FEDERAL UNIVERSITY OF TECHNOLOGY MINNA

THE ROLE OF GEOTECHNICAL ENGINEERS IN THE STABILITY AND SUSTAINABILITY OF CIVIL INFRASTRUCTURE IN A GROWING ECONOMY

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INAUGURAL LECTURE SERIES 117

THURSDAY 28TH AUGUST, 2025

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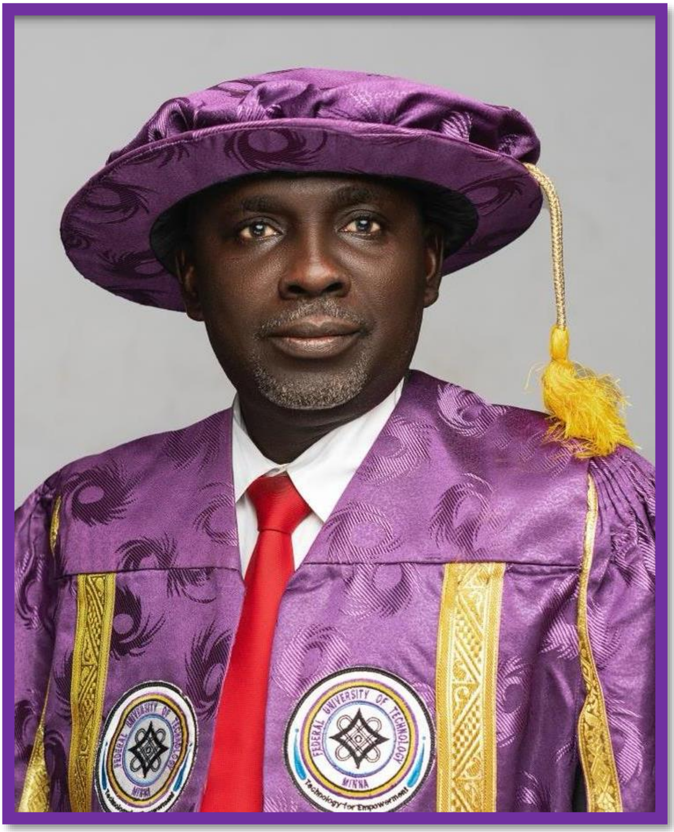

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PREAMBLE

In the name of the only potentate, the eternal and the immortal God the Almighty, I feel highly privileged to stand here today to deliver the 117th Inaugural Lecture of Federal University, Minna.

Mr. Vice-Chancellor, other principal officers, members of the University community and distinguished guests. The theme of today's lecture is "*The role of geotechnical engineers in the stability and sustainability of civil infrastructure*". It provides an overview of the pivotal role of geotechnical engineers in ensuring the functionality, stability, and sustainability of civil infrastructure in a growing economy. It covers fundamental concepts, challenges, economic implications, case studies, future directions, and concludes with a call for collaboration and investment in this critical field towards meeting the sustainable Development Goal (SDG) 9 (Industry, Innovation and Infrastructure) of Agenda 2030 and Goal 11 (Sustainable Cities and Communities) – for Agenda 2063 of the Africa we desire. Against this background, this presentation dwells on the critical roles played by geotechnical engineers on sustainable civil infrastructure in a growing economy like Nigeria.

I.0 INTRODUCTION

Is soil so important? What do we gain by studying the mechanics of soil? Every structure, especially civil infrastructure is built on the soil. Therefore, knowing their properties in order to understand their behaviour under built infrastructure loading conditions is a key to the functionality, stability and sustainability of such infrastructure. So, what are *Infrastructure projects*? Infrastructure are projects such as high-speed railways, port construction, long-span bridges, tunnels, and hydropower projects, provide essential public services for social development and citizens' lives (Morris *et al*., 2011). Sustainable infrastructure is infrastructure that delivers long-term economic, social, and environmental (ESE) benefits. It is critical to achieving global climate targets and Sustainable Development Goals, and to a strong and resilient global economy. This lecture is on the role of geotechnical engineers in the stability and sustainability of civil infrastructure in a growing economy

1.1 Engineering:

Engineering, being a vast and multifaceted field, is often explored through specific branches or applications in academic works. According to Aguwa (2021), the American Accreditation Board for Engineering and Technology (AABET) provides one of the most widely accepted definitions of engineering. AABET defines engineering as the profession that applies knowledge of mathematics and natural sciences, acquired through study, experience, and practice, to develop economical solutions to technical problems for the benefit of humankind.

Engineering has many branches such as Civil Engineering, Aeronautics (aerospace engineering), Mechanical Engineering, Electrical Engineering, Chemical Engineering, Computer Engineering, Biomedical Engineering, Industrial Engineering, Materials Engineering, Petroleum Engineering, Environmental Engineering, Nuclear Engineering, Agricultural Engineering, Marine Engineering, Mining Engineering and Software Engineering etc.

1.2 Civil Engineering

Civil engineering is a broad discipline encompassing several specialized areas. ***Structural engineering*** focuses on designing and analyzing structures such as buildings and bridges, while ***Geotechnical engineering*** deals with soil and rock behaviour. ***Transportation engineering*** involves planning, designing, and managing transportation systems. ***Water resources & environmental engineering*** concentrates on managing, developing, and conserving water resources. As one of the oldest engineering disciplines, civil engineering has evolved significantly since its inception over 2000 years ago and continues to expand its scope and impact.

According to Sadiku (2016), the term "civil engineering" was coined by John Smeaton in the 1770s, leading to the formation of the Smeatonian Society of Civil Engineers, the first known professional body in the field. The enduring impact of civil engineering is evident in ancient civilizations like Egypt, Rome, Greece, and China, where remarkable structures such as buildings, roads, bridges, and city walls were constructed and other hydraulic structures (Figures 1-2).

Figure 1: The Appian Way, Rome (MacDonald, 1994)

Figure 2: Cornalvo Dam, Wikipedia. (2023, August 30)

Today, the discipline continues to profoundly influence human life. As noted by Aguwa (2021), the training of civil engineers in various institutions worldwide has spurred the establishment of professional civil engineering associations, such as the Nigerian Institution of Civil Engineers, Nigerian Institution of Geotechnical Engineers, Nigerian Institution of Highway & Transportation Engineers, Nigerian Institution of Water & Environmental Engineers.

1.3 Geotechnical Engineering:

Geotechnical engineering is a specialized branch of civil engineering, which focuses on understanding and utilizing earth materials like soil and rock. By applying principles from soil and rock mechanics, geotechnical engineers address complex engineering challenges. Soil mechanics is a branch of engineering mechanics that describes the behaviour of soils. Soil mechanics provide the theoretical basis for analysis in geotechnical engineering.

Key areas within geotechnical engineering include soil mechanics, rock mechanics, foundation engineering, slope stability analysis, ground improvement techniques, and subsurface exploration. These fields are essential for designing and constructing safe and stable structures. A geotechnical engineer then determines and designs the type of foundations, earthworks and pavement subgrades required for the intended man-made structures to be built. Foundations are designed and constructed for structures of various sizes such as high-rise buildings, bridges, medium to large commercial buildings, and smaller structures where the soil conditions do not allow code-based design. Foundations built for above-ground structures include shallow and deep foundations. Retaining structures include earth-filled dams and retaining walls. Earthworks include embankments, tunnels and sanitary landfills.

Geotechnical engineering is also related to coastal and ocean engineering. Coastal engineering can involve the design and construction of wharves (structures on the shore of harbour where ships may dock to load and unload cargo or passengers) and jetties (structures that projects into a body of water to influence the current or tide or to protect a harbour or shoreline from storms or erosion)

Geotechnical engineers play a critical role in ensuring the safety and stability of various structures, such as buildings, bridges, tunnels, and dams. Their expertise is invaluable in mitigating risks associated with ground conditions and natural hazards

1.4 Roles of Geotechnical Engineering in contemporary society

Geotechnical engineers play a critical role in modern society by ensuring the safety and sustainability of built environments. Their expertise is essential in a wide range of projects.

Key roles of geotechnical engineers include:

- **Site investigation and assessment:** Conducting thorough investigations to understand subsurface conditions, including soil and rock properties, groundwater levels, and potential hazards (Figure 3).

Figure 3: Geotechnical Engineer on Site Investigation (Source: Omnia Consulting)

- **Foundation design:** Designing appropriate foundations for structures based on soil and rock characteristics, ensuring stability and preventing settlement (Figure 4).

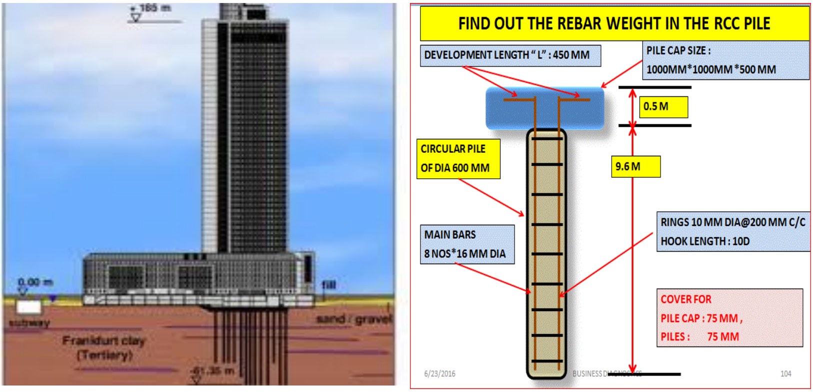
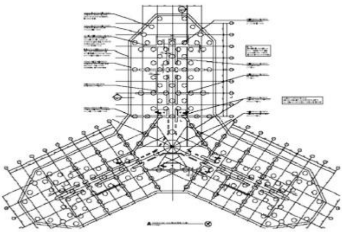


Figure 4: Innovative foundation systems for high-rise buildings (Quick *et al*.,2019)

- **Slope stability analysis:** Assessing the stability of slopes, such as hillsides and embankments, to prevent landslides and erosion; embankments, to prevent landslides and erosion (Figure 5).

Figure 5: Landslide

- **Ground improvement:** Developing and implementing techniques to improve soil conditions for construction purposes, such as compaction, grouting, and soil reinforcement (Figure 6).




Plan Foundation

Figure 6: Burj Khalifa, U.A.E (Danjuma *et al*., 2023)

- **Environmental geotechnical engineering:** Addressing environmental concerns related to soil and groundwater contamination, remediation, and waste disposal.

Figure 7: Oil spills in Nigeria

Figure 8: Open dumpsite in Nigeria

- **Natural hazard assessment:** Evaluating the potential impact of earthquakes, floods, and other natural hazards on structures and infrastructure.

Figure 9: Collapse of Building during Earthquake

- **Offshore geotechnical engineering:** Supporting the development of offshore structures, such as wind turbines and oil platforms, by understanding seabed conditions.

1.5 Challenges of Infrastructure Development in Nigeria: The Influence of Soil Conditions

Nigeria, like many developing nations, faces significant challenges in infrastructure development. A critical factor hindering progress is the complex interplay of various factors, with soil conditions emerging as a particularly formidable obstacle.

The intricate nature of Nigerian soils. The intricate nature of soil poses a substantial challenge to infrastructure development and sustainability. The country's diverse geological formations give rise to a wide range of soil types, each with its unique characteristics and engineering properties. From expansive clays to lateritic soils and coastal alluvium, the variability in soil behaviour presents significant difficulties for engineers and construction professionals.

The implications of these complex soil conditions are far-reaching. Foundation failures, structural instability, and premature deterioration of infrastructure are common consequences. Roads, bridges, buildings, and other critical assets are susceptible to damage due to factors such as differential settlement, erosion, and bearing capacity issues. These problems not only lead to economic losses but also pose significant safety risks.

Figure 10: Lagos Building Collapse

Geotechnical engineers play a pivotal role in safeguarding Nigeria's infrastructure by assessing subsurface conditions, designing appropriate foundations, and implementing sustainable solutions, thereby ensuring the functionality, stability, and longevity of the nation's-built environment.

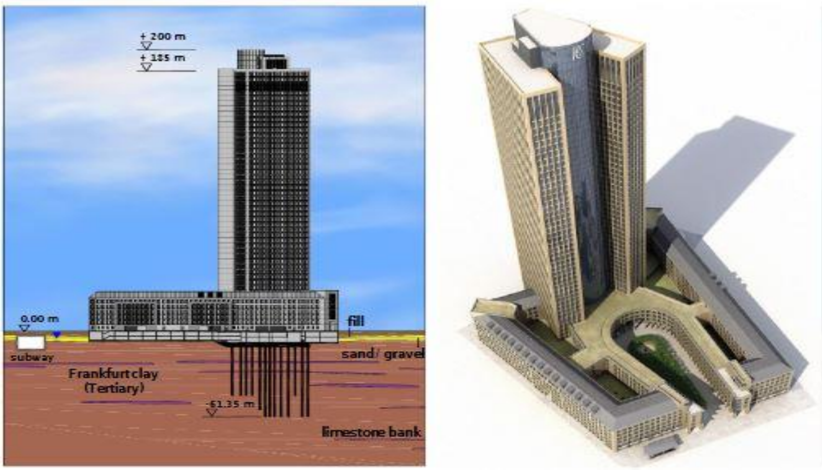


Figure 11: Innovative foundation systems for high-rise buildings (Quick *et al*.,2019)

2.0 SOIL CONDITIONS IN NIGERIA

Nigeria is characterized by a diverse range of soil types, each with distinct properties and engineering behaviours.

- **Lateritic soils:** These are highly weathered soils prevalent in the southern regions. They exhibit high clay content, expansive properties, and low bearing capacity, posing significant challenges for infrastructure development.

- **Black cotton soils (vertisols):** Found predominantly in the northern parts of the country, these soils have high plasticity, shrink-swell potential, and low strength, making them problematic for foundations and pavements.
- **Sandy soils:** Common in coastal areas and parts of the northern region, these soils offer good drainage but can be susceptible to erosion and liquefaction.
- **Alluvial soils:** Deposited by rivers and found in river valleys, these soils vary in composition but often exhibit high compressibility and low strength.

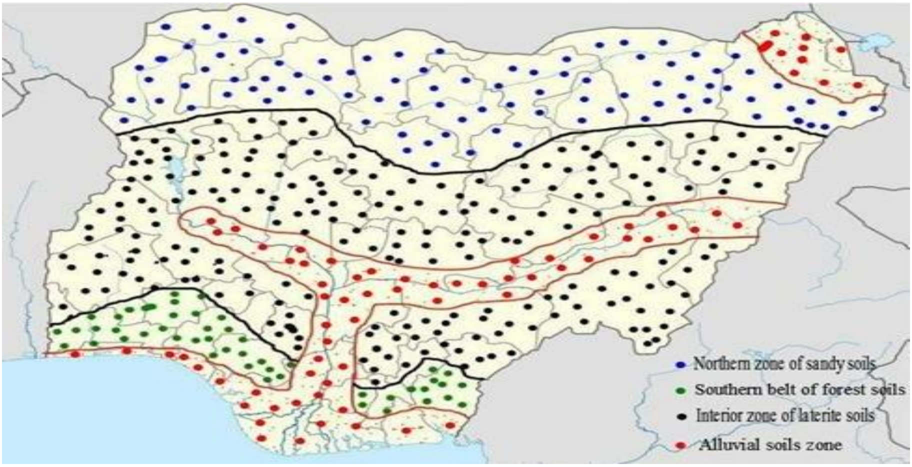


Figure 12: Soil types in Nigeria (Source: Oke *et al.*, 2021)

2.1 **Challenges Posed by These Soils**

Nigeria's diverse soil profile presents significant challenges for infrastructure development. As highlighted in studies by Alhassan, **Adejumo** and Boiko, I. L. (2012), the classification of subsoil bases in Nigeria reveals a complex interplay of soil types with varying bearing capacities and settlement characteristics. The subsequent work by **Adejumo** *et al.* (2012) on the physio-mechanical properties of weak soils provides further insights into the specific challenges posed by these materials.

Lateritic and black cotton soils, identified as prevalent and problematic in both studies, exhibit high shrink-swell potential, leading to structural damage. The low bearing capacity characteristic of many Nigerian soils, as emphasized in both research efforts, necessitates extensive foundation design and construction. Additionally, sandy soils are susceptible to erosion, and the differential settlement caused by varying soil properties compound the infrastructure development challenges faced by the nation.

Figure 13: Nnewi-erosion

Figure 14: Landslide along marina road, Calabar

Figure 15: Lagos building collapse

Figure 16: Enugu-collapsed-bridge

3.0 FOUNDATION DESIGN AND CONSTRUCTION

3.1 Importance of Foundation Design

A well-designed foundation is the cornerstone of any stable structure.

It transfers the building's loads safely to the underlying soil. In regions with challenging soil conditions like Nigeria, proper foundation design is paramount to prevent structural failures, ensuring the building's longevity and safety.

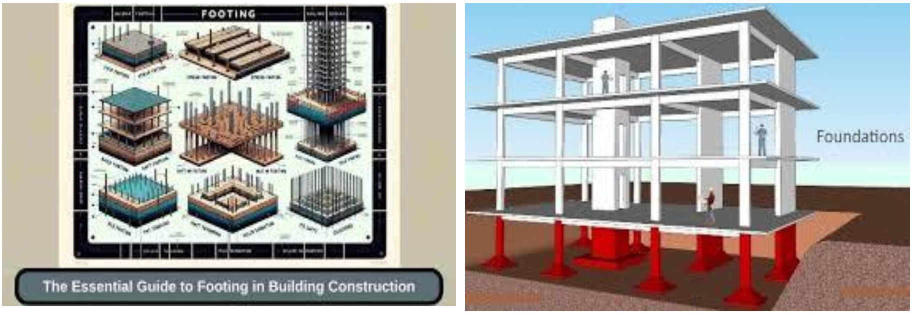


Figure 17: Footing in Building Construction

3.2 Pile Foundations as a Solution

Pile foundations are often the preferred choice for structures built on weak or unstable soils. They transfer loads to deeper, more competent soil layers. In Nigeria, where many areas have expansive or low-bearing capacity soils, pile foundations are essential for supporting heavy structures such as high-rise buildings, bridges, and industrial facilities. By transferring loads to deeper, more stable soil layers, pile foundations mitigate the risks associated with differential settlement, heave, and foundation failures.

Adejumo (2013) carried out comprehensive laboratory investigations on conditioned clay in order to analyze its behaviour in relation to settlement, deformation pattern and response to incremental loading under axially loaded modelled wooden prototype piles.

Figure 18: Prototype foundation test in Test tank

Table 1: Some Geotechnical Properties of the Clay Sample

Parameters	Modelled strong clay (γ = 19 kN/m^3, w =10%)	Modelled weak clay (γ = 17 kN/m^3, w = 20%)
Specific gravity of solids	2.66	2.61
Liquid Limit (%)	23	24
Plastic Limit (%)	17	18
Plasticity Index (%)	6	6
Liquidity Index (%)	IL < 0	0.3
Void ration (e)	0.51	0.84
Cohesion (kPa)	20	0
Relative consistency	2.32	2.38
Angle of internal friction (φ^o)	25	33
Modulus of Deformation E (kPa)	8.5	5.4

Table 2: Ultimate Bearing Capacity of prototype piles in modeled soil conditions

Pile Foundation Prototype shape	**Ultimate Bearing Capacity (kPa)**			
	Model 1	Model 1	Model 1	Model 1
Circular shape	634	358	486	510
Square	640	365	495	516

Model 1- Modelled soil condition for strong clay

Model 2- Modelled soil condition for weak clay

Model 3- Modelled soil condition for weak on strong clay

Model 4- Modelled soil condition for reinforced weak clay

3.3 Case studies: Pile Foundation and Installation Methods in Nigeria

Lagos Third Mainland Bridge: As one of Nigeria's busiest bridges, it is built on pile foundations to withstand heavy traffic loads and the challenging soil conditions of the Lagos lagoon.

Figure 19: Lagos Third Mainland Bridge

High-Rise Buildings in Lagos: Given the city's rapid urbanization and soft soil conditions, many high-rise buildings rely on pile foundations. Case studies of successful projects could highlight the challenges faced, the foundation solutions implemented, and the long-term performance of these structures.

Figure 20: Eko White Pearl Tower, Lagos: Height 443 ft: 31 floors

Oil and Gas Platforms: The offshore oil and gas industry in Nigeria heavily relies on pile foundations for platform stability. Case studies of successful platform installations could showcase the engineering challenges and solutions employed in these complex environments.

Figure 21: Oil Installations platform in Nigeria

Crude oil Terminal in Nigeria

Infrastructure Projects in Challenging Terrain: Projects in areas with particularly difficult soil conditions, such as the Niger Delta or the North-Eastern regions, could provide valuable case studies. These projects would highlight the adaptation of pile foundation design to specific site challenges

Figure 22: Second Niger Bridge

4.0 INFRASTRUCTURE STABILITY AND SUSTAINABILITY

Geotechnical engineering is a vital discipline that underpins the functionality, stability, and sustainability of civil infrastructure. By understanding the principles of geotechnical engineering and applying them effectively, we can build infrastructure that is resilient, durable, and environmentally responsible. As Nigeria continues to grow and develop, the role of geotechnical engineers will become even more critical in shaping the nation's future.

4.1 Infrastructure Stability

The stability of infrastructure is essential for its long-term performance and safety. Geotechnical engineers contribute significantly to ensuring stability through:

- **Foundation Design:** Selecting suitable foundation types and depths to prevent excessive settlement and differential movement.
- **Slope Stability Analysis:** Identifying potential instability issues and implementing remedial measures to enhance slope stability.
- **Ground Improvement:** Strengthening weak or unstable ground conditions to improve structural support.
- **Earthquake Engineering:** Designing structures to resist seismic forces and minimize damage during earthquakes.

4.1.1 The Impact of Soil Contamination on Infrastructure Stability

Soil contamination, as extensively explored by **Adejumo** (2012), can have a profound impact on the stability and longevity of infrastructure. The study discuss how various contaminants can compromise the geotechnical properties of soil used in buildings, roads, bridges, and other civil engineering projects.

4.2 Mechanisms of Soil Contamination

Soil contamination can occur through a variety of sources, including:

- **Industrial activities:** Chemical spills, leaks, and improper waste disposal can introduce contaminants into the soil.
- **Agricultural practices:** Excessive use of pesticides, herbicides, and fertilizers can contaminate the soil.
- **Waste disposal:** Improperly managed landfills and hazardous waste sites can release contaminants into the surrounding environment.

- **Natural processes:** Geological processes, such as erosion and weathering, can release naturally occurring contaminants into the soil.

4.3 Impact of Soil Contamination on Infrastructure Stability

Contaminated soil can adversely affect infrastructure stability in several ways:

1. **Reduced Soil Strength:** Many contaminants, such as organic compounds and heavy metals, can weaken the structural properties of soil. This can lead to reduced bearing capacity, increased settlement, and potential failure of foundations.
2. **Chemical Reactions:** Chemical reactions between contaminants and soil minerals can result in the formation of new compounds that may have deleterious effects on soil properties. For example, the reaction between acidic contaminants and carbonate-rich soils can cause dissolution of the carbonate mineralHKGJ s, leading to reduced soil strength.
3. **Corrosion:** Some contaminants, particularly heavy metals and salts, can accelerate the corrosion of metals used in infrastructure, such as steel reinforcement in concrete structures. This can compromise the structural integrity of these components and lead to premature failure.
4. **Environmental Hazards:** Contaminated soil can pose environmental hazards, such as groundwater contamination and soil erosion. These hazards can further exacerbate the impact of soil contamination on infrastructure stability.

4.3.1 Case Studies of Effect of soil contamination

Several case studies have highlighted the devastating effects of soil contamination on infrastructure. For example, in Love Canal, New York, the disposal of toxic waste contaminated the soil and groundwater, leading to health problems and property damage.

Similarly, the collapse of the Hyatt Regency walkway in Kansas City, Missouri, was attributed, in part, to the use of non-code-compliant connections that were susceptible to corrosion due to exposure to contaminated soil.

Figure 23: The Tragedy of the Love Canal

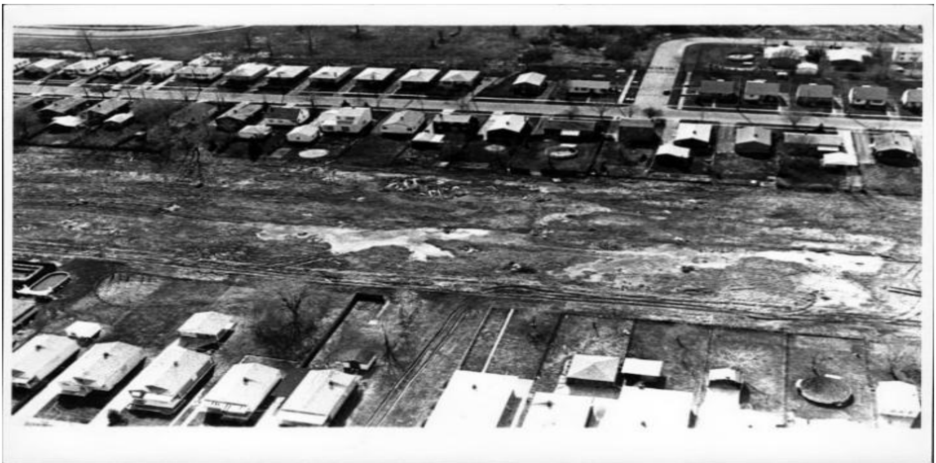


Figure 24: Oil Spill in Niger Delta

4.3.2 Mitigation Strategies

To mitigate the impact of soil contamination on infrastructure stability, it is essential to:

- **Conduct thorough site investigations:** Before construction, conduct thorough site investigations to identify potential contamination issues.
- **Remediate contaminated soil:** If contamination is detected, implement appropriate remediation techniques to remove or contain the contaminants.
- **Design for contaminated conditions:** If remediation is not feasible or cost-effective, design the infrastructure to accommodate the contaminated conditions, such as using deeper foundations or specialized construction materials.
- **Monitor and maintain infrastructure:** Regularly monitor the condition of infrastructure in contaminated areas and conduct necessary maintenance to ensure its long-term stability.

4.4 Infrastructure Sustainability

Sustainability is another critical aspect of infrastructure development. Geotechnical engineers can contribute to sustainable infrastructure by:

- **Resource Conservation:** Selecting materials and construction methods that minimize environmental impact.
- **Energy Efficiency:** Designing structures that optimize energy consumption, such as using energy-efficient materials and systems.
- **Climate Change Adaptation:** Incorporating measures to mitigate the effects of climate change, such as designing for extreme weather events.

- **Long-Term Performance:** Ensuring that infrastructure can withstand the test of time and maintain its functionality over its intended lifespan.

4.4.1 Sustainability Considerations in Geotechnical Engineering

Sustainability is increasingly becoming a critical factor in infrastructure development. In the context of geotechnical engineering, sustainable practices aim to minimize environmental impact, conserve resources, and ensure the long-term viability of projects.

- **Resource conservation:** Efficient use of materials and energy, such as recycling excavated materials and minimizing the use of virgin resources.
- **Environmental protection:** Minimizing the impact on ecosystems, water resources, and air quality.
- **Climate change adaptation:** Designing infrastructure to withstand the effects of climate change, including rising sea levels, extreme weather events, and changes in soil conditions.
- **Social and economic impacts:** Considering the social and economic implications of infrastructure projects, ensuring benefits are distributed equitably.

4.4.2 Specific strategies for sustainable geotechnical engineering include:

- **Green infrastructure:** Incorporating natural elements, such as green roofs and rain gardens, to improve environmental performance.
- **Soil stabilization techniques:** Using environmentally friendly methods to improve soil properties, such as bioremediation or the use of recycled materials.

- **Life cycle assessment:** Evaluating the environmental impact of infrastructure projects throughout their entire life cycle.
- **Community engagement:** Involving local communities in decision-making processes to ensure sustainable outcomes.

4.5 Role of Geotechnical Engineering in Nigeria's Development

Geotechnical engineering is a cornerstone of sustainable and resilient infrastructure development in Nigeria. By understanding soil behaviour, designing appropriate foundations, and implementing effective construction techniques, geotechnical engineers contribute significantly to the nation's progress.

From ensuring the stability of high-rise buildings to mitigating the risks posed by natural hazards, geotechnical engineering plays a vital role in safeguarding lives, property, and economic assets. By addressing the challenges posed by complex soil conditions, geotechnical engineers help to create a more sustainable and equitable future for Nigeria.

4.6 To further advance the field of geotechnical engineering in Nigeria, it is imperative to:

- **Invest in research and development:** Support ongoing research to improve our understanding of soil behaviour and develop innovative solutions.
- **Foster collaboration:** Encourage collaboration among academia, industry, and government agencies to share knowledge and resources.
- **Develop capacity:** Invest in training and education to build a skilled workforce of geotechnical engineers.
- **Promote sustainable practices:** Integrate sustainability considerations into geotechnical engineering projects to minimize environmental impact and ensure long-term viability

5.0 The Big Questions

5.1 Subsoil Classification and Characterization

5.1.1 Can we improve subsoil classification systems for Nigerian soils to better predict engineering behaviour?

The answer to this question is YES, the Sub soil classification system in Nigerian can be improved. the following are some concluded researches to support the answer. Alhassan et al., (2012), The paper presents classification of Nigerian subsoil bases. Numerous subsoil investigation reports from across the country were collected, studied and analyzed. The study laid much emphasis on the numbers of soil strata and the variation of their bearing capacities and settlement characteristics in relation to the types of foundations recommended in each of the reports. Based on the study and depending on the complexity of the soil strata, subsoil bases in Nigeria were grouped into three: Simple, Less Complex and Complex. Also, research by Adejumo *et al*. (2012) provides a valuable foundation for understanding the challenges posed by weak soils in Nigeria. By focusing on vertisols, Sokoto soft clay shale, and organic clay. The study's focus on the physio-mechanical properties of specific weak soil types provides valuable data for weak soils and their detailed characterization is a crucial step in developing a more refined classification system. By identifying the unique properties of these soils, we can establish parameters that better differentiate them and predict their engineering behaviour.

5.1.2 Key Findings and Implications

- **Soil Strata Complexity:** The classification system highlights the variability of soil strata across Nigeria, emphasizing the need for site-specific assessments.
- **Bearing Capacity and Settlement:** The study identifies variations in bearing capacity and settlement characteristics among different soil types, informing foundation design decisions.

- **Foundation Recommendations:** The research provides guidance on suitable foundation types based on subsoil complexity, aiding in the selection of appropriate engineering solutions.

5.2 Foundation Design and Construction

5.2.1 How can site investigation techniques be effectively employed to select suitable foundation types for various soil conditions in Nigeria? What factors influence the design and installation of pile foundations in Nigerian soils, and how can these factors be considered to ensure optimal performance?

6.0 MY CONTRIBUTIONS

6.1 Foundation types for various soil types

While not explicitly focused on site investigation techniques, research by **Adejumo** and Boiko (2012) provides insights into the types of investigations required for various soil conditions and foundation types.

The study presents a handy compendium and general overview of the state of pile foundation works in Nigeria which may hardly be found in any single volume or write up. It furnishes with a brief history of pile foundation construction in Nigeria, types of pile in use as well as installation methods mostly employed in pilling work for the construction of houses, bridges, roads, exploration platforms, ports, assembly plants, transmission tower bases and other projects, especially on weak soils in Nigeria. Depending on the terrain, use and finance, wooden piles, steel piles, reinforced concrete piles or combination piles known as composite piles have been used to supports various structures especially where the firm bedrock is far below the ground. **This research** offers a comprehensive overview of pile foundation practices in Nigeria, providing valuable insights into the types of piles used and installation methods employed. This research is particularly relevant to understanding the challenges and solutions associated with foundation design in Nigeria.

6.1.1 Key Findings and Implications

- **Pile Type Diversity:** The study highlights the use of various pile types, including wooden, steel, reinforced concrete, and composite piles, demonstrating the adaptability of pile foundations to different soil conditions and project requirements.
- **Installation Methods:** The research discusses the common installation methods employed in Nigeria, such as driving and boring, providing insights into their suitability for specific soil conditions and construction constraints.
- **Project Applications:** The paper outlines the wide range of projects utilizing pile foundations, including houses, bridges, roads, and industrial facilities.

Furthermore, Adejumo and Boiko (2013b) on pile foundation opined that driving installation techniques cause wider pulverization/ loosening, as a result of higher settlement of the soils around the piles and therefore results in lesser Capacity for the piles than in bored installation.

The unsuitability of vibratory hammer for driven or displacement piles could be responsible for the low resistance and hence bearing capacity of the piles than the piles installed by boring during the field tests. Boring installation technique displaces less soil in comparison with driving installation. A radial displacement of 2d and 3.5d from pile centerline were recorded for boring technique and driving technique respectively; where d is the pile diameter in millimeter.

The settlement at the middle of the instrumental piles was less for the driven installation, i.e. displaces more soils than boring installation which seems to mobilize less soil along the pile stems. Driving installation displaces more soils around the piles and therefore reduces the bearing capacity of the piles (by approximately 12 - 18%) in comparison with boring installation in a fully mobilized soil resistance and loading case as reflected in Plate

Figure 25: 200T capacity Jack for Loading

Figure 26: Boring during test

Figure 27: Dial Gauges for settlement reading

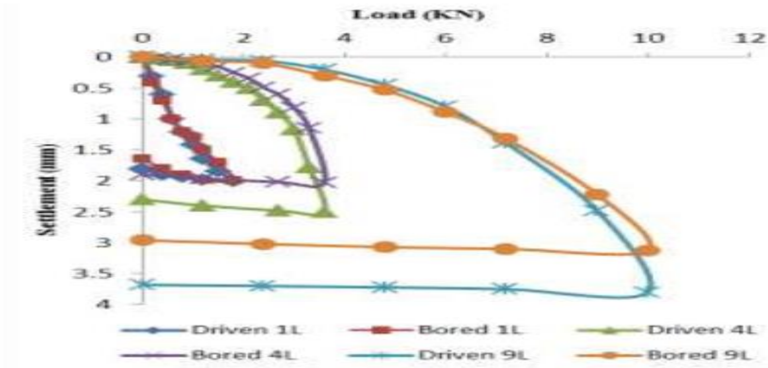


Figure 28: Load settlement curve

6.2 Pile foundation and Applications in Civil Infrastructure

Adejumo (2013b) provides valuable insights into the behaviour of pile groups in layered clay soils, a common geological condition in Nigeria. The research offers crucial information for the design and analysis of pile foundations in such environments.

6.2.1 Key Findings and Implications

- Pile Spacing and Settlement: The research demonstrates the influence of pile spacing on settlement, highlighting the importance of optimizing spacing to minimize differential settlements.

- Soil Layering: The study investigates the impact of layered clay soils on pile performance, providing valuable data for design considerations in such environments.
- Load-Settlement Behaviour: The analysis of load-settlement curves offers insights into the relationship between applied loads and pile displacements, aiding in the prediction of foundation behaviour.

The following research summaries offer a comprehensive understanding of site investigation techniques, pile foundation design, and the factors influencing their performance in Nigerian soil conditions. By combining the insights from these studies, geotechnical engineers can make informed decisions regarding foundation selection and design to ensure the stability and durability of structures in Nigeria.

Adejumo and Boiko (2012): This comprehensive study provides a valuable overview of pile foundation practices in Nigeria, encompassing various pile types, installation methods, and their applications in diverse projects.

Adejumo (2013a): This research delves into the behavior of pile groups in layered clay soils, a common geological condition in Nigeria. It offers insights into the influence of pile spacing, soil layering, and loading rate on pile performance.

Adejumo and Boiko (2013): This study presents a model for predicting the settlement of pile groups in soft clay soils, providing a valuable tool for foundation design.

Adejumo and Boiko (2013a): This study examines the settlement and deformation patterns of pile groups in clay soils, providing valuable data for understanding the behavior of pile foundations in various soil conditions.

Adejumo (2013b): This research investigates the influence of loading rate on pile settlement, offering insights into the impact of dynamic loading on foundation performance.

Adejumo and Boiko (2013b): This study compares the performance of driven and bored piles in layered soil, providing valuable information for selecting the most suitable installation method based on soil conditions.

6.3 Foundation on Weak Soils

Soils which cannot be structurally used for construction purposes without some measures of stabilization are referred to as 'weak soils'. In Nigeria, Organic Clay soils belong to this category. Organic soils of Lagos, a city located towards the Atlantic Ocean bed before the Gulf of Guinea, have been investigated and reported by researchers. Its natural water content varies from 30% to 75%; Liquid limit of 75 - 250%; Plastic limit of 30 - 175%; Plasticity indices of 20-120%; Specific gravity of 2.0 - 2.68; void ratio of 0.45 - 2.25; Organic content of 10-40% (Farrington, 1983). This highly compressible clay has Dry density of 7.84 - 15.69 kN/m^3 (Ajayi, 1983). Sometimes they have a high concentration of sulphide and even elemental sulphur. They are therefore highly reducing and corrosive. Steel piles are not recommended for use in them (Malomo, 1983).

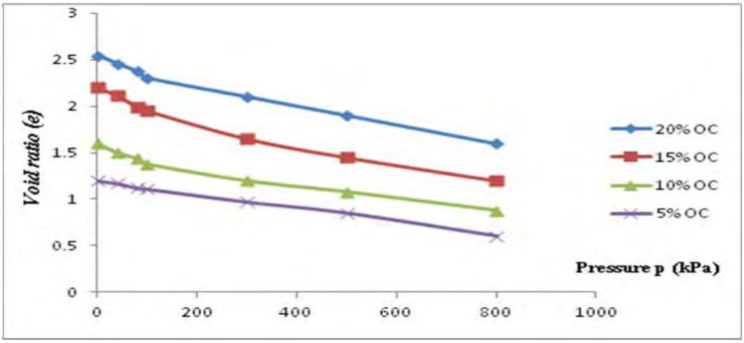


Figure 29: Variation of void ratio with pressure (e-log p) with organic content

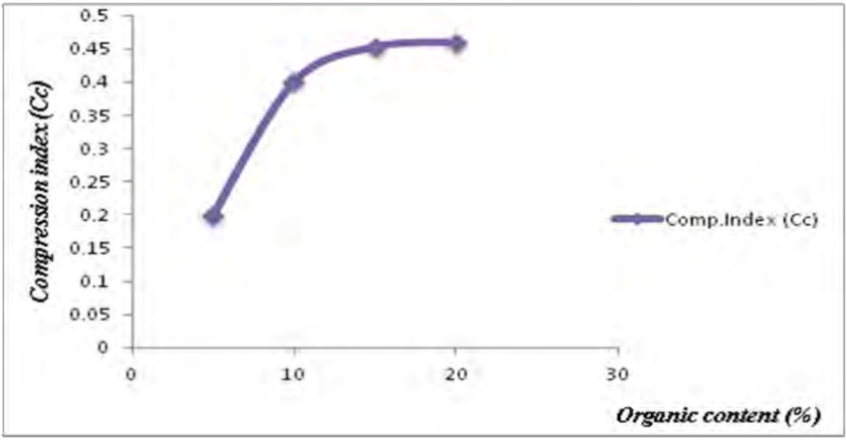


Figure 30: Variation of Compression index (Cc) with percentage organic content

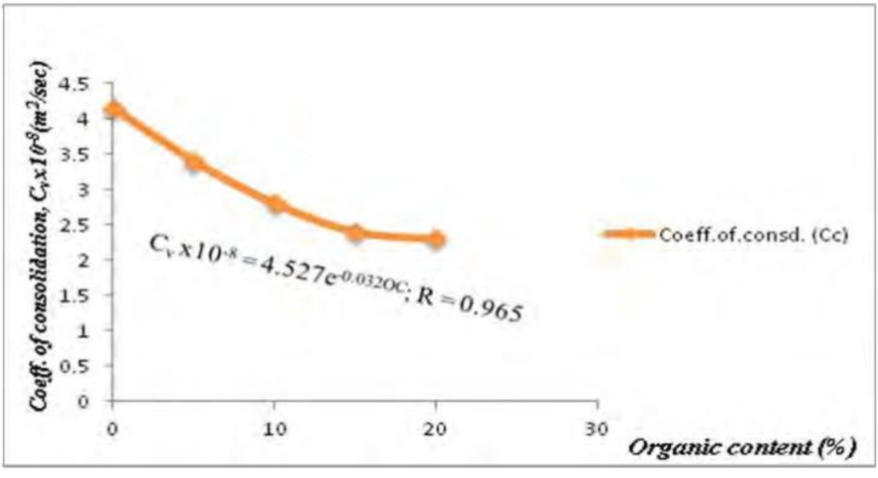


Figure 31: Variation of coefficient of primary consolidation (Cv) with organic content

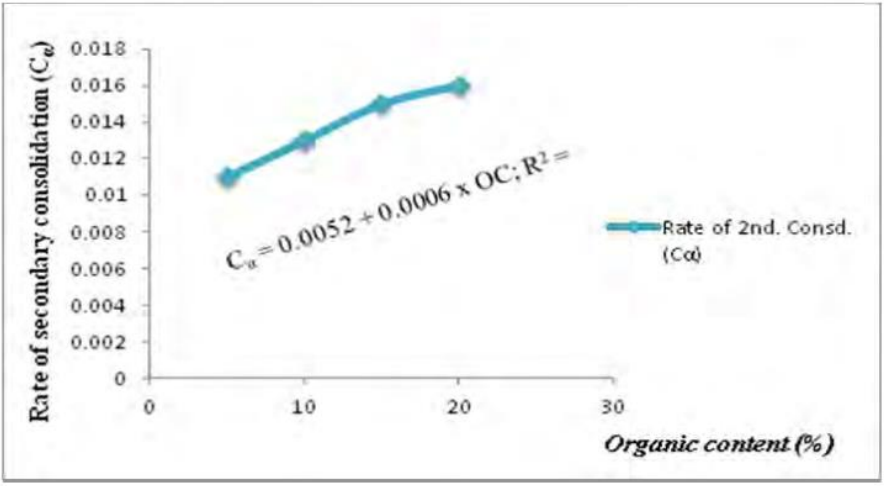


Figure 32: Variation of rate of secondary compression (Cα) with percentage organic content

From the results of experimental investigations carried out on the effect of organic content on compaction and consolidation characteristics of Organic Clay soils in Ikoyi area of Lagos, (Figures 29 -32) the following conclusions are drawn: The plasticity of investigated samples increase linearly with increase in organic content; Increase in organic content resulted in an increase in optimum moisture content; The initial void ratio eo increase with increase in organic content OC; Compression index (*Cc*) increase with increase in organic content OC; The shear strength of the clay (τ) significantly decreased with increase in organic content; The coefficient of primary consolidation (*Cv*) decreased with increase in organic content; The rate of secondary consolidation (*Cα*) and coefficient of compressibility (*av*) increase with increase in organic content; In all, organic content significantly affect the selected and other engineering properties of the clay investigated. Generally, the influence of organic content on the compressibility of soils is largely dependent on their initial void ratio.

6.4 Sustainability and Environmental Impact

Adejumo (2012): This research investigates the impact of crude oil contamination on the geotechnical properties of soft clay soils, highlighting the potential challenges for foundation design in contaminated areas.

- What are the challenges and opportunities for sustainable infrastructure development in Nigeria?

The research provides valuable insights into the impact of crude oil contamination on the geotechnical properties of soft clay soils in the Niger Delta region of Nigeria. This research is particularly relevant to understanding the environmental challenges and potential implications for infrastructure development in the region.

6.4 Foundation on Weak Soils

Soils which cannot be structurally used for construction purposes without some measures of stabilization are referred to as 'weak soils'. In Nigeria, Organic Clay soils belong to this category. Organic soils of Lagos, a city located towards the Atlantic Ocean bed before the Gulf of Guinea (fig.1), have been investigated and reported by researchers. Its natural water content varies from 30% to75%; Liquid limit of 75 - 250%; Plastic limit of 30 - 175%; Plasticity indices of 20-120%; Specific gravity of 2.0 - 2.68; void ratio of 0.45 - 2.25; Organic content of 10-40% (Farrington, 1983). This highly compressible clay has Dry density of 7.84 - 15.69 kN/m^3 (Ajayi, 1983). Sometimes they have a high concentration of sulphide and even elemental sulphur. They are therefore highly reducing and corrosive. Steel piles are not recommended for use in them (Malomo, 1983).

From the results of experimental investigations carried out on the effect of organic content on compaction and consolidation characteristics of Organic Clay soils in Ikoyi area of Lagos, the following conclusions are drawn: The plasticity of investigated samples increase linearly with increase in organic content; Increase in organic content resulted in an increase in optimum moisture content; The initial void ratio eo increase with increase in organic content OC; Compression index (*Cc*) increase with increase in organic content OC; The shear strength of the clay (τ) significantly decreased with increase in organic content; The coefficient of primary consolidation (*Cv*) decreased with increase in organic content; The rate of secondary consolidation (*Cα*) and coefficient of compressibility (*av*) increase with increase in organic content; In all, organic content significantly affect the selected and other engineering properties of the clay investigated. Generally, the influence of organic content on the compressibility of soils is largely dependent on their initial void ratio.

6.4.1 Contaminated soil

On the soil properties and foundation on contaminated soil, the effect of crude oil contamination on geotechnical properties of soft clay soils taken from three oilfields in Niger Delta region of Nigeria where crude oil spills occurred were investigated. Some of the properties investigated include Atterberg limits, strength parameters as shown in (Figures 33-34) (Triaxial compressive strength and direct shear tests), compaction characteristics, porosity and swelling pressure.

Figure 33: Down in the Niger-Delta, Nigeria

Figure 34: Oil spill at K-Dere, Gokana, River State, Nigeria

The geotechnical properties used to investigate the influence of microstructure and physicochemical changes on the physical and mechanical behavior (engineering properties) of soft clay under investigation were determined for both the uncontaminated and oil-contaminated soft clays soils. The summary of various properties investigated are shown in Table 3.

Table 3: Summary of Selected Properties of Uncontaminated and Contaminated Clays

Property	Uncontaminated Soft clay	Contaminated Soft Clay
Liquid Limit (%)	67	79
Plastic Limit (%)	43	46
Plasticity Index (%)	24	33
Shrinkage Limit (%)	18	21
Compression Index (%)	0.312	0.851
Swell Percentage (%)	27.7	28.3
Swelling Pressure (kPa)	594	182
Max. Dry Density (kN/m^3)	14.1	16.7
Opt. Moisture Content (%)	22.8	8.3

The following conclusions are drawn from the tests conducted: Crude oil contamination of soft clay leads to a marked increase in maximum dry density at relatively low optimum moisture content; The constitution of various crude oil samples has appreciable influence on the geotechnical properties of soft clay soils and the sorption process. Light crude oil samples (i.e. with low THC), impact lesser influence on the bulk density and porosity of soft clay soils than heavier ones; At high confining pressures, the strength is relatively high, indicating the dependency of the strength of contaminated soft clay on confining pressure; Crude oil contamination induces a reduction in permeability and strength of soft clay soils. Soil texture and crude oil hydrocarbon contents influenced the observed changes in the porosity of contaminated clay soils; The bulk density of oil-contaminated soft clay soil increased linearly with sorption time, while its porosity of decreases with increase in sorption time; The swelling pressure exerted by the oil-contaminated soft clay was far less (about 32 %) of that exerted by the uncontaminated soft clay.

In another research, soft clays samples obtained around three oil wells located in Bonny community as well as crude oil samples from three oil wells in Bonny, Brass River and Qua-Ibo communities respectively in Niger Delta region of Nigeria were used in this study. Oil-contaminated clay near the oil wells and uncontaminated clay samples were collected from the study areas. A total of 30 soil samples (10 around each oil well) and 18 crude oil samples (6 from each oil well) were randomly collected from the three designated oilfields. The soil is classified CL according to Unified Soil Classification System (USCS). It is inorganic medium plastic clay, having medium Dry strength with very slow Dilatancy and medium Toughness. The soil samples were air-dried for one week in order to stimulate field environmental condition, and thoroughly pulverized thereafter. Predetermined quantities of these oils were mixed with the pulverized soft clay soils at 14 kN/m^3 natural dry density until the samples were fully saturated. The oils used as the contaminants were Bonny light crude of 350 API gravity, Brass River crude of 360 API gravity and Qua Ibo crude of 360 API gravity respectively. The three selected oils are light grade crude oils. A comprehensive laboratory investigation was then carried out on the conditioned contaminated soft clay in order to determine the effect of temperature variation on geotechnical properties of crude oil-contaminated soft clays. Laboratory investigations conducted on clean (uncontaminated) as well as oil-contaminated soft clays to determine variation in its geotechnical properties as a result of temperature change include:

- Crude oil characterization using Gas Chromatographic (GC) method and ASTM D1160-06;

- The Moisture - Density and CBR Tests according to ASTM D4251-91, ASTM D1883-05 and D4429-05 methods;

- Consolidated Undrained Triaxial Tests on cylindrical specimens 71mm in diameter and 142 mm long with the triaxial cell housing the oedometer -Modified Oedometer, (ASTM D2850-07);

- One - Dimensional compressibility test on samples 70 mm in diameter and 142 mm in thickness, using modified oedometer according to (ASTM D2435-91);

- Constant head permeability tests using the modified oedometer set (ASTM D2435-91).

The values for the total hydrocarbon content (THC) as well as other parameters of the crude oil samples are in agreement with the study of (Uzoije and Agunwamba, 2011) and (Platt oil, 2012). The results of moisture density tests performed for both uncontaminated and different level of oil-contaminated soft clay samples presented in Figure 35 revealed that, the dry density (γ_{dry}) increases as water added to the oil-clay mix (oil-contaminated samples) increases, after which it dropped. Further increase in the water content diminishes its density. The maximum dry density of oil-contaminated soft clay at near zero water content is lower than that of uncontaminated samples. The variations in dry density have direct effect on the strength of the material at the initial stage as shown in Figure 36. The increase in the strength of the crude oil-contaminated soft clays could be attributed to the agglomeration of its particles in the presence of oil. For soft clay soils investigated, the CBR value initially increases as dry density increases and as moisture content decreases. Further increase of water above the optimum moisture content reduces the CBR value.

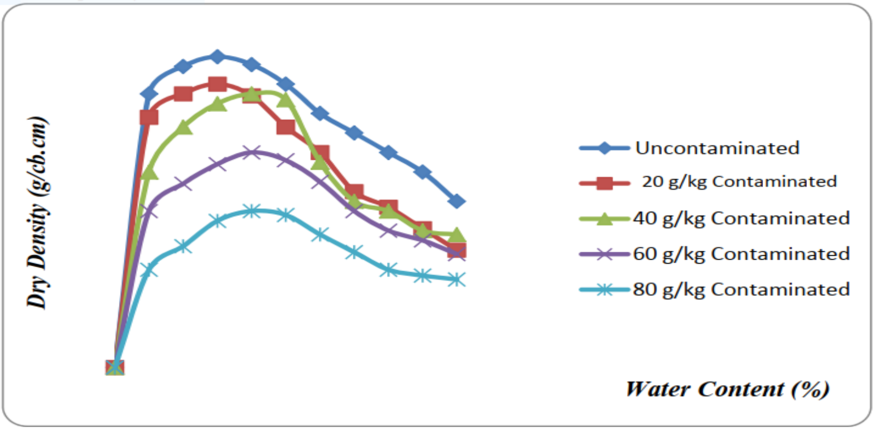


Figure 35: Moisture-Density relationship for Uncontaminated and Oil-contaminated Clays

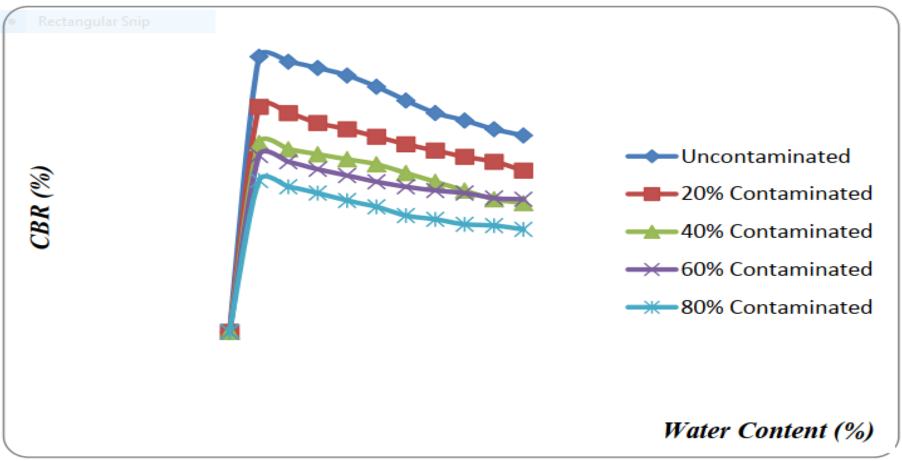


Figure 35: CBR-Moisture relationship for Uncontaminated and Oil-contaminated Clays

Key Findings and Implications

- **Changes in Soil Properties:** Crude oil contamination significantly alters the geotechnical properties of soft clayey soils, including increases in liquid limit, plastic limit, and plasticity index.
- **Impact on Foundation Behaviour:** These changes can affect the behaviour of foundations built on contaminated soils, potentially leading to increased settlement, reduced shear strength, and other stability issues.
- **Environmental Implications:** The contamination of soils with crude oil poses significant environmental risks, including pollution of water bodies and harm to ecosystems.
- **How can geotechnical engineering practices be made more sustainable**, considering factors like resource conservation and environmental protection?
- **Emerging trends in soil-structure interaction** research
- **Technologies shaping the future of foundation design**
- **Importance of innovation and adaptation** in sustainable foundation practices

7.0 CONCLUSION

Summarily, Geotechnical investigation and foundation design are fundamental to the sustainability of civil infrastructure. Here's why they're so crucial:

1. **Safety and Stability**: Proper geotechnical investigation ensures that the soil and rock conditions are well understood before construction begins. This helps in designing foundations that provide the necessary stability and support to structures, reducing the risk of settlement, tilting, or collapse.

2. **Cost Efficiency**: By identifying the soil properties and potential challenges early, geotechnical investigations can help in selecting the most appropriate and cost-effective foundation type. This can avoid expensive modifications or repairs later in the construction process.
3. **Durability and Sustainability**: A well-designed foundation tailored to the specific soil conditions can enhance the longevity of the structure. It minimizes the risks of deterioration caused by soil movement or other geotechnical issues, contributing to the overall sustainability of the infrastructure.
4. **Environmental Impact**: Understanding the geotechnical conditions can guide the selection of environmentally friendly construction practices. For instance, it can help in designing foundations that minimize soil disruption and reduce the impact on local ecosystems

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Great Nigerian Students! Great Engineering Student!! Great FUT Future Leaders!!! I appreciate all my Undergraduate, Postgraduate Diploma, Master and PhD students.

Finally, to the audience, I really cherish and appreciate your rapt attention. God bless you.

As a geotechnical engineer and foundation specialist, I say: stand well, stand right, stand on a solid foundation of knowledge and truth…………..*.If the foundations be destroyed, what can the righteous do*? If you don't build it right on a well-engineered foundation, whatever you build on it will not stand the test of time here or hereafter. Thank you.

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PROFILE OF THE INAUGURAL LECTURER

Taiye Elisha Adejumo was born on 6th November 1970 at Ikotun, Lagos, Nigeria to the family of Late Mr. Isiaka Amao Adejumo and Late Mrs. Abibat Asunke. He attended Ansar-Islam Primary School, Ikotun from 1976 to 1983 (Did primary 4 twice, so he won't have to graduate too early (or too young) according to his grandfather) He was selected and finished as the ***Head Boy***. He later proceeded to Ikotun High School in 1983 and was made ***Senior Prefect*** right from Form 3. He left for Nawair-Ud-Deen Grammar School Offa and graduated in 1988. He proceeded to Kwara State Polytechnic Ilorin, Institute of Basic and Applied Sciences for the A 'Level in Physics, Chemistry and Biology, and finished with grade 'B' in the three subjects in 1990. Changing his career direction to Engineering, he wrote JAMB Examination and was admitted to Federal Polytechnic Bida, Niger State in 1991 and graduated in 1993. Through Direct Entry, he gained admission to Federal University of Technology, Minna in 1993 and graduated as the best Graduating student in 1998. He also won the Nigerian Society of Engineers' prize for best graduating student in 1998. He was with DCLM, Kano, Works Department for the one-year mandatory National Youth Service Corps (NYSC) Scheme from March 1999 to February 2000.

His working career started in year 2001 with Engineering Services, Kano State Environmental Protection Agency (KASEPA) as volunteer Engineering Trainee. He later joined Federal Civil Service as Civil Engineer II, National Orthopaedic Hospital, Dala, Kano in 2003. He obtained his Master Degree (MEng) from Bayero University Kano in 2006. He joined the services of Federal University of Technology, Minna as Lecturer II in 2007. He obtained Research Scientist Degree from Belarusian National Technical University, Minsk, Belarus in 2013 and PhD Civil Engineering from Federal University of Technology, Minna in 2016. He was promoted to the rank of Professor in 2023.

At Federal University of Technology, Minna he has been involved in teaching, research, community services and administrative duties. He has held several administrative positions such as Level Adviser, Welfare Officer, Project Coordinator, Postgraduate Coordinator, School Timetable Officer, School COREN Outcome-Based Education (OBE) Dest Officer, IBR Research Proposal Assessor, School Facilities Manager, FUT Representative on COREN OBE Evaluators. He has also served in some committees at Departmental, School and University level. He is currently, Deputy Dean, School of Infrastructure, Process Engineering and Technology.

He has over 65 publications in national, and international journal and conferences. He has supervised several Undergraduate PGD, MEng and PhD Students. He has also served as external examiner to several institutions at all educational levels. He has served as resource person to the Council for the Regulation of Engineering in Nigeria (COREN). Team Leader, African Standards Organisations (ARSO) Technical Committee on Civil Infrastructure, and Transportation on Road, Air and Water. (ARSO/TC-29). He currently serves as the Vice chairman of Three (3) National Technical Committees of SON: NMC/NTC-3; NMC/NTC-4; MMB. He has served and still serving in several national and African Regional Standard Organisations committees representing Nigeria.

Prof. Taiye Elisha Adejumo is a corporate member of The Nigerian Society of Engineers (NSE), Fellow, Nigerian Institution of Civil Engineers (FNICE), and registered engineer with the Council for the Regulation of Engineering in Nigeria (COREN).

He is happily married with children.

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