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Predictive Approach on Evaluation of Settlement Parameters on Clayey Soils in Parts of Port Harcourt, Nigeria

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ABSTRACT

Predictive modelling of settlement parameters in clayey soils has been carried out in selected areas in Port Harcourt city, Nigeria. Laboratory results of 50 oedometer tests on soil samples within six study areas were analysed for void ratios, e , coefficient of volume compressibility, m_v , and compression modulus, E_c , for varying pressures. Results of e , and m_v generally showed a decreasing trend with increase in pressure, while E_c increased with pressure. Predictive models relating void ratio and pressure, coefficient of volume compressibility and pressure, and that of compression modulus and pressure were subsequently generated. The models can be used for quick determination of settlement input parameters needed in deformation analysis of foundation placed on clayey soils.

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1. Introduction

The settlement of foundation substructure placed on cohesive soils is assessed using relevant settlement parameters of the soil supporting the foundation. These parameters include void ratio, e , and coefficient of volume compressibility, m_v , of the compressible soil formation that is significantly affected by the foundation induced vertical stress. The void ratio of a soil expresses the ratio of volume of void to volume of solid (Barnes, 2000), while coefficient of volume compressibility is the compression of a soil layer per unit of original thickness due to a given unit increase in pressure (Raj, 2008). Compressibility values of various types of clays are presented

in Tomlinson (2001). These parameters are derived from results of oedometer test; test procedures are presented in BS 1377. In settlement analysis, both immediate and consolidation settlement are assessed to determine if envisaged settlement is within the tolerance limit of the superstructure. Details on limiting settlement criteria for shallow foundations placed on either cohesive or granular soils have been presented by scholars (Polshin and Tokar, 1957; Wahls, 1981; Skempton and McDonald, 1956, Murthy, 2007). Knowledge of undrained modulus, E_u , of the supporting soil is required in evaluation of immediate settlement of shallow foundation placed on cohesive soils; however, its determination is faced with difficulties. Jamiolkowski et al. (1979) is reported in Barnes (2000) to have proposed evaluation of E_u from ratio of undrained modulus to undrained cohesion (E_u/c_u) depending on overconsolidation ratio and plasticity index. Butler (1974) proposed E_u/c_u ratio of 400 for overconsolidated London clay while Bjerrum (1973) proposed c_u/p ratios in the range of 500 to 1500 for normally consolidated clays. In Smith (1984), Skempton (1951) is reported to have presented a procedure of obtaining undrained modulus directly from triaxial test results by determining the strain corresponding to 65% of the maximum deviator stress and dividing this value into its corresponding stress. It is also known that compression modulus, E_c , is the reciprocal of m_v and is analogous to Youngs modulus (Garg, 1987) and in Bowles (1997), E_u for various soils is presented in wide range of values, and adoption of values depends on engineering judgement.

2. Materials and methods

2.1. Field exploration/analysis

Soil sampling for evaluation of settlement parameters on shallow foundations were carried out through borings to depths of 5m. Fifty soil samples were obtained from six different areas in PortHarcourt; Rukpoku, Choba, Woji, Rumuogbolu, Amadi-Ama and Amadi flat areas. Oedometer tests were carried out on the soil samples, from which settlement parameters such as void ratio, coefficient of compressibility and compression modulus were evaluated using the following equations (Smith, 1984; and Raj, 2008).

$$e_1 = \frac{H_1}{\frac{M_s}{AG \rho_w}} - 1 \quad (1)$$

$$m_v = \frac{1}{1+e_0} \left(\frac{e_0 - e_1}{p_1 - p_0} \right) = \frac{1}{1+e_0} \left(\frac{\Delta e}{\Delta p} \right) \quad (2)$$

$$E_c = (1 + e_0) \left(\frac{p_1 - p_0}{e_0 - e_1} \right) = (1 + e_0) \left(\frac{\Delta p}{\Delta e} \right) \quad (3)$$

Where H_1 is thickness at the end of any increment period, M_s is mass of sample measured at the end of test, A is area of specimen, G is specific gravity of soil sample, ρ_w is density of water, e_1 is void ratio corresponding to pressure p_1 , e_0 is void ratio corresponding to pressure p_0 , m_v is coefficient of volume compressibility, E_c is compression modulus, Δe and Δp are change in void ratio and pressure respectively. The average values of void ratios and coefficient of volume compressibility of soil samples from each study area were obtained for varying pressure. Subsequently, the following relationships were analysed; void ratio versus pressure, coefficient of volume compressibility versus pressure and reciprocal of coefficient of volume compressibility, E_c , versus pressure.

3. Results and discussion

3.1. Void ratio and pressure variation

In Figure 1.0, the variation of void ratio and pressure is depicted. The trend line showed a gradual decrease in void ratio, e , versus pressure up to an overburden pressure of 800kN/m² for Rukpoku, Choba, Woji, Rumuogba, Amadi-Ama and Amadi flat areas, Values of void ratio ranged between 0.70-0.45 for pressure range of 0-800kN/m² respectively in these five areas and m_v values are indicative of medium compressibility clays.

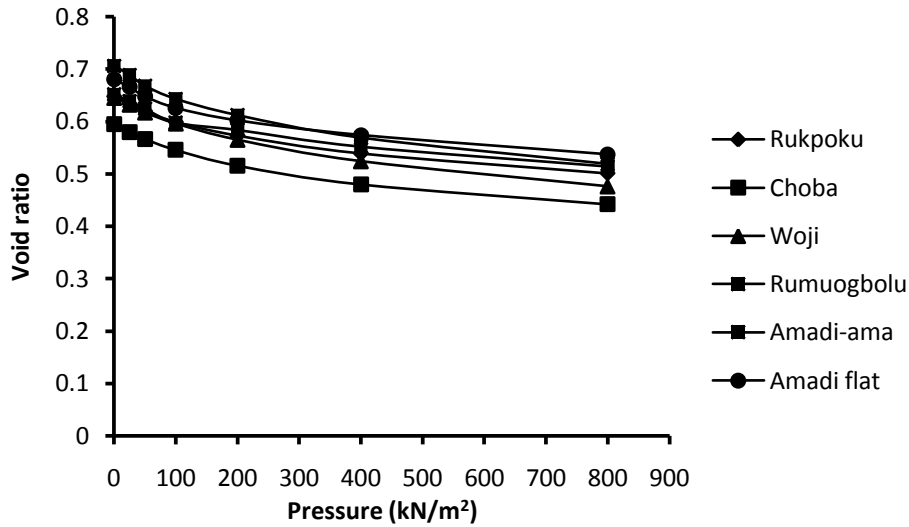


Fig. 1. Variation of void ratio versus pressure.

The model equations expressing variation of void ratio versus pressure for each study area are given as follows:

$$\text{Rukpoku: } e = -6E-10p^3 + 9E-07p^2 + 0.646; R^2 = 0.999 \quad (4)$$

$$\text{Choba: } e = -5E-10p^3 + 9E-07p^2 + 0.593; R^2 = 0.999 \quad (5)$$

$$\text{Woji: } e = -5E-10p^3 + 8E-07p^2 + 0.644; R^2 = 0.999 \quad (6)$$

$$\text{Rumuogbolu: } e = -8E-10p^3 + 1E-06p^2 + 0.703; R^2 = 0.998 \quad (7)$$

$$\text{Amadi-Ama: } e = -7E-10p^3 + 1E-06p^2 + 0.650; R^2 = 0.992 \quad (8)$$

$$\text{Amadi flat: } e = -8E-10p^3 + 1E-06p^2 + 0.678; R^2 = 0.997 \quad (9)$$

3.2. Coefficient of volume compressibility and pressure variation

The variation of coefficient of volume compressibility with pressure is shown in Figure 2.0. The trend lines showed a rapid decrease in m_v through a pressure range of 0-100kN/m², beyond which m_v had a gradual decrease as pressure increases. At pressures exceeding 100kN/m², the compressibility characteristics of soils within Rukpoku, Choba, Woji, Rumuogba, Amadi-Ama and Amadi flat areas showed very close approximation. Except for soils within Rumuogbo, m_v values of soils in five areas of study converged at pressure value of 400kN/m². Generally, m_v values are indicative of medium compressibility soils. The predictive models relating coefficient of volume compressibility and pressure are presented in Equations (10-15).

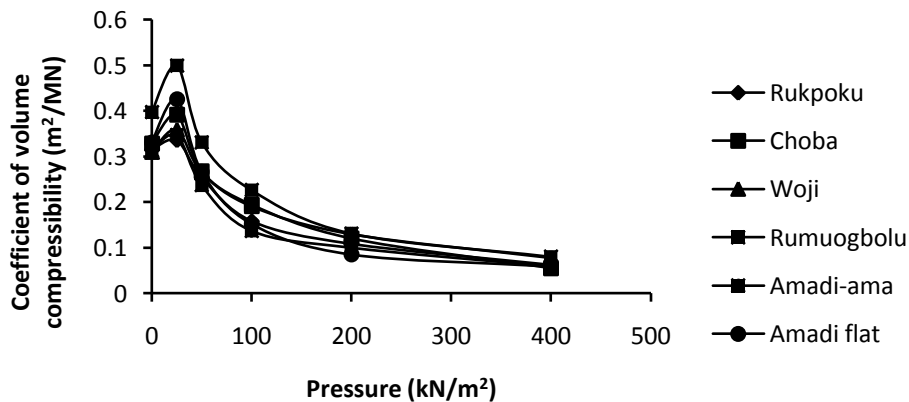


Fig. 2. Variation of coefficient of volume compressibility versus pressure.

$$\begin{aligned} \text{Rukpoku: } m_v &= -4E-09p^3 + 5E-06p^2 - 0.002p + 0.340, R^2=0.949 & (10) \\ \text{Choba: } m_v &= 8E-10p^3 + 2E-06p^2 - 0.001p + 0.364, R^2=0.916 & (11) \\ \text{Woji: } m_v &= 2E-06p^2 - 0.001p + 0.342, R^2=0.924 & (12) \\ \text{Rumuogbolu: } m_v &= 4E-06p^2 - 0.002p + 0.456, R^2=0.887 & (13) \\ \text{Amadi-Ama: } m_v &= -8E-09p^3 + 8E-06p^2 - 0.002p + 0.347, R^2=0.921 & (14) \\ \text{Amadi flat: } m_v &= 4E-06p^2 - 0.002p + 0.385, R^2=0.868 & (15) \end{aligned}$$

3.3. Compression modulus versus pressure

The variation of E_c , with change in pressure within the six study areas is shown in Figure 3.0, where E_c increases with pressure and the values are easily predictable at pressures exceeding 50kN/m².

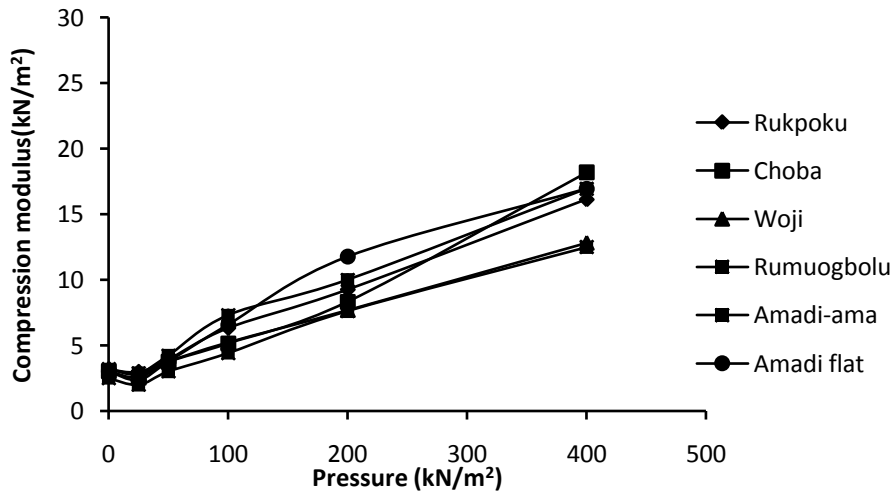


Fig. 3. Variation of Compression modulus versus pressure.

The predictive models relating compression modulus and pressure in the six areas are presented in Equations (16-21).

$$\text{Rukpoku: } 1/m_v = 0.033p + 2.621, R^2 = 0.993 \quad (16)$$

$$\text{Choba: } 1/m_v = -5E-08p^3 + 8E-05p^2 + 0.014p + 2.723, R^2=0.997 \quad (17)$$

$$\text{Woji: } 1/m_v = 0.025p + 2.654, R^2=0.991 \quad (18)$$

$$\text{Rumuogbolu: } 1/m_v = 0.026p + 1.894, R^2=0.988 \quad (19)$$

$$\text{Amadi-Ama } 1/m_v = 0.035p + 2.807, R^2=0.987 \quad (20)$$

$$\text{Amadi flat: } 1/m_v = -4E-05p^2 + 0.054p + 1.817, R^2=0.981 \quad (21)$$

3.4. Model calibration

Models calibration results are presented in Tables 1, 2, 3 and generally, a perfect positive correlation on measured values to predict values were obtained.

4. Conclusion

Based on the study the following conclusions can be drawn;

Input parameters of void ratio, coefficient of volume compressibility and compression modulus of soils in the studied areas can be easily accessed from the generated predictive models for purposes of preliminary foundation settlement analysis and design.

The predictive models generated for the areas show promising reproducibility of measured and predicted values.

Table 1

Model Calibration of void ratio.

Location	Pressure 100kN/m ²		Pressure 200kN/m ²		Pressure 400kN/m ²	
	e	e	e	e	e	e
	measured	predicted	measured	predicted	measured	predicted
Rukpoku	0.599	0.654	0.573	0.677	0.539	0.789
Choba	0.546	0.602	0.516	0.625	0.480	0.705
Woji	0.596	0.651	0.563	0.672	0.0524	0.740
Rumuogba	0.643	0.712	0.612	0.736	10.569	0.812
Amadi- Ama	0.598	0.659	0.584	0.684	0.552	0.765
Amadi- flat	0.626	0.687	0.602	0.712	0.574	0.786

Table 2

Model Calibration of coefficient of volume compressibility.

Location	Pressure 100kN/m ²		Pressure 200kN/m ²		Pressure 400kN/m ²	
	m _v	m _v	m _v	m _v	m _v	m _v
	measured	predicted	measured	predicted	measured	predicted
Rukpoku	0.158	0.186	0.108	0.108	0.062	0.084
Choba	0.194	0.283	0.120	0.237	0.055	0.232
Woji	0.191	0.252	0.130	0.222	0.078	0.262
Rumuogba	0.226	0.296	0.131	0.216	0.080	0.296
Amadi- Ama	0.137	0.226	0.100	0.203	0.059	0.315
Amadi- flat	0.152	0.225	0.085	0.145	0.059	0.225

Table 3

Model calibration of compression modulus.

Location	Pressure 100kN/m ²		Pressure 200kN/m ²		Pressure 400kN/m ²	
	E _c	E _c	E _c	E _c	E _c	E _c
	measured	predicted	measured	predicted	measured	Predicted
Rukpoku	6.32	5.920	9.26	9.221	16.13	15.821
Choba	5.155	4.873	8.333	8.323	18.182	17.923
Woji	5.236	5.154	7.692	7.654	12.821	12.654
Rumuogba	4.425	4.494	7.634	7.094	12.500	12.294
Amadi- Ama	7.299	6.307	10.00	9.807	16.949	16.807
Amadi- flat	6.578	6.817	11.764	11.017	16.949	17.017

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