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DESIGN AND CONSTRUCTION OF SHALLOW FOUNDATIONS FOR LOW-RISE RESIDENTIAL BUILDINGS IN NIGERIA

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Most residential buildings in Nigeria, especially the low-rise types are founded on shallow (slab) foundations, with the most widely used of them as strip and pad. This is perhaps because of the prevalent types of residential buildings (bungalows) and the soil conditions i.e. stable tropical residual soils. Traditional foundation design practice in Nigeria relies largely, on the British Code of Practice for Foundations BS 8004 of 1986 [1] (now Eurocode 7), and a little of empirical rules formulated from local experience with foundations in tropical region. A thorough understanding of the geology and soil conditions of an area, in which foundation is to be sited, is a pre-requisite to the success of a foundation project.

Types of Shallow Foundations used in Nigeria

Most residential buildings in Nigeria are low-rise buildings founded on shallow (pad, strip and raft) foundations. Statistically, more than 80 % of these residential buildings are bungalows (building with single floor), which are mostly founded on strip foundations, while most of the few multi-floor low-rise residential buildings are founded on pad foundations. Only few rare cases occur, were residential buildings in Nigeria are founded on raft foundations, even in areas with extremely weak or very troublesome soils. The following are the different types of shallow foundations:

Pad Foundation—are used to support point loads from columns. There are a number of different types of pad foundations available in use in the country (Fig. 1).

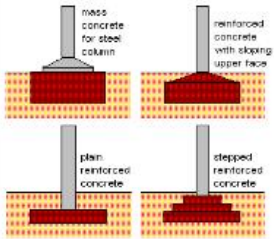

Fig. 1: Types of pad foundations

Fig. 2: Houses on pad foundations

Strip Footing —used under relatively uniform point loads or mostly under walls. The strip distributes the concentration of the load sideways into an increased width of sub-strata to reduce the bearing stress and settlement to an allowable limit [2]. Strip footings are used under bearing wall or when rows of columns are spaced so closely that individual pad foundation will nearly touched each other. They are the most widely used shallow foundations in Nigeria for the construction of low-rise residential buildings.

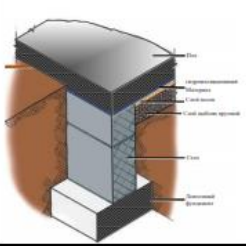

Fig. 3: Strip footing.

Fig. 4: House constructed on strip footing.

Raft Foundation —also known as mat foundation. It is a large spread footing that supports most of the structure loads. A raft foundation spreads the structural load over a large area to reduce the bearing pressure.

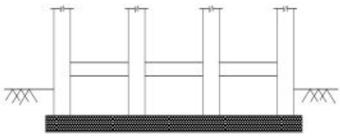

Fig. 5: Raft Foundation

Fig. 6: Construction of raft foundation

Design of Bases on Sand

Shallow foundations are generally designed to satisfy bearing capacity and settlement criteria. The bearing capacity criterion stipulates that there is adequate safety against bearing capacity failure beneath the foundation, and a factor of safety of three is generally used on the computed ultimate bearing capacity. Settlement criterion is to ensure that the settlement is within tolerable limits.

Foundations on silt or sand deposits may consist of spread (pad and strip) footings, mats or piles, depending on the density, thickness, and cost of densifying the deposit, and on the building loads. Spread footings are used if the deposit is dense enough to support the loads without excessive settlements. Rapid or immediate settlements occur on noncohesive silt or sand deposits.

Bearing Capacity of foundations on sand

In proportioning shallow foundations parameters in Nigeria, the Terzaghi general bearing capacity equation as given by equation 1, is generally used.

$$q_{ult} = cN_c + qN_q + \frac{1}{2}\gamma B N_\gamma \qquad (1)$$

where q_{ult} is the ultimate bearing capacity, c is the unit cohesion, q is the surcharge ($D\gamma$), γ the unit weight of soil, D the depth of foundation, B is foundation width, N_c, N_γ *and* N_q are coefficients that depend on the effective friction angle of the soil, ϕ. It is commonly accepted that:

$$N_c = (N_q - 1)\cot\phi \qquad (2)$$

$$N_q = e^{\pi \tan\phi} \tan^2\left(45^o + \frac{1}{2}\phi\right) \qquad (3)$$

However, for calculating N_γ, different equations have been recommended. One of the most popular equations is that of Brinch-Hansen [3]:

$$N_\gamma = 1.5(N_q - 1)\tan\phi \qquad (4)$$

Values of N_c, N_γ and N_q are usually tabulated or graphically given against ϕ in literatures for easy reference.

For a granular, non-cohesive (c=0) material, the ultimate bearing capacity q_{ult} of the soil is given by:

$$q_{ult} = qN_q + \frac{1}{2}\gamma B N_\gamma \quad (5)$$

The ultimate bearing capacity of foundations, q_{ult} in sand can also be determined from results of plate load test by the following equation:

$$q_{ult} = q_{up}\left(\frac{B_f}{B_p}\right) \quad (6)$$

Where q_{up} is the ultimate bearing capacity of the test plate, B_f and B_p are foundation and test plate widths respectively.

Recognizing the uncertainties involved, factors of safety are applied to reduce the estimated ultimate bearing capacity from equation 5. The allowable bearing capacity q_{allow} is:

$$q_{allow} = \frac{q_{ult}}{FS} \quad (7)$$

The factor of safety (*FS*) is a function of the importance of the structure, the consequences of failure, and the uncertainty of the subsurface investigation. Its value ranges between 2 and 3 in Nigeria.

Settlement of foundations in sand

It is commonly believed that the settlement criterion is more critical than the bearing capacity one in the designs of shallow foundations, especially for foundation width greater than 1.5 m, which is often the case. By limiting the total settlements, differential settlements and any subsequent distresses to the structure are limited. Generally the settlements of shallow foundations such as pad or strip footings are limited to 25 mm [4].

The general equation for the calculation of elastic settlement S_e in sand is given as:

$$S_e = q_n B \frac{(1-\mu^2)}{E} I_f \quad (8)$$

where q_n is the net foundation pressure, B the width of foundation, E the modulus of elasticity of soil, μ the Poisson's ratio and I_f is the influence factor for settlement.

Terzaghi and Peck equation for the calculation of foundation settlement S_f in sand from the result of field plate load test is also commonly used:

$$S_f = S_p \left[\frac{B_f(B_p+0.3)}{B_p(B_f+0.3)}\right]^2 \quad (9)$$

Where S_p is test plate settlement, B_f and B_p are foundation and test plate widths respectively.

Design of Bases on Clay Soils

In clay soil it is necessary to make best estimate of the allowable bearing capacity to control a shear failure with a suitable factor of safety and to estimate the probable consolidation settlements. The bearing capacity is most often determined using the undrained shear strength as obtained from quality tube samples. If the soil is highly sensitive, consideration are given to in situ strength testing such as the vane shear or the cone penetration test.

Consolidation tests are made to determine the expected settlement if the structure has a relatively high cost per unit area. For smaller or less important structures, some type of settlement estimate based on the index properties might be justified.

The net ultimate bearing pressure for vertical loads on clay soils is normally computed as a simplification of Terzaghi, Meyerhof or Hansen equations. For ϕ=0, equation 1 becomes:

$$q_{net} = C_u N_c \quad (10)$$

Since $N_c = 5.14$ and $N_\gamma = 1$ from table of values of N_c, N_γ *and* N_q, when ϕ=0, therefore:

$$q_{net} = 5.14 C_u \quad (11)$$

For the computation of consolidation settlement, the following equation is generally used for normally consolidated clays:

$$S_c = H \frac{C_c}{1+e_0} \log \frac{P_0 + \Delta P}{P_0} \quad (12)$$

where H is the thickness of the clay layer, C_c is the compressive index from e-logP graph, e_0 the initial void ratio, P_0 is the effective overburden pressure and ΔP is the increase in the effective stress at the middle of the layer due to the foundation load.

Foundation settlement in clay soils can also be estimated from the results of plate load test using the following equation:

$$S_f = S_p \left(\frac{B_f}{B_p}\right) \tag{13}$$

The maximum settlement allowed for foundations on clay soils is 25mm.

Technology and Equipment for the Construction of Shallow Foundations in Nigeria

Foundation construction consists of a series of activities ranging from site preparation, foundation trench excavation and the actual construction or installation of the foundation.

Foundation construction for residential buildings in Nigeria is still been dominated by manual methods of cast in-situ construction, using local implements. This is perhaps because most residential buildings in the country are constructed by individuals, who have no sufficient capital to use modern construction equipment. Only few cases occur where construction of foundation for residential buildings involves the use of modern equipment and technology.

Site preparation

Although in Nigeria, manual methods of site preparation and foundation construction still predominate, the present-day foundation construction methods involve a high degree of mechanization. Optimum working speeds of plant are achieved only in clear working conditions giving maximum mobility for the plant and vehicles. Therefore, an efficient and well-maintained system of temporary roads should be provided on extensive sites in order to achieve and maintain a rapid tempo of construction in all weathers. Equally important is attention to site drainage to give dry working conditions and to avoid unnecessary pumping.

Foundation trench excavation

Most construction sites in Nigeria for buildings that are to be founded on either pad or strip foundations uses manual method and simple equipment for excavation of foundation trench. The usual materials used for this operation are mostly diggers and shovels (fig. 7).

Fig. 7: Excavation for strip foundation using diggers and shovels

Fig. 8: Excavated tend for strip foundation

After the site clearance and the removal of the top organic soil, the usual practice for foundation trench excavation, for the construction of either pad or strip foundations, is to pile the excavated materials on the unexcavated portions within the site (fig. 8). These materials are later on used for backfilling after the foundation construction. But excavating a trench for the construction of raft (mat) foundation, more comprehensive operations are required because of the large quantity of the excavated material that is usually involved.

The choice of plant for bulk excavation is largely determined by the quantity and by the length of haul to the disposal point. If the tip area is close to the excavation, say within 100 m, then the earth can be moved by *loading shovel* or *bulldozer*. Longer hauls (say 100-600 m) require crawler or rubber-tyred tractor-drawn *scrapers* [5].

To ensure the safety of the workers in the trench, stability of the trench's sides is seriously taken into consideration, especially for relatively dipper excavations in cohesionless soils. The sides of the trenches are usually protected by designed sheet piles.

Placement of Shallow Foundations

After the trenches are prepared, for plain concrete footing (and for reinforced concrete, the reinforcement arranged, fig. 9-11), the concrete is carefully poured to the designed dimensions. There still exist in Nigeria, especially for pad and strip footings, manual methods of mixing and placing concrete during foundation construction. For large scale foundation construction, mechanical methods of mixing and placements of the concrete foundations are used (fig. 11).

Fig. 9: A pad footing under construction

Fig. 10: Strip/pad footings under construction

Fig. 11: A raft Foundation under construction

Conclusion

–Shallow foundations are widely used in Nigeria for the constructions of buildings for both commercial and residential purposes. Most of the low-rise residential buildings in Nigeria, which are mostly bungalows are founded on shallow foundations especially the strip type.

–The selection and usage of these foundations depends to a large extent on the geological and soil condition of the area. For the determination of shallow foundations' parameters, the Terzaghi bearing capacity equation, as modified by Brinch-Hansen, still remains the most often used equation in Nigeria.

–Foundation construction for residential buildings in Nigeria is still been dominated by manual methods of construction using cast in-situ technology. This is perhaps because most residential buildings in the country are constructed by individuals, who have no sufficient means to use modern construction methods and technology.

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