Time Dependent Settlement Response Model of Tested Piles in Coastal Region of Nigeria

Akpila S. B., Jaja G. W. T.

Department of Civil Engineering, Faculty of Engineering, Rivers State University, Port Harcourt, Nigeria

ABSTRACT

Prediction of pile settlement has been a major challenge to geotechnical engineering researchers and professionals, due to the nonlinear behavior of the soil. This paper focuses on developing a predictive model for determining settlement-time response of pile load tests from the coastal region of Nigeria. Non-parametric statistical analysis was carried out on the load-settlement response data of static load test of piles from five locations in Lagos metropolis, Nigeria. Regression analysis was done on the predictive settlement data to determine the required predictive model. The maximum settlement observed was 9.991 mm with a mean value of 7.892 mm. A significant correlation of more than 50 % existed for the various settlement data. Consequently, a predictive model was developed for determining settlement- time response of static pile load tests.

KEYWORDS: *static pile load test, load-settlement response, predictive model, coastal region, Lagos Metropolis*

1. INTRODUCTION

Pile load testing provides an opportunity for continuous improvement in foundation design and construction practices, while at the same time fulfilling its traditional role of design validation and routine quality control of the piling works. In order to achieve this improvement, data from pile tests has to be collected and analyzed to enable the piling industry, both individually and collectively, make the best use of resources (Federation of Piling Specialist, 2006). Generally, many uncertainties are inherent in the design and construction of piles; it is therefore difficult to predict with accuracy the performance of a pile.

Sales et al (2017) proposed a method to predict the load-settlement response of a pile group based on the response of a single pile. The method was shown to produce estimates that were in good agreement with measurements. The influence of pile group configuration, pile spacing, soil density and method of pile installation were also studied.

Jean and Paulo (2017) assessed two methods for nonlinear prediction of the settlement of a 23 m long and 31 cm diameter instrumented pile tested via slow maintained load (SML) test. The local subsoil was composed of colluvional silty-sandy, lateritic clay with a collapsible surface layer (6.5 m), followed by silty clayey sandy soil (diabase residue) down to 20 m. The results showed that the models of nonlinear behavior were in appropriate agreement with the experimentally obtained results. It was also noted that, for small displacements of the top (5.1 mm), the tip load increased continuously from its reaction to the final stage of the test.

Qian-qing et al (2017) presented a simplified approach for nonlinear analysis of the load-displacement response of a single pile and a pile group using the load-transfer approach. A hyperbolic model was used to capture the relationship between unit skin friction and pile-soil relative displacement developed at the pile-soil interface and the load-displacement relationship developed at the pile end. As to the nonlinear analysis of the single pile response, a highly effective iterative computer program was developed using the proposed hyperbolic model.

Shahin (2017) used recurrent neural networks (RNNs) were used to develop a prediction model that can resemble the full load-settlement response of drilled shafts (bored piles) subjected to axial loading. The developed RNN model was calibrated and validated using several in-situ full-scale pile load tests, as well as cone penetration test (CPT) data. The results indicated that the RNN model had the ability to reliably predict the load settlement response of axially loaded drilled shafts and can thus be used by geotechnical engineers for routine design practice.

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 Phase 1, Ikorodu, Lekki, Aja and Onikan as shown in Figure 2.

Figure1. Map showing the study area.
(Source: Google Maps, 2019)

Figure 2: Map showing the locations of the static pile load test within the study area. (Source: Google Maps, 2019)

2. Materials and Methods
Static Load Test
Static load test of a pile or group of piles is used to establish an allowable load. Static load test were carried out on piles located in include Lekki Phase 1, Ikorodu, Lekki, Aja and Onikan. The applied load is usually maximum of 150 % to 200 % of the design safe working load. The Primary objectives of Static load test are;

➢ To establish load-deflection relationships in the pile-soil system,
➢ To determine capacity of the pile-soil system, and
➢ To determine load distribution in the pile-soil system.

These tests will confirm design assumptions or provide information to allow those assumptions and the pile design to be modified (Geotechnical Engineering Bureau, 2007).

Equipment and Instrumentation for Static Load Test
Major equipment required for applying compressive load on a test pile generally include, but are not limited to the following:
1. test beams - primary and secondary
2. bearing plates

3. Hydraulic jack of appropriate capacity (800tons); connected to hydraulic pump
4. Oil manometer of suitable capacity
5. Kentledge or Dead weights (normally in form of concrete cubes of 1m³ and 24 kN or 2.4 tons), etc.
6. nos. steel reference beams
7. Nos. dial gauges, capable of measuring movements within an accuracy of 0.01mm.

Arrangement of Load Test Platform
The arrangement for an axial compression test is generally done using either;
(a) By means of a jack which obtains its reaction from kentledge heavier than the required test load
(b) By means of jack which obtains its reaction from tension piles or other suitable anchors (section 7.5.5.2 of BS 8004; 1986).

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. 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 0.05 mm /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 0.05 mm /30 minutes. Unloading of pile is done in decrements of 25 % of the maximum load or as specified by the client.

3. Results and Discussion
Figure 3 shows the settlement measured from the static pile load tests at Lekki Phase 1, Ikorodu, Lekki , Aja and Onikan. It can be observed from Figure 3 that Aja has the least settlement values whereas the highest settlement values where observed in Ikorodu. Table 1 shows that the maximum settlement observed from the various settlement was 9.991 mm with a mean value of 7.892 mm.
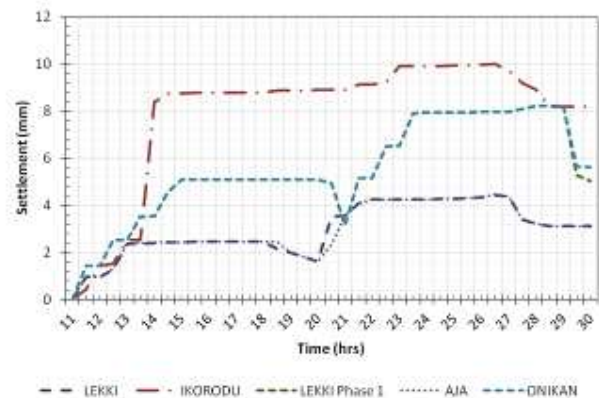

Figure 3: Settlement measured from static pile load tests from the various locations.

Table 1: Descriptive statistics of settlement measured from static pile load test

Test Type	LEKKI	IKORODU	LEKKI PHASE 1	AJA	ONIKAN
Mean	2.94132	7.89220	5.468	2.92067	5.4934
Standard Error		0.46096	0.34550	0.18162	0.3453
Median	3.097	8.876	5.0725	2.463	5.073
Mode	2.4625	8.775	5.0725	2.463	5.073
Standard Deviation	1.13692	2.87868	2.15766	1.1342	2.1564
Sample Variance	1.29258	8.28679	4.65548	1.2865	4.6499
Kurtosis	-0.3194	2.22868	-0.1844	-0.3184	-0.151
Skewness	-0.4493	-1.9201	-0.4734	-0.3887	-0.511
Range	4.43	9.991	8.23	4.47	8.23
Minimum	0	0	0	0	0
Maximum	4.43	9.991	8.23	4.47	8.23
Sum	114.716	307.8	213.252	113.91	214.24
Count	39	39	39	39	39
Confidence Level (95.0%)	0.3686	0.9332	0.6994	0.36767	0.69901

In order to develop a model to predict the settlement from static pile load test in the coastal region of Nigeria, a predicted settlement which is the mean settlement observed from the static pile load tests at Lekki Phase 1, Ikorodu, Lekki, Aja and Onikan at the same time interval is assumed. Kendall's tau_b test which is a non-parametric test is used to check for significant correlations between the settlement measured from static pile load tests from the various locations and the predicted settlement. Table 2 shows the result of the   Kendall's tau_b test on the settlement data and a significant correlation of more than 50 % existed for the various settlement data.

Based on the significant correlation of the settlement data from the Kendall's tau_b the values from the calculated predicted settlement will be used for modelling the relationship between the settlement and time for soils from the coastal region of Nigeria. Figure 4 shows the relationship between the settlement and time for predicted settlement of soils from the coastal region of Nigeria.
.

Table 2: Kendall's tau b correlation of settlement measured from static pile load tests

| Test			Time (Hrs)	Lekki	Ikorodu	Lekki Phase 1	Aja	Onikan	Predicted Settlement (Mm)
Kendall's tau_b	TIME (hrs)	Correlation Coefficient	1.000	.534**	.514**	.738**	.534**	.774**	.657**
		Sig. (2-tailed)		.000	.000	.000	.000	.000	.000
		N	39	39	39	39	39	39	39
	LEKKI	Correlation Coefficient	.534**	1.000	.595**	.536**	.932**	.562**	.796**
		Sig. (2-tailed)	.000		.000	.000	.000	.000	.000
		N	39	39	39	39	39	39	39
	IKORODU	Correlation Coefficient	.514**	.595**	1.000	.552**	.570**	.512**	.594**
		Sig. (2-tailed)	.000	.000		.000	.000	.000	.000
		N	39	39	39	39	39	39	39
	LEKKI PHASE 1	Correlation Coefficient	.738**	.536**	.552**	1.000	.577**	.962**	.742**
		Sig. (2-tailed)	.000	.000	.000		.000	.000	.000
		N	39	39	39	39	39	39	39
	AJA	Correlation Coefficient	.534**	.932**	.570**	.577**	1.000	.603**	.783**
		Sig. (2-tailed)	.000	.000	.000	.000		.000	.000
		N	39	39	39	39	39	39	39
	ONIKAN	Correlation Coefficient	.774**	.562**	.512**	.962**	.603**	1.000	.767**
		Sig. (2-tailed)	.000	.000	.000	.000	.000		.000
		N	39	39	39	39	39	39	39
	PREDICTED SETTLEMENT (mm)	Correlation Coefficient	.657**	.796**	.594**	.742**	.783**	.767**	1.000
		Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	
		N	39	39	39	39	39	39	39
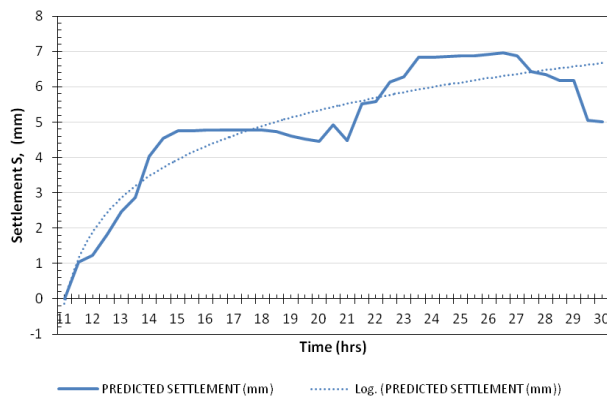
Figure 4: Relationship between the settlement and time for predicted settlement

In Figure 3, there is a positive relation between the settlement and time with an R^2 correlation coefficient of 0.8567. The predictive model is given in Equation 1 as follows;

$$S = 1.8626 \ln(t) - 0.1495 \quad (R^2 = 0.8567) \quad (1)$$

4. Conclusion
Based on the results of this study, the following conclusions are drawn:
1. The maximum settlement observed from the various settlement from the coastal region of Nigeria was 9.991 mm with a mean value of 7.892 mm.
2. A significant correlation of more than 50 % existed for the various settlement data from various locations in the coastal region of Nigeria.
3. A positive correlation exists between settlement and time with an R^2 correlation coefficient of 0.8567. The predictive model of Equation 1 may be used to evaluate pile settlement.

4.1 Recommendations
Based on the results of this study, it is recommended that the predictive model developed in this study should be used in predicting settlement- time response of static pile load tests.

5. References
[1] British Standard Code of Practice for Foundations BS 8004: (1996).

[2] Geotechnical Engineering Bureau. (2007). Geotechnical Control Procedure. New York State Department of Transportation.

[3] Federation of Piling Specialists (2006). Handbook on pile load testing. Forum Court, Bromley, UK.

[4] Garcia, J. R. & Rocha-de Albuquerque P.J. (2018). Model of nonlinear behavior applied to prediction of settlement in deep foundations. DYNA, 85(205), pp. 171-178, June, 2018.

[5] Google (2019). Retrieved from https://espace.curtin.edu.au, 14th February, 2019.

[6] Qian-qing, Z., Shu-cai, L., Fa-yun, L., Min, Y., & Qian, Z. (2014). Simplified method for settlement prediction of single pile and pile group using a hyperbolic model. *International Journal of Civil Engineering Transaction B: Geotechnical Engineering,* Vol. 12, No. 2, 146-159

[7] Sales, M.M., Prezzi, M., Salgado, R., Choi, Y. S., & Lee, J. (2017). Load-Settlement Behaviour of Model Pile Groups in Sand under Vertical Load. *Journal of Civil Engineering and Management*, 23(8), 1148–1163. https://doi.org/10.3846/13923730.2017.1396559.

[8] Shahin, M. A. (2017). Load-Settlement Modeling of Axially Loaded Drilled Shafts 26 using CPT-Based Recurrent Neural Networks. Technical Note. Department of Civil Engineering, Curtin University, Australia.