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Research article

STABILITY AND DEFORMATION RESPONSE OF PAD FOUNDATIONONS ON SAND USING STANDARD PENETRATION TEST METHOD

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Abstract

Stability and deformation response of pad foundations placed on sand was carried out using in-situ test method of standard penetration test on soil lithology consisting of loose, silty to slightly silty SAND, overlying medium-dense, slightly silty SAND. Results showed that at different foundation depths, D_f, allowable bearing capacity, q_a, assumed same value at foundation breadth, B, of 1m and it subsequently decreased as foundation breadth increased. However, for a given foundation breadth, q_a increased with foundation depth. For cases of variation of q_a and D_f/B ratio, it was noticed that q_a values increased with increase in D_f/B ratio, tending to 102kN/m^2 for D_f/B> 1.0.Immediate and total settlement increased with foundation breadth and foundation depth. Comparatively, Burland and Burbidge approach had higher total settlement against those of Harr.The predictive models on total settlement can be useful for preliminary design purposes on sites having similar conditions.

Key words: Shear failure. Poisson ratio.Modulus of Elasticity. Influence factor, Model.

Introduction

Stability and deformation requirements are two basic criteria to be satisfied in foundation analysis and design of shallow foundations. Stability criterion ensures that foundations do not undergo shear failure under loading, while deformation requirement ensures that settlement of the structure is within the tolerance limit of the superstructure. In the failure of shallow foundations, three types of shear failures have been identified to occur under foundation induced loading. These are general shear failure, punching shear failure and local shear failure; details of their failure mechanisms have been reported in many literatures (Singh, 1992; Caquot, 1934;Terzaghi, 1943; De Beer and Vesic, 1958; Vesic, 1967). The use of standard penetration test in the analysis of bearing capacity and settlement of shallow foundations have been reported in numerous literatures including Craig, (1987),Bowles (1997) and Tomlinson (2001). In the Niger Delta region of Nigeria, recent studies on stability and deformation of shallow foundations have been reported by Akpila (2007a), Akpila (2007b), Akpila and ThankGod (2008),Akpila et al. (2008) and Akpila (2013). Details of the field application of Standard Penetration Test are specified in BS 1377. This paper attempts to report on stability and deformation of pad foundations placed on sand using results and methods of standard penetration test.

Materials and Methods

Field Exploration/ Laboratory Analysis

Subsurface conditions at the site were studied through ground borings to depths of 24m each using a percussion boring rig.Both disturbed and undisturbed samples were collected for visual examination, laboratory testing and classification. Standard Penetration Tests (SPT) was conducted to determine the penetration resistance values of sand bodies at specific depths within the boreholes.Requisite laboratory tests on soil samples to obtain input parameters for bearing capacity and settlement assessment were conducted.The water table at site was observed to vary from about 1.0-1.1m below the existing ground level.

Bearing Capacity Analysis on sand

A bearing capacity analysis of pad foundation placed on soil formation consisting of loose,silty to slightly silty SAND, overlying medium-dense, slightly silty SAND formation was carried out. The proposed foundations were to be placed at one metre below the sand formation which had previously been reclaimed with hydraulically dredged sand that meet desired grade level existing between the highway pavement and the project location (Figure 4).

The modified Meyerhof (1956) correlation for bearing capacity using Standard Penetration Resistance presented by Bowles (1977) for an allowable settlement of 25.4mm has been used. The choice of modified Meyerhof method is based on the middle bound values associated with the model compared to that of Parry (1977) with higher bound values and Meyerhof (1956) with lower bound values of bearing capacity (Akpila, 2013). The modified Meyerhof expressions are given by;

$$q_{n(a)} = 19.16NF_d\left(\frac{s}{25.4}\right) for B \leq 1.2m \quad (1)$$

$$q_{n(a)} = 11.98N\left(\frac{3.28B+1}{3.28B}\right)^2 F_d\left(\frac{s}{25.4}\right) for B > 1.2m \quad (2)$$

here F_d = depth factor = 1+ 0.33 (D_f/ B) $\leq$ 1.33

S = tolerable settlement

N = average penetration number

Settlement Analysis on Sand

Immediate Settlement

Immediate foundation settlement at a corner of a rigid foundation of breadth B varingfrom 1-1.6m were obtained using the expression proposed by Harr (1966) and reported in Braja (1999) as follows;

$$s_i = \frac{q_{nB}}{E_o}(1-\mu^2)I_p \quad (3)$$

where S_i is immediate settlement, B is breadth of foundation at a corner, q_n is net foundation pressure, E_o is modulus of elasticity, μ is Poisson ratio, I_p is influence factor for rigid foundation. To obtain the settlement at the centre of a square foundation, the principle of superposition was adopted and settlement value is usually four times the settlement at any corner.

The modulus of Elasticity, E,is evaluated from the expression;

$$E_o = 0.478N + 7.17MPa \tag{4}$$

and for cohesionless soils, Poisson ratio, μ can be obtained from;

$$\mu = \frac{1-\sin\phi}{2-\sin\phi} \tag{5}$$

where ϕ is angle of internal friction of sand and N is average SPT blow count for sand stratum. Values of influence factor, I_p, for various length to breadth (L/B) ratios were obtained from standard curves presented in Braja (1999).In Burland and Burbidge (1985) approach, they proposed that for normally consolidated sand, the average settlement is expressed in terms of net foundation pressure, foundation breadth and compressibility index as;

$$s_i = \frac{q_n B^{0.7}}{3}\left(\frac{1.71}{N^{1.4}}\right) \tag{6}$$

where q_n is the net foundation pressure, B is foundation breadth and N is average value of standard penetration resistance.

Consolidation Settlement:

While settlement on sand is generally treated as immediate, the consolidation settlement was carried out using Equations (4, 5, 7 and 8).The coefficient of volume compressibility, m_v, is obtained from the following expression;

$$m_v = \frac{(1+\mu)(1-2\mu)}{E_o(1-\mu)} \tag{7}$$

where $E_o$and μ and are as defined in Equations (4 and 5) and the consolidation settlement was evaluated from Skempton and Bjerrum (1957) expression presented as follows:

$$\begin{aligned} \rho_c &= \frac{\Delta e}{1+e_o}\left(\frac{1}{\Delta p}\right)\Delta\sigma_z H \\ &= \frac{\Delta e}{1+e_o}\left(\frac{1}{\Delta p}\right)\frac{q_{nBL}}{(B+Z)(L+Z)}H \\ &= 0.55\left\{\frac{\Delta e}{1+e_o}\left(\frac{1}{\Delta p}\right)q_n x 1.5B\right\} \\ &= 0.55 m_v q_n x 1.5B \end{aligned} \tag{8}$$

where ρ_c is consolidation settlement, q_n is net foundation pressure, B is foundation breadth, Δp is change in pressure, Δe is change in void ratio, e_o is initial void ratio, $\Delta\sigma_z$ is induced vertical stress and $\frac{\Delta e}{1+e_o}\left(\frac{1}{\Delta p}\right)$ is coefficient of volume compressibility, m_v. Substituting Equation (7) into Equation (8) yields;

$$\rho_c = 0.55\frac{(1+\mu)(1-2\mu)}{E_o(1-\mu)}q_n x 1.5B \tag{9}$$

The total settlement from pad foundation can then be expressed as;

$$\rho_t = \frac{q_n B}{E_o}(1-\mu^2)I_p + 0.55\frac{(1+\mu)(1-2\mu)}{E_o(1-\mu)}q_n x 1.5B \tag{10}$$

When immediate settlement is considered based on Equation (6), then for normally consolidated sand, total settlement can be expressed as;

$$\rho_t = \frac{q_n B^{0.7}}{3}\left(\frac{1.71}{N^{1.4}}\right) + 0.55\frac{(1+\mu)(1-2\mu)}{E_o(1-\mu)}q_n x 1.5B \tag{11}$$

Scholars including Skempton and MacDonald (1956), Polshin and Tokar (1957), and Wahls (1981) have specified limiting values for allowable settlement of different structures founded on either clay or sand. The limiting specification for pad foundations on soils forms the basis for assessment of vertical deformation on the foundation.

Discussion of Results

Soil Classification

The soil generally consists of loose, silty to slightly silty SAND, and overlying medium-dense, slightly silty SAND formation.

Soil Stratification

This is obtained from boring records and laboratory tests. The soil profile generally consists of loose, silty to slightly silty SAND, overlying medium-dense, slightly silty SAND formation up to the 24m depth of exploration.

Bearing Capacity

The results of allowable bearing capacity, q_a, for isolated pad foundations with B, ranging from 1.0-1.6m and placed at different foundation depth, D_f and also under varying D_f/B ratios are shown in Table 1 and Figures 1-2. Generally, at different foundation depths, q_a assumed same value at foundation breadth of 1m and subsequently, q_a decreased as foundation breadth increased. However, for a given foundation breadth, q_a increased with foundation depth. For cases of variation of q_a and D_f/B ratio, it was noticed that q_a values increased with increase in D_f/B ratio, tending to 102kN/m^2 for D_f/B> 1.0. The respective predictive models relating allowable bearing capacity and foundation breadth for varying foundation depths are presented as follows;

$$q_{a(1.6)} = -151.5B^4 + 954.5B^3 - 2190B^2 + 2153B - 664.1, \quad R^2 = 0.983 \qquad (12)$$

$$q_{a(1.4)} = 138.8B^3 - 572.6B^2 + 749.2B - 213.5, \quad R^2 = 0.988 \qquad (13)$$

$$q_{a(1.2)} = -4583B^5 + 30057B^4 - 78108B^3 + 10049B^2 - 64011B + 16258, R^2 = 0.989 \qquad (14)$$

$$q_{a(1.0)} = -340.9B^4 + 1911B^3 - 3967B^2 + 3571B - 1072, \quad R^2 = 0.997 \qquad (15)$$

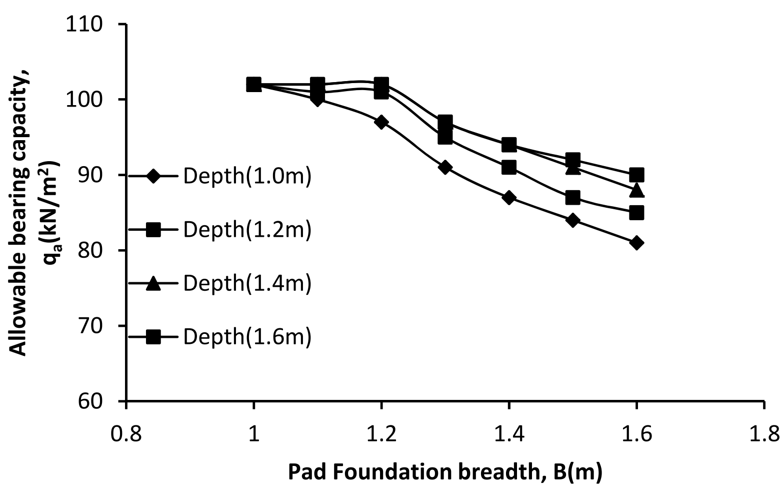

Figure 1: Variation of Allowable bearing capacity with pad foundation breadth

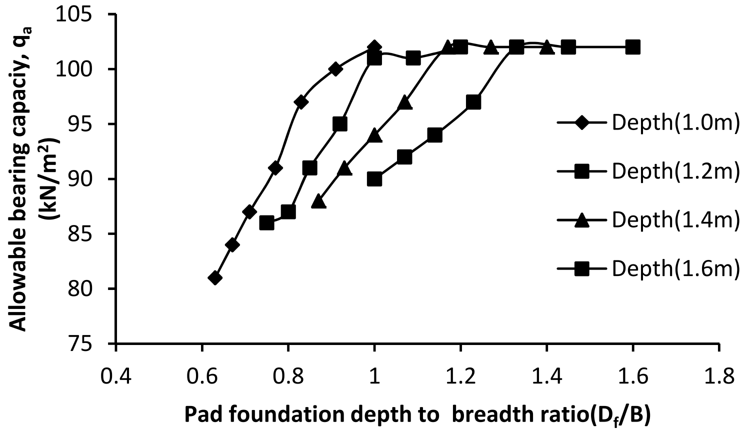

Figure 2: Variation of Allowable bearing capacity with pad depth to breadth ratio

Settlement Analysis on Sand

Immediate Settlement on Pad Foundation

The results of immediate settlement were analysed for net foundation pressure of 50kN/m^2 in Equation (3). The modulus of elasticity was obtained from Equation (4) as 9.08MPa, Poisson's ratio of 0.35 was obtained from Equation (5) while the coefficient of volume compressibility, m_v, of 0.069m^2/MN was evaluated from Equation (7).The results of immediate settlement using methods of Burland and Burbidge, and Harr are presented in Table 2 and Figure 3. Immediate settlement vary from 4.1-5.7mm for foundation breadth varying from 1-1.6m depth respectively for Burland and Burbidge approach while Harr's model gave immediate settlement values of 7.7-12.4mm for the range of foundation breadth. Comparatively, Burland and Burbidge approach gave conservative values of immediate settlement to that of Harr's approach. Their settlement variation with foundation breadth are depicted in Figure 3, while the models describing Burland and Burbidge, and Harr's approaches are presented in Equations (16) and (17) respectively.

$$s_i = 2.607B + 1.525, R^2 = 0.997 \quad (16)$$

$$s_i = 7.821B - 0.110, R^2 = 0.999 \quad (17)$$

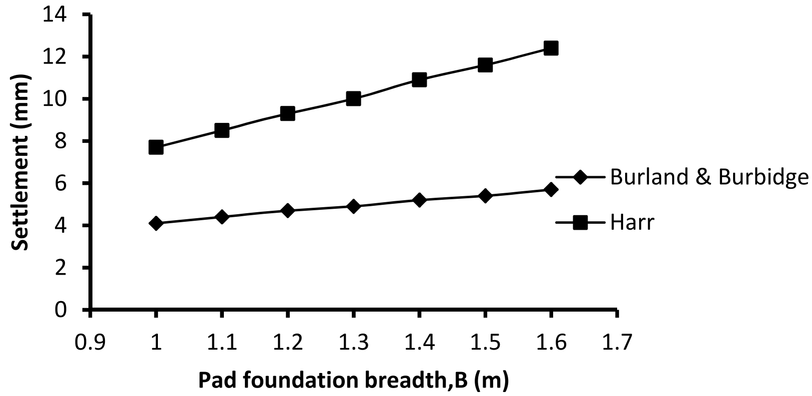

Figure 3: Variation of Immediate settlement with Pad foundation breadth

Total Settlement on Pad Foundation

Consolidation settlement of pad foundation of breadth, B, varying from 1-1.6m was found to increase with footing size. The relationship between foundation breadth and total settlement is shown in Figure 4, where Harr's approach had higher total settlement compared to those obtained from Burland and Burbidge approach. The models describing Burland and Burbidge, and Harr's total settlement are presented in Equations (18) and (19).

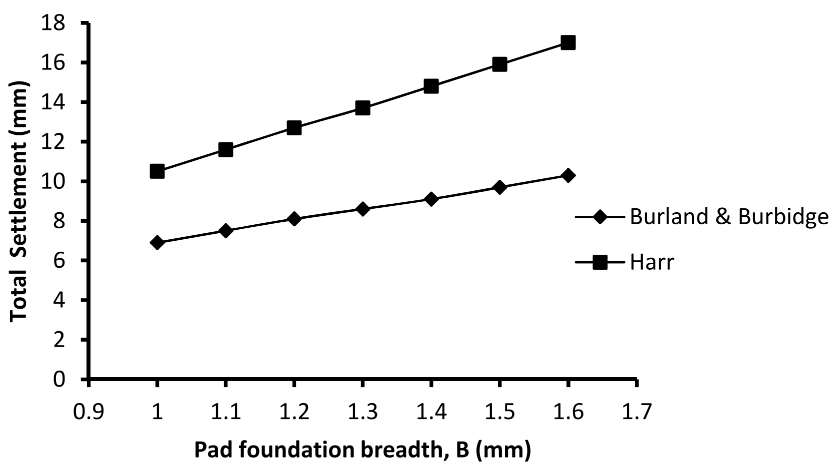

Figure 4: Variation of total settlement with Pad foundation breadth.

$$\rho_t = 5.571B + 1.357, R^2 = 0.999 \quad (18)$$

$$\rho_t = 10.78B - 0.278, R^2 = 0.999 \quad (19)$$

The critical foundation breadth for deformation requirement of pad placed on sand can be determined using Harr,s model of Equation (19). The maximum allowable total settlement values suggested by Skempton and MacDonald (1956) may be used in assessing pad foundation deformation.

Conclusion/ Recommendation

Based on the findings, the following conclusions can be drawn;

i. At different foundation depths, D_f, allowable bearing capacity, q_a, assumed same value at foundation breadth, B, of 1m and subsequently decreased as foundation breadth increased.

ii. However, for a given foundation breadth, q_a increased with foundation depth.

iii. For cases of variation of q_a and D_f/B ratio, it was noticed that q_a values increased with increase in D_f/B ratio, tending to 102kN/m^2 for D_f/B> 1.0

iv. Immediate settlement of pad foundation breadth varying from 1-1.6m was found to increase with footing size and foundation depth.

v. In Burland and Burbidge approach immediate settlement vary from 4.1-5.7mm for foundation depth varying from 1-1.6m depth.

vi. Harr's model gave immediate settlement value of 7.7-12.4mm for foundation depth varying from 1-1.6m depth.

vii. Comparatively, Burland and Burbidge approach gave conservative values of total settlement than Harr's approach.

viii. The predictive models generated can be used for preliminary design purposes on sites that have similar conditions.

Table 1: Bearing Capacity of Pad Foundation

Depth of Foundation (m)	Foundation Breadth B (m)	D_f/ B	SPT value N	Depth Factor F_d	Allowable bearing capacity, q_a (kN/m^2)
1.0	8	0.125	4	1.041	53.75
	9	0.111		1.036	53.06
	10	0.100		1.033	52.56
	11	0.090		1.029	52.08
	12	0.083		1.027	51.74
	13	0.076		1.025	51.44
	14	0.071		1.023	51.18
	15	0.066		1.021	50.93
1.2	8	0.150	4	1.049	54.17
	9	0.133		1.043	53.42
	10	0.120		1.039	52.87
	11	0.109		1.035	52.38
	12	0.100		1.033	52.04
	13	0.092		1.030	51.69
	14	0.085		1.028	51.43
	15	0.080		1.026	51.18
1.4	8	0.175	4	1.057	54.58
	9	0.155		1.051	53.83
	10	0.140		1.046	53.22
	11	0.127		1.041	52.68
	12	0.116		1.038	52.30
	13	0.107		1.035	51.85
	14	0.100		1.033	51.68
	15	0.093		1.030	51.38
1.6	8	0.200	4	1.066	55.05
	9	0.177		1.058	54.19
	10	0.160		1.052	53.53
	11	0.145		1.047	52.99
	12	0.133		1.043	52.55
	13	0.123		1.040	52.20
	14	0.114		1.037	51.88
	15	0.106		1.034	51.58

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Table 2: Settlement analysis of Pad foundation

Analytical Approach	Foundation Breadth B(m)	Average SPT value N	Poisson ratio, μ	Angle of friction (ϕ)	Elastic Modulus E(Mpa)	Coefficient of vol. compressibility m_v (m^2/MN)	Immediate settlement s_e (mm)	Consolidation settlement ρ_c (mm)
Burland & Burbidge	1.0 1.1 1.2 1.3 1.4 1.5 1.6	4	0.35	28	9.08	0.069	4.1 4.4 4.7 4.9 5.2 5.4 5.7	2.8 3.1 3.4 3.7 3.9 4.3 4.6
Harr	1.0 1.1 1.2 1.3 1.4 1.5 1.6	4	0.35	28	9.08	0.069	7.7 8.5 9.3 10.0 10.9 11.6 12.4	2.8 3.1 3.4 3.7 3.9 4.3 4.6

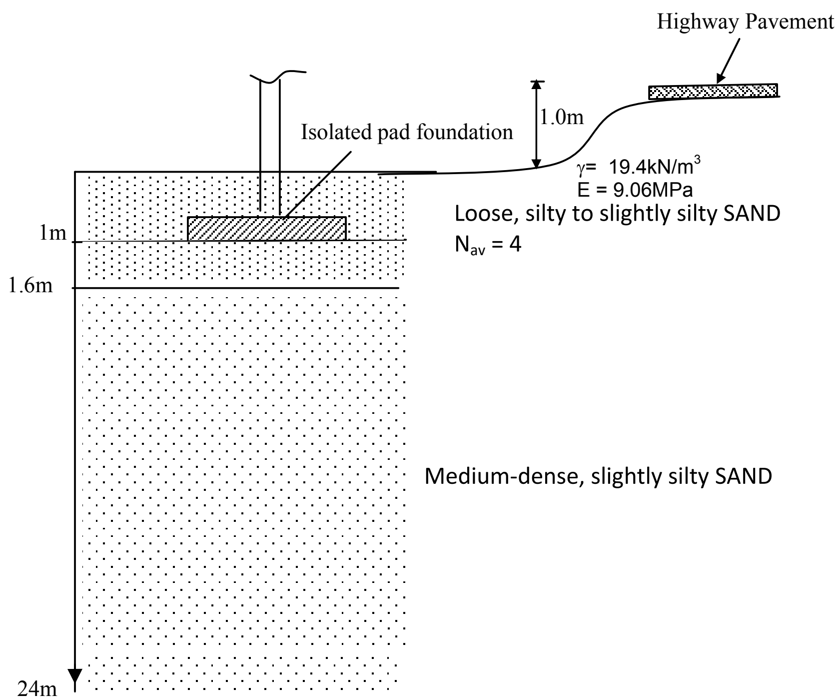

Figure 1: Pad foundation placed on Sand formation

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