Piled Foundation Practice in Nigeria

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Up to about three decades ago, the use of piled foundations in Nigeria was generally restricted to maritime structures—wharfs, jetties and bridges. Timber piles were most commonly used to support wharfs, slipways and jetties while only a few important bridges were on steel piles. The trend has changed considerably due to greater understanding of foundation problems and higher loadings. Now, various forms of piles are being widely used for supporting all types of structures, both maritime and on land.

There are several types of piles and piling systems in use in various parts of the world depending on the economic, technological and geological conditions. Here in Nigeria, where almost everything needed for a piled foundation requires to be imported from outside the country, the engineer's choice of piling systems or techniques is somewhat limited and often he has to use whichever appear appropriate from those available.

Types of Piles

Foundation piles are usually made of wood, concrete, steel or a combination thereof, and according to Armstrong (1974), piles can generally be grouped into two basic types:

(a) **Displacement Piles**—being those whose construction requires no excavation of material from the ground, rather they merely displace their own volume of in-situ soil.

(b) **Replacement Piles**—those in which the in-situ material is excavated by one of a variety of means, the void is then backfilled usually with in-situ concrete or a combination of in-situ and precast concrete or sometimes other materials.

Piles can also be grouped into Bearing and Non-Bearing depending on the role they are meant to perform in the entire project.

(c) **Bearing Piles**—are installed for the purpose of sustaining and transmitting foundation loads to the surrounding soil either through their tips (End Bearing Piles) or through the frictional resistance developed between the soil and their shaft contact areas (Friction Piles). In some cases, the piles would be required to resist lateral loads (Raking Piles) or uplift (Tension Piles).

Bearing piles have been used extensively in Nigeria for supporting multi-storey buildings, factories, swampland roadways, flyovers and most bridges constructed within the last two decades.

(d) **Non-Bearing Piles**—are those installed principally for the purpose of improving some physical characteristics of the surrounding in-situ soil, such as consistency, compressibility and strength or to ensure safety and stability against groundwater, scour, erosion, slips etc. during and/or after construction.

Examples of Non-Bearing Piles used in Nigeria are:—

(i) **Vibratory Compaction**—A system of densifying loose sand deposits by vibration. It was used for the 25-Storey Independence Building, 20-Storey NPA/NEPA Headquarters, Apapa Flour Mills, Ikoyi Hotel and Tinubu Square Fountain all in Lagos. Also at Sokoto and Ughelli Power Stations.

(ii) **Driven Compaction Piles**—these are essentially the precast concrete piles closely driven to density the loose sand deposits supporting the 32-Storey Necom House, 18-Storey NIDB Building and 15-Storey CSS Bookshop all in Lagos.

(iii) **Sand (Drains) Piles**—used for accelerating settlement of compressible deposits such as at the LSTC Keffi Street Bus Depot in Lagos and Oil Storage Tanks at Forcados Oil Terminal in Bendel State.

(iv) **Piled Wall**—the contiguous bored pile retaining wall constructed at the new Standard Bank Building, Marina, Lagos.

(v) **Steel Sheet Piles**—used for excavation supports at building sites, such as the Central Bank, U.B.A. Building, CSS Bookshop House and NICON Building in Lagos. At water works sites of Sokoto, Birnin-Kebbi, Bida and Lagos. Water pumping stations of Ikoyi and LUTH in Lagos. For maritime works like the Jetties at Sapele, Koko and Escravos in Bendel State, the Apapa and Tincan Island Wharfs in Lagos, as well as the Federal Palace Hotel and Marina Foreshores in Lagos.

(vi) **Dynamic Consolidation**—a system by which a weight of 5 to 200 tonnes is repeatedly dropped from a height of 6 to 30 metres on to the ground so that the induced shock waves and high stresses in the soil can result in rapid compaction and consolidation. The depth of effective treatment is therefore proportional to the drop energy. This system of piling was used for the 4-Storey Flour Mills Flats at Apapa.

It is possible to further classify piles by considering the various methods of their installation.

(e) **Driven Piles**—the most familar method of pile installation is by driving them into the soil with diesel, steam or drop hammers. This system of piling is generally suitable for most types of ground conditions except where environmental limitations like working space, headroom, vibrations, groundwater and weak superficial deposits preclude their use. The most significant limitation however

is the effect of pile driving vibrations on the stability of adjacent structures. Therefore, in order to minimise vibrations, it is sometimes necessary to combine pile driving with other systems of pile installation.

Piles installed by driving can be either Bearing or Non-Bearing as defined above and in Nigeria, they are commonly of cast-in-situ, steel cased or precast concrete. These piles support many of the multi-storey building and factories in our urban areas as well as numerous bridges and swamp-land highways.

In marine and riverine works and where environmental conditions do not favour concrete piles, Steel 'H', Box or Pipe sections are driven. Thus, at Hinna Bridge in Gongola State and Oluwa Bridge in Ondo State Steel 'H' piles were used.

Driven timber piles are not used very often these days.

(f) **Bored Piles**—A suitable size hole is excavated by percussion or rotary drilling methods to the required pile base level. Depending on the subsoil conditions and length of pile, the sides of the hole may be supported by steel casing or bentonite slurry. The hole is eventually filled with concrete or sometimes other selected material.

According to the British Standard C.P. 2004: 1972, when the hole is bigger than about 0.6m. diameter, the pile is regarded as Large Diameter Pile.

This system of piling offers a suitable solution to the limitations of the driven pile as it produces virtually no vibration and in stiff clays eliminates the problem of heave. The technique may also be used to eliminate high driving resistance and excessive vibrations in penetrating dense strata which are unsuitable for pile bearing.

However, the system is not suitable in soft peaty and loose granular water bearing ground where special measures such as, the installation of permanent casings are necessary, to reduce the dangers of 'necking' or waisting of the pile shaft concrete.

Basically, all Replacement Piles are bored and as in the case of driven piles, bored piles may be either Bearing or Non-Bearing. For a given size of bored pile the bearing capacity that can be mobilised depends on the method of boring used. The boring technique should produce minimal disturbance of the soil around and beneath the pile.

Bored piles generally mobilise considerable wall friction and are therefore often used as Friction Piles.

Examples of the use of conventional bored piles in Nigeria are at the Cement Factories of Ewekoro and Shagamu, the 8-Storey UNILIFE Office at Nnamdi Azikiwe Street, 6-Storey SARAH House at Martins Street, Lagos and several Power Transmission Pylons in the hinterland.

Large diameter bored piles were used for supporting the Wuya Bridge on River Kaduna near Bida and the 3rd Lagos Mainland Bridge.

Grouted Auger Pile—a proprietary type of bored pile is becoming popular in Lagos for supporting new multi-storey buildings owing to the dangers of pile driving vibrations. The technique has been used for the 20-Storey NICON Building at Customs Street and Eagle House behind, the 15-Storey Standard Bank Building at Marina, 12-Storey Blocks of Flats at Ikoyi, 10-Storey DUMEZ House at Campbell Street, 10 and 7 Storey Office Blocks at Macarthy Street, as well as the Ikoyi Telephone Exchange.

(g) **Jetted Piles**—In some dense granular and very stiff clay formations where bored piling is difficult and driving produces unacceptable vibrations, pile installation can be accomplished by forcing jets of water, air or mixture of both under high pressure through the soil beneath the pile tip to weaken and fluidify and soil, thus allowing easy penetration of pile or pile casing under gravity. This technique is generally used in conjunction with driven piles to facilitate penetration through relatively thin compact or cemented bands.

Load bearing capacities of jetted piles are low owing to excessive soil disturbance at the tips and periphery of the pile. Consequently, it is normal to hammer drive a jetted pile to its final bearing level.

Examples of jetted piles in Nigeria are the 'Pilgrim Piles' used for the support of some Blocks of Flats in Ikoyi and Apapa in the early 1960's.

(h) **Vibrated Piles**— These are piles installed by the application of high amplitude vibrators, especially in water-logged or loose sand and gravel deposits where densification of the material surrounding the pile is also achieved. The vibratory piling technique is therefore most useful for installing Steel Sheet Piles, Steel Cased Piles and Compaction Piles.

Except where the cross-sectional area of the pile is small vibrations from this method of piling produce significant ground movements which can cause settlement and damage to nearby structures. These detrimental effects of vibration demands very careful consideration when adopting this system of piling in built-up areas.

Examples of the use of vibrated piles in Nigeria had been given at Sections (ii) and (v) above.

Pile Selection

Selecting the most appropriate type of piled foundation for any given set of circumstances depends upon many variables which may be grouped generally into Subsoil Conditions, Type of Structure, Resources Available and Environmental Limitations.

Generally, the first step towards any foundation design and selection exercise is to carry out a comprehensive subsoil investigation by means of exploratory boreholes, taking of samples, and carrying out field and laboratory tests appropriate to the prevailing ground conditions. However, before adopting a piled foundation solution, it is essential to examine the stability and order of settlement of comparative spread foundations and assertain the advantages of a piled solution. Pile design should be considered in relation to constructional methods available and the geological conditions in which the anticipated pile load will be supported. Furthermore, the intimate interrelationship of the foundation and superstructure must be borne in mind in selecting the right type of pile and manner of installation.

Blessey (1974) suggested the following as being some of the important factors that influences the choice of piled foundation solution for a given project:—

(a) The length, number and size of piles capable of supporting the envisaged superimposed load and/or to resist uplift and lateral loads.
(b) The unsupported length of the pile in very soft soils and/or above ground level.
(c) Handling and construction problems of the type of pile to be selected.
(d) The available headroom and accessibility, presence of other structures nearby and location of water table.
(e) Ability to withstand hard driving and penetrate any dense strata to the specified level.
(f) Ability to withstand lateral driving pressures and resulting displacements.
(g) Requirements of the local building code and availability of local materials.
(h) Future construction requirements and possibility of a change in the superstructure.
(i) Economic considerations. It should be noted that sometime the most economical foundation does not require the pile type with the lowest cost per unit load.

Bearing Capacity of Piles

The prime function of a piled foundation is its ability to support the superimposed load without settling or moving to an extent detrimental to the structure being supported. The bearing capacity of a pile is dependent on its size, shape and type as well as the properties of the soil in which it is embedded. For practical purposes, the ultimate bearing capacity of a piled foundation has been defined in British Standard Code of Practice C. P. 2004: 1972 as that load, applied to the head of the pile, which causes the pile head to settle 10% of the pile diameter. Alternatively, ultimate bearing capacity of a pile may be defined by some clearly recognisable feature of the load/settlement curve.

The ultimate bearing capacity of a pile may be calculated approximately be means of a 'dynamic' pile formula based on data obtained during Test Driving' of the pile, or by 'static' formula based on soil test results. or from 'Pile Loading Tests'

Dynamic pile driving formulae should not be used as criteria for establishing load capacity without correlation with the results of subsoil investigations and pile load tests, or local experience confirmed by loading tests.

Static or theoretical bearing capacity formulae such as Meyerhof's (1951) or Terzaghi and Peck's (1948) must not be relied on exclusively, owing tc possible reversal of side friction on piles by consolidation of surrounding soil and uncertainties of the degree of accuracy with which soil parameters used in the calculations might have been obtained. Therefore, results obtained must be verified by pile load tests and a study of the pile installation record sheets.

For piles in cohesionless soils, the ultimate bearing capacity may be estimated from results of the various forms of in-situ penetration tests; the Dutch Cone Penetrometer Test being the most popular. From correllation of the cone penetrometer test results with pile load tests, reliable formulae, such as of Van der Veen and Boersma (1957) for end bearing capacity of driven piles in granular deposits are now available. However, it is desirable to confirm values obtained from these formulae by actual load test.

(a) **Shaft Adhesion**

For piles in cohesive soils, adhesion plays an important role in the mobilisation of load support and it depends principally on the strength and sensitivity of the clay, as well as type of pile and method of installation used. Experience shows that pile driving permanently alters surface adhesion of firm and stiff clays; but in softer clays, the remoulded material consolidate with time to regain adhesion approximately equal to the original shear strength of the clay. It is also known that pile driving does not essentially alter the shear strength of a clay stratum. Furthermore, the position of ground water has no effect on ultimate load capacity unless cohesion is changed.

Where a pile penetrates several different strata, the supporting adhesion of the individual layers should be added, except where a soft layer that may consolidate and reverse load or cause down drag on the pile is penetrated. Adhesion is adversely influenced by drilling disturbance and softening as a result of water becoming available during the construction process. Consequently, no adhesion should be considered effective within the depth that jetting had been conducted.

From reports of various studies on adhesion Morgan & Poulos (1968) suggested that for preliminary design, Adhesion/Undrained Cohesion (Ca/Cu) of 0.4 be used for piles in firm to stiff insensitive clays and Adhesion/Remoulded Cohesion (Ca/Cr) of 1 for sensitive clays. These values may be varied depending on the degree of supervision.

(b) **Pile Loading Tests**

It is therefore essential to ensure that a piled foundation will perform effectively, before any structure is erected thereon. For this purpose loading tests are usually carried out. The tests are of two types and a minimum of two tests should be carried out per site with uniform subsoil conditions.

(a) Pile Load (Compression) or Pulling (Tension) Tests.
(b) Pile Tests.

Pile Load Tests are carried out to test the subsoil in which the pile is embended and can be regarded as a part of subsoil investigation programme to facilitate pile design. Ultimate loading is attainable from the test.

Pile Tests are carried out to determine whether the design criteria have been attained in the working piles. Therefore, the loading is not usually applied to the ultimate but merely to the design load plus a safety margin.

Consequently, Pile Load or Pile Tests are carried out for any of the following conditions:-

i) To verify or modify estimate of pile bearing capacity determined by theoretical methods (LOAD TESTS).
ii) To evaluate expected settlement at pile working load or some multiple thereof or to check structural soundness of the pile (PILE TEST).
iii) Where unique or unfamiliar type of pile or piling system is to be used (PILE AND LOAD TESTS).

(iv) Where a bearing stratum is underlain by a more compressible or questionable stratum (PILE TEST).

All pile loading tests must stimulate as far as practicable, the conditions expected during construction. In particular, it must be ensured that skin friction of the overburden which will be eventually removed does not support the test piles. Thus, if skin friction of an upper compressible stratum will act downwards, as 'Negative' or 'down-drag' on the piles after construction, 'Pulling Tests' may also be carried out.

For details of Pile Loading or Pulling Tests reference may be made to The British Standard Code of Practice C.P. 2004 : 1972 or A.S.T.M. D1143 : 74 for the 'Maintained Load' technique. Or to Whitaker & Cooke (1961) for the 'Constant Rate of Penetration' method.

In recent years, other methods of pile testing besides loading are being introduced e.g. the Sonic or Vibration Methods. These new methods give rapid results and are less expensive but should be carried out by experts.

Pile Behaviour

In practice, piles are more commonly installed in groups but owing to the difficulty of performing full-scale tests on pile groups, model test studies have been widely used to examine pile behaviour. From such studies, the following effects amongst others, had been established:—

i) That efficiency of a pile group is the ratio of the ultimate bearing capacity of a pile in the group to its capacity as an individual pile.

ii) That the bearing capacity of a pile group is usually less than the sum of the individual piles, depending on the degree of overlap of pressures transmitted by adjacent piles.

iii) That pile group efficiency depends on the spacings between the piles in the group, but efficiencies of unity are never attained, even at large spacings.

iv) That the failure pattern of an isolated pile changes as its zone of influence is being interrupted by that of another pile and at a certain close spacing, failure parttern of the group as a block eventually predominate. Terzachi and Peck (1948) gave a formula for estimating bearing capacity of pile group when block failure occurs and Tomlinson (1975) gave that for determining ultimate bearing capacity.

v) In cohesive soils, group efficiency increases with pile spacing. However, Tomlinson (1975) suggested that in order to avoid block failure, pile spacing should not as a general rule be closer than one metre centre to centre.

vi) In cohesionless soils, shear failure is highly unlikely at normal pile loads. Hence, for pile spacing less than three diameters, the group acts like a large pier, mobilising side friction on the outer boundary of the group. For pile spacing exceeding eight diameters, individual resistance of each pile is mobilised. However, owing to increasing soil density as piles are being driven, a spacing of two to three diameters is usually specified and the driving of piles in the group should start from the centre of the group, working outwards in all directions.

vii) With the use of Large Diameter Bored Piles, ultimate resistance is provided by both skin friction and base resistance and very high working loads are obtainable. The design principles and behaviour are similar to those of the conventional smaller diameter piles.

viii) Completed piles move both vertically and horizontally as a result of driving adjacent piles. The former is very pronounced and most common for displacement piles in soft clays and medium to compact granular soils.

Heave, an upward vertical movement, will also most likely occur when the pile shafts are wholly embedded in firm to stiff clays. This ground displacement by piles driven in groups can cause high lateral pressures to develop on nearby buried culverts sewers or tunnels with consequent risk of serious damage.

ix) Stiff and brittle clays, clay shales or shales are vulnerable to fracturing or softening at the tips of completed piles during driving of adjacent piles, hence open-ended pipe piles are more suitable in these materials.

x) Where piles are driven through an upper compressible material into the bearing stratum, skin friction resists movement during pile driving or load test. Thereafter, consolidation of the compressible strata may reverse skin friction, throwing additional loads on the pile. Then, the skin friction becomes a down-drag or negative frictional load and is then transmitted to the bearing stratum.

For a pile group in sensitive clays that consolidate on remoulding the downdrag is at a maximum. For clays with a sensitivity of less than two, consolidation produced by remoulding from pile driving is limited to a thin annular space surrounding pile and the drag may therefore be neglected.

Settlement of Piled Foundation

Some correlations of settlement of single pile to that of a group had been suggested by Skempton (1953) but there is no published data on the relationship between immediate and long term settlement of groups of piles and those of individual piles.

In practice, settlement of a piled foundation is computed from results of laboratory consolidation tests for clays, in accordance with Terzachi's (1943) method and from penetration test data for sands, using the De Beer and Marten's (1957) method. The usual approach is to assume the pile group loading as being concentrated, acting as a flexible footing at the level of the pile base or to consider the load as acting at two-thirds the depth of piles. Both methods are known to under-estimate the actual settlements but with the advent of computers, more satisfactory methods of calculation based on the analysis of a pile in an elastic mass are now available.

Conclusion

The foregoing has briefly discussed the piling system available in this country and bring into focus some basic considerations necessary for good pile selection and installation. It was deliberately decided to adopt a less academic but practical approach in presenting the paper

because it is meant to stimulate thoughts towards a deeper study of the use of piles for foundation works.

Much research work has been carried out and volumes of publications available on piling techniques and practice based on experiences gained at places where both technological and climatic conditions are not entirely similar to ours. These studies have contributed immensely to today's development of equipment and techniques. It advocated therefore that we in Nigeria should strive to add our experience to the available bank of knowledge by monitoring the piling processes being used and the resulting behaviour of piled foundations in our ground conditions.

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