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Stress-Settlement Model of Piles in the Coastal Regions of Nigeria

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Abstract

A model that predicts the settlement of pile in the coastal regions of Nigeria (Lekki, Aja, Ikoyi, Victoria Island, Magodo, Ikorodu, Ipakodo and Festac) in Lagos was studied through the use of statistical analysis. Descriptive analysis, parametric test, correlation and regression were used to determine a significant relationship between stress and its settlement. A predictive model describing the relationship between stress and maximum settlement of these piles was generated. The results reveal that the settlement increased by 0.0009mm for every one-point increase in stress. A predictive stress-settlement model was developed with a regression coefficient of 0.8428. The model may be useful in providing settlement information on piles driven within the Lagos.

Keywords: Static pile; Load test; Load settlement response; Predictive model; Coastal region

Introduction

The steady increase in the rate of urbanization within the coastal region of Nigeria, necessitated by the increase in population in the area is quite remarkable. A number of factors are responsible for this increase, one of the reasons is the presence of oil exploration and exploitation companies in the region. This has made Government, and many multinationals invest in the region, thus creating infrastructure driven investments opportunities such as loads, buildings, bridges, water retaining structures, transmission towers among others, and the resultant high ingress of people to the region. There is therefore an increase in the demand for pile foundation to support these structures as they are principally used to transfer the large loads from superstructure, through weak, compressible strata, or water onto a stronger, more compact, less compressible and stiffer soil [1].

Burland et al. [2] pointed out that traditionally engineers have asked themselves how many piles are required to carry the weight of the building and claimed that designers should perhaps better ask themselves the question of how many piles are required to reduce the settlement to an acceptable limit. The number of piles in answer to the second question is invariably significantly less than in answer to the first question.

There are a number of compelling arguments for moving towards a settlement-based design methodology for pile foundations, and since 1977 a number of interesting developments have occurred in this direction, including some outstanding applications [3,4] nevertheless, the capacity-based design is still dominant, as is evident for instance in current revisions of national and regional design codes. Venkata [5] developed a simple but rational method of estimating settlement of pile groups based on load transfer approach for single piles and equivalent pier method. The method takes into account layered soil system and makes use of input parameters obtained from usually conducted field tests such as standard penetration test (SCPT) in cohesionless soils and consolidation test in cohesive soils. Chandra et al. [6] addressed the issue of settlement of pile-supported structures due to the loss of pile capacity in liquefied soil. A simple mathematical model that can be implemented in an EXCEL type program was proposed for characterizing the above phenomenon. The method used envelopes of unit load transfer curve that describes the axial load transfer mechanism of the pile foundation in liquefied soil. Tomislav et al. [7] analyzed the bearing capacity and settlement of bored piles, as the most frequently used type of piles in local practice. It was observed that empirical methods based on geotechnical soil parameters for capacity estimation, introduced some simplifications which lead to neglecting certain elements of a complex pile-soil interaction. On the other hand, the results of pile field testing methods were a direct summary consequence of the overall complex conditions on pile-soil contact. This study will provide an in-depth understanding of the settlement of piles in the coastal region of Nigeria and subsequently, develop a pile settlement- stress model [8,9].

Area of Study

The study area is situated in Lagos, Nigeria with latitude

6.465422°**N** and longitude 3.406448°**E** with the gps coordinates of 6° 27' **55.5192**'' N and 3° 24'**23.2128**'' E shown in Figure 1. Static Pile load tests were carried out on five locations within the study area. The locations include Lekki, Aja, Ikoyi, Victoria Island, Magodo, Ikorodu, Ipakodo and Festac Figure 1.

Figure 1: Map showing the study area. (Source: Google Maps, 2019).

Materials and Methods

Static load test

Static load test of a pile or group of piles is used to establish an allowable load. This was carried out on piles located in Lekki, Aja, Ikoyi, Victoria Island, Magodo, Ikorodu, Ipakodo and Festac. The applied load is usually maximum of 150 % to 200 % of the design safe working load. These tests were guided in accordance to the Geotechnical Engineering Bureau (2007).

Equipment and Instrumentation for Static Load Test

The major equipment includes the following:

1) Test beams - primary and secondary

2) Bearing plates

3) Hydraulic jack of appropriate capacity (800 tons); connected to hydraulic pump

4) Oil manometer of suitable capacity

5) Kentledge or dead weights (normally in form of concrete cubes of $1m^3$ and 24kN or 2.4 tons), etc.

6) Steel reference beams

7) Dial gauges, capable of measuring movements within an accuracy of 0.01mm.

Arrangement of load test platform

Load transfer is by means of a jack which obtains its reaction from kentledge heavier than the required test load Figure 2.

Figure 2: The Typical Compression Pile Load Test Set-up by Kentledge (Dead Weight Method.)

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Pile load test procedure

The pile load test involves the application of the load in stages, with the load at each stage being maintained constant until the resulting settlement of the pile virtually ceases before the application of the next load increment. Maximum load to be applied on a single pile for this method will not exceed 2.0 x safe working load (S. W. L). The load is applied in increments of 25 % of the design load. Each load increment is maintained until the rate of settlement is not greater than 0.05mm/30 minutes or until a maximum of about 2 hours have elapsed, whichever occurs first. The maximum load is maintained on the pile for 6 hours, except in the event that the average rate of settlement is not greater than 0.05mm/30minutes. Unloading of pile is done in decrements of 25 % of the maximum load or as specified by the client

Results and Discussion

Table 1: Result of maximum settlement and stress at different location in lagos.

Location	Pile Length	Diameter (mm)	Area (m^2)	Load (kN)	Stress (kN/m^2)	Max. Settlement (mm)
Lekki	20	800	0.5	1717.5	3415.48	2.355
Lekki	20	450	0.16	1125	7070.71	5.23
Magodo	12	500	0.2	1050	5345.45	4.035
Ikorodu	20	800	0.5	1665	3311.08	3.5
Ipakodo	18	600	0.28	1138.5	4025	3.045
Lekki	20	600	0.28	1215	4295.45	4.233
Aja	18	450	0.16	474	2979.12	1.947
Aja	18	450	0.16	890	5593.71	4.622
Victoria Island	18	450	0.16	948	5958.25	4.86
Victoria Island	18	450	0.16	474	2979.12	1.402
Victoria Island	18	450	0.16	948	5958.25	4.879
Victoria Island	18	450	0.16	474	2979.12	1.402
Victoria Island	18	450	0.16	474	2979.12	1.421
Onikan	12	500	0.2	948	4826.18	3.247
Onikan	18	450	0.16	474	2979.12	1.414
Onikan	18	450	0.16	948	5958.25	4.348
Ikoyi	12	600	0.28	1214.6	4294.04	3.005
Festac	12	500	0.2	1058	5386.18	3.674
Magodo	20	600	0.28	1253	4429.8	3.056
Aja	12	500	0.2	1100	5600	4.268

Table 1 consists of raw data obtained from the series of static pile load test (SPLT), which include the test location, length of pile, diameter and area of pile, safe working load, maximum stress and most importantly the maximum settlement. It is observed that Lekki had the highest settlement followed by Aja, Ikoyi, and Victoria Island. The high settlement observed in Lekki is liken to the reclamation of area and in Figure 3, the bar chart depicts the variation of maximum settlement at the various static pile load test locations. In order to obtain the model that predicts the settlement of pile in the coastal region of Nigeria, the following statistical analysis were conducted:

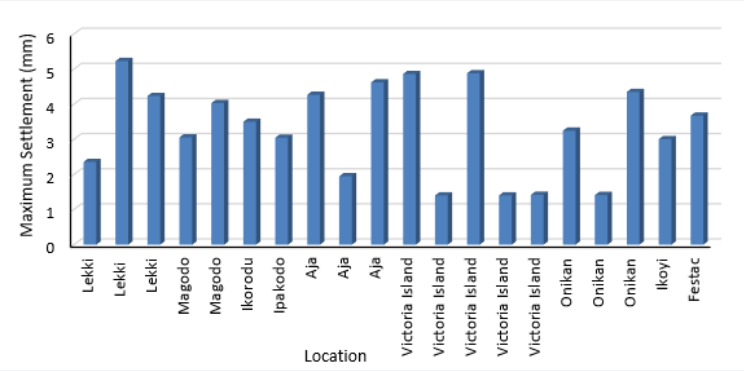

Figure 3: Variation of Maximum Settlement at the various static pile load test location

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I. Descriptive Analysis

II. Parametric test

III. Pearson's Correlation Test

IV. Regression Analysis

Descriptive Analysis

This analysis provided an opportunity to assess the variables in terms of the mean, median, mode, standard deviation, variance, range, minimum and maximum value as shown in Table 2. Also, some very useful descriptive statistics, which include the mean, standard deviation and 95 % confidence intervals for the dependent variable (maximum settlement) for each separate group (Lekki, Magodo, Ikorodu, Ipakodo, Aja, V.I, Onikan, Ikoyi, Festac), as well as when all the groups are combined (total) are also presented Table 2.

Parametric Test: The function of this parametric test is to analyze the test group mean of the data.

Table 2: Descriptive analysis of all nominal variable.

Test	Pile Length	Diameter	Area	Load	Stress	Max. Settlement
N Valid Missing	20	20	20	20	20	20
	0	0	0	0	0	0
Mean	17	525	0.224	979.43	4518.1715	3.2972
Median	18	475	0.16	999	4362.625	3.3735
Mode	18	450	0.16	474	2979.12	1.4
Std. Deviation	3.07794	110.62026	0.10555	367.19586	1286.85	1.28259
Variance	9.474	12236.842	0.011	134832.798	1656001.4	1.645
Range	8	350	0.34	1243.5	4091.59	3.83
Minimum	12	450	0.16	474	2979.12	1.4
Maximum	20	800	0.5	1717.5	7070.71	5.23

One-way ANOVA

Table 3: Descriptive analysis of all nominal variable.

Site	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min	Max
					Lower Bound	Upper Bound		
Lekki	3	4.2727	1.66075	0.95883	0.1471	8.3982	2.36	5.23
Magodo	2	3.5455	0.69226	0.4895	-2.6742	9.7652	3.06	4.04
Ikorodu	1	3.5					3.5	3.5
Ipakodo	1	3.045					3.05	3.05
Aja	3	3.5123	1.3945	0.80511	0.0482	6.9765	1.95	4.62
V.I	5	2.6928	1.76839	0.79085	0.4971	4.8885	1.4	4.88
Onikan	3	2.7697	0.91563	0.52864	0.4951	5.0442	1.71	3.35
Ikoyi	1	3.005					3.01	3.01
Festac	1	3.674					3.67	3.67
Total	20	3.2722	1.26007	0.28176	2.6824	3.8619	1.4	5.23

Table 4: Output of the Anova on maximum settlement.

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	6.098	8	0.762	0.348	0.027
Within Groups	24.07	11	2.188		
Total	30.168	19			

The purpose of this test was to determine whether there were any statistically significant differences between categorical independent variables and a normally distributed interval dependent variable. Table 3 shows the output of the one-way ANOVA analysis on maximum settlement. The output of the ANOVA analysis shows whether there is a statistical difference between the groups of means Table 4. It can be seen that the significant value is 0.027 (i.e., p = 0.027), which is below 0.05. And therefore, there is statistically significant difference in the mean maximum settlement with respect to its location.

Correlation Analysis

The purpose of a correlation analysis is to determine a significant relation between two variables, in this case, it is the relationship between stress and maximum settlement. The Pearson's correlation test estimates the strength of the linear relationship between the two variables, correlation coefficients range from -1.0 (a perfect negative correlation) to positive 1.0 (a perfect positive correlation). The closer the correlation coefficient get to -1.0 or 1.0, the stronger the correlation. The closer the correlation coefficient get to zero, the weaker the correlations between

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the two variables. Table 5 shows the result of the Pearson's correlation test analysis between stress and maximum settlement. It is evident that stress has a strong positive correlation with maximum settlement, which implies that an increase in stress influence increase in maximum settlement. This was indicated by the Pearson correlation coefficient (R) = 0.92 which is positive as indicated by the beta coefficient of the independent variable (stress). In Figure 4, the variation of maximum settlement (mm) with stress is shown and there is a positive relation between the maximum settlement and stress with an R^2 regression correlation coefficient of 0.8428. The predictive model is given in equation 1 as follows:

$$S = 0.0009\sigma - 0.864 \quad (R^2 = 0.8428) \quad (1)$$

Table 5: Result of the correlation analysis between stress and maximum settlement.

Test		MAX._SETTLEMENT (mm)	STRESS (kN/m²)
MAX._SETTLEMENT	Pearson Correlation	1	0.921
	Sig. (2-tailed)		0
	N	20	20
STRESS	Pearson Correlation	0.921	1
	Sig. (2-tailed)	0	
	N	20	20

Note: correlation is significant at the 0.01 level (2-tailed).

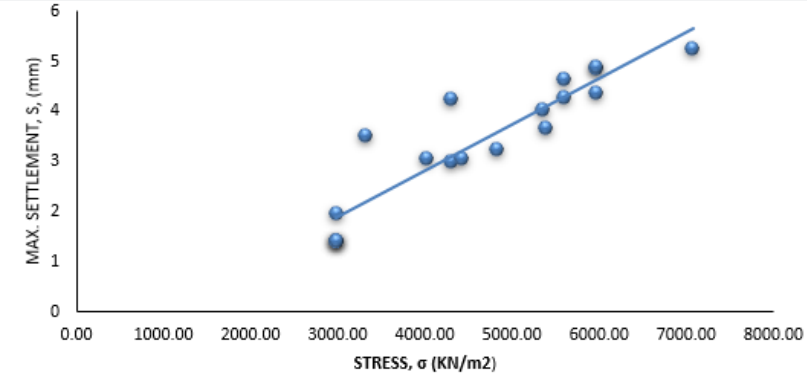

Figure 4: Maximum Settlement (mm) versus Stress (kN/m²).

Conclusion

Based on the results of this study, the following conclusions can be drawn:

1) Stress had a strong positive correlation with settlement, this implied that an increase in stress influenced increase in maximum settlement. This was indicated by the Pearson correlation coefficient (R) = 0.92 which was positive as indicated by the beta coefficient of the independent variable (stress). The implication is that as the stress increased, the maximum settlement also increased by 92 %.

2) That Lekki a reclaimed area has the highest settlement followed by Aja, Ikoyi and Victoria Island.

3) A model for predicting the maximum settlement of a pile in the coastal regions of Lagos was formulated in this research as:

$$S = 0.0009\sigma - 0.864$$

Recommendations

Based on the results of this study, it is recommended that the developed predictive model developed may be used in predicting Stress- maximum settlement response of static pile load tests in the coastal regions of Lagos.

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