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Review

Installation techniques of pile foundation on some low bearing capacity soils in Nigeria

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ABSTRACT

This paper presents some techniques used in the installation of pile foundations to support foundation and structural loads on some low bearing capacity soils in Nigeria. Depending on use, soil conditions (especially the physico-mechanical properties of the soil), expertise and cost, driven piles installation techniques mostly used in Nigeria include dropping weight (hammer), explosion, vibration, jacking and jetting. Installation techniques for bored piles include mechanical auger (continuous/straight flight auger), cable percussion drilling as well as under-reaming for large diameter piles. Recently, newer installation techniques such as oscillated piling technique, GeoJet piling technique as well as Tubex grout injection piling technique were introduced to the piling work in Nigeria.

Keywords: Pile foundations, installation techniques, construction, low bearing capacity soils, Nigeria.

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INTRODUCTION

Piles can be driven, augured or jetted into place. The installation technique will vary with soil conditions, load bearing requirements, equipment available, and local practice. The load capacity of bored piles is a function of the geotechnical capacity of the pile, the installation technique chosen, and the structural capacity of the pile shaft.

Prior to Carter Bridge, Lagos, the first officially documented bridge built on steel piles in 1901, indigenous settlers along river banks and coastal areas in Nigeria have been using wooden piles as foundation of structures which they use for residence, storage, surveillance or for other purposes. However, application of piles for construction, especially on weak soils with difficult engineering-geological conditions where other foundation types are considered impracticable gained prominence towards the end of the 1960s and early 1970s, when many construction firms from Europe used it for the construction of houses, bridges, roads, exploration platforms, ports, assembly plants, transmission tower bases.

The arrival of English colonists followed-up by German, Italian and French ones gave a new dimension on the implementation of pile driving in particular, with the construction of more complex and heavier buildings and structures that needed a more rationalized scientific approach. Several structures were constructed on pile foundations mainly by colonial/foreign companies that used non-qualified local laborers (Lezin et al., 2009; FMWHD, 2009; Adejumo and Boiko, 2012).

Originally constructed as a steel bridge, the Carter Bridge, Lagos - Nigeria was built in 1901, by the British colonial government before Nigeria's independence in 1960. After independence, the bridge was dismantled, redesigned and rebuilt in the late 1970s (FMWHD, 1982). Many other bridges built on pile foundations include: Niger Bridge, Onitsha -1965, Eko Bridge, Lagos -1965, the third mainland bridge, Lagos -1990 (http:/www.julius-berger.com/nigeria/project-portfolio/infrastructutes) to mention just a few. Several of these bridges and other constructions were erected on difficult terrains in Lagos, Abuja and other parts of the country as documented by (FMWHD, 1982). Although some of these records are inconsistent and inadequately insufficient.

Low bearing capacity soils otherwise described as “weak soil or problematic soils” having weak physico-

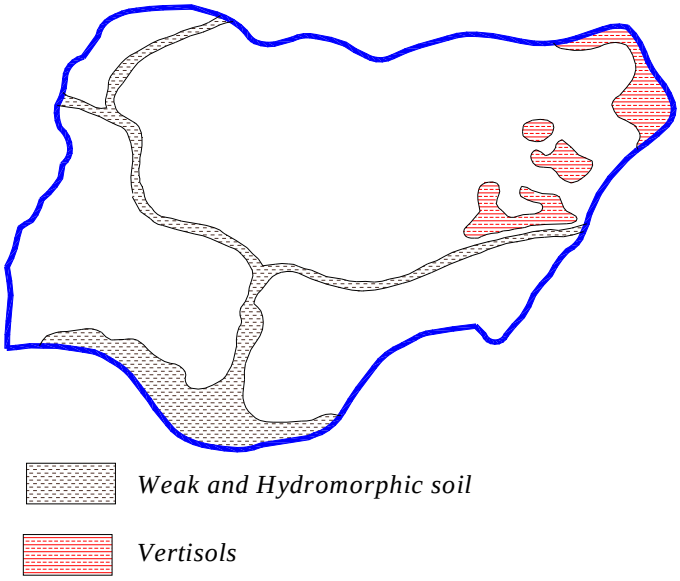


Figure 1. Simplified low bearing capacity soil groups in Nigeria.

mechanical properties especially as it affects its strength parameters are spread across Nigerian territory (Figure 1). Major weak load bearing soils, on which pile foundations are employed to support structural loads in Nigeria, include among others, the vertisols (black cotton soil) of the North-eastern region, Sokoto soft clay shale of the North-west region, organic clay of the South-west region as well as soft sedimentary deposits of Niger-Delta region of Nigeria (Sadiku, 1985; Ola, 1987; Adesunloye, 1987; Omange et al., 1988; Chukwueze, 1991; Ige and Ogunsanwo, 2009; Oriola and Moses, 2010; Abolarinwa, 2010). A simplified low bearing capacity soil groups in Nigeria is shown in Figure 1. According to Ola (1987), the basic physico-mechanical properties of soft clay of Sokoto, north-west Nigeria have the following ranges: Natural Moisture Content (NMC) = 10 to 40%; Liquid Limit (LL) = 170 to 250%; Plastic Limit (PL) = 7 to 10%; Plasticity Index (PI) = 163 to 240%; Cohesion (c) = 0 κPa; Angle of internal friction (ϕ) = 16 to 30°; Linear Shrinkage (LS) = 18 to 24 %; Specific Gravity (Gs) = 2.42 to 2.55; swelling pressure = 145 to 240 κPa; Bulk unit weight (γb) = 14 to 17 κN/m^3; Void ratio (e) = 0.4 to 1.3; Degree of saturation (Sr) = 0.5 to 1.0; Compressive index (Cc) = 0.19 to 0.25. They are usually classified as CH on Unified Soil Classification Systems (Ola, 1983).

The physico-mechanical properties of the organic clay of Lagos, south-west Nigeria have been found to be in the ranges: Natural Moisture Content (NMC) = 50 to 250%; Liquid Limit (LL) = 75 to 250%; Plastic Limit (PL) = 30 to 175%; Plasticity Index (PI) = 20 to 120%; Cohesion (c) = 3 to 200 κPa; Angle of internal friction (ϕ) = 0 to 7°; Specific Gravity (Gs) = 2.20 to 2.68; Bulk unit weight (γb) = 24.0 to 28 κN/m^3; Void ratio (e) = 0.5 to 2.20; Degree of saturation (Sr) = 0.5 to 1.0; Coefficient of consolidation (Cv) = 0.3 to 10 m^2/year; Coefficient of volume compressibility (Mv) = 0.04 to 0.32 m^2/MN. They are usually classified as OL to OH on Unified Soil Classification Systems (Ajayi, 1983; Farrington, 1983).

The installation method and techniques are important factors in the design process of pile foundations. In order to avoid damages to the piles during design, methods, techniques as well as equipment for pile installation should be carefully selected (Ascalew and Ian Smith, 2007). In Nigeria, techniques of pile installation include: a) Driving by procedures such as dropping weight (hammering), explosion, vibration, jacking- for micro pilling, and jetting; b) boring by procedures such as continuous/straight flight augering, cable percussion drilling, under-reaming for large diameter piles. Recently, newer installation technologies such as oscillated pilling technique, GeoJet pilling technique as well as Tubex grout injection pilling technique were introduced in Nigeria.

PILE FOUNDATIONS INSTALLATION TECHNIQUES

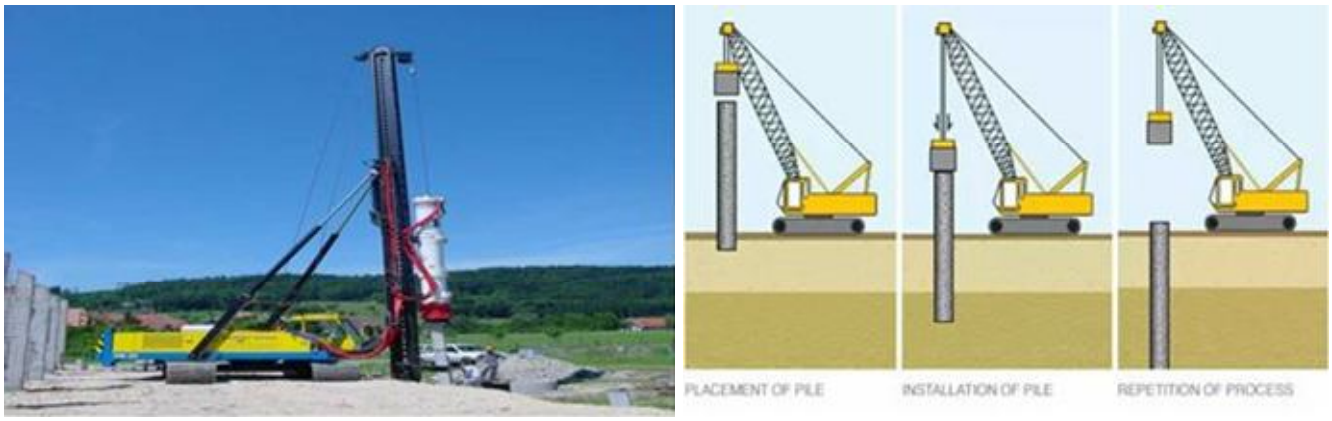
Treated wooden piles - are the most common type of pile used in coastal construction. They can be square or round in cross section. Wooden piles are easily cut and adjusted in the field and are typically the most economical type (FEMA 499, 2005). Concrete and steel piles are also be used, especially in heavy construction or when the underlined soil is expected, to bear large construction and/or structural load. Concrete piles are more expensive, but they are stronger and more durable. Steel piles are rarely used in waterlogged or marine area, because of potential corrosion problems associated with steel.

The type of pile influences the method selected for its installation. For example, impact hammers may not be able to drive timber or closed-end pipe piles into firm ground without damage to the pile, and assisted installation may be required (UFC 3-220-0216, 2004). The specific pile construction method depends on the soil condition, the groundwater elevations, site conditions and the length of the pile (Bilfinger Berger, 2012).

In Nigeria, with respect to load transmission and functional behavior, piles are classified as end bearing piles (bearing piles), friction piles (cohesion piles) and combination of end bearing and cohesion piles. With respect to type of material, pile could be classified as timber piles, steel piles, concrete pile or composite piles. With respect to effects on the soil, pile could be classified simply as driven (or displacement) piles and bored (or non-displacement) piles. There are screwed piles in some cases.

Driven (displacement) piles installation

Driven piles - are considered to be displacement piles. In the process of driving the pile into the ground, soil is



(a) (b)

Figure 2. Pile driver: a) Drop weight hammer; b) Pile driving sequence.

moved radially as the pile shaft enters the ground. There may also be a component of movement of the soil in the vertical direction (Ascalew and Ian Smith, 2007). These piles are installed using modern, very high torque hydraulic drilling rigs which rotate a specialized displacement tool into the ground. The action of the specially designed tool causes the ground to be compacted, when the tool has reached the required depth it is withdrawn whilst concrete is pumped out through the hollow stem. Installation techniques used for driven i.e. displacement piles include:

a) Dropping weight- hammer
b) Explosion
c) Vibration
d) Jacking- for micro pilling
e) Jetting- applying water to weaken the soil; preferable in sandy or sandy-gravel soil.

Piles are installed or - driven into the ground by a rig which supports the leads, raises the pile, and operates the hammer. Modern commercial rigs use vibratory drivers while most older and expedient rigs use impact hammers. Pile-driving rigs are mounted in different ways, depending on their use. These include railway, barge, skid, crawler and truck-mounted drivers. Specialized machines are available for driving piles. Most pile driving operations are performed using a steel-frame, skid-mounted pile driver or power cranes, crawlers, or truck-mounted units, with standard pile-driving attachment (UFC 3-220-0216, 2004). The attachments available include adapters for connecting the leads to the top of the crane boom leads and a catwalk or lead braces used to connect the foot of the leads to the base of the boom. The leads and catwalk assembly support drop hammers weighing up to 3,000 pounds (1.5 tons) and diesel hammers weighing up to 13,000 pounds (6.5 tons) like in Figure 2a and b.

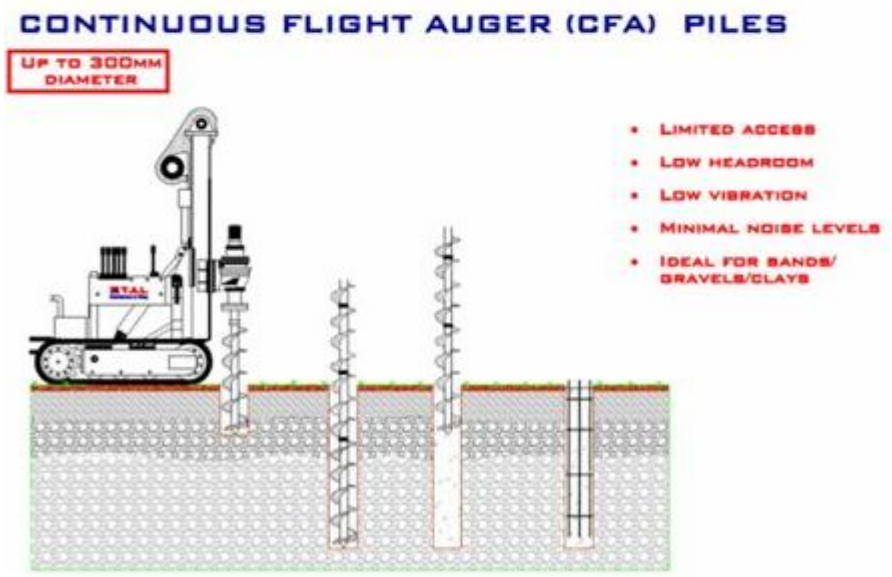
There are three impact hammers used for pile-driving: drop hammer, pneumatic or steam hammer, and diesel hammer. Vibratory drivers/extractors are not classified as hammers and do not require pile caps for protection against impact stresses. They are clamped to the pile to vibrate as a unit. Vibratory drivers are a recent development in pile-driving equipment. They are used in large scale pilling work.

Timber is popular in marine applications as it is a tough resilient material which can absorb considerable shock without serious damage by such incidents as collision. They are also more easily repaired than steel or concrete piles. Timber is renowned for its inertness and as such has the natural ability to perform its task long term in hostile chemical soil conditions. The availability of modern timber preservation technology has increased this popularity of timber piles in chemically aggressive soils. It is ideally suited to applications where an economical pile is required to carry small axial loads. Driving rigs are well suited for the fast and economical installation of timber piles both on land and also in marine applications.

Bored (non-displacement) piles installation

Bored piles (replacement piles) are generally considered to be non-displacement piles; a void is formed by boring or excavation before piles is produced. Bored piles can be produced by casting concrete in the void. Some soils such as stiff clays are particularly amenable to the formation of piles in this way, since the bore hole walls do not requires temporary support except cloth to the ground surface. In unstable ground, such as gravel the ground requires temporary support from casing or bentonite slurry (Ascalew and Ian Smith, 2007). Being non displacement type piles, bored piles can be installed with little or no vibration, and with much lower noise levels than driven piles. Installation techniques used for bored,

(a)



(b)

Figure 3. Mechanical auger: a) CFA; b) CFA bored pile process (http://www.talconstruction/piling/auger).

that is, non-displacement piles include:

a) Cable percussion drilling
b) Mechanical augers - continuous flight auger (CFA) (Figure 3a and b) or straight flight auger (SFA)
c) Under-reaming - enlarged base for large diameter piles, rarely in use.

In contrast to - driven piles, bored piles enable the immediate *in-situ* evaluation of drilled soil layers to revise foundation length due to changed soil conditions.

Construction methods of bored piles can be categorized as:

(i) The ***bored holed stabilization*** process of fully cased, partial cased, uncased and fluid stabilized excavation.
(ii) The ***casing installation method***– either by driving the casing with a free fall hammer or weight, vibrating the casing, pneumatic installation or hydraulic installation with the help of a rotary drive, an oscillator or rotator. Concrete is cast - into a hole drilled with the rebar reinforcement in already place.

(iii) The ***excavation method*** – either by grab excavation, rotary drilling, airlifting, and flush boring. Combinations of air-lifting and reversed circulation drilling can drill bore holes up to 150 m depth efficiently, depending on soil conditions (Bilfinger Berger, 2012).

Bored (non-displacement) piles installation techniques

Due to its advantages of variability to suited length, accommodation for large diameter, the possibility of being installed in very long length and easy monitoring among others, bore piles are more common in use in Nigeria. Depending on the operational mechanism, technical know-how and financial strength of the handlers, installation techniques of bored piles can be further grouped into:

Cast-in-drilled-hole pile technique

Concrete is cast into a hole drilled with the rebar reinforcement already in place. Depending on ground conditions, these piles can range up to 12 - 126 inches in diameter and 10-126 feet in length. There is minimum vibration, although there may be cave-ins if the soil is weak. In wet ground condition, slurry may be used for the installation and a tank provided for the slurry/water.

Cast-in-steel-shell pile technique

A steel shell is driven into the ground, it is then cleaned up, and the reinforcing bars are put in place. Concrete is then cast *in situ* to the required length. Cast-in-steel-shell piles can accommodate longer length than cast-in-drilled-hole piles, and are commonly used for bridges and other structures on low bearing capacity soils. Vibration and noise are usually associated with this type of installation technique.

Oscillated pile technique

The steel shell has a drill ring attached at the top so that the pile being cast can be oscillated/rotated into the ground. This installation technique produces much lower ground vibration to the adjacent soil and structures and less noise than most driven pile techniques. However, it is slower and expensive.

GeoJet piling technique

Under GeoJet pile installation technique, a hole is drilled while mixing cement with the natural soil to produce a soil-cement column/shaft. A circular steel pile is then lifted and lowered into the soil-cement shaft. After setup of the soil cement, the pile reacts like cast-in-steel-shell. This is a newer technology of pile installation; the diameter and depth are limited to 1.2 and 46 m, respectively. Ground vibrations are almost eliminated, and noise is minimal when compared to pile driving. However, there is flow of geogrout to the surface during drilling operations, which may render the working platform messy.

Tubex grout injection pile technique

A steel shell with a drilling tip is screwed/drilled into the ground while injecting grout to form a bond with the soil. This forms a closed-end system, which may cause soil heaving/displacement depending on soil type. Like the GeoJet piling technique, it is a newer technology, and the pile diameter is limited to 30 inches. It produces minimal vibration and noise, but ground monitoring is required due to the potential for soil displacement, which may lift adjacent structures.

PILING WORK IN NIGERIA AND TECHNOLOGY TRANSFER

Piling work is labor, human and capital intensive. Foreign construction firms mostly from Europe, America or Canada carry out nearly all piling works in Nigeria. This may not be unconnected with high skill expertise required for piling, and particularly due to the fact that most of the machineries and pile installation equipments are imported from these countries. Some of these firms mentioned by Adejumo and Boiko (2012) bring the equipments needed for the work to Nigeria along with personnel to operate, maintain and service them. Nonetheless a sizeable number of Nigerian workers now serve as intermediate artisans, welders, workmen, surveyors, mini operators and so on, who work along with the foreign experts. However, much ground needs be covered, so that trained indigenous personnel working with these experts will gain practical experience in the actual pile installation techniques, although most of these firms are not readily disposed to transfer their technologies.

Installation techniques such as of GeoJet piling, Tubex grout injection piling, which are fairly new in their introduction to piling work, mechanical augers and other driven pile techniques need be further explored and adapted to soil, geological and climatic conditions prevalent in Nigeria.

CONCLUSIONS

1. Low bearing capacity soils having weak physico-

mechanical properties requiring thorough investigations especially when pile foundations are to be constructed on them are spread across Nigerian territory.

2. The major low bearing soils in Nigeria, on which pile foundations are recommended depending on other conditions include among others, the vertisols (black cotton soil) of the North-eastern region, soft clay shale of North-west region and organic clay of the South-west region as well as soft sedimentary deposits of the Niger-Delta region of Nigeria.

3. Depending on the type of structure, soil conditions, expertise and finance, driven piles (displacement piles) foundations installation techniques mostly used in Nigeria include: dropping weight- hammer, explosion, vibration, jacking, screwing, jetting or combination of any of these.

4. Installation techniques for bored piles (non-displacement piles) include: cast-in-drilled-hole, cast-in-steel-shell, as well as the fairly new techniques of oscillated piling, GeoJet piling and Tubex grout injection piling.

5. Pile foundations construction in Nigeria is mostly executed by foreign construction firms from Europe, America or Canada, from where most of the installation equipments are imported.

6. Due to the dominance of foreign construction firms with foreign equipments in the piling work in Nigeria, there are usually loss of man-hour and its associated financial loss with delay in project execution when these equipments not manufactured for Nigerian environment break down.

7. The fairly new bore pile installation techniques of GeoJet piling and Tubex grout injection piling need to be adapted to Nigerian soil conditions and technology transfer better ensured for improvement in the piling work in Nigeria.

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