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BEARING CAPACITY AND SETTLEMENT RESPONSE OF RAFT FOUNDATION ON SAND USING STANDARD PENETRATION TEST METHOD

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ABSTRACT

Bearing capacity and settlement response of raft foundations placed on sand was carried out using standard penetration test on soil lithology consisting of loose, silty to slightly silty SAND, overlying medium-dense slightly silty SAND. Results showed that allowable bearing capacity, q_a, had a decreasing trend with an increase in raft foundation breadth whereas for a given foundation breadth, q_a increased with foundation depth. Allowable bearing capacity also decreased as the ratio of foundation depth, D_f, to breadth, B ratio (D_f/B) decreased. Immediate and consolidation settlement increased with foundation breadth, bearing pressure and foundation depth. Comparatively, Burland and Burbidge approach had a higher total settlement against those of Harr. The predictive models can be useful for preliminary design purposes on sites with similar conditions.

Keywords: Immediate settlement, poisson ratio, modulus of elasticity, models.

INTRODUCTION

Bearing capacity and settlement requirements are two basic criteria to be satisfied in the analysis and design of shallow foundations. The criterion on bearing capacity ensures that the foundation does not undergo shear failure under loading, while settlement requirement ensures that settlement of the structure is within the tolerance limit of the superstructure. Three types of shear failures have been identified to occur under foundation induced loading; general shear failure, punching shear failure and local shear failure. Details of these failures and their mechanisms have been reported by Singh (1992), Caquot (1934), Terzaghi (1943), De Beer and Vesic (1958) and Vesic (1967). The use of standard penetration test in the analysis of bearing capacity and settlement has also received numerous attentions (Craig, 1987; Bowles, 1997; Som and Das, 2006; Tomlinson, 2001). In the Niger Delta region of Nigeria, recent studies on bearing capacity and settlement of shallow foundations have been reported by Akpila (2007a), Akpila (2007b), Akpila and ThankGod (2008) and Akpila *et al*. (2008). Details of the field application of Standard Penetration Test are specified in BS 1377. This paper attempts to report on bearing capacity and settlement of raft foundations placed on sand using methods based on the standard penetration test.

MATERIALS AND METHODS

Data Acquisition

Information on subsurface conditions at the site was 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) were conducted to determine the penetration resistance values of cohessionless soils at specific depths within the bore holes. Requisite laboratory tests were also carried out on soil samples to obtain input parameters for bearing capacity and settlement assessment. The water table at the 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 raft foundation has been necessitated by the soil stratigraphy at the site which generally consists of loose, silty to slightly silty SAND, overlying medium-dense, slightly silty SAND formation. The proposed foundation was to be placed at 1.6m below the sand formation which had previously been reclaimed with hydraulically dredged sand to meet desired grade level existing between the highway pavement and the project location (Fig. 1). The modified Meyerhof (1956) correlation for bearing capacity using Standard Penetration Resistance presented by Bowles (1997) for an allowable settlement of 50.8mm was used. The choice of using modified Meyerhof method is based on the middle bound values associated with the model compared to that of Parry (1977) which gives higher bound value and Meyerhof (1956) with lower bound values of bearing capacity (Akpila, 2013). The modified Meyerhof

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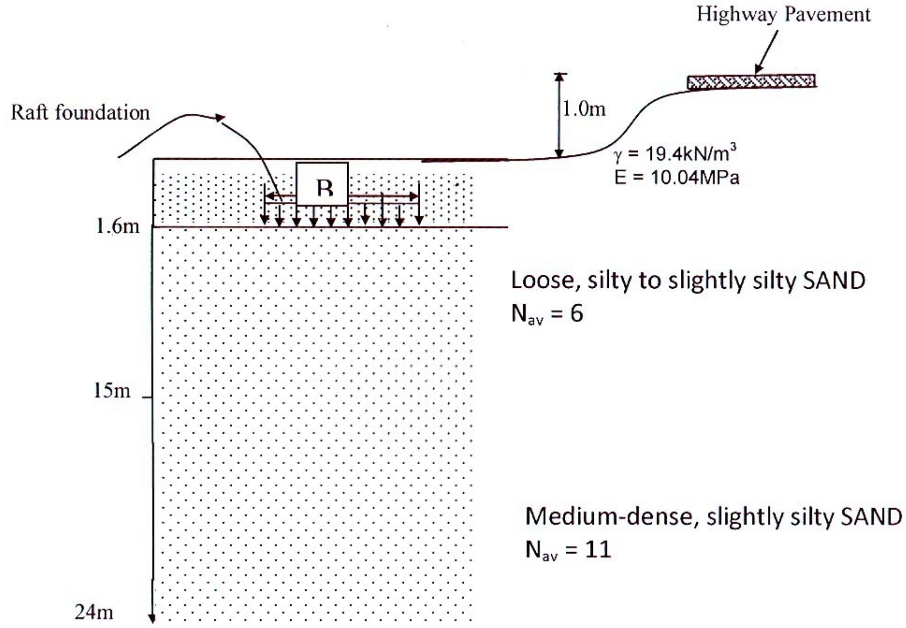

Fig. 1. Raft foundation on Sand formation.

expressions are given by;

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

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

where F_d = depth factor = 1+ 0.33 (D_f/ B) ≤ 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 ranging from 8-12m is respectively obtained using the expression proposed by Harr (1966) and reported in Braja (1999) as follows;

$$s_i = \frac{q_n B}{E_o}(1-\mu^2)\alpha_r \quad (3)$$

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

The values of E and μ are obtained from the expressions;

$$E_o = 0.478N + 7.17MPa \quad (4)$$

$$\mu = \frac{1-\sin\phi}{2-\sin\phi} \quad (5)$$

Where ϕ is angle of internal friction of sand and N is the average SPT blow count for sand stratum. Values of influence factor, α_r, for various lengths 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 as;

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

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

Consolidation Settlement:

Although settlement of sand is generally treated as immediate, the consolidation settlement was attempted adopting Equations (4, 5, 7 and 8). The coefficient of volumetric compressibility, m_v, is obtained from the following expression;

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

Where E_o and μ and are as defined in Equations (4 and 5). Consolidation settlement was evaluated from the expression proposed by Skempton and Bjerrum (1957) as follows:

$$\rho_c = \frac{\Delta_e}{1+e_o}\left(\frac{1}{\Delta p}\right)\Delta\sigma_z H$$

$$= 0.55\left\{\frac{\Delta e}{1+e_o}\left(\frac{1}{\Delta p}\right)q_n x 1.5B\right\}$$

$$= 0.55 m_v q_n x 1.5B \quad (8)$$

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;

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

The total settlement from the Raft foundation can then be expressed as;

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

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

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

Limiting values for allowable settlement of different structures founded on either clay or sand have been presented by scholars including Skempton and MacDonald (1956), Polshin and Tokar (1957) and Wahls (1981). The vertical deformation of the raft foundation was assessed based on the stipulated limiting values.

RESULTS AND DISCUSSION

Soil Classification/Stratigraphy

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 allowable bearing capacity values of raft foundation with B, ranging from 8-15m and placed at varying foundation depth, D_f, are shown in table 1. Generally, allowable bearing capacity, q_a, showed a decreasing trend with an increase in raft foundation breadth whereas for a given foundation breadth, q_a increased with foundation depth (Fig. 2). 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. The respective predictive models relating allowable bearing capacity and foundation breadth for varying foundation depths are presented as follows;

$$q_{a(1.6)} = -0.02B^3 + 0.839B^2 - 12.44B + 221.3,\ R^2 = 0.999 \quad (12)$$

$$q_{a(1.4)} = -0.007B^3 + 0.381B^2 - 7.046B + 199.4, R^2 = 0.998 \quad (13)$$

$$q_{a(1.2)} = -0.012B^3 + 0.538B^2 - 8.698B + 203.7,\ R^2 = 0.999 \quad (14)$$

$$q_{a(1.0)} = -0.010B^3 + 0.475B^2 - 7.809B + 198.6,\ R^2 = 0.999 \quad (15)$$

Settlement Analysis on Sand:

Immediate Settlement on Raft Foundation

In Equation (3), immediate settlement values were analyzed for net foundation pressures varying from 161-152kN/m^2, the modulus of elasticity was obtained from Equation (4) as 10.04MPa while Poisson's ratio of 0.35 was obtained from Equation (5). Also, the coefficient of volumetric compressibility, m_v, of 0.062m^2/MN was evaluated from Equation (7). The results of immediate settlement using methods of Burland and Burbidge (1985) and Harr (1966) are presented in table 2 and figure 3. Immediate settlement values for foundation breadth varying from 8-15mm were found to increase with footing size, bearing pressure and foundation depth. Immediate settlement vary from 32 - 47mm for a bearing pressure varying from 161-152kN/m^2 and foundation depth varying from 1-1.6m depth respectively for Burland and Burbidge approach. Harr's model gave immediate settlement values of 19.8-35.2mm for bearing pressure range of 161-152kN/m^2 respectively. Comparatively, Harr's approach gave conservative values of immediate settlement compared to that of Burland and Burbidge approach. The models describing Burland and Burbidge, and Harr's models are presented in Equations (16) and (17).

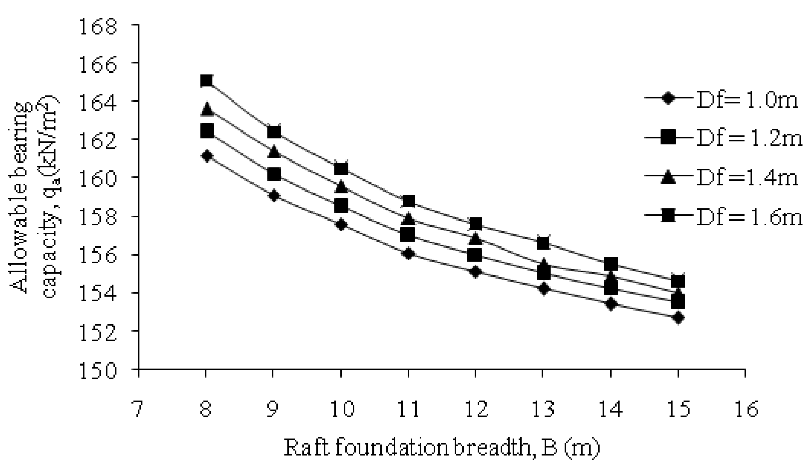

Fig. 2. Variation of allowable bearing capacity with Raft foundation breadth.

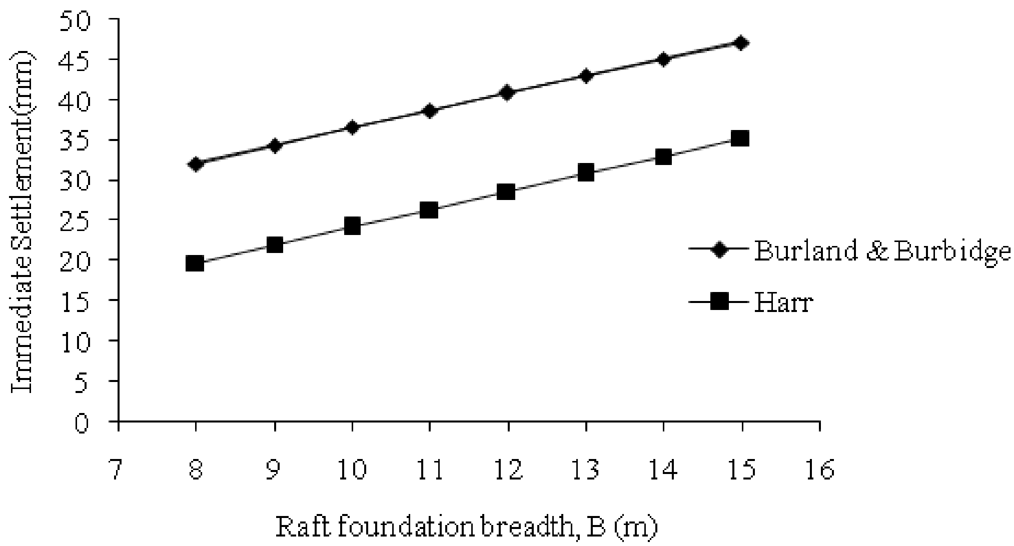

Fig. 3. Variation of Immediate settlement with Raft foundation breadth.

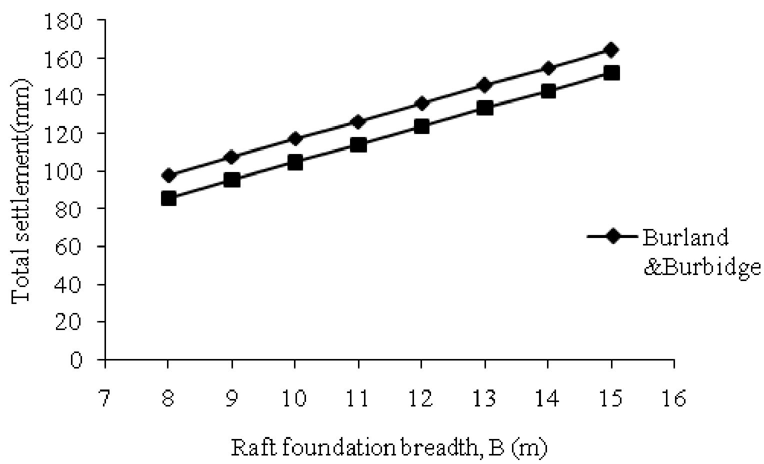

Fig. 4. Variation of total settlement and Raft foundation breadth.

$$s_i = 2.156B + 14.91, \ R^2 = 0.999 \quad (16)$$

$$s_i = 2.2B + 2.2, \ R^2 = 0.999 \quad (17)$$

Total Settlement on Raft Foundation

Consolidation settlement values for the Raft foundation of breadth, B, varying from 8-12m were found to increase with footing size. The relationship between foundation breadth and total settlement is shown in figure 4, where Burland and Burbidge approach had higher total settlement compared to those obtained from Harr's approach. The models describing Burland and Burbidge, and Harr's total settlement are presented in Equations (18) and (19).

$$\rho_t = 9.471B + 22.30, \ R^2 = 0.999 \quad (18)$$

$$\rho_t = 9.533B + 9.441, \ R^2 = 0.999 \quad (19)$$

Critical foundation breadth for deformation requirement of Raft placed on sand can be determined using Equation (18). Maximum allowable total settlement values suggested by Skempton and MacDonald (1956) may be adopted.

CONCLUSION AND RECOMMENDATIONS

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

i. The allowable bearing capacity, q_a, had a decreasing trend with an increase in raft foundation breadth whereas for a given foundation breadth, q_a increased with foundation depth.

Table 1. Bearing Capacity of Raft 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	6	1.041	161.2
	9	0.111		1.036	159.1
	10	0.100		1.033	157.6
	11	0.090		1.029	156.1
	12	0.083		1.027	155.1
	13	0.076		1.025	154.2
	14	0.071		1.023	153.4
	15	0.066		1.021	152.7
1.2	8	0.150	6	1.049	162.4
	9	0.133		1.043	160.2
	10	0.120		1.039	158.5
	11	0.109		1.035	157.0
	12	0.100		1.033	156.0
	13	0.092		1.030	155.0
	14	0.085		1.028	154.2
	15	0.080		1.026	153.5
1.4	8	0.175	6	1.057	163.6
	9	0.155		1.051	161.4
	10	0.140		1.046	159.6
	11	0.127		1.041	157.9
	12	0.116		1.038	156.9
	13	0.107		1.035	155.5
	14	0.100		1.033	154.9
	15	0.093		1.030	154.0
1.6	8	0.200	6	1.066	165.1
	9	0.177		1.058	162.4
	10	0.160		1.052	160.5
	11	0.145		1.047	158.8
	12	0.133		1.043	157.6
	13	0.123		1.040	156.6
	14	0.114		1.037	155.5
	15	0.106		1.034	154.6

Table 2. Settlement Analysis on Raft Foundation.

Analytical Approach	Foundation Breadth B(m)	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_i (mm)	Consolidation settlement, ρ_c (mm)
Burland & Burbidge	8	6	0.35	28	10.04	0.062	32.0	65.9
	9						34.3	73.2
	10						36.6	80.6
	11						38.7	87.8
	12						40.9	95.2
	13						43.0	102.5
	14						45.1	109.8
	15						47.1	117.1
Harr	8	6	0.35	28	10.04	0.062	19.8	65.9
	9						22.0	73.2
	10						24.2	80.6
	11						26.4	87.8
	12						28.6	95.2
	13						30.8	102.5
	14						33.0	109.8
	15						35.2	117.1

ii. Allowable bearing capacity also decreased as the ratio of foundation depth, D_f, to breadth, B ratio (D_f/B) decreased.
iii. Immediate settlement values for foundation breadth varying from 8-15mm were found to increase with footing size, bearing pressure and foundation depth.
iv. Immediate settlement vary from 32 - 47mm for a bearing pressure varying from 161-152kN/m^2 and foundation depth varying from 1-1.6m depth respectively for Burland and Burbidge approach.
v. Harr's model gave immediate settlement values of 19.8-35.2mm for a bearing pressure range of 161-152kN/m^2 respectively.
vi. The predictive models can be useful for preliminary design purposes on sites having similar conditions.

REFERENCES

Akpila, SB. 2007. The Design of a Shallow Foundation on Sand Overlying Soft Clay. Inter-World Journal of Science and Technology. 3(3):200-205.

Akpila, SB. 2007. Stability and Deformation Assessment of Crude Oil Tank Foundation in the Niger Delta: A case Study. Inter-World Journal of Science and Technology. 3(4):600-607.

Akpila, SB. and ThankGod, O. 2008. Comparison of Stability and Deformation Characteristics of Two Crude Oil Tank Foundation in the Niger Delta: A case Study. International Journal of Physical Sciences. 3(1):51-58.

Akpila, SB., ThankGod, O. and Igwe, A. 2008. Bearing Capacity and Settlement Analysis of a Shallow Foundation on Reclaimed Sand Overlying Soft Clay. Journal of Scientific and Industrial Studies. 6(9):84-89.

Akpila, SB. 2013. Comparison of Standard Penetration Test Methods on Bearing Capacity of Shallow Foundations on Sand. Scientific Journal of Pure and Applied Sciences. 2(2):72-78.

Bowles, JE. 1997. Foundation Analysis and Design (5th edi.). McGraw-Hill, New York, USA. 263-266.

Braja, MD. 1999. Principle of Foundation Engineering (4th edi.). PWE Publishing Company, USA. pp243.

British Standard Institution, BS 1377. 1977. Methods of Test for Soils for Civil Engineering Purposes.

Burland, J. B. and Burbidge, MC. 1985. Settlement of Foundations on Sand and Gravel. Proceedings of Institution of Civil Engineers. 78(1):1325-1381.

Craig, RF. 1987. Soil Mechanics (4th edi.). ELBS Edition, Great Britain.

Caquot, A. 1934., Equilibrium des Massifs a frottement Interne. Gauthier-Villars, Paris, France. 1-91.

DeBeer, EE. and Vesic, A. 1958. Etude experimental de la capacitie Portante du sable sous des foundations directes etablies en surface Annale des Travaux publics de Belqique. 59(3):5-58.

Harr, ME. 1966. Fundamentals of Theoretical Soil Mechanics. McGrey-Hill, New York, USA.

Meyerhof, GG. 1956. Penetration Test and Bearing Capacity of Cohesionless Soils. Journal of the Soil Mechanics and Foundation Division, ASCE. 82(1):1-19.

Parry, RHG. 1977. Estimating Bearing Capacity in Sand from SPT Values. Journal of Geotechnical Engineering Division, ASCE. 103(9):1014-1019.

Polshin, DE. and Tokar, RA. 1957. Maximum Non Uniform Settlement of Structures. Proc. of the 4th International Conference of Soil Mechanics and Foundation Engineering, London. 1:402-405.

Skempton, AW. and Bjeruum, L. 1957. A Contribution to the Settlement Analysis of Foundation on Clays. Geotechnique 7:168-178.

Skempton, AW. and MacDonald. 1956. The Allowable Settlement of Buildings," Proceedings, Institute of Civil Engineers. 5(III):727-784.

Singh, A. 1992. A Modern Geotechnical Engineering (3rd edi.). CBS Publishers Delhi, India.

Som, NN. and Das, SS. 2006. Theory and Practice of Foundation Design, Prentice- Hall of India, New Delhi, India.

Terzaghi, K. 1943. Theoretical Soil Mechanics, John Wiley and Sons Inc. New York, USA.

Tomlinson, MJ. 2001. Foundation Design and Construction (7th edi.). Pearson Education Ltd. 73-74.

Vesic, AS. 1967. A study of Bearing Capacity of Deep Foundations. Final Report, Project B-119, Georgia Inst. Techn., Atlanta Georgia, USA.

Wahls, HE. 1981. Tolerable Settlement of Buildings. Journal of the Geotechnical Division, ASCE. 107(11):1489-1504.

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