Leonardo Electronic Journal of Practices and Technologies
ISSN 1583-1078
Issue 33, July-December 2018
p. 159-188

Engineering, Environment

Evaluation of foundation settlement characteristics and analytical model development

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Received: January 12, 2017 / Accepted: October 31, 2018 / Published: December 30, 2018

Abstract

Foundation settlement characteristics were evaluated based on standard penetration test (SPT) results obtained from the six zones of Nigeria using some conventional analytical models and numerical modelling. The study aimed at developing an improved approximation of foundation settlement based on numerical modelling method that better represents soil constitutive behaviour and to determine the most appropriate settlement prediction analytical methods that are most suitable to Nigerian soil peculiarities based on SPT data, being the most commonly used geotechnical field test in Nigeria. Footing dimension of $2 \times 2 \times 0.4\ m$ size and applied foundation pressure of 300 kN/m^2 at foundation embedment depths of 0.6, 2.1, 3.6, 5.1, 6.6, 8.1, 9.6, 11.1 and 12.6 m were considered. Results show that the predicted compressibility is higher in the southern zones compared with their northern counterparts based on the recommendation of Eurocode 7 which allows a maximum total settlement of 25 mm for serviceability limit state. Based on the numerical analysis results using Plaxis 3D Foundation, a finite element code package, it was observed that settlement prediction methods proposed by Schmertmann et al., Burland and Burbidge, Canadian Foundation Engineering Manual and Mayne and Poulos gave good estimations of foundation settlement among others. The analytical models developed with soil parameters N_{60}, angle of internal friction and Poisson ratio as predictor gave the best results and are recommended for foundation settlement prediction.

Keywords

Analytical models, Foundation; Numerical modelling; Plaxis 3D; Settlement models; Standard Penetration Test.

Introduction

Site investigation and estimation of soil settlement characteristics are essential parts of a geotechnical design process. Geotechnical engineers must determine the average values and variability of soil properties [1]. When soil is subjected to an increase in compressive stress due to foundation load, the resulting soil compression is known as settlement of the foundation [2]. In situ testing is important in geotechnical engineering, as simple laboratory tests may not be reliable while more sophisticated laboratory testing can be time consuming and costly. One of in situ testing methods is the Standard Penetration Test (SPT) that is used to identify soil type and stratigraphy along with being a relative measure of strength [3]. The results of in situ test reveal the bearing capacity and settlement characteristics of the soil used to determine the type of foundation required to effectively carry structural load without bearing capacity failure and/or excessive settlement. Bowles [4] stated that 85–90% of conventional foundation design in North and South America is made using SPT results. SPT data have been used in correlations for unit weight, relative density, angle of internal friction and unconfined compressive strength [5].

Housing demands due to the growing population and migration of people to urban areas in Nigeria, coupled with the fact that the limited areas of land suitable for building constructions are gradually being depleted, construction on less desirable soils such as soft saturated clays and silts is increasing in order to meet the demands of the society [6]. These demands require alternative construction methods that provide fast, safe and affordable quality housing. However, some Nigerian soils are problematic and adversely affect foundations of structures there by compromise the stability of the structures. These soil problems have resulted to excessive settlement, tilting and collapse of many buildings not only in Nigeria but also around the world [3, 7]. The geology of the soil types in Nigeria, the study area, according to Ola [8] and Obaje [9] is crystalline in nature in the north while those of the south are sedimentary from the basement complex (see Figure 1).

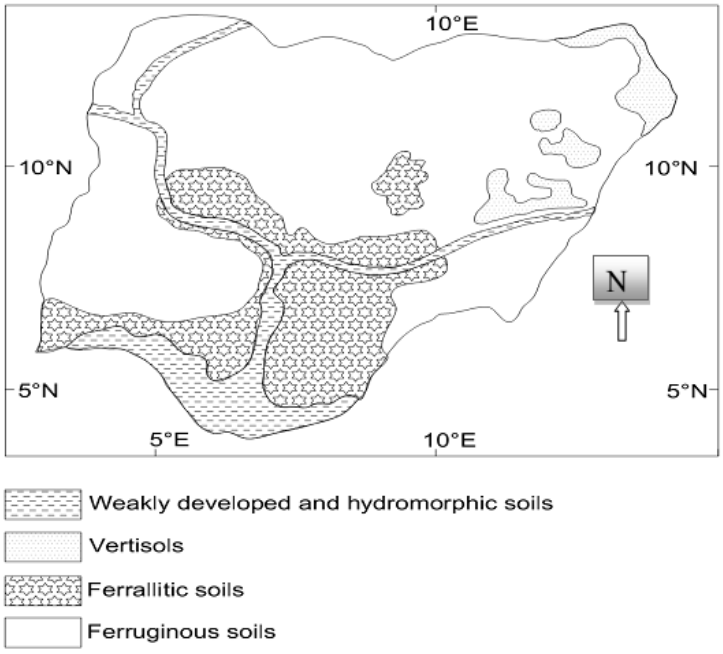

Figure 1. Map of Nigeria showing the soil groups (Adapted from Ola, 1983)

The aim of this research is to develop an improved approximation of foundation settlement based on numerical modelling method that better represents soil constitutive behaviour. Also, to investigate and determine the most appropriate settlement prediction analytical methods that are most suitable to Nigerian soil peculiarities and distinctions based on SPT data, being the most commonly used geotechnical field test in Nigeria. The study focused on the prediction of foundation settlement based on SPT N-values using empirical/analytical (deterministic) models and Plaxis 3D numerical modelling in the Federal Republic of Nigeria with the objectives of estimating the settlement of foundation soils from measured penetration resistance in terms of the SPT corrected N-values at various depths.

Material and Methods

Standard penetration test (SPT) data (using Donut hammer type) collected from 4,181 test holes (37,629 data set) distributed over the study area was used as the sole input data in both the analytical models and numerical modelling. Computations were done based on the average that reliably represents each state in the zone and the average of the states was used for the zone. Compressibility characteristics and foundation settlement estimations were made at depths of 0.6, 2.1, 3.6, 5.1, 6.6, 8.1, 9.6, 11.1 and 12.6 m and applied foundation pressure of 300 kN/m^2.

Based on empirical/analytical methods, foundation settlement estimations were performed using the most commonly used models as presented in Table 1. On the other hand, numerical analysis of foundation settlement was performed using a 3D non-linear finite element analysis software, Plaxis, which uses finite element method (FEM) for deformation analysis and modelling of geotechnical problems.

The input data in Plaxis are index, elastic and strength parameters obtained from the processed SPT N-values. The software portfolio includes simulation of soil and soil-structure interaction. Plaxis 3D Foundation is a three-dimensional Plaxis programme and advanced of the 2D version, developed for the analysis of foundation constructions including raft foundations and offshore structures. A project's geometry is modelled using a top view approach. The input of soil data, structures, construction stages, loads and boundary conditions was based on convenient computer aided design (CAD) drawing procedures, which allows for a detailed and accurate modelling of the major geometry. From this geometry a 3D finite element mesh is generated. Soil layers are defined by means of boreholes. Structures were defined in horizontal work planes. The Plaxis 3D Foundation program allows for an automatic generation of unstructured 2D finite element meshes based on the top view. There are options for global and local mesh refinement. From this 2D mesh, a 3D mesh is automatically generated, taking into account the soil stratigraphy and structure levels as defined in the bore holes and work planes. The Plaxis postprocessor has enhanced 3D graphical features for displaying computational results. Exact values of displacements, stresses, strains and structural forces can be obtained from the output tables. A special tool is available for drawing load-displacement curves, stress paths and stress-strain diagrams. Particularly the visualization of stress paths provides a valuable insight into local soil behaviour and enables a detailed analysis of the results of a Plaxis 3D Foundation calculation [10].

Table 1. Empirical/analytical models for elastic settlement analysis

S/N	Model	Reference
1	$S_e = \mu_1 \mu_0 \frac{qB}{E}$	[30]
2	$S_e = \frac{3q}{N_{60}} \left(\frac{B}{B+0.3}\right)^2 c_W c_D$	[35]
3	$S_e = C_1 C_2 q \sum_0^{2B} \frac{I_z}{E_s} \Delta z$	[22]

4	$S_e = \frac{fq\sqrt{B}}{N^{0.87}\left(1+\frac{0.4D_f}{B}\right)}$	[23]
5	$S_e = \frac{\Delta PB}{2\Delta \hat{C}_r}$	[24]
6	$S_e = q\sum_{0}^{Z_1}\frac{I_z}{E_s}Z_1$	[25]
7	$S_e = qB\frac{1-\mu^2}{E_s}I_s$	[31]
8	$S_e = 0.14\alpha\left(\frac{1.71}{(N_{60(a)})^{1.4}}\right)\left(\frac{1.25(L/B)}{0.25+(L/B)}\right)^2\left(\frac{B}{B_R}\right)^{0.7}\left(\frac{q}{P_a}\right)$	[26]
9	$S_e = q_0\alpha B^1\left(\frac{1-\mu_s^2}{E_s}\right)I_s I_f$	[32]
10	$S_e = \frac{2.37q^{0.87}B^{0.7}}{N^{1.2}}$	[36]
11	$S_e = \frac{q_0 Bi_c}{E_s}$	[27]
12	$S_e = \left(\frac{qB}{E_s}\right)f$	[37]
13	$S_e = B^{0.75}\frac{1.7}{\acute{N}_{60}^{1.4}}q$	[33]
14	$S_e = \frac{q_0 B_e I_G I_F I_E}{E_0}(1-\mu_s^2)$	[28]
15	$S_e = \frac{12q}{N'}\left(\frac{B}{B+1}\right)^2$	[34]

Where: N_{60} - corrected standard penetration number for field conditions, $(N_1)_{60}$ - N_{60} correction for overburden pressure, N - measured penetration number (N-value), η_H - Hammer efficiency (%), η_B - correction for borehole diameter, η_S - sampler correction, η_R - correction for rod length, σ^1_0 - effective overburden pressure in kN/m^2, P_a - atmospheric pressure - 100 kN/m^2, P_a - atmospheric pressure - 100 kN/m^2, E_s - elastic modulus of soil, μ = Poisson's ratio of soil, q_n - net pressure on the foundation (kN/m^2), Es - appropriate value of elastic modulus of soil (kN/m^2), q - applied foundation pressure (kN/m^2), S_e - elastic settlement (mm), q - applied foundation pressure (kN/m^2), B - width of foundation (m), D_f - depth of embedment (m), q - net effective pressure applied at the level of the foundation (kN/m^2), $N_{60(a)}$ - adjusted N_{60} value, B_R - reference width = 0.3 m, H - thickness of the compressible layer (m), L - length of foundation (m), $S_{e(1)}$ - elastic settlement of piles, $S_{e(2)}$ - Settlement of pile caused by the load at the pile tip, $S_{e(3)}$ - Settlement of pile caused by the load transmitted along the pile shaft.

The steps involved in developing the numerical model can be depicted by the chart shown in Figure 2.

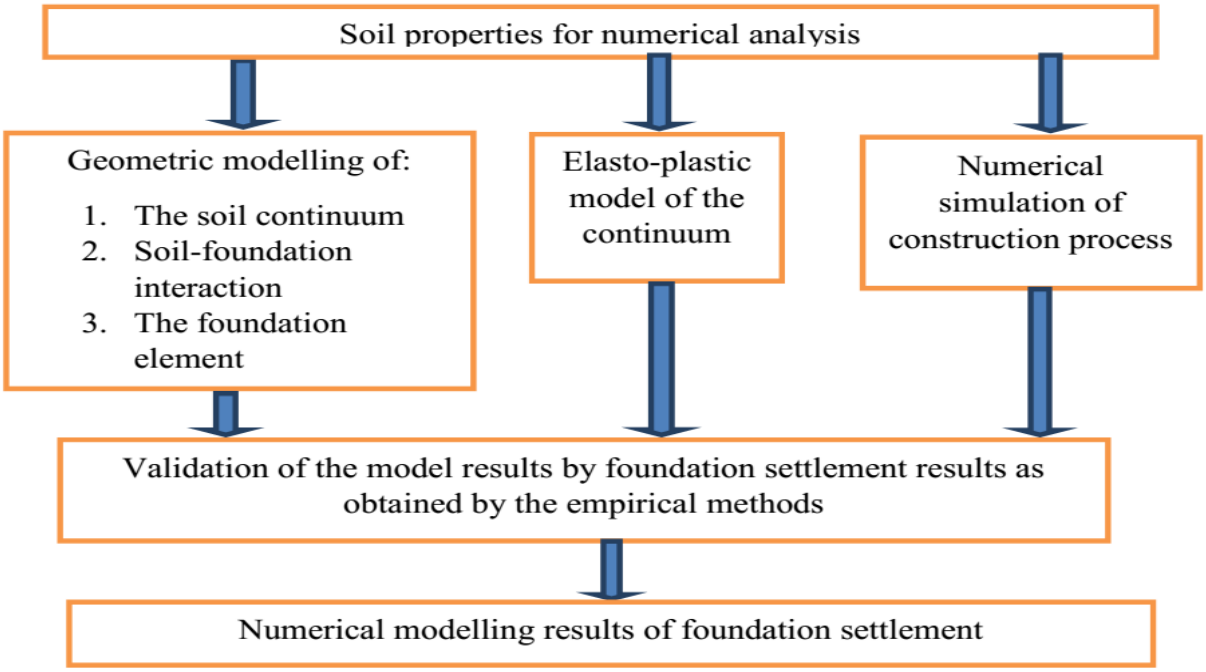

Figure 2. Chart depicting the steps involved in developing the numerical models

Results and Discussion

Corrected N-values (N_{60})

The variation of N_{60} with depth of test is shown in Figure 3.

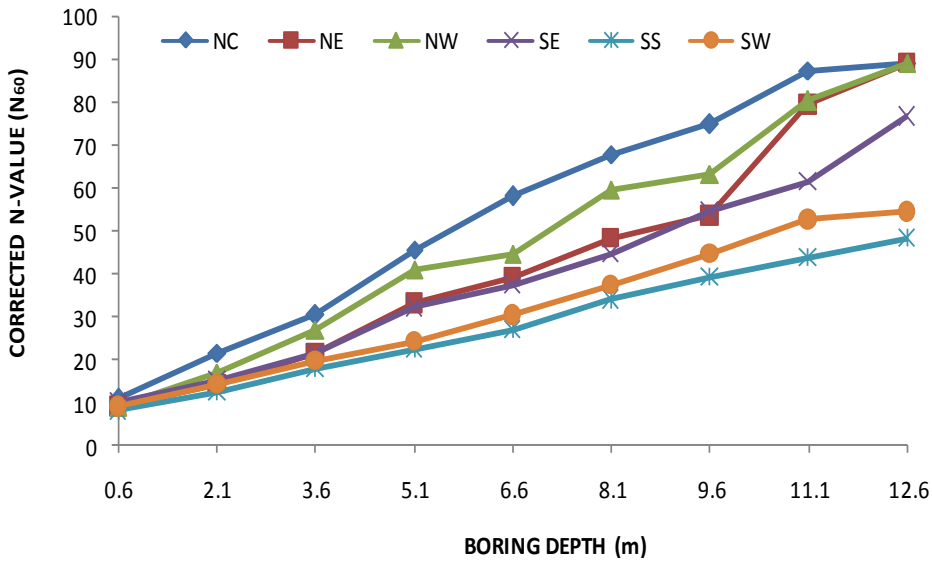

Figure 3. Variation of corrected N-values with boring depth

Because of the greater confinement caused by the increasing overburden pressure, Bezgin [11] recommended a correction to average energy ratio of 60% (N_{60}) to the field values of the SPT N-values. The correction factors used in the study are those proposed by Das [12] to standardize the field penetration number as a function of the input driving energy and its dissipation around the sampler into the surrounding soil. N_{60} increased with depth having the highest value of 89.25 in the North Central (NC) and decreased in the order of North Central (NC), North West (NW), North East (NE), South East (SE), South West (SW) and South South (SS). The highest N_{60} value obtained in the South South zone is 48.20. This confirms the conclusion of Salahudeen and Sadeeq [3] that while the soils in the southern part of Nigeria are sedimentary in nature, those of the north are crystalline from the basement complex. These N_{60} values are needed for more accurate design analyses.

Poisson's ratio

The variation of Poisson's ratio with boring depth is shown in Figure 4.

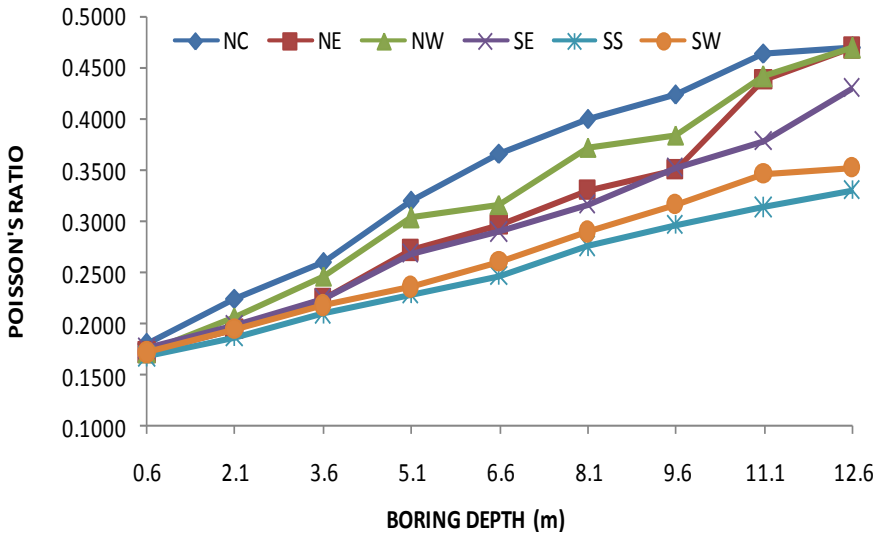

Figure 4. Variation of Poisson's ratio with boring depth

For the calculation of elastic settlement, relations for the theory of elasticity are used in most cases. These relations contain parameters such as modulus of elasticity and Poisson's ratio. Poisson's ratio of a material is the ratio of lateral strain to longitudinal strain resulting from a change in normal stress and also presents the elastic behaviour of the material. The nearer the Poisson's ratio to 0.5, the more plastic the material will be and the nearer the

Poisson's ratio to 0, the less plastic that material will be. The value of Poisson's ratio in soils ranges extensively from 0.1 to 0.5 [13]. Essien *et al.* [14] attributed the low values of Poisson's ratio in Akwa-Ibom state (south-south zone of Nigeria) to the complex muddy materials and flooding events in this region. The results of Poisson's ratio in this study, 0.179 to 0.469 and 0.167 to 0.33 respectively for north central and south south zones at 0.6 and 12.6 m depths, show that soil is not truly an elastic material but rather elasto-plastic in nature.

Moduli of elasticity and rigidity

The variations of elastic and shear (rigidity) moduli with depth are shown in Figures 5-6.

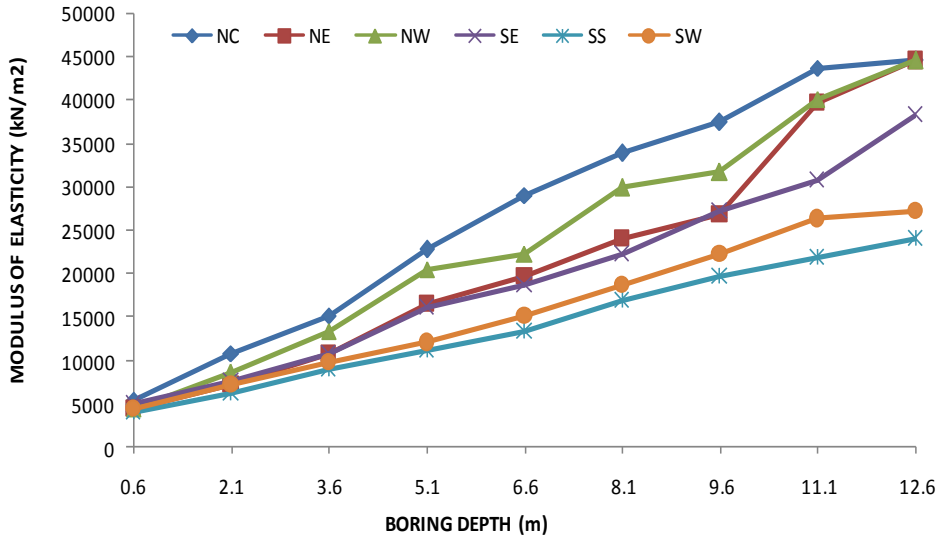

Figure 5. Variation of modulus of elasticity with boring depth

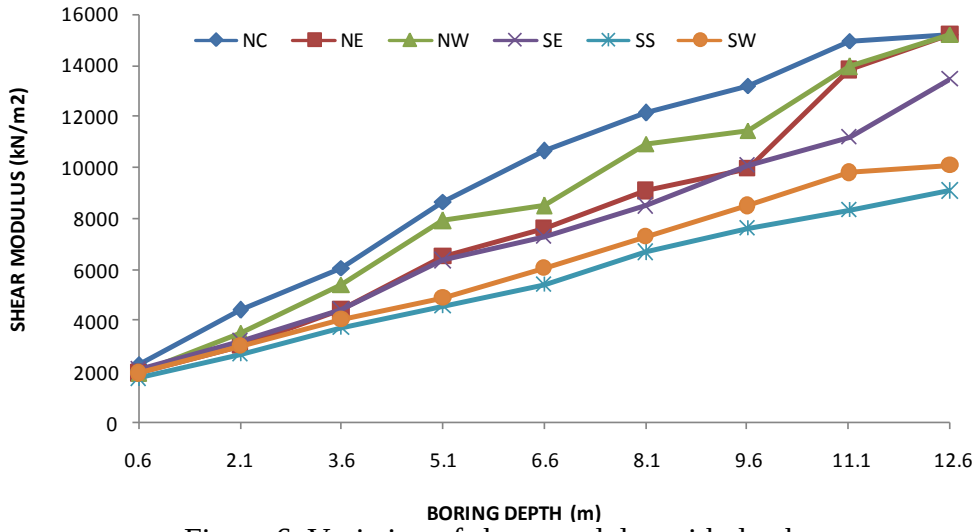

Figure 6. Variation of shear modulus with depth

The physical significance of modulus of elasticity (Young's modulus) is that it measures the inter-atomic bonding forces and therefore the stiffness of the material. A material with high modulus of elasticity is comparatively stiff, which means it exhibits a small amount of deformation under an applied load. The modulus of elasticity is used for estimation of settlement and elastic deformation analysis. It depends on the consistency and density of the soil. The shear modulus (modulus of rigidity) on the other hand is used to measure the stiffness of soils. The elastic modulus describes the response of soil to uniaxial stress while the shear modulus describes the soils response to shear stress. The modulus of elasticity increased from a value of 5355 to 44625 kN/m^2 and 4016 to 24098, respectively, for the North Central and South South zones while the modulus of rigidity increased from a value of 2271 to 15193 kN/m^2 and 1721 to 9062, respectively, for the North Central and South South zones. From Figures 5 and 6, low values of settlements are expected in the northern part compared with the southern part of the country.

Vertical strain

The variation of strain with depth is shown in Figure 7.

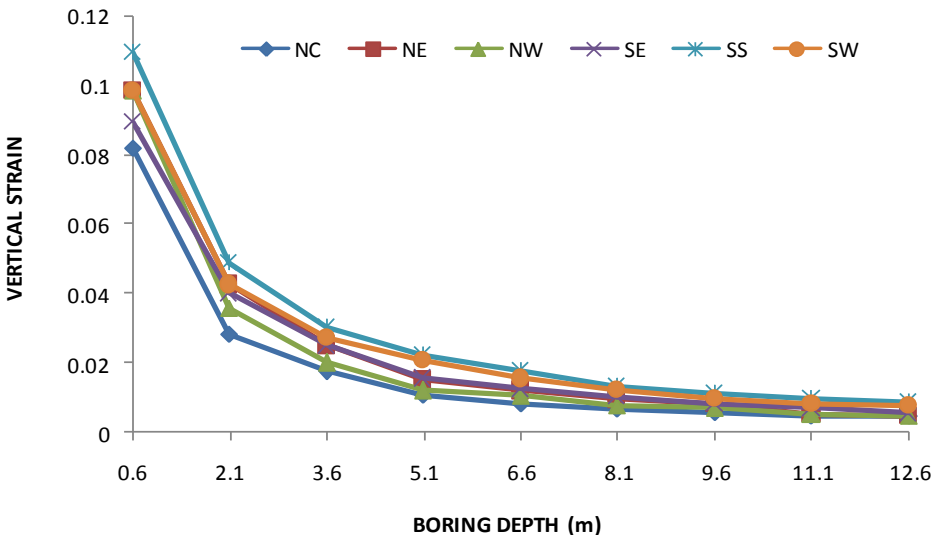

Figure 7. Variation of vertical strain with boring depth

The Schmertmann method of settlement estimation is based on a simplified distribution of vertical strain under the centre, or centre-line, of a shallow foundation, expressed in the form of a strain influence factor [15]. The deformation of a soil layer is the strain times the thickness of the soil layer. The settlement of the foundation is the sum of the

deformations of the soil layers below the foundation [16]. The values of vertical strains decreased with boring depth and with increase in N_{60} value. Generally, the vertical strain curves show a tendency to decrease with increased depth which implies that higher values of settlements are expected from the soils in the southern zones compared to the northern zone.

Compressibility index and coefficient of volume compressibility

The variations of compressibility index and coefficient of volume compressibility respectively with depth are shown in Figures 8 and 9.

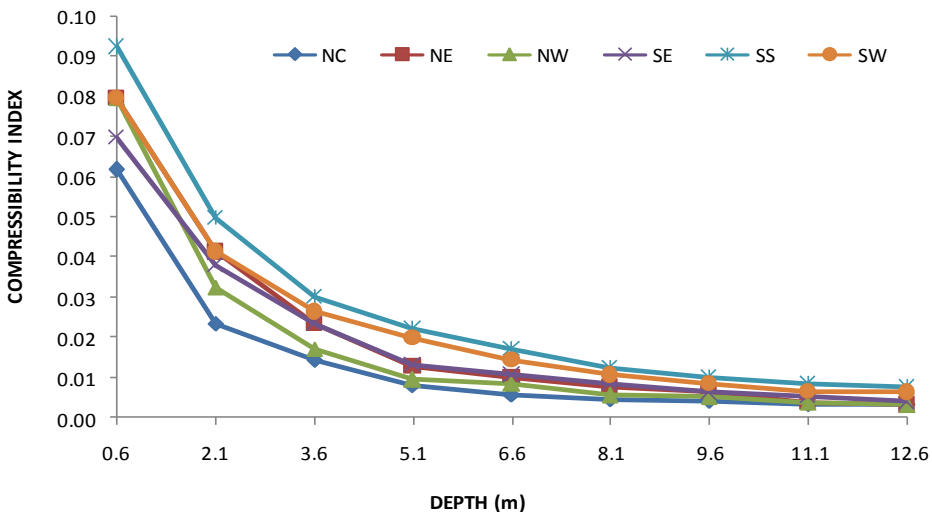

Figure 8. Variation of compressibility index with depth

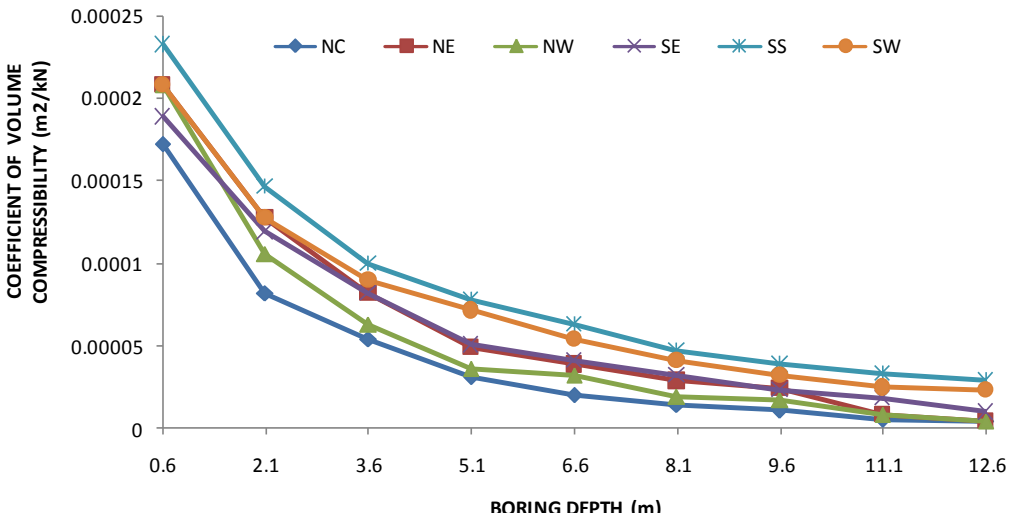

Figure 9. Variation of coefficient of volume compressibility with depth

Compressibility characteristics of soils are often the most important parameters for settlement evaluation of the founded layers. The compressibility of a soil mass is its susceptibility to decrease in volume under pressure. The main source of inaccuracy in the prediction of both magnitude and rate of consolidation settlement in the laboratory compared with in-situ measurements are the inaccuracies in the measurement of consolidation characteristics such as compressibility index and coefficient of volume compressibility [17].

The values of compressibility index and coefficient of volume compressibility respectively decreased from 0.0618 to 0.0032 and 1.72 x 10^{-4} to 3.89 x 10^{-6} m^2/kN in the North Central zone and from 0.0925 to 0.0075 and 2.32 x 10^{-4} to 2.81 x 10^{-5} m^2/kN in the South South zone. These two compressibility characteristics parameters indicate that the soils in the three zones in southern Nigeria are more susceptible to settlements compared with the soils in the three northern zones.

A detailed study by Lav and Ansal [18] on 300 soil samples taken from different construction sites distributed throughout Turkey suggests that consolidation settlement highly depends on the compression index. Badmus [19] reported an average value of 0.00142 for coefficient of volume compressibility based on laboratory study carried out on south-western Nigeria lateritic soils. Akpila [20] also reported a value of 0.06 m^2/kN at 400 kN/m^2 applied pressure for coefficient of volume compressibility based on laboratory study carried out on Port-Harcourt soil in the South South zone of Nigeria.

Elastic settlement of shallow foundations

For the elastic settlement of shallow foundations, plan dimensions of 2 m x 2 m x 0.4 m for length, breadth and depth respectively were assumed. Variations of elastic settlement of shallow foundations with foundation embedment depth are shown in Figure 10 - 15.

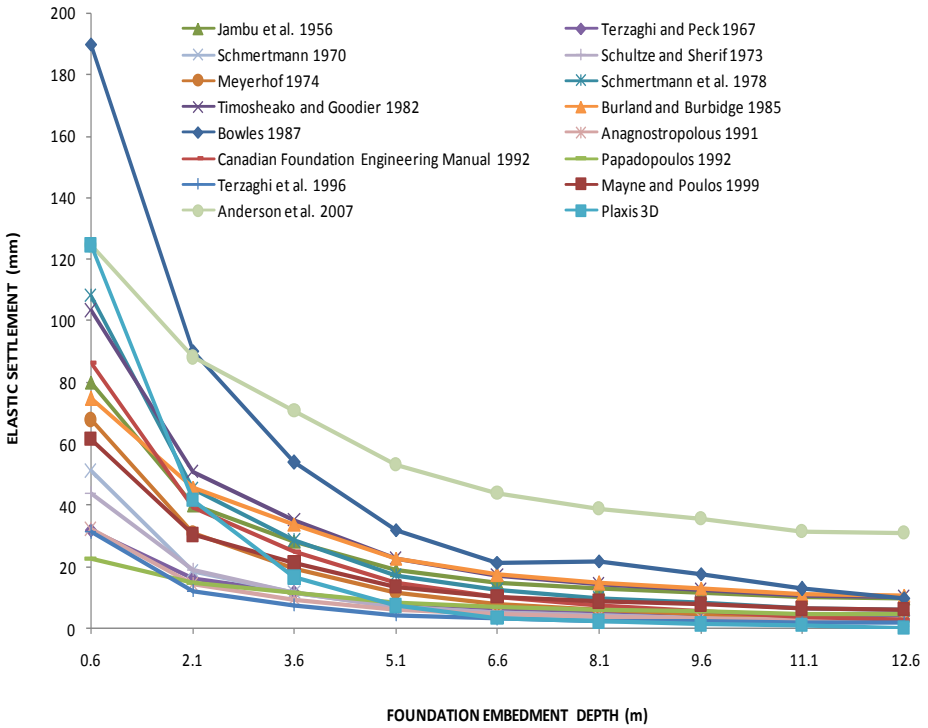

Figure 10. Variation of elastic settlement with embedment depth (North Central zone)

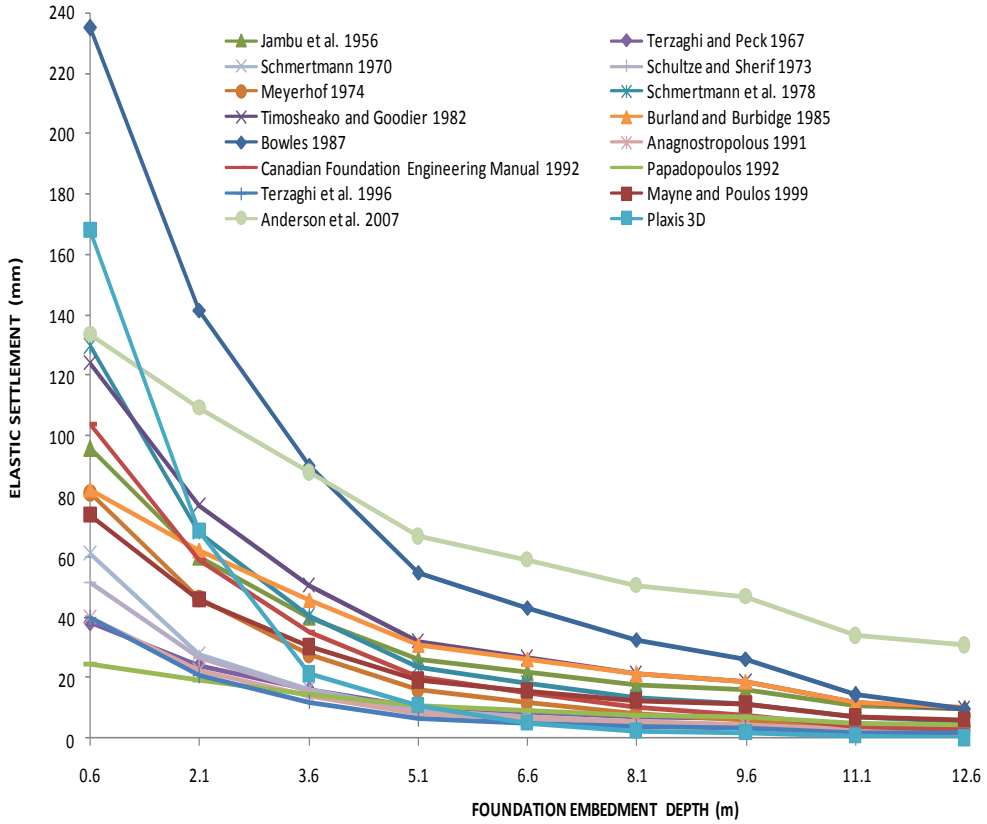

Figure 11. Variation of elastic settlement with embedment depth (North East zone)

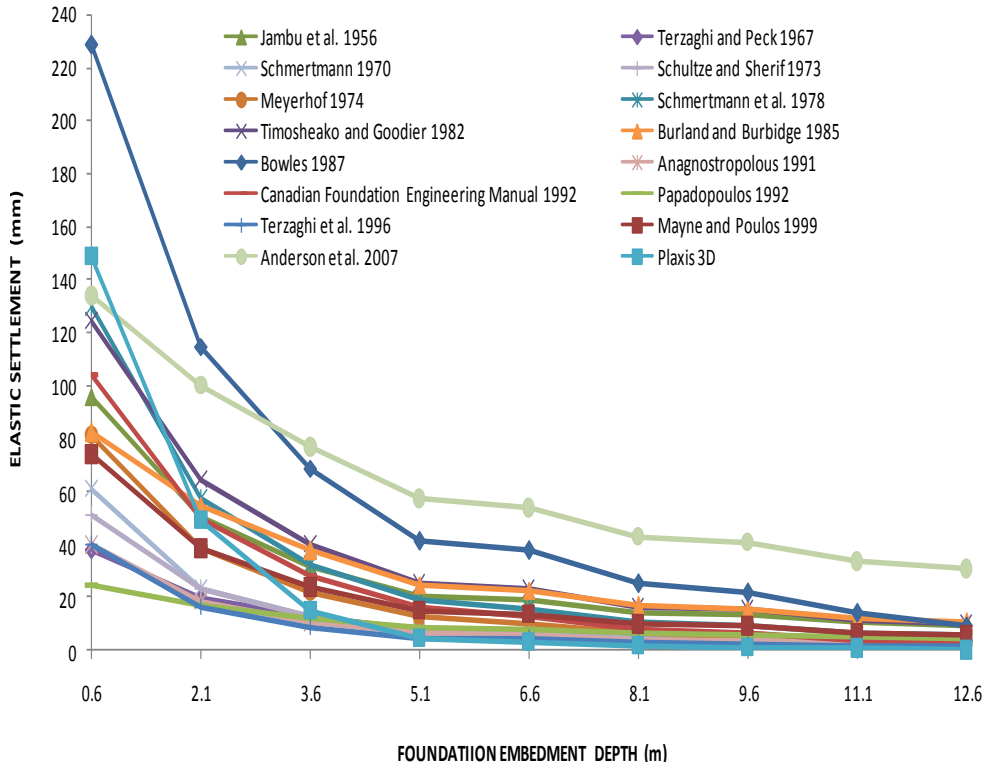

Figure 12. Variation of elastic settlement with embedment depth (North West zone)

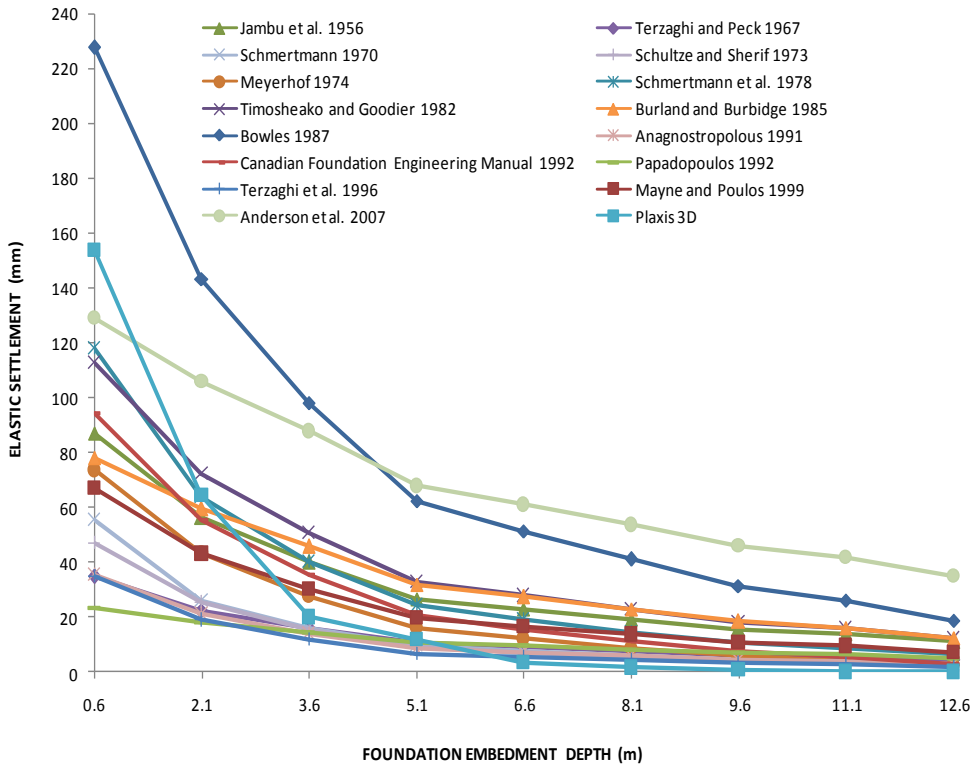

Figure 13. Variation of elastic settlement with embedment depth (South East zone)

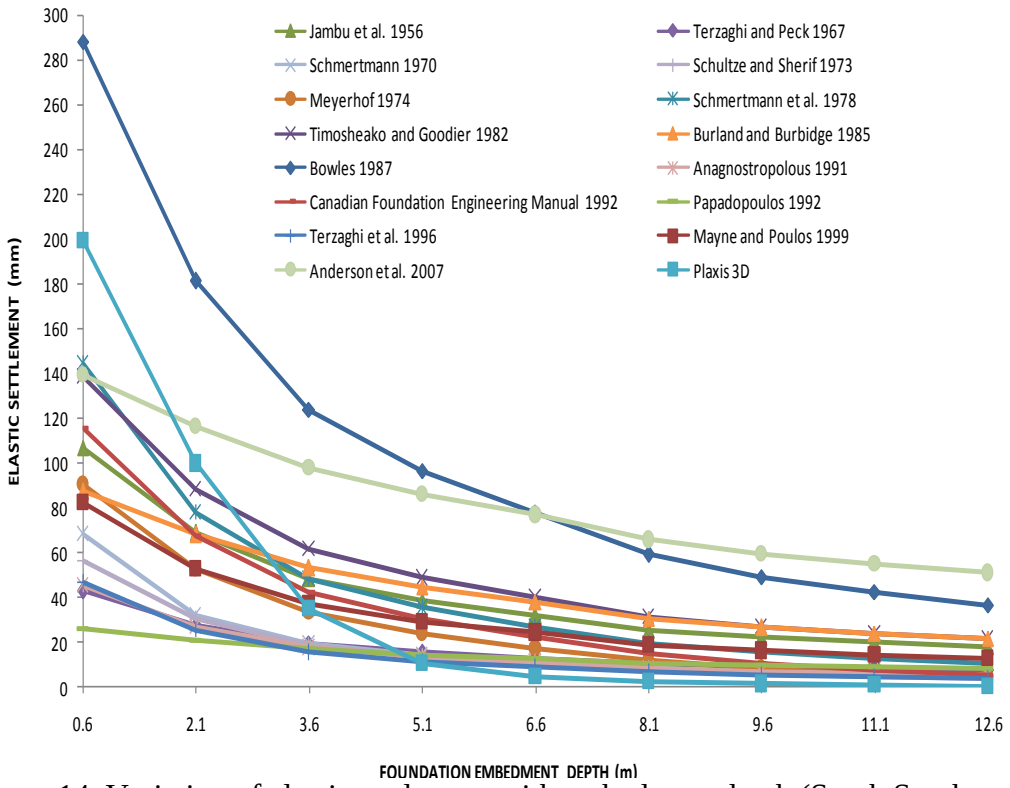

Figure 14. Variation of elastic settlement with embedment depth (South South zone)

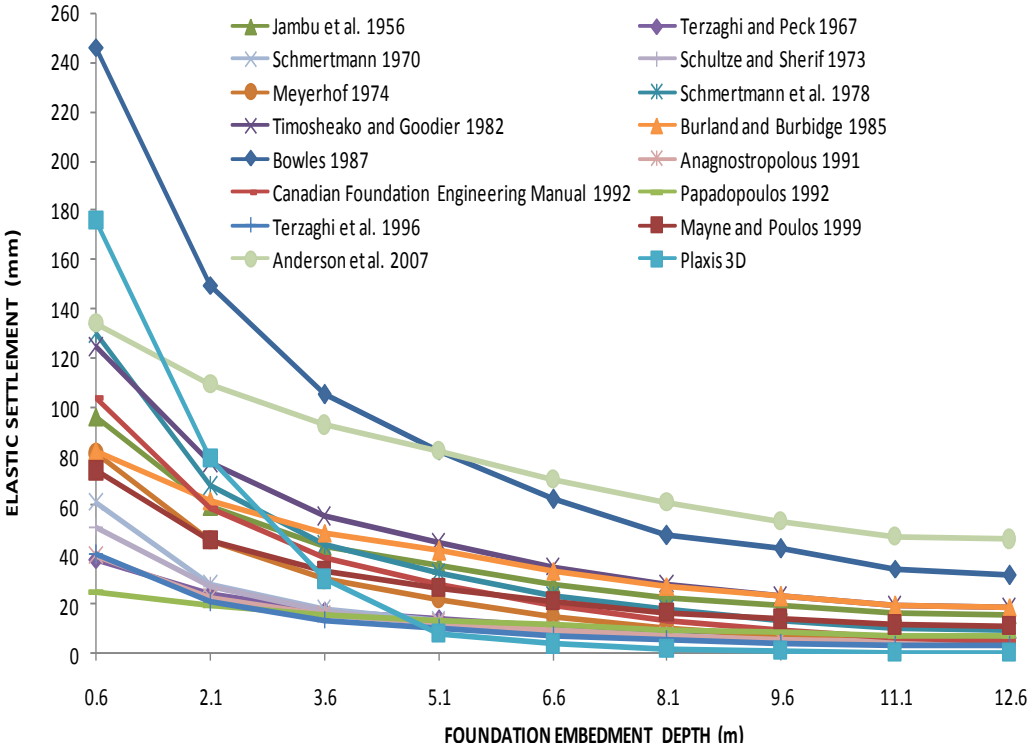

Figure 15. Variation of elastic settlement with embedment depth (South West zone)

The Figures show the different empirical/analytical models commonly used in computing elastic settlement of shallow foundations. Based on numerical modelling results, a maximum elastic settlement value of 124.47, 16.26 and 0.00 were respectively recorded at embedment depths of 0.6, 3.6 and 12.6 m for the North Central zone while 199.37, 34.56 and 0.00 were recorded for the South South zone . As indicated in the results of previous parameters (compressibility characteristics and vertical strains) that the settlement values will be higher in the southern region compared with those of the north, this suggestion was obviously confirmed in the elastic settlement results.

A comparison carried out by Shahin et al. [21] based on field measurement and artificial neural networks (ANN) results of the methods proposed by Schmertmann [22], Schltze and Sherif [23] and Meyerhof [24] rated the Schltze and Sherif [23] method as the best for estimating shallow foundation settlements. However, based on the observations of this study, comparison of the fifteen empirical/analytical methods considered with the numerical modelling results showed that the Schmertmann*et al*. [25], Burland and Burbidge [26], Canadian Foundation engineering Manual [27] as well as the Mayne and Poulos [28] methods gave good estimations of foundation settlement. The recorded trend is consistent with observations reported by Rasin [29]. Figures 16 - 18 show the numerical analysis results of soil body deformation, stress distribution and settlement respectively at collapse of the soil body, they are results for the North Central zone at 0.6 m depth of embedment.

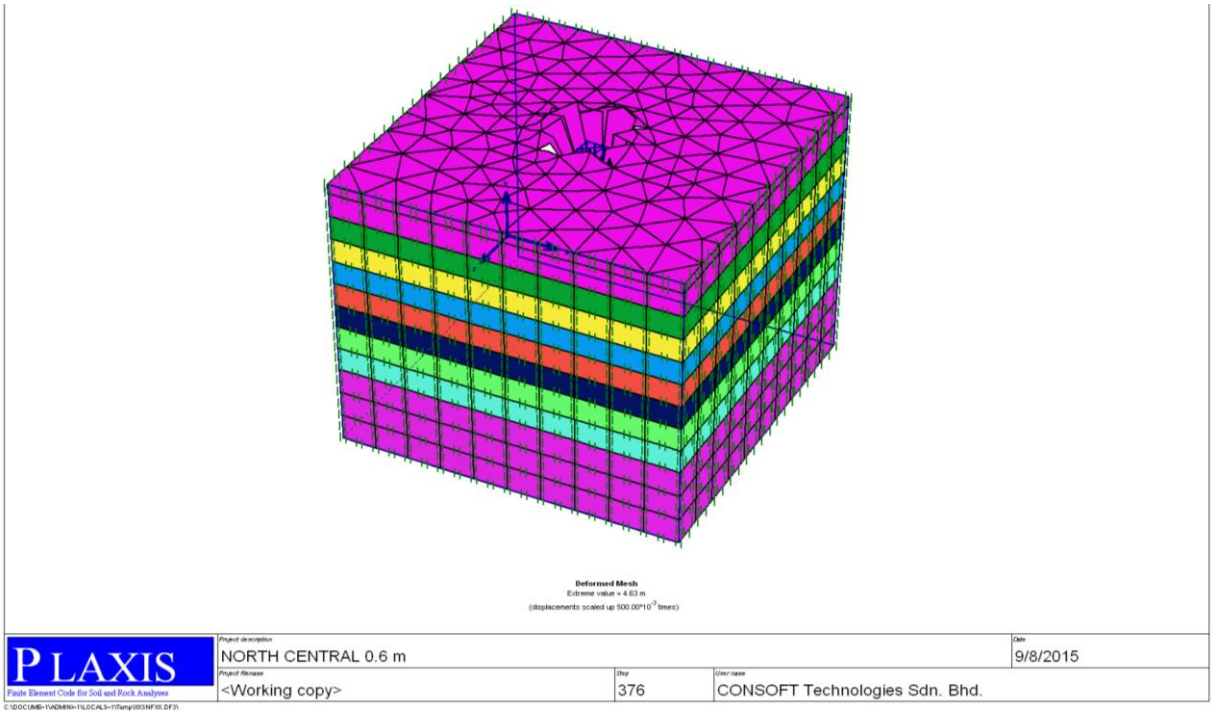

Figure 16. Numerical analysis mesh showing deformation of the soil body at collapse

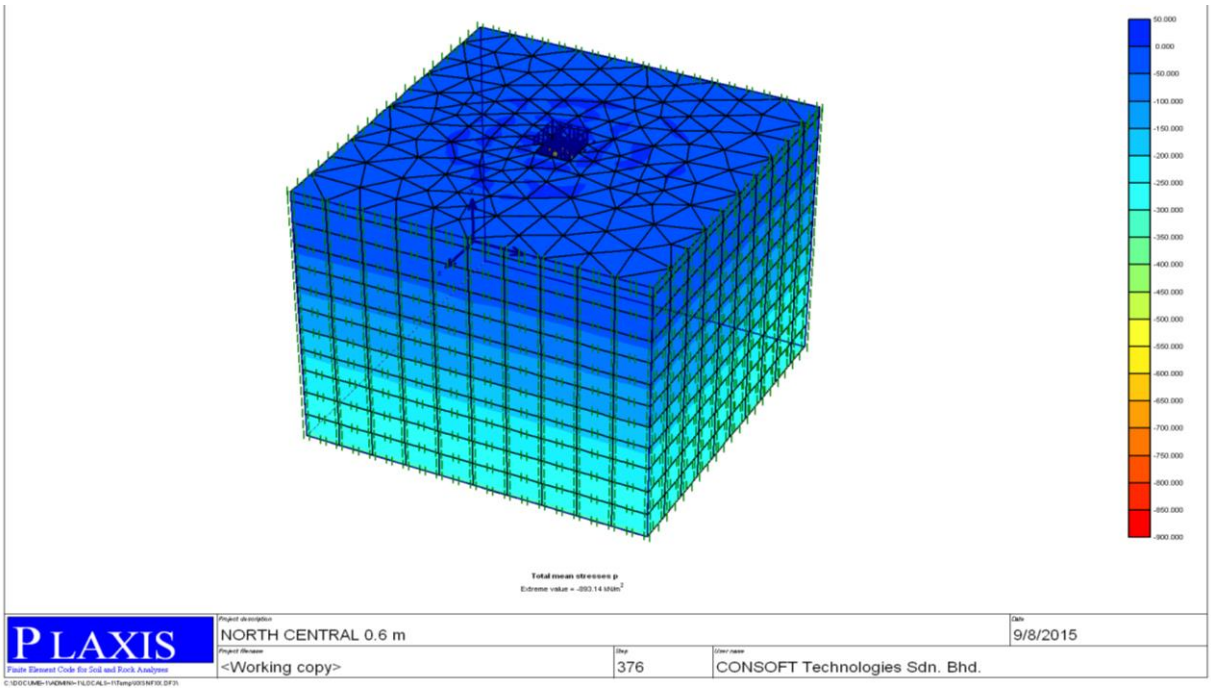

Figure 17. Numerical analysis result of stress distribution up to the collapse

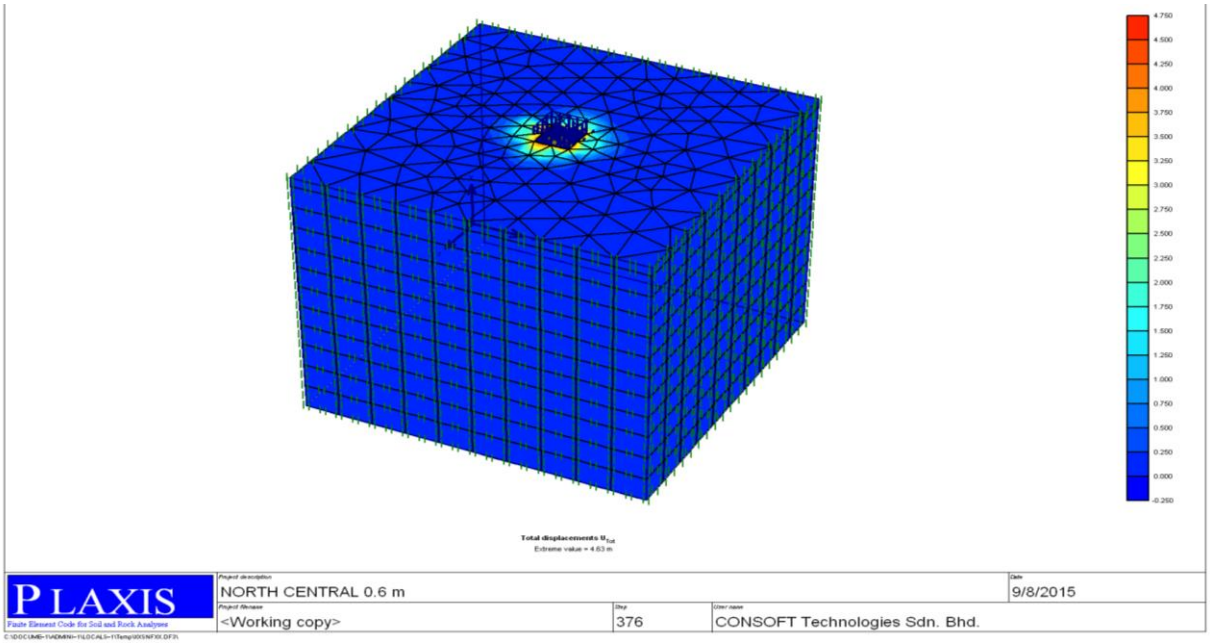

Figure 18. Numerical analysis result of settlement up to the collapse of the soil body

Settlement prediction models development

The influences of some soil parameters on foundation settlement were considered in analytical models. For a single dependent variable (settlement), several independent variables were considered. Therefore, Polynomial Regression Analysis (PRA) and Multiple Regression

Analysis (MRA) techniques were used to model the settlement pattern analytically using MINITAB 17 statistical software package. The models were developed using the North Central zone which has the least SPT based settlement values as case study and tested for the other five zones for validation and verifications of their conformity. The models were developed for isolated 2 x 2 m square footing with applied foundation pressure of 300 kN/m^2. The models were developed for elastic settlement (S_e) as response (dependent variable) and corrected N-value (N_{60}), angle of internal friction (φ), elastic modulus of soil (E_s), Poisson ratio (ν), soil parameters combinations (N_{60}, φ φ and ν), (N_{60} and φ) and (N_{60}, and ν) as predictors (independent variables).

Development of models based Burland and Burbidge method

Foundation settlement prediction models were first developed based on Burland and Burbidge [26] method because of its wide acceptance and application in order to have a good judgment of the numerical modelling results models. The models are shown in Eqs. [1 – 7].

$$S_{e\,(N60)} = 91 - 2.231N_{60} + 0.01564N_{60}^2 \quad (1)$$

$$S_{e\,(\varphi)} = 512.4 - 21.8\varphi + 0.2375\varphi^2 \quad (2)$$

$$S_{e\,(Es)} = 91 - 0.004463E_s \quad (3)$$

$$S_{e\,(\nu)} = 192.5 - 872.8\nu + 1056\nu^2 \quad (4)$$

$$S_{e\,(N60,\varphi \text{ and } \nu)} = -4167 + 252.48\varphi + 322.19N_{60}v - 715\varphi\nu - 2.5066N_{60}\varphi\nu \quad (5)$$

$$S_{e\,(N60 \text{ and } \varphi)} = -5689 - 84.36N_{60} + 214.02\varphi + 0.5913N_{60}\varphi \quad (6)$$

$$S_{e\,(N60 \text{ and } \nu)} = -1765.1 - 73.52N_{60} + 14268\nu + 39.417N_{60}\nu \quad (7)$$

Development of models based on numerical analysis method

The developed models based on numerical modelling results using Plaxis 3D are shown in Eqs. [8 – 14].

$$S_{e\ (N60)} = 147.4 - 4.739N_{60} + 0.0357N_{60}^2 \quad (8)$$

$$S_{e\ (\varphi)} = 1140 - 52.03\varphi + 0.5893\varphi^2 \quad (9)$$

$$S_{e\ (Es)} = 147.4 - 0.009478E_s \quad (10)$$

$$S_{e\ (\nu)} = 383.9 - 2028\nu + 2619\nu^2 \quad (11)$$

$$S_{e\ (N60,\varphi\ and\ \nu)} = -17140 + 1016\varphi + 1274N_{60}\nu - 2838\varphi\nu - 9.94N_{60}\varphi\nu \quad (12)$$

$$S_{e\ (N60\ and\ \varphi)} = -19701 - 286.5N_{60} + 735\varphi + 1.994N_{60}\varphi \quad (13)$$

$$S_{e\ (N60\ and\ \nu)} = -6221 - 250N_{60} + 49018\nu + 132.9N_{60}\nu \quad (14)$$

Where: S_e - elastic settlement, N_{60} - corrected SPT N-value, φ - angle of internal friction, E_s - elastic modulus of soil, ν - Poisson ratio.

Validation of development of models based Burland and Burbidge method

The results of application of the models developed for North Central (NC) zone in terms of elastic settlement parameters are presented in this section. The testing of the models was done using data from the other five zones of Nigeria, namely; North East (NE), North West (NW), South East (SE), South South (SS) and South West (SW) zones. This data was not used in the formulation of the regression models and thus gives an unbiased assessment of correlation between the empirical and statistical model results. This data was used only to test the accuracy of the developed models in order to provide a good judgment when used to test the equations and the results compared with those of numerical modelling. The variation of predicted settlements with foundation embedment depths are shown in Figures 19 - 24 for the six zones.

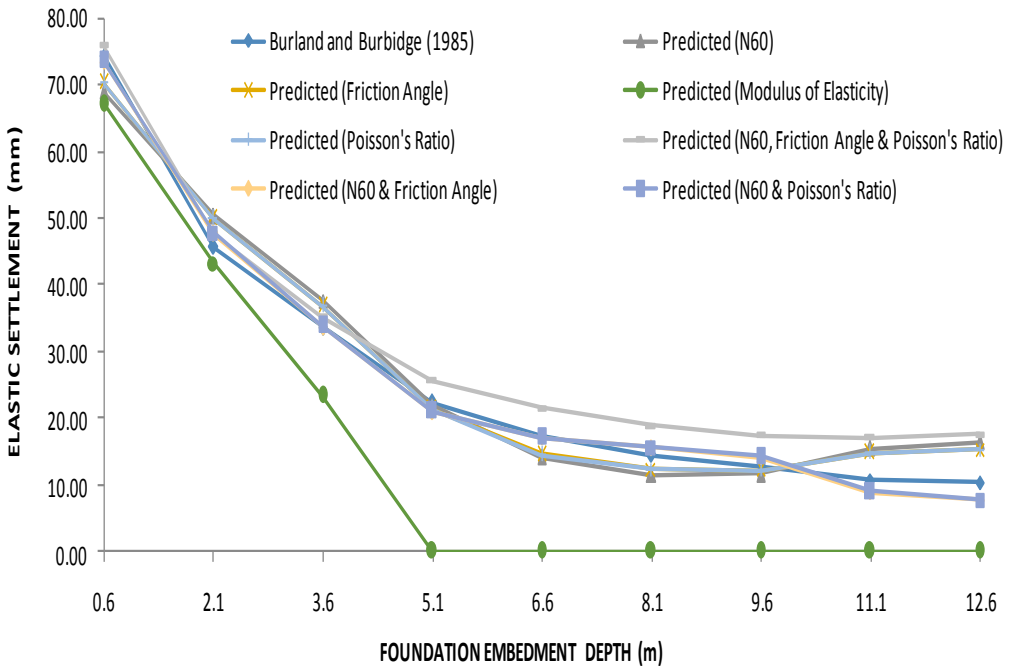

Figure 19. Variation of predicted elastic settlement with embedment depth (North Central zone)

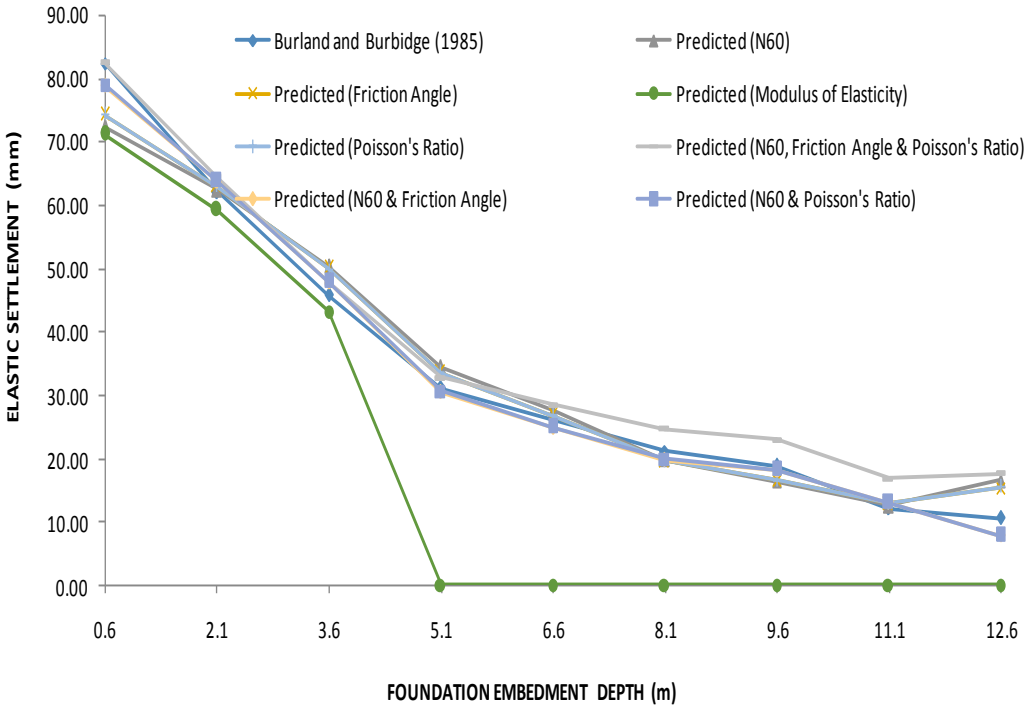

Figure 20. Variation of predicted elastic settlement with embedment depth (North East zone)

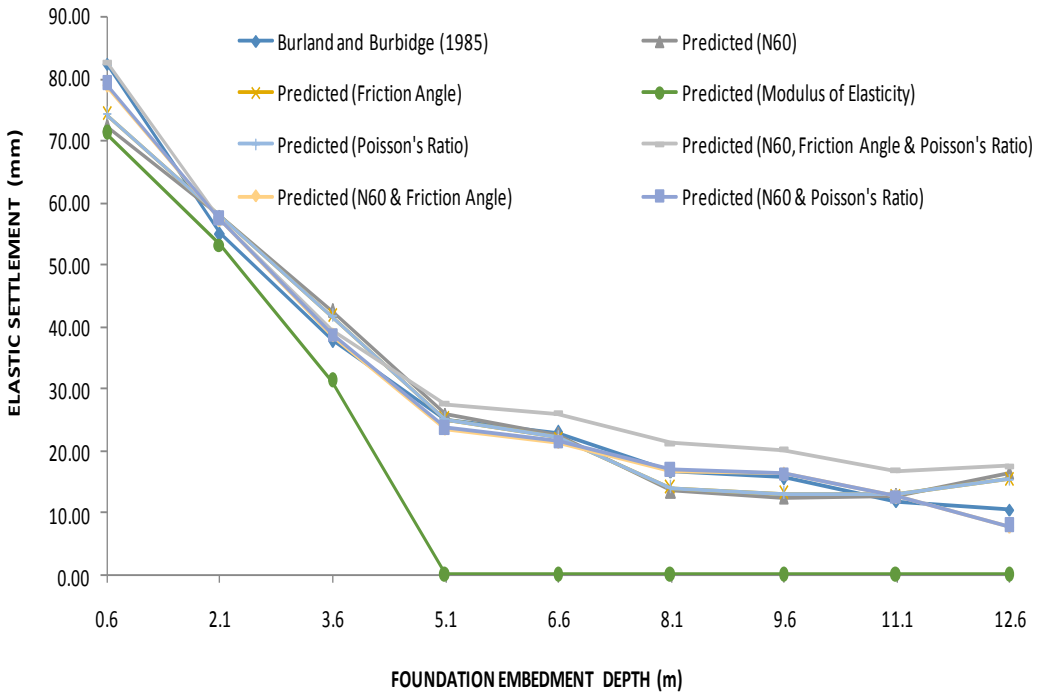

Figure 21. Variation of predicted elastic settlement with embedment depth (North West zone)

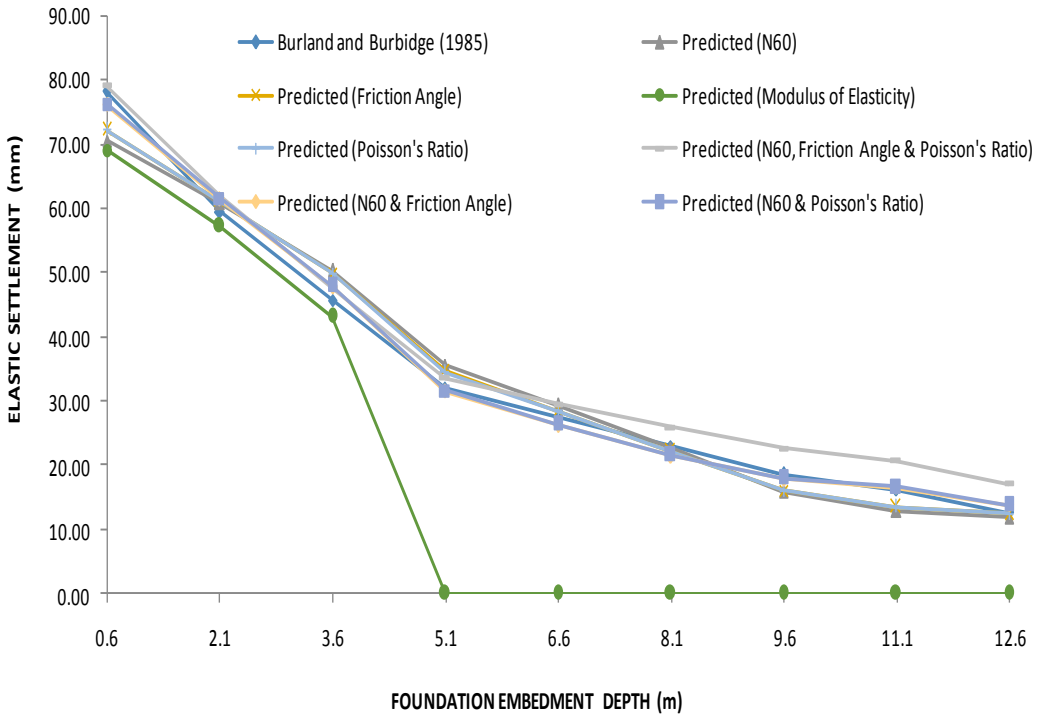

Figure 22. Variation of predicted elastic settlement with embedment depth (South East zone)

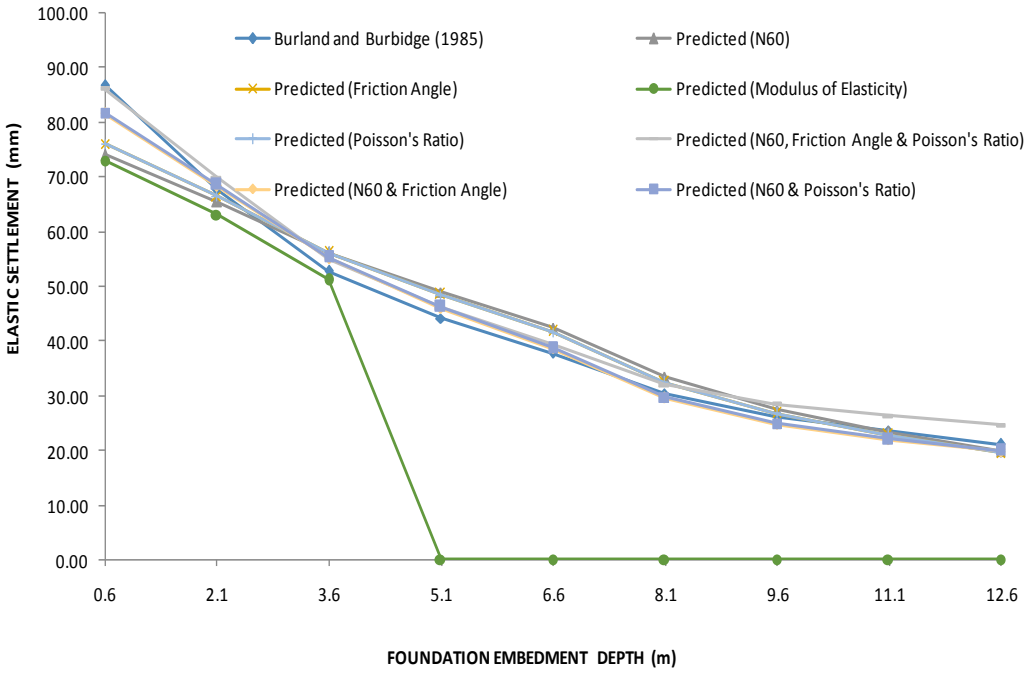

Figure 23. Variation of predicted elastic settlement with embedment depth (South South zone)

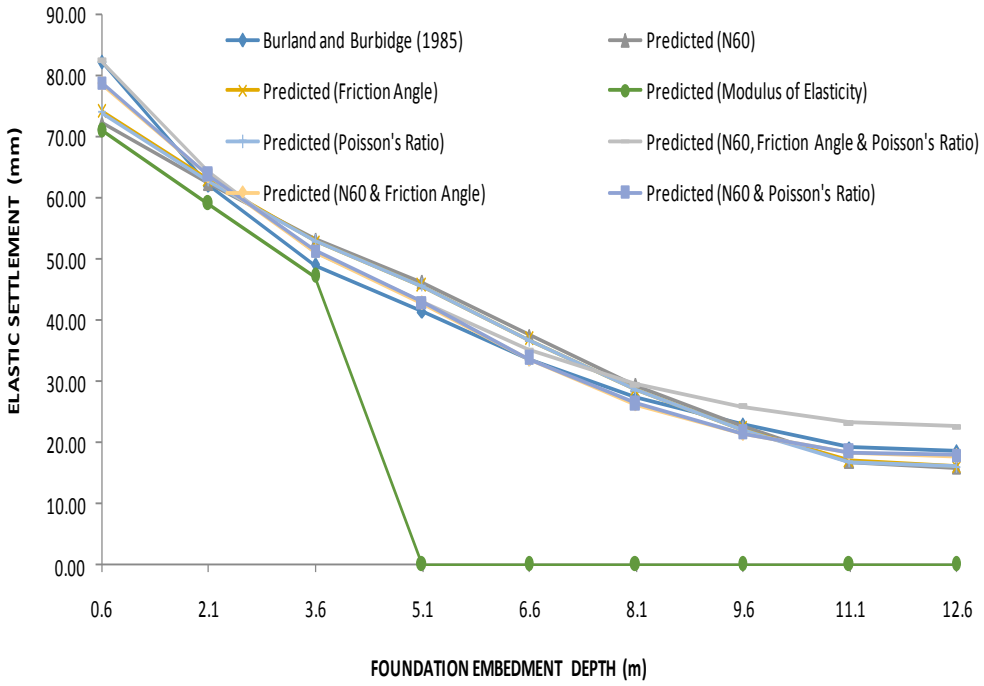

Figure 24. Variation of predicted elastic settlement with embedment depth (South West zone)

Settlement parameters estimated using back calculation from the developed polynomial regression models were compared with empirical results based on SPT data and found to be accurate having a minimum R^2 value of 96%. The developed models statistically

performed satisfactorily when tested with other data sets. All the polynomial and multiple regression models of settlement accounted for more than 96% R^2 value of the independent variables (N_{60}, angle of internal friction, modulus of elasticity, Poisson ratio and their combinations). The best model for the prediction of elastic settlement of footings is the one that has N_{60}, angle of internal friction and Poisson ratio as predictors.

It was generally observed that modulus of elasticity compared with other soil parameters used is not suitable for the prediction of foundation settlement.

The developed models have $R^2 > 96$ % and adjusted $R^2 > 96$ % thus implying that the independent variables explain over 96% of the variability of the dependent variable (i.e., Settlement). The adjusted R^2 is also an estimate of the effect size, which at 96%, is indicative of a large effect size according to the classification given by Cohen [38]. Therefore, all the regression models are statistically significant ($p = 0 < 0.05$). The standard error (S) values indicate that the average distances of the data points from the fitted lines are very close and 95% of the observations should fall closely to the fitted lines, which are close matches for the prediction intervals. This indicates that, in general, the models applied can statistically significantly predict the dependent variable (i.e., Settlement).

Validation of development of models based on numerical analysis method

Polynomial and multiple regression models of settlement based on Plaxis 3D results accounted for more than 85% (R^2 value) of the independent variables (N_{60}, angle of internal friction, and modulus of elasticity, Poisson's ratio and their combinations).

The best model for the prediction of settlement of footings is the one developed using N_{60}, angle of internal friction and Poisson ratio as predictors. Comparison of the variations of numerical analysis results and predicted footing settlements using developed models with SPT boring depth are shown in Figures 25 - 30 for the six zones.

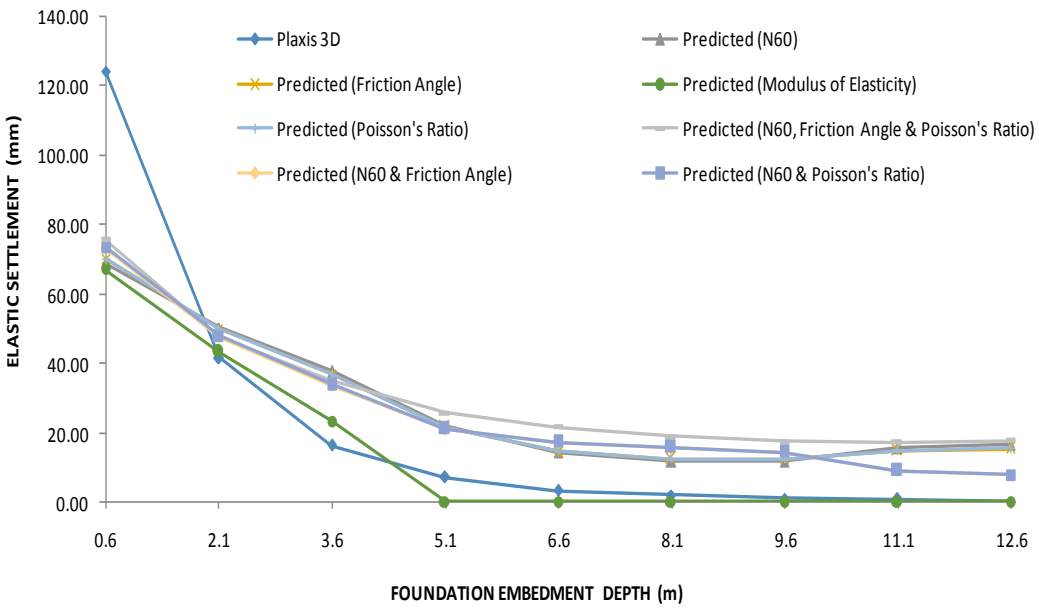

Figure 25. Variation of predicted elastic settlement with embedment depth (North Central zone)

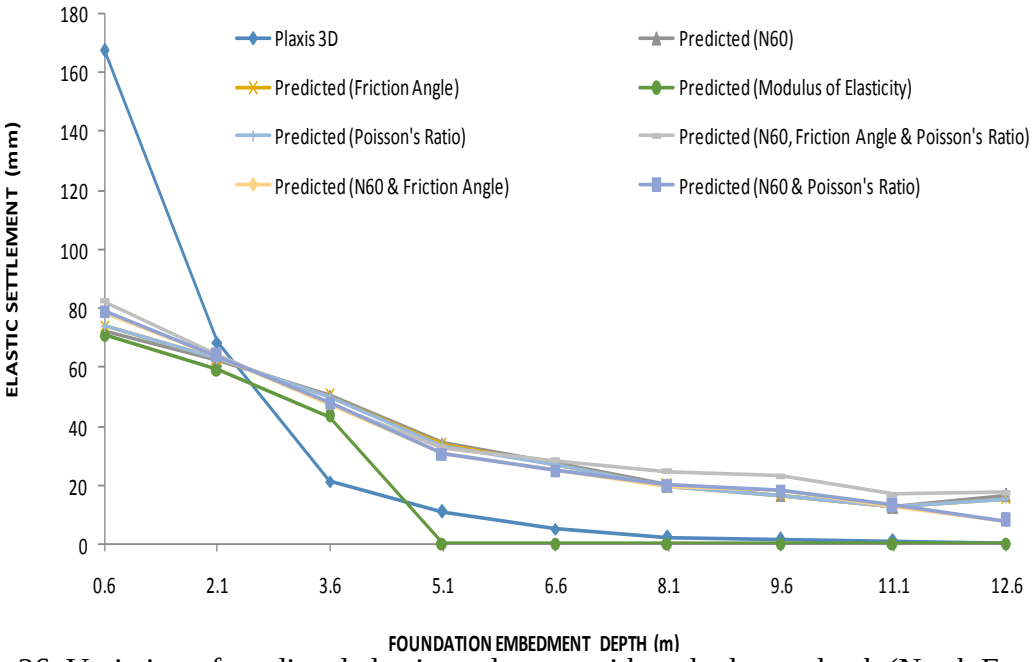

Figure 26. Variation of predicted elastic settlement with embedment depth (North East zone)

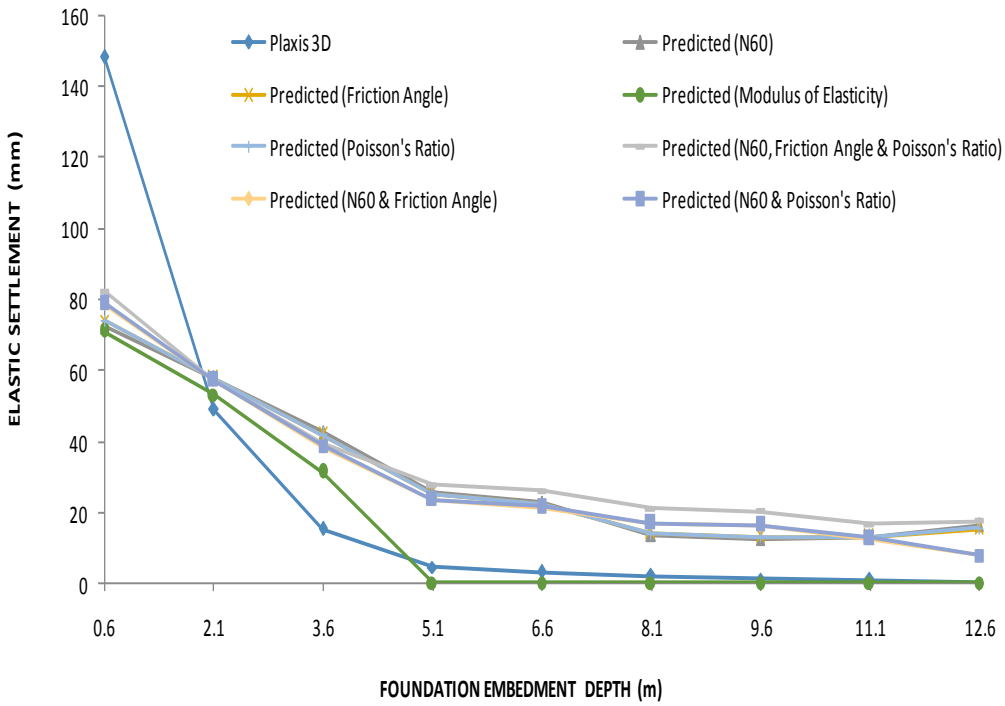

Figure 27. Variation of predicted elastic settlement with embedment depth (North West zone)

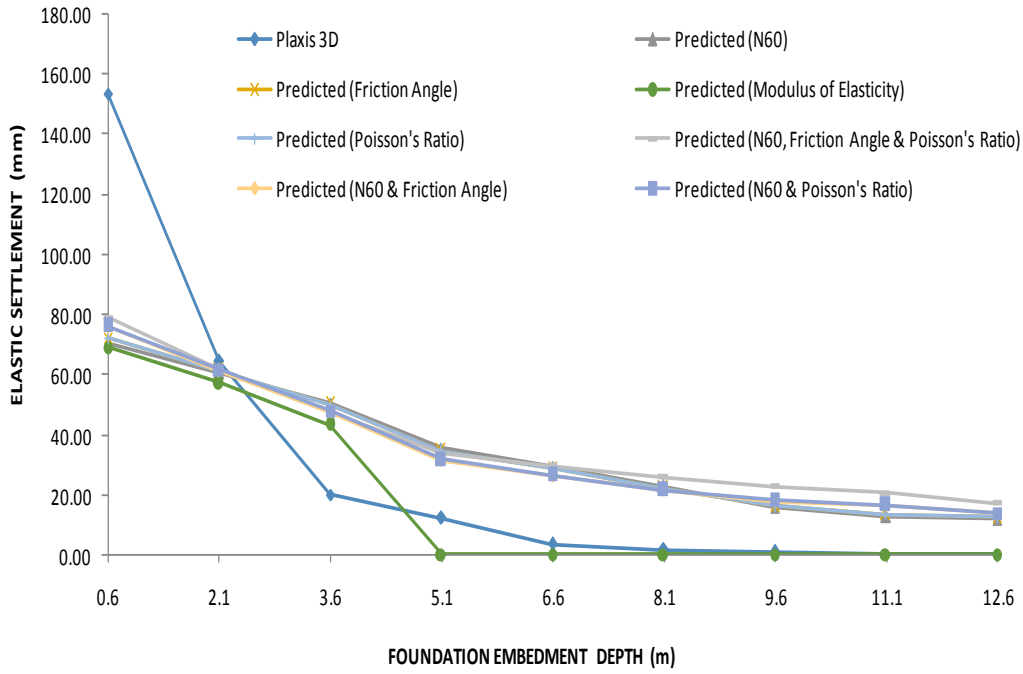

Figure 28. Variation of predicted elastic settlement with embedment depth (South East zone)

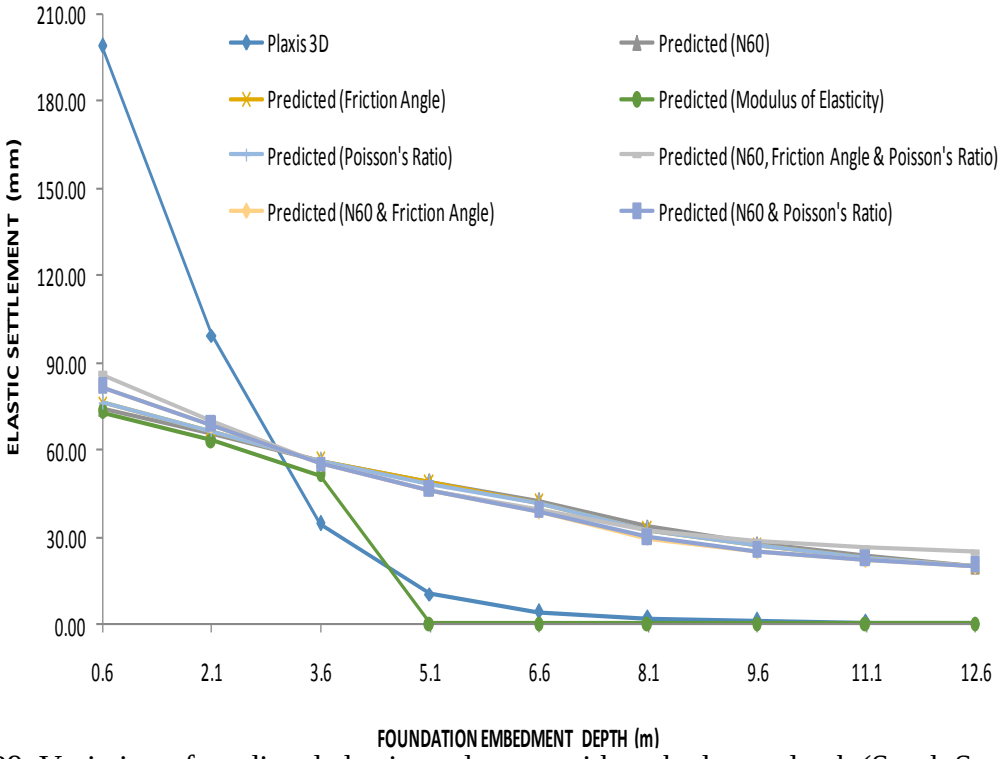

Figure 29. Variation of predicted elastic settlement with embedment depth (South South zone)

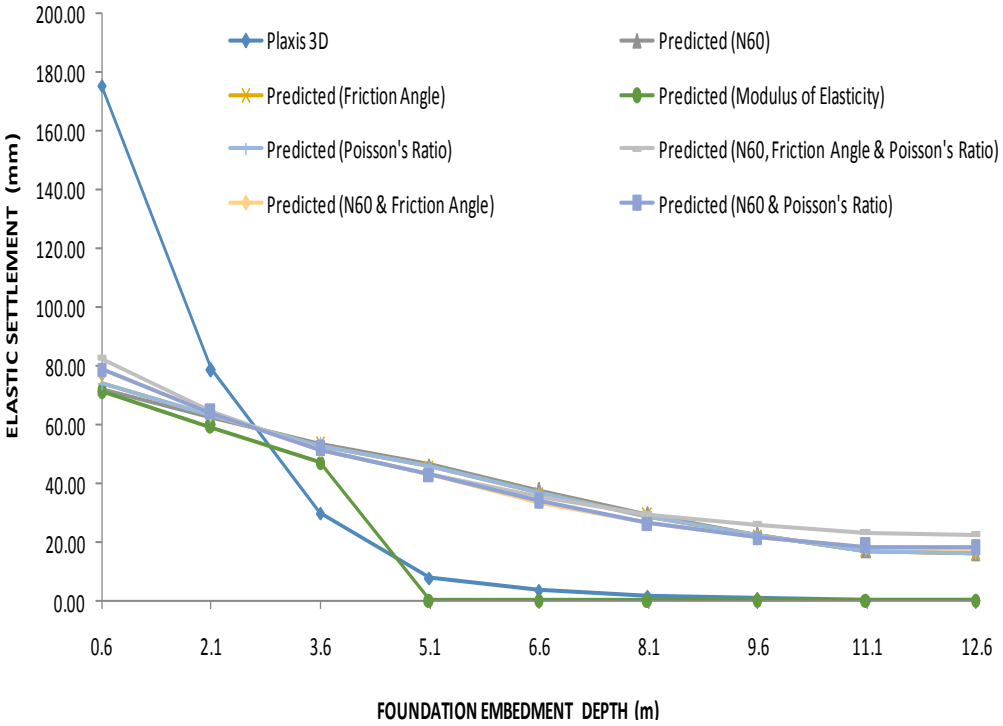

Figure 30. Variation of predicted elastic settlement with embedment depth (South West zone)

Conclusion

Standard penetration test (SPT) results corrected to the standard average energy of 60% (N_{60}) correlated to soil properties were used in this study for the evaluation of foundation settlement characteristics in the six zones of Nigeria. Based on the results of this study, the following were concluded:

1. The results of Poisson's ratio, modulus of elasticity, shear modulus, vertical strain, compressibility index and coefficient of volume compressibility show that the susceptibility of Nigerian soils to compression is highest on the average in the South South zone, followed by South West, South East, North East, North West and the North Central geo-political zone has the least prediction of compressibility.
2. The compressibility parameters obtained which indicated that the settlement values will be higher in the southern zones compared with those in the northern zones was confirmed by the settlement results.
3. A comparison of results obtained using the fifteen empirical/analytical methods considered in this study with those of numerical modelling showed that methods proposed by Schmertmann *et al*. [25], Burland and Burbidge [26], Canadian Foundation Engineering Manual [27] as well as the Mayne and Poulos [28] gave good estimations of foundation settlement. However, Plaxis 3D, using SPT derived input parameters for embedment up to 2 m, tend to overestimate the elastic settlement of footings.
4. Based on the empirical/analytical and numerical analysis methods using 300 kN/m^2 applied foundation pressure, computational models were developed for elastic settlement (S_e) as response and corrected N-value (N_{60}), angle of internal friction (φ), elastic modulus of soil (E_s), Poisson's ratio (μ), combination ($N_{60,}$ φ and ν), combination (N_{60} and φ) and combination ($N_{60,}$ and ν) respectively as predictors. The developed models were verified and confirmed to be generally applicable across Nigeria. All the polynomial and multiple regression models of settlement based on empirical method accounted for 96% R^2 value of the predictors while those of numerical analysis accounted for more than 85% R^2 value and therefore all the regression models are statistically significant ($p = 0 < 0.05$).

5. The best model for the prediction of elastics settlement of footings is the one developed with combination (N_{60}, φ and ν) as predictors.

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