has been carried out using rigorous analytical methods and Microsoft – Excel spreadsheet optimization. The two approaches produced fairly similar results for parameters obtained from conventional and probabilistic soil analysis. On this basis, it is therefore affirmed that parameters derived from conventional analysis of samples of homogenous and slightly heterogeneous soils are adequate for design. Hence, there is no need to embark on the rigorous and complex probabilistic analysis, particularly in projects of moderate scale. This may only be necessary in large scale projects and in sites where soils exhibit pronounced heterogeneity. The spreadsheet-based reliability analysis however exhibits versatility and is recommended as a convenient analytical tool in the stability analysis of retaining walls. Its ability to explicitly reflect the correlation, standard deviation, probability distributions and sensitivities and to automatically seek the most probable failure combination of parametric values for any case under consideration gives it an edge over other methods of analysis.

5.0 CONCLUDING REMARKS

Vice-Chancellor Sir, each time I momentarily tried meditating on what I have been saying this past hour or so I felt like someone singing a unique engineering anthem. "Unique" because it sounds more like a newly composed and adopted rebranding hymn which both Engineers and non-Engineers are compelled to chant with the same degree of enthusiasm. Indeed, a professional anthem without discipline boarders! And almost instantaneously I realised that this forum is appropriate for chorusing this anthem because it is for the good of humanity and there is no alternative way to communicate the message. Moreover, the benefits accruable from the singing are worth the effort as summarised subsequently.

5.1 The Niger Delta and Nigeria's Coastal Region

The Niger Delta, in its present form, contains a thick sedimentary accumulation with environments of deposition ranging from non-marine to deep water. Available geological information puts the sediment thickness at about 12.5 km, representing a sequence of under-compacted marine clays, overlain by mixed deposits which, in turn, are overlain by continental sands and gravels.

The coastline is dominated by relatively calm shallow waters. The edge of the continental shelf extends to about 300 Nautical Miles from the coast. The average water depth for most of this stretch is generally not more than 100 metres. This is relatively small compared to the more than 3,000 metres (3 kilometres) water depth below which the multi-national oil companies are currently producing oil and gas off the Gulf of Guinea – in Nigeria's coastal waters. In fact, when one listens to the various accusations of difficult terrain frequently levelled against the Niger Delta, one would feel the urge to quickly and unequivocally affirm that the prevailing terrain is not bad at all as a price for the resources underneath.

5.2 Potentials of Geotechnical Engineering in the Development of the Niger Delta Region

Vice-Chancellor Sir, my distinguished audience; I have navigated through Geotechnical Engineering with you. I have told you what Geotechnical Engineering is (I do not know what it is not!). In particular, I have made it known that Geotechnical Engineering is that engineering discipline that transforms the so-called "uninhabitable land" into a flourishing residential estate. It is a unique discipline that offers a unique service namely, it "enables you to build your house on any land available to you irrespective of the site condition".

For a long time there has been persistent outcry, even by impartial observers, over the lack of development or apparent neglect of the Niger Delta. The hope for a solution was however enkindled some years ago with the setting up of Commissions and Agencies, and even Ministries to drive the process. One had expected that after all these years the vast swamps ought to have been transformed into dry lands! The "shallow" waters surrounding the crowded riverine communities ought to have been made to recede to allow the communities room for expansion. Road transportation within and between all communities in the Niger Delta would have been taken for granted! After all these years the so-called Master Plan for the development of the Niger Delta should have been transformed from dream to reality. By now the Niger Delta ought to have become a tourist destination in the world!

Unfortunately, these are still mere fantasy. But why have they remained unrealisable despite the non-existence of any natural hazards or inhibitors? This question, Vice-Chancellor, does not have a unique answer. Different people surely have their diverse views depending on their persuasions. Some may even quickly retort: "Because this is Nigeria"! – An answer that is probably more complex than the question itself.

On my part, I will simply answer in a manner that suits this occasion – And that is: "The cornerstone" aka "the Facilitator" of development of difficult ground environments may not have been given the opportunity to drive the process. By this I am positing that geotechnical engineering frontiers should be invoked and fully mobilised to develop and transform the Niger Delta. This has worked in many countries of the world – South Korea, Japan, United States of America, The Netherlands, Norway, to mention but a few. Back home, the same geotechnical engineering was the unsung hero in the development of Lagos! The magic can be replicated in the Niger Delta. In fact, a megacity of at least the size of Abuja or Lagos is long overdue for the

Niger Delta Region. This could integrate riverine and upland communities and eliminate unhealthy dichotomy – a panacea for conflict resolution.

5.3 Conclusion

Vice-Chancellor Sir, we build on the surface of the earth! We build in the subsurface of the earth! We use earth as construction material! The output is the built environment comprising the beautiful cities around the world adorned with complex structures – the sky scrapers competing for height supremacy (with BurjKhalifa in Dubai recently emerging as current champion), the long-spanning bridges crossing large water bodies, and the sophisticated underground transportation network of tunnels, in all types of soil and rock.

These marvellous works of human hands are attributable largely to the ingenuity of Geotechnical Engineers. Through the correct application of the principles and practice of geotechnical engineering almost every piece or parcel of land anywhere can be made habitable. Where the ground is weak and soft the Geotechnical Engineer designs appropriate foundation modification and adopts suitable soil and site improvement techniques to ensure the safety of the structure from failure.

Geotechnical Engineering has effectively demystified “Building Failures” by revealing the potential causes, properly directing the investigation process, and proffering preventive measures. Although some people may, out of ignorance, ascribe failures to unscientific superstitious beliefs, the fact remains that geotechnical engineering principles and procedures can guarantee your building safety even on difficult ground if strictly adhered to. And this adherence is the only acceptable option in the modern world. I have demonstrated the potency of this assertion through my outstanding works in this discipline which include the following achievements:

- Developed a classification scheme for the humid tropical soils of Nigeria, and frameworks for predicting the engineering performance and in-situ shear strength of the soils.
- Developed innovative solutions for typical foundation engineering problems in parts of the Niger Delta
- Developed solutions for mitigating soil-structure interaction problems and environmental hazards resulting from induced ground

vibrations associated with deep foundation construction (pile driving) and use of explosives.

- Developed models for the engineering behaviour of soils and prediction of soil responses to dynamic loading, including pore pressure, strength, and deformation models.
- Developed innovative failure analysis and design concepts for geotechnical structures which have been successfully applied to coastal protection works and slope failure mitigation works in various parts of the Niger Delta.

On the whole, my contributions to geotechnical engineering as captured in the research and field activities summarised herein have added appreciable impetus to the potential growth in awareness of the profession in the Niger Delta in particular, and Nigeria in general, in line with best practices around the world.

5.4 Recommendations

Vice-Chancellor Sir, the presentation so far, appears to incorporate most of the salient recommendations. Nevertheless, repetition would not be out of place because our subject matter concerns human lives and welfare. The following therefore are considered worthy of emphasis:

1. Every building construction must involve the services of a qualified Geotechnical Engineer right from inception. The common attitude of assuming that "Nothing will happen" should be jettisoned because prevention of building failure is orders of magnitude cheaper than cost of failure.
2. The Government should directly get involved in fighting quackery in Geotechnical Engineering Practice, preferably by enacting and enforcing appropriate legislation or amendment of existing ones to make the Engineering Regulating Body more effective in check-mating quacks. This has become very necessary because human lives are at stake. A defect in any part of the substructure would most likely result in total collapse of the entire building, with the usual unpleasant consequences.
3. Developers, both private and corporate, should always ask for evidence of "licence to practice" before patronising anybody who shows up as a Geotechnical Engineering Consultant as some people,

for pecuniary gains, claim to be experts in the profession even though they barely have awareness.

4. Developers should always insist on witnessing, first hand or through reliable representatives, the progress of site-specific geotechnical investigation work carried out by the consultant before accepting any report.
5. The Ministries charged with housing and urban development and approval of building plans should liaise with COREN, NSE and Geotechnical Division of NSE in particular to obtain reliable information on registered engineers in the Geotechnical Engineering discipline.
6. Extrapolation of results from one site to the other should be avoided as much as possible. This is because subsurface materials exhibit a high degree of variability both vertically and laterally and in both space and time. Whenever in doubt, consult your qualified Geotechnical Engineer.
7. The critical nature of geotechnical engineering calls for dedicated research and development to guarantee improved safety of our constructed facilities and also render our environment habitable. The University of Port Harcourt has taken the lead, as usual, by establishing a Centre for Geotechnical and Coastal Engineering Research. It is hoped that when fully operational, this Centre would be a referral Centre of Excellence for all Geotechnical and Coastal Engineering problems in the sub-region. It is highly recommended that all who need Geotechnical Engineering services, both in research and practice should patronise the Centre.

Finally, Vice-Chancellor Sir; Distinguished audience;
In consonance with the famous chorus by the brilliant song writer:

- **"I'll always set my house on a solid foundation!" (***Why?)*
- **"I know a man who loved to love high.**
- **He built his castle near up to the sky.**
- **Through summer and spring it stood pretty well.**
- **When winter winds whistled it toppled and fell".**

And I don't want to be like him; and would not advise anybody to be either!!!

Thank you for your attention.

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CITATION

OF

Professor Samuel Uchechukwu Ejezie

BSc (Ibadan), MS (Cornell), PhD (Carnegie-Mellon), R. Engr. (COREN), *FNSE, FNICE, FNGA, M.ISSMGE, M.ASCE, M.DFI, M.Sigma Xi;*

Professor of Civil and Geotechnical Engineering;
Enoch George Distinguished Professor of Geotechnical Engineering;
Director, Centre for Geotechnical and Coastal Engineering Research;
Dean, Faculty of Engineering, University of Port Harcourt (2011 – 2013);
Vice-President, International Society for Soil Mechanics and Geotechnical Engineering, (2009 – 2013).

Samuel Uchechukwu Ejezie is a Professor of Civil & Geotechnical Engineering at the University of Port Harcourt, Nigeria. He was born at Idima Autonomous Community (formerly a village in Osina) in Ideato North Local Government Area of Imo State into the family of Mr. John Ogidi Ejezie and Mrs. Stella Esonwanne Ejezie (nee Anozie), both of blessed memory.

His early education was marked with brilliant and outstanding performances at every stage. He passed his First School Leaving Certificate Examination with Distinction and attended the famous Government Secondary School, Afikpo where he won the highly coveted “School Scholarship” Award for the entire duration of his stay in the school, including the Higher School. He passed the West African School Certificate (WASC) Examination in Division One and the Higher School Certificate (HSC) Examination at Principal Level in Mathematics, Physics, and Chemistry.

He had his undergraduate education at the University of Ibadan, where he again won the prestigious “Shell Scholar” Award for academic excellence. He subsequently graduated as the best student of his set in 1977 with Second Class Honours Upper Division. After his NYSC in 1978, he took up employment as a Graduate Assistant with the University of Port Harcourt. In 1979 he proceeded to the United States of America for his Post Graduate studies under the university’s “Staff Development Award”. He got his Master’s Degree in Civil Engineering from Cornell University, Ithaca, New York, in January 1982; and his PhD in Civil Engineering from Carnegie – Mellon University in Pittsburgh PA, in 1984.

On completion of his studies, Samuel worked for GAI Inc. of Monroeville, PA, USA as a Senior Engineer II before returning to Nigeria. He resumed duty at the University of Port Harcourt in the then newly established Department of Civil Engineering where, presently, he is very active as a Professor of Civil and Geotechnical Engineering. He is the **Holder of** the newly endowed **Enoch George Professorial Chair in Geotechnical Engineering and** was recently appointed **Director,** of the **Centre for Geotechnical and Coastal Engineering Research.**

In addition to his normal duties here, he has, at various times, also served the neighbouring Rivers State University of Science and Technology, PH and the Federal University of Technology, Owerri either as a part-time or Adjunct Professor. Between 1999 and 2011 he served as a Training Consultant to Shell Petroleum Development Company of Nigeria Limited and a Lecturer at the Shell Special Intensive Training Programme for university graduates (SITP/1).

Professor Ejezie has made outstanding contributions to Engineering Education in the university system in Nigeria. He developed the undergraduate (B. Eng) and post-graduate (M. Eng& PhD) Civil and Geotechnical Engineering curricula currently being run in the University of Port Harcourt. He has supervised several Undergraduate, Masters and PhD students in the course of his university teaching career and many more are currently working under him. He is as external examiner for both undergraduate and post-graduate programmes in different Nigerian as well as other African universities. He is also serving as Professorial Assessor for universities in Sudan, Ghana and Nigeria.

Professor Ejezie has made an indelible mark in the University of Port Harcourt through his outstanding services in several academic and administrative capacities. He was the founding Coordinator of the Post HND B.Eng Degree Programme in the then Faculty of Engineering from 1987 to 1991 and later, Coordinator of the Master of Engineering Management Programme. He was Head of the Department of Civil Engineering (including when it was Department of Civil and Environmental Engineering) for a record three times!, and each tenure was marked by remarkable improvements in the Department. He was Dean of the Faculty of Engineering from 2011 to 2013, during which period the Faculty witnessed substantial improvement and an all-time high rating.

Besides direct academic responsibilities, his services also extended to other arms of the University. He was a member of Board of the University Demonstration Secondary School in the late eighties to early nineties and served as Chairman of the Board's Appointments and Promotions Committee. He was Coordinator of the Students Industrial Work Experience Scheme (SIWES) and later, Director after transforming the Unit into a Directorate. He was the Founding Chairman of the now-defunct Students Work-study Programme, an organ used by the University to help indigent students and check restiveness. He has at various times served as member of University Appointments and Promotions Committee (Academic), Development Committee, Housing Committee, and Publications Committee, to mention but a few. At present he is Chairman of the Staff Training and

Development Unit (STADU) Committee and a **Member of the Governing Council of the University of Port Harcourt as a Senate Representative.**

This loaded schedule of responsibilities did not debar Professor Ejezie from religiously pursuing his intellectual goal namely, academic research. His principal areas of interest include

- Foundations in difficult ground conditions,
- Soil dynamics,
- Earth structures and embankments,
- Soil-structure interaction,
- Offshore Geotechnical Engineering,
- Reliability and Probabilistic Designs of geotechnical systems and
- Robotics and Expert Systems.

He has authored several papers for journals, edited conference proceedings, seminars and workshops. He is well-known internationally in the field of Soil Mechanics and Geotechnical Engineering.

On the industrial scene, Prof. Ejezie has been active as a Consulting Civil and Geotechnical Engineer in Nigeria since his return to the country. He has handled several projects for major oil companies, construction firms, government departments, and private industrial establishments and these provided the highly-desired exposure to hands-on experience for students working under him. He has written more than 300 Technical reports from his consulting engagements.

In professional activities, Prof. Ejezie is a COREN Registered Professional Civil & Geotechnical Engineer. He is a **Fellow** of the Nigerian Society of Engineers (NSE), **Fellow** Nigerian Institution of Civil Engineers (NICE) and **Fellow** Nigerian Geotechnical Association (NGA). He served as Acting Chief Examiner for COREN in the Port Harcourt zone from 2004 to 2008. He is currently a member of both the Council and the Executive Committee of Nigerian Society of Engineers, Chairman of Geotechnical Engineering Division, and member of Professional Development Board of the Society. He is also a member of several international professional bodies, including Deep Foundations Institute (DFI), American Society of Civil Engineers (ASCE), Sigma Xi and the **International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE), which he served as Vice-President for Africa for the Term 2009 – 2013.**

Prof. Ejezie is blessed with five children namely: Engr. (Mrs.) Ijeoma Winifred Anusiem, Nee Ejezie (a Senior Civil Engineer with Texas State Department of Transportation, Houston, Texas, USA); Mr. Francis Uchechukwu Ejezie (Post-Graduate Student, Texas A&M University, Corpus Christi, Texas, USA); Engr. John Okechukwu Ejezie (PhD Student, University of Manchester, UK); Miss Chinenye Lynette Ejezie (Post-Graduate Student, Texas A&M University, College Station, Texas, USA); Miss Chinwendu Rose Ejezie (Human Resources Consultant, Austin, Texas, USA); and a granddaughter, Miss Munachimso Anusiem (Houston, Texas, USA).

Vice-Chancellor Sir, Distinguished ladies and gentlemen,
I present to you an erudite Professional Engineer;
A Professor of Civil and Geotechnical Engineering;
A Fellow of the Nigerian Society of Engineers;
A Fellow of the Nigerian Institution of Civil Engineers;
A Fellow of the Nigerian Geotechnical Association;
Former Head, Department of Civil and Environmental Engineering;
Former Dean, Faculty of Engineering;
Former Vice-President of the International Society for Soil Mechanics and Geotechnical Engineering;
Enoch George Distinguished Professor of Geotechnical Engineering;
Director, Centre for Geotechnical and Coastal Engineering Research;
Member, University of Port Harcourt Governing Council;
The Ariri-Eri-Mba of Idima and Osina Autonomous Communities;
I present to you a Renowned Consulting Geotechnical Engineer,
Engineer Professor Samuel Uchechukwu Ejezie.

Professor Adewale Dosunmu