KGS Fall '96 National Conference / 25~26, October, 1996 / Seoul / Korea

CPT를 이용한 말뚝의 지지력평가 방법연구
Pile Capacity Predictions by CPT-Based Methods

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개요: 기초설계를 위해서 지반조사을 할 경우에 일반적으로 많이 이용되고 있는 콘관입시험기(Cone Penetration Test, CPT)의 자료를 이용하여 말뚝의 지지력을 평가할 수 있는 다양한 예측식들의 신뢰성을 파악하고자 과압밀된 점토지반에서 연구를 수행하였다. 연구대상말뚝은 11본의 폐단식 강관말뚝이며 이미 시공되어 정재하시험을 거쳐서 그 지지력은 알고있었다.

본 연구를 위해서 사용한 말뚝기초의 지지력 산정식은 실무에서 흔히 적용하고 있는 Schmertmann's method, Tumay & Fakhroo's Method, LPC method이었다. 연구방법은 각각의 예측식으로 각각의 말뚝의 지지력을 산정하고 11본의 말뚝의 실측치와 비교하여 각각의 방법들의 신뢰성을 검토했다. 연구결과로서는 대체적으로 CPT를 이용한 예측식들이 과압밀된 점토지반에서 양호하게 실측치를 예측하였으며 이것은 말뚝의 항타과정과 콘시험기를 관입하는 메카니즘이 유사하고, 말뚝의 지지력을 예측하는데 쓰이는 콘자료가 말뚝의 전체관입깊이에 따른 강도변화를 비교적 잘 대변한 것으로 설명될 수 있다.

주요어: 말뚝기초, 콘관입시험, 피조콘, 말뚝지지력, 신뢰성

1. Introduction

In foundation engineering much interest has been devoted to the problem of predicting the ultimate capacity of single piles. However, determinig axial ultimate pile capacity is challenge under the best of circumstances. The engineering practice has developed several methods including static method, dynamic method and several numerical medeling to overcome the uncertainty in the analysis and design. However, due to simplifying assumptions regarding soil stratigraphy, disribution of shaft resistance along a pile, and soil-pile structure interation, the methods provide qualitative results rather than truly quantititive values directly useful in the pile design.

In recent years, the Cone Penetration Test (CPT) has been found to be one of the best methods to estimate the pile capacity by using CPT data (q_c, f_s) in geotechnical engineering because of its simplicity and cost-effectiveness. The objective of this paper is to determine the ultimate pile capacities by CPT-based methods at the overconsolidated clay site. Pile load test results of eleven identitically-loaded steel pipe piles and twelve seven CPT data, which were performed closely at the pile locations, were used in this study.

2. Decriptions of the Site

The site is located on the University of Houston Central Campus, Houston, Texas. The study site has been extensively investigated during last 10 years for deep foundation research such as single and group pile behaviors and drilled shaft behaviors. This site has been recently designated as a National Geotechnical Experimentation Site (NGES-UH). Detailed geological descriptions of the site, geotechnical properties of thre soil and information of previous tests are presented by O'Neill and Yoon(1996), and Yoon and O'Neill(1996). A generalized soil profiles with depth are shown in Fig. 1. The depth of ground water is about 2 m with some seasonal fluctuations. The site consists of Beaumont clay overlying the Montogomery clay formation. The Beaumont clay from ground surface to about 8 m is highly overconsolidated due to dessication, with OCR values decreasing with depth. Beaumont clay(layers I, IA and II in Figs. 2 and 3) is stiff to hard gray and tan clay with tan sandy caly, and Montogomery caly(layes III, IV and V in Figs. 2 and 3) is very stiff to hard gray sandy caly, interbedded with caly, sand and silt layers.

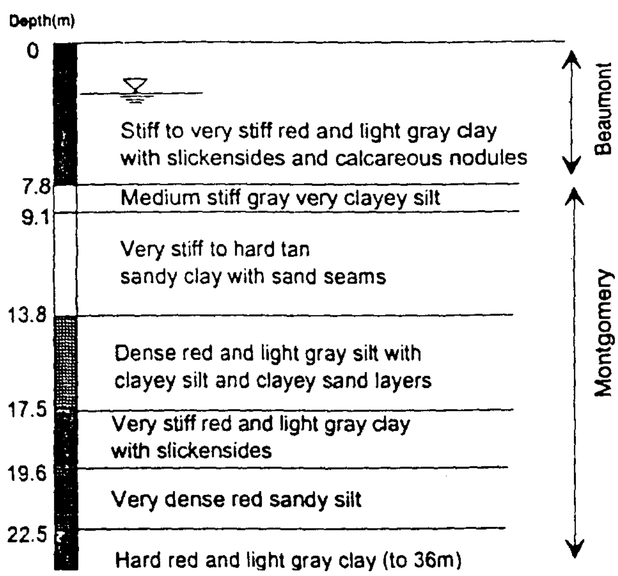

Fig. 1 General Soil Profiles of the NGES-UH Site.

3. Cone Penetration Test (CPT)

The CPT was first developed in the early 1930s in the Netherland. Since then the CPT has become so accepted and trusted in European contries. During the last decade, the usefulness and practicability of the CPT has also been accepted in the Japan, USA and others. The basis of the CPT method is a probe pushed into the ground at a standard penetration rate of 20mm/sec while sleeve friction(f_s) and cone tip resistance(q_c) are recorded. It is obvious that the geotechnical engineer does not measure the "true" value of every geotechnical property in every single element of soil, but rather he/she attempts an estimate of the most probable value of the property in the point of space occupied by the element. The electric-type CPT was used at the site with help of Fugro-Geoscience, Co., for this study. Data from twenty seven CPT tests are plotted in Figs. 2 and 3, which are utilized to compute ultimate pile capacities in this study.

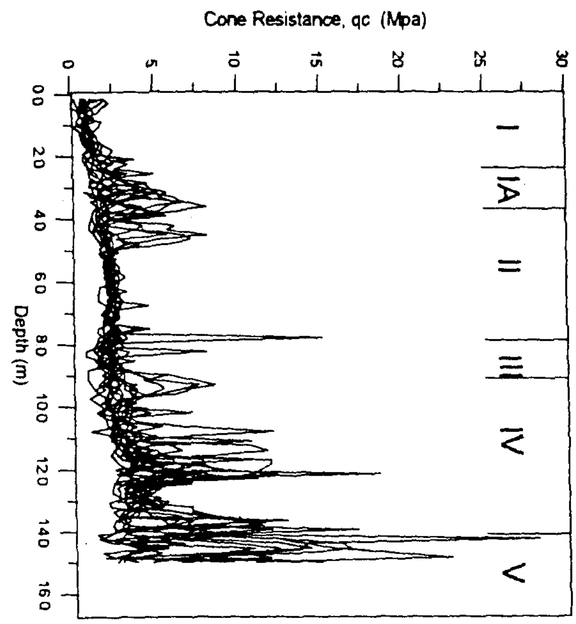

Fig. 2. Plot of Cone Tip Resistance (q_c) of NGES-UH

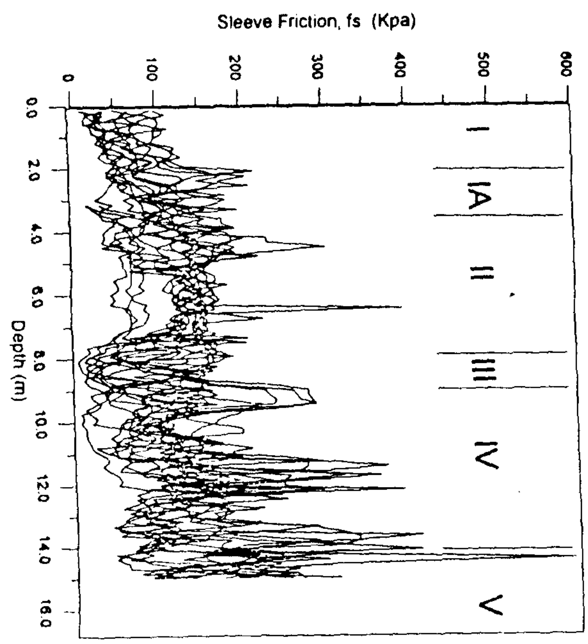

Fig. 3. Plot of Sleeve Friction (f_s) of the NGES-UH

4. Pile Tests

Eleven identical steel pipe pile were driven to a depth of 13.1 m below the ground surface. The piles, which had an outside diameter of 273 mm, a wall thickness of 9.27 mm, and a mill-scale surface texture, were all driven closed-ended with a Raymond No. 1 hammer over a period of three days in 1979 into very shallow (3 m), undersized (200 mm diameter) pile holes to assist with vertical alignment. The test piles were loaded axially to plunging failure, which is the definition of failure load. Load testing occurred approximately four weeks after installation, after all excess pore water pressures produced by driving had dissipated. Nine of the piles were loaded simultaneously, but there was no physical evidence of any of these piles mutually affecting the capacity of neighboring piles. Two of the piles, which were the reference piles, were loaded independently. These pile had mean capacity almost identical to those of the nine piles loaded simultaneously.

Histogram in Fig. 4 summaries the results of the pile load tests. The class interval in Fig. 4 has been selected approximately based on standard deviation of ultimate pile capacity.

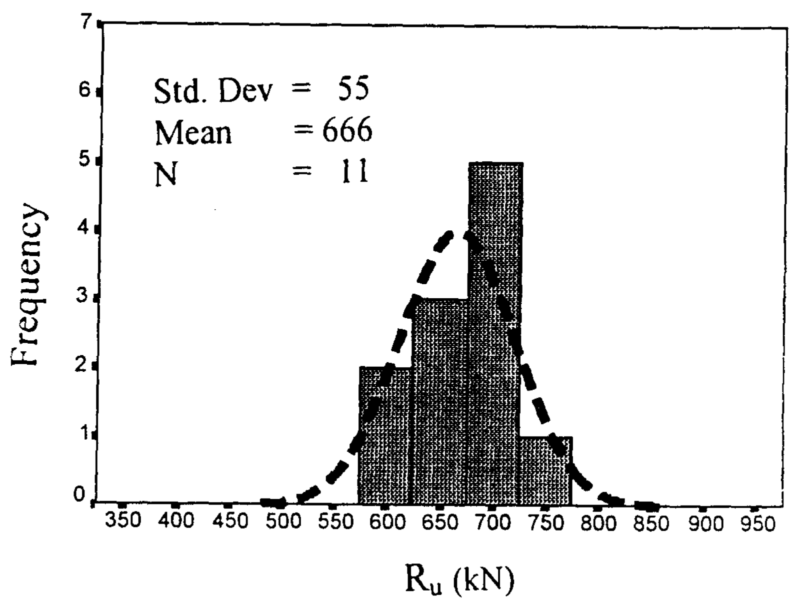

Fig. 4 Histogram of Ultimate Pile Capacity

5. CPT-based Predictions

The CPT is oridinarily simple, fast and economical test that can be regarded as a miniature pile test because the process of conducting the CPT is so similar to driving and loading piles. Numerous applied researchers have proposed various methods to predict the axial capacity of driven piles from the results of CPT tests. These include the methods of Schmertmann(1978), Tumay and Fakhroo(1981), and the LPC(Laboratorie Central des Ponts et Chausessees) (Bustamannte and Gianeselli, 1982). The general procedure for predicting axial capacities from the CPT results in all three methods employ CPT results directly or indirectly using correlations between unit cone toe resistance, q_c, which is analogous to unit end bearing resistance q_b in a pile, and unit cone sleeve or shaft resistance, f_s. In this study the average cone values of the f_s and q_c data for each 0.3 m of penetration vertically were used to make the computations for both unit shaft resistance and unit toe resistance of driven piles.

The selected three CPT-based methods were used to compute ultimate pile resistance of the subject piles using values of q_c and f_s from Figs. 2 and 3. Space limitations prohibit descriptions of each prediction method; readers are referred to the references such as Schmertmann(1978), Briaud and Miran(1991) for the computational details. The LPC method has the practical advantage that it requires only q_c values, which normally exhibit samaller variations than f_s values, and it corporates the installation method (driving or boring). The other two methods require both the q_c values and f_s values.

Table 1 shows that the summary of the ultimate pile capacity computed by the selected three CPT-based methods. All three methods in general underestimated the measured mean value(666 kN), but all methods predicted relatively well with less than 15 % of the measured values. There is relatively little difference between methods in estimating ultimate toe resistance of pile driven into clay because most of the prediction methods use essentially the same bearing capacity procedure.

Table 1. Summary of Pile Capacuty Computed by Three CPT-based Methods

Method	Schmertmann's Method			Tumay and Fakhroo's Method			LPC Method		
CPT No.	R_s	R_b	R_u (kN)	R_s	R_b	R_u (kN)	R_s	R_b	R_u (kN)
1	355	270	625	253	336	589	397	164	561
2	390	174	564	355	196	551	399	130	529
3	390	211	601	355	256	611	411	156	567
4	450	156	606	404	167	571	392	114	506
5	454	249	703	404	308	712	373	155	528
6	461	202	663	404	245	649	402	138	540
7	465	178	643	404	213	617	383	138	521
8	449	235	684	404	287	691	401	173	574
27	443	154	597	404	204	608	389	156	545
28	416	150	566	404	200	604	401	130	531
29	409	141	550	404	162	566	393	104	497
30	391	127	518	404	147	551	416	138	554
Mean	**423**	**187**	**610**	**383**	**227**	**610**	**398**	**141**	**539**

6. Conclusions

The results of CPT data have been used to compute ultimate pile capacity at the overconsolidated clay site. The predicted ultimate pile capacity by selected three CPT-based methods showed a good agreement with the measured values by pile load test. This can be explained by the fact that CPT data used to predict the ultimate pile capacity, q_c and f_s, are continuous data throughout pile penetration depth, and the mechanism between pile driving and CPT penetration are similar.

7. References

1. Bustamante, M., and Gianeselli, L. (1982), "Pile Bearing Capacity by Means of Static Penetrometer CPT", *Proc.*, 2nd European Symp. on Penetration Testing, pp. 493-500.

2. Yoon, G. L., and O'Neill, M. W., (1996), "Engineering Properties of Plestocene Clay", *Transportation Research Board*, TRR No. 1479, National Research Council, Washington, D. C.

3. Briaud, and Miran (1992), *The Cone Penetrometer Test*, Publication No. FHWA-SA-91-043, Federal Higway Administarion, Washington, D. C.

4. Yoon, G. L., (1995), *Reliability Analysis of Driven Pile for Load and Resistance actor Design at the Overconsolidated Clay*, Ph. D. Dissertation , Graduate School of Unviersity of Houston, Houston, Texas.

5. Schmertmann, J. H. (1978), "Guide for Cone Penetrometer: Performance and Design", *Report No. FHWA-TS-209*, Federal Highway Administration, Washington, D. C.

6. Tumay, M. T., and Fakhroo, M. (1981), "Pile Capacity in Soft Clay Using Electric QCPT Data", ASCE, *Spec. Pub. on Cone Penetration Testing and Experience*, pp. 434-455.

7. Yoon, G. L. and O'Neill, M. W. (1996), "Design Model Bias Factor for Driven Pile from Experiments at NGES-UH" ASCE, Geotechnical Specitial Publication No. 58, *Proceeding*, Uncertainty in the Geological Environments, From theory to Practice, pp. 759 - 773.