Geotechnical Investigation Requirements for Buildings in Nigeria

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Abstract
Geotechnical investigation is an integral component of any civil engineering project. This is because the safety, durability and economic usage of the intended structure depend on the proper analysis and understanding of the foundation subsoil. Investigation of the subsoil conditions at a site is prerequisite to the economical design of the substructure elements. Nigeria, as a developing country, presently lacks a generalized functional document that provides requirements and guidelines for geotechnical investigation. Based on these, some functional documents from other countries with similar geological conditions to Nigeria and coupled with the authors' experiences in geotechnical investigation in regions with residual soil deposits in Nigeria over the years, a geotechnical investigation requirement for buildings, which could serve as a point of reference and a checklist, is presented.

Keywords: *Buildings; Foundation; Geotechnical investigation; Nigeria; Requirement; Residual soil; Subsoil.*

Introduction

Standard processes and requirements for geotechnical investigation and analysis for building structures is completely lacking in some developing countries including Nigeria. In Nigeria, the law enforcing geotechnical investigation and analysis for proposed buildings are very limited and in some states or cities where it exists, the standard guidelines or requirements to support the firm executing these works are absent. Consequently, the executing firms and the contractors are left to carry out the investigation base on the dictate of the clients. This has always resulted to shady works which compromises important aspects of geotechnical investigation and analysis and can consequently result to collapse, as being recorded in Nigeria today.

Standard processes and requirements are available for geotechnical investigation and analysis for building structures in developed countries and even some specific cities of the world. The aspects that are common in most geotechnical investigation requirements, as highlighted in these standards are: Site reconnaissance survey, number of boring, spacing of boring, depth of boring, frequency of sampling, laboratory tests and analysis and report writing (NYC Environmental Protection, 2015; Golder Associates, 2007; Michigan Dept. of Transp. Constr. and Tech, 2004; Harris County, 2011; City of Bellevue, 1999; Main Roads Western Australia, 2011; Gisborne District Council, 2011 etc). These aspects differ from one country to the other depending on the geology and weather condition in the country.

This work is therefore aimed at proposing a Geotechnical Investigation Requirement for building structures that suites Nigeria geotechnical needs and can serve as a check list based on the residual soil deposit, predominant in the country.

Literature Review

According to Main Roads, Western Australia (2011), it is necessary to conduct field reconnaissance survey as the first stage of geotechnical investigation in order to observe the possibility of accessing the site and some other environmental problems that can adversely affect the cost of investigation. The survey should revealed the legal and physical aspects of access to the site, availability of any services, photographs of surface conditions, traffic control requirements, on-ground survey details, type of vegetation on the area and any exposed geological formation. The position and number of boring on a site should be prepared using available soil and geologic maps, water well records, reports, publications and other reference materials (Michigan Dept. of Transp. Constr. and Tech, 2004). Boring shall then be selectively allocated during a field check. Sowers and Sowers (1970) recommended boring spacing of 25-30m for one-storey buildings and 15-25m for multistory buildings. The authors also recommended a boring depth as a function of the number of storeys in a building:

$$z_b(m) = 3s^{0.7} \text{ (for narrow concrete buildings)} \quad (1)$$

and

$$z_b(m) = 6s^{0.7} \text{ (for wide storey buildings)} \quad (2)$$

where
s is number of storeys

Michigan Dept. of Transp. Constr. and Tech. (2004) recommended depth of boring into clay soils to be two times the footing width or 30ft (9m) whichever one is greater. The author recommended frequency of sampling to be every 5ft (2.7m) depth. Gisborne District Council, (2011) recommended five holes for building sites not exceeding 200m^2, to be arranged at the four edges and in the center of the site and to be extended to a minimum depth of 2.0m below foundation depth. Buildings occupying space of more than 200m^2 will attract 1 extra test point per additional 50m^2. The author's area of consideration is New Zealand whose geology is completely different from that of Nigeria. NYC Department of Environmental Protection (2015) recommends 20ft as total depth of boring for shallow foundations for green infrastructures.

Golder Associates (2007) observed that excavation of test pits is more suitable for light structures whose depth of influence of the loading will be shallow, the bedrock is also shallow and the soil overburden is not highly compressible. The author recommended boring and test pit spacing of 30 to 50m within the building area. The author further recommended depth of exploration of 4-5m for residential buildings whose subsoil are underlain by competent soils, 5-6m depth for residential buildings whose subsoil are underlain by potentially compressible soils. 6-7m depth for ≤ 2 storeys, 8-10m depth for 3 to 5 storeys and 10-15m depth for ≥ 6 storeys. The author recommended frequency of sampling to be between 0.75 to 1.5m depth intervals.

The use of penetration tests including Static Cone Penetration (CPT) and Dynamic Cone penetration tests were recognized by Golder Associates (2007), Gisborne District Council (2011) and Indian Standards Institution (1985). These authors agreed to the use of both Static Cone Penetration (CPT) test and Dynamic Cone Penetration (DCP) tests with appropriate correlation to evaluate the density and consequently, the approximate bearing capacity of subsoil below shallow foundations depth. Water table within close range below trial pits can also be identified on the shaft of Dynamic Cone Penetration test (DCP) equipment.

The depth to water table for any building site must be determined if it lies within the depth of exploration. It is unanimously agreed by all authors on geotechnical investigation requirements for various countries or cities (NYC Environmental Protection, 2015; Golder Associates, 2007; Michigan Dept. of Transp. Constr. and Tech, 2004; Harris County, 2011; City of Bellevue, 1999; Main Roads Western Australia, 2011; Gisborne District Council, 2011), that water table in a proposed building site and its variation with season should be determined. In fact, Michigan Dept. of Transp. Constr. and Tech, 2004 recommended that groundwater level should be measured 24 hours after completion of boring and the hole should be suitably covered to avoid any future hazard arising from the bore hole.

Laboratory tests are usually conducted on the soil samples retrieved from either trial pits or boreholes conducted on a proposed building site. Golder Associates (2007) highlighted some conventional laboratory testing to include water content testing on fine grained soils, Atterberg limits on fine grained soils, Grain size distribution testing on cohesionless soils, consolidation test on compressible clays and chemical tests. Indian Standard Institution (1985) categorized soil tests into: physical test, which includes liquid and plastic limits, grain size analysis, specific gravity, natural moisture content, unit weight, consolidation test, unconfined compression test, triaxial compression test and direct shear tests; chemical tests include chloride and sulphate tests, calcium carbonate content and organic matter content; rock sample test, which include unit weight test, water absorption test, petrographic analysis, compressive strength and shear strength. Michigan Depart. of Tranp. (2004) recommended that all laboratory tests shall be performed in accordance with AASHTO and/or ASTM standard methods of testing.

Nigeria, as a developing country, presently lacks a generalized functional document that provides requirements and guidelines for geotechnical investigation and its reporting.

Brief Description of Geology of Nigeria

Nigeria is one of the West African countries located within the tropical region of the world. It lies close to the equator between latitude 4^o N and 14^o N and longitude 2^o E and 15^o E. The country is geologically bounded on the South by the gulf of Guinea and on the North by the southern edge of the Sahara desert (Durotoye, 1983) and has a total surface area of 923,770 km^2.

The climate in Nigeria is typified by hot tropical condition, which is humid in the South and semi-arid in the North. Seasonal rainfall, results from the influence of the wet south westerly monsoon winds from the sea and the hot dry dusty northeast trade wind from the Sahara, known locally as hamattan. The geomorphology and the quaternary history of Nigeria have evolved under the remarkable changes brought about by the intensity and periodicity of rainfall in the past (Durotoye, 1983).

Studies conducted by Rahaman and Malomo (1983), Durotoye (1983), Rahaman (1989), McCurry (1989) and Shitta (2007) showed that, the geology of Nigeria is dominated by sedimentary and crystalline basement complex formations which occur in about equal proportions all over the territory. The crystalline rocks are largely distributed around three main areas namely: A roughly circular area in the North-central part of Nigeria; A triangular area in the South-western part of Nigeria; and a third area in the Eastern and North-eastern parts where crystalline rocks occur in in three main units. While the sedimentary rocks are distributed within seven sedimentary basins namely: Dahomey basin, Niger delta basin, Anambra basin, Benue trough, Chad basin, Bida basin and Southern sector of Iullemeden basin (Rahaman and Malomo, 1983). The sedimentary rocks are mainly Upper Cretaceous to recent in age while the basement complex rocks are thought to be Precambrian.

Due to the climatic conditions in the tropical region, soil formation from the parent rocks (igneous, sedimentary or metamorphic), is mainly by process of chemical weathering (Huat and Ali, 2006). Although, Bowles (1997) asserted that, mechanical process of weathering is also encountered within the tropics. The weathered material is usually untransported residue of both chemical and physical process of rock weathering. The most important end products are clays and the resistant minerals, quartz. Other end products depend very much on the type of rock. In this part of the world, however, iron oxides are also common residues. They impart the reddish, brownish and yellowish coloration on the weathering residues, which are generally referred to as "laterite" (Durotoye, 1983).

Under the humid tropical climate of Nigeria and the extensive gentle slopes of the terrain, deep in-situ weathering takes place. The depth of weathering, though variable, is generally about 30 m below the surface, and may be greater in highly jointed and fractured rocks. In the more arid part of Northern Nigeria, depth of weathering of less than 15 m has been reported. The composition and characteristics of the weathered materials depend very much on the parent rock from which they were formed (Malomo, 1983).

In addition to the influence of parent rocks, residual soils in the tropics (Nigeria), have a vertical soil section, called the soil profile, which consists of a distinct layering, termed the soil horizons, formed almost parallel to the ground surface. These genetically related horizons are a reflection of the weathering process (Huat and Ali, 2006). The weathering profile reflects the state of weathering along the soil profile or vertical soil section from the bedrock to the ground surface (Huat *et al*, 2004). It consists of materials that show progressive stages of transformation or "grading" from fresh rock to completely weathered material towards the ground surface. The weathering profile portrays considerable variation from place to place due to the local variation in rock type and structure, topography and rates of erosion because of regional climatic variation, particularly rainfall (Huat and Ali, 2006). According to Huat *et al* (2004), the entire weathering profile, generally, indicates a gradual change from fresh rock to a completely weathered soil (fig. 1). Bowles (1997) stated that residual soils are usually preferred to support foundations as they tend to have better engineering properties than transported soils.

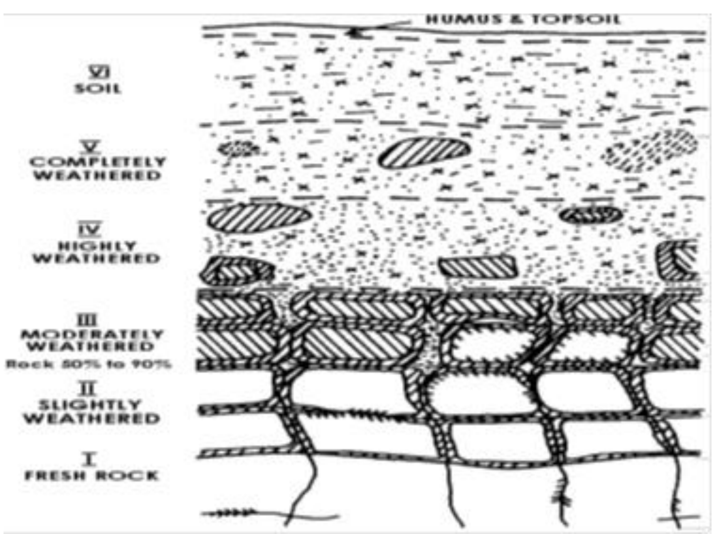

Fig. 1: Typical tropical (Nigerian residual) soil profile (*source: Huat et al, 2004*)

In addition to the residual soils, weakly developed and hydromorphic soils are also found in Nigeria especially along rivers banks and coastal area, though in terms of coverage, but not necessarily in the order of significance, they are less in extent than the residual soils. Vertisol, which is also a tropical residual soil group, having distinct engineering properties are also found in the North-eastern part of Nigeria.

There are basically four major soil groups in Nigeria: Weakly developed and hydromorphic soils, Vertisols, Ferrallitic and Ferruginous tropical soils (fig. 2). Ferruginous and ferrallitic tropical soils are the most abundant (Malomo, 1983) and most stable under engineering structures. The vertisols and weakly developed soils occur less in Nigeria and are generally considered as weak bases for engineering structures.

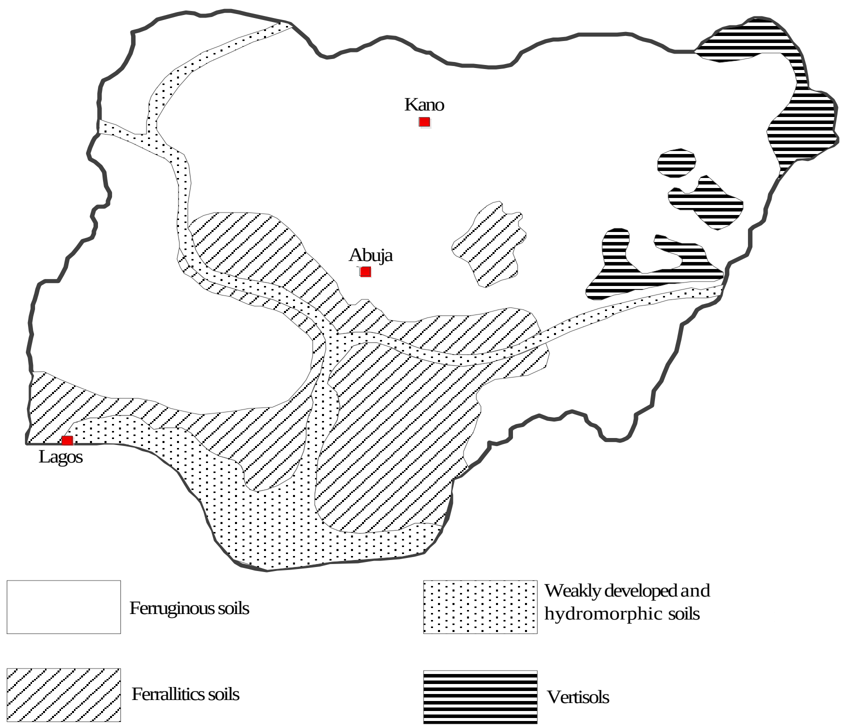

Fig. 2: Nigerian soil groups (*source: Malomo, 1983*)

Requirements for Geotechnical Investigation and Reporting

Michigan Department of Transportation (2004) categorized the content of geotechnical report writing into general information which has to do with clear description of project site, date of investigation, the prevailing climate at the time of investigation, description of the geology of the site and any other relevant information that may contribute to proper interpretation of field survey. According to the author, the second category is general recommendations concerning the designing and construction of the proposed structure. NYC Department of Environmental protection (2015) summarized the general requirements of geotechnical report to include: project description, site condition, geotechnical investigation results, summary and conclusion. The author also recommended attachments in appendix to include boring plan map, historical boring logs, geotechnical report summary table, soil boring logs, laboratory test results and soil profile. Harris County Texas (2011) suggested a format for geotechnical report to include: transmittal letter from professional Engineer with seal and approval signature, executive summary, introduction, Purpose and scope of work, site exploration, field work, laboratory testing, description of subsurface soil and ground water conditions, engineering analysis and recommendations and finally construction consideration. City of North Las Vegas (1996) recommended a geotechnical investigation checklist which is categorized under project information, location and development description, geotechnical investigation, laboratory testing, site preparation and grading, foundations/retaining wall, slab on grade/exterior flat works, utility trenches, street and pavement design.

Table 1: Requirements for Geotechnical Investigation and Reporting

Activity	Reasons for carrying out the activity	Possible contribution of the activity
Light to Moderately Heavy Structures e.g 0 – 2 storey Buildings, Retaining Walls, etc.		
Reconnaissance survey of the site.	To identify relevant features like wells, natural or artificial cuttings, possible existence of any structure in the past.	Could help in siting test points, identify possible depth of water table.
Interaction with the Architect, Surveyor and Structural design Engineer of the proposed Building.	To obtain the site layout, topographic map and magnitude of the anticipated loads transferred to the foundation base through the columns.	Proper identification of position of the structure, elevation of this position, the column positions and anticipated load transferred through column for settlement determination.
Conduct light weight Dynamic Cone Penetration tests to 6m depth or point of refusal (10kg mass, 60^0 cone head) within the structure area at spacing of not more than 10m.	Explore the in-situ soil deposit to 6m depth. Analyze the results in a graphical form for ease of interpretation.	Obtain indirect bearing capacity of the subsoil to 6m depth. Water table can be also be observed on the shaft of the DCPT rod if it is within 6m depth
Conduct trial pits within the structure area to minimum depth of 2.5m and maximum spacing of 20m.	Visually observe the sequence of the soil strata to 2.5m depth and collection of both undisturbed and disturbed soil samples for laboratory tests.	Draw the sketch of the trial pits showing the strata and the discontinuity.
Carry out index properties test on the disturbed soil samples, shear strength and settlement tests on the undisturbed soil samples collected. Take note of the water table if available.	Collect, organize and analyze the results obtained from all the tests.	Characterize the soil samples collected and obtain the shear strength parameters and settlement characteristics of the undisturbed soils.
Heavy Structures e.g 3 – 10 storey Buildings, Heavy Machinery Buildings, etc.		
Reconnaissance survey of the site.	To identify relevant features like wells, natural or artificial cuttings, possible existence of any	Could help in siting test points, identify possible depth of water table.

	structure in the past.	
Interaction with the Architect, Surveyor and the structural design Engineer of the proposed Building.	To obtain the site layout, topographic map and the magnitude of the anticipated loads transferred to the foundation base through the columns.	Proper identification of position of the structure, elevation of this position, the column positions and anticipated load transferred through column for settlement determination.
Boring and conducting Standard Penetration tests (SPT) to minimum depth of 10m or point of refusal (50 blows for penetration of less than 30cm) within the structure area at spacing of not more than 20m.	Explore the in-situ soil deposit to minimum of depth of 10m. Conduct SPT test at 1.5m depth interval, collect undisturbed soil samples after each SPT test or where ever a change is observed in the soil.	Obtain direct bearing capacity of the in-situ soil deposit to 10m depth. Water table can be observed in the boreholes using water level indicator. The soil samples collected are tested and analyzed. Borehole logs are then plotted for each borehole.
Carry out index properties test on the soil samples, shear strength and settlement tests on the undisturbed soil samples collected. Take note of the water table if available.	Collect, organize and analyze the results obtained from all the tests.	Characterize the soil samples collected and obtain the shear strength parameters and settlement characteristics of the undisturbed soils.
Minimum Requirement for Geotechnics Report Writing		
Title of the report	This will show briefly the site or plot number where the test was conducted and the type of structure anticipated.	This in conjunction with the site pictures taken during the test will be used to confirm the location of the test.
Introduction of the report	This section will discuss briefly the client and the executing firm, some observations during reconnaissance survey and how it aid in the selection of test points. The magnitude of the structure and the anticipated loads transferred through the columns.	This will help to encourage geotechnical firms to carry out reconnaissance survey visit before the execution of the job.
General Description of Site	This section will explain the street where the site is located and all visible structure bounding the site. The roads/features bounding the site will also be highlighted.	The tested site can easily be accessed using the geotechnical report.
General Geology of the site	This is to discuss the general geology of the tested site and the sequence of soil strata anticipated	The strata observations during boring can easily be compared with the general

	in this type of geologic formation. The type of weather predominant in this area will also be discussed.	geology of the tested area.
Scope of work	This section will highlight all the works (both field work and laboratory tests) carried out on this site. The total number of various tests conducted on the site and in the laboratory.	This will be compared with the site investigation requirement for the type of structure anticipated on the site.
The Methodology	This section discusses the methods employed in the various tests conducted on the site and in the laboratory. The correlation used for in-situ testing equipment to obtain relevant soil parameters shall be explained.	These methods will be checked for relevance and authenticity.
Analysis and Discussion of Results	This section will analyze both the in-situ and laboratory results obtained. Graphical presentation and borehole logging are very good tools to achieve some of these results.	The analyzed soil parameters and the in-situ test results will show the implication of siting the anticipated structure on the proposed site.
Conclusions and Recommendations	Relevant conclusions which are derived from the analyzed results shall be drawn. Recommendation on the type of foundations that suit the tested site will be given. The method of constructing the recommended foundation shall be suggested.	The design Engineer will use his professional experience and economic consideration to choose one among the foundation types suggested.
Professional Civil Engineers Signature and COREN Stamp	A geotechnical report should be signed by a professional Civil Engineer and stamped using COREN seal.	The Engineer will be liable to any error arising from the report.

Conclusions

The geotechnical investigation and report writing requirement obtained in some developed countries and some cities of the world were studied in detail alongside the geology of these countries. This study coupled with the geotechnical investigation experiences of the authors in Nigeria over the years, were used to propose a geotechnical investigation and report writing requirement for Nigeria residual soil deposits. The following conclusions were drawn:

1 Recognisance survey of the intended site should be the first aspect of geotechnical investigation and the influence of the observations on siting of the test points shall be highlighted in the introductory part of the report.

2 The general geology of most developed countries considered in this study is transported soils with very deep bedrock depth as against the residual soil deposit predominant in Nigeria with relatively shallow bedrock.
3 Light-weight Dynamic Cone Penetration tests (DCP) to maximum depth of 6.0m and trial pits to minimum depth of 2.5m is proposed to be adequate for light-weight structures.
4 Standard Penetration Tests (SPT) and sample collection in SPT boreholes at 1.5m depth interval to minimum depth of 10m is proposed for medium to heavy structures.
5 The minimum requirement for geotechnical report writing was proposed to include: title of the report, Introduction, description of site, general geology of the site, scope of work, methodology, discussion of results, conclusions and recommendations and finally a signatory by COREN registered Engineer.

Recommendations
1 The test point spacing proposed is the maximum, lower spacing are very much acceptable.
2 These proposals should be applied to residual soil deposits and not soil deposits within a basin or delta areas.

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