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Update the Pile Design by CPT Software to Incorporate Newly Developed Pile-CPT Methods and Other Design Features

INTRODUCTION

Design engineers usually consider using deep foundations when the conditions of upper soil layers are weak and unable to support the structural loads. Most soil deposits in southern Louisiana are soft in nature. In addition, the high percentage of wetlands makes it necessary to consider deep foundations in the design of infrastructure. Due to uncertainties associated with pile design, pile load tests (which are very expensive) are usually conducted to verify the design loads and to evaluate the actual response of pile under loading.

The use of in-situ tests, such as the cone penetration test (CPT), can provide faster and more accurate estimation of pile capacity than the traditional methods. Due to similarity between the cone and pile, the estimation of pile capacity using CPT data is considered among the earliest applications of the CPT. Several direct pile-CPT methods were proposed in literature to estimate the pile capacity utilizing the CPT data, which correlate the uncorrected or corrected cone resistance (q_c, q_t) and sleeve friction (f_s) to ultimate pile capacity (Q_u) using correlation factors.

This study presents the current research effort undertaken to identify the top-performed pile-CPT methods for accurately estimating the ultimate capacity of piles driven into Louisiana soils. Statistical analysis, MultiDimensional Unfolding (MDU), and reliability analysis criteria were used to investigate the performance of 21 pile-CPT methods. The findings of this study showed that the estimation of top-ranked pile-CPT methods can be used in a combined method to yield an optimized method for estimating ultimate capacity of driven piles.

OBJECTIVES

- Evaluate the different direct pile-CPT methods for estimating the ultimate capacity of driven PPC piles from CPT data for use in Louisiana soils;
- Select, modify, and/or develop a new pile-CPT method for use in design of piles in Louisiana;
- Identify the most appropriate pile-CPT methods for implementing into the Louisiana Pile Design-Cone Penetration Test (LPD-CPT) software;
- Re-calibrate the resistance factor (Φ) for the selected pile-CPT methods; and
- Update the LPD-CPT software to incorporate newly selected pile-CPT prediction methods and new features, such as the effect of scour on long-term pile capacity and patching process.

SCOPE

This study was focused on evaluating the 21 direct pile-CPT methods for accurately estimating the ultimate capacity of driven piles utilizing CPT data. The predicted capacities from these methods were compared with the pile capacity obtained from pile load tests using Davisson interpretation method. The direct pile-CPT methods were used to investigate the ultimate capacity of PPC piles driven into Louisiana soils. To achieve the objective of this study, a total of 80 pile load tests database and corresponding CPT soundings and soil borings close to the test pile locations were collected from DOTD files.

Different evaluation techniques were adopted in this study to evaluate the best-performed direct pile-CPT methods for estimating the ultimate capacity of PPC piles: (a) evaluation based on mathematical and statistical analysis; (b) evaluation using MultiDimensional Unfolding; and (c) evaluation based on reliability analysis.

A combined pile-CPT method was develop based on contribution of sand layers to total ultimate capacity (kind of optimization). In addition, new pile-CPT methods were developed using the artificial intelligent and machine learning techniques [artificial neural networks (ANN), decision trees (DT), random forests (RF), and gradient boosted tree (GBT)].

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METHODOLOGY

In this study, a database of 80 PPC piles that were loaded to failure and the corresponding pile load tests and CPT tests conducted close to them were used to evaluate the performance of 21 direct pile-CPT methods. The measured ultimate load capacity (Q_m) for each pile was determined from the load-settlement curve using Davisson interpretation methods. The ultimate load capacity of each pile (Q_p) was determined using the 21 direct pile-CPT methods, and the values were compared with the measured pile capacities from static pile load tests.

Three approaches were used to evaluate the pile-CPT methods. In the first approach, three statistical criteria (best fit line for Q_p versus Q_m, arithmetic mean and standard deviation of Q_p/Q_m, and the cumulative probability of Q_p/Q_m) were adopted to evaluate the performance of pile-CPT methods. These criteria were used to rank the CPT methods. The final rank of each method was then determined from the Rank Index (RI). The second approach used for evaluating the pile-CPT methods is the MultiDimensional Unfolding (MDU), which is a technique for representing different objects and judges in a 2-dimensional space. In this approach, the result of each pile load test was regarded as a judge that ranks the 21 pile-CPT methods, based on the value of Qp/Qm. According to MDU, the pile-CPT methods located close to the center of the measured pile capacities were considered as high performance methods; while those methods located far from the center were considered as low performance methods, as shown in Figure 1.

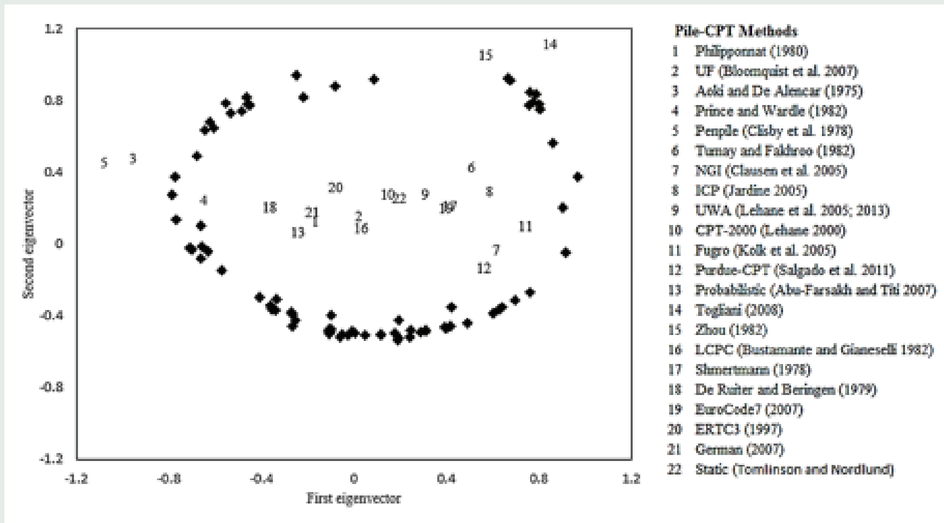

Figure 1. Results of MDU for the 21 pile-CPT methods and static analysis method

The third approach used for evaluating pile-CPT methods is based on LRFD reliability analysis in terms of resistance factor and efficiency. The results of evaluation showed the following best performed pile-CPT methods: LCPC, ERTC3, Probabilistic, UF, Philipponnat, De Ruiter and Beringen, CPT2000, UWA, and Schmertmann methods.

The log-normal distribution of predicted to measured (Q_p/Q_m) ratio was used to develop combined pile-CPT methods to estimate the ultimate pile capacity for four soil categories based on the contribution of sandy layers to the total capacity. In addition, another combined pile-CPT method was developed for the general case for all piles without considering soil categories.

Four machine learning (ML) techniques were also used to develop models to estimate the ultimate pile capacity from CPT data. The comparison results between ML models and direct pile-CPT methods showed that the ANN and GBT models outperform the top-performed pile-CPT methods in all evaluation criteria.

The top-performed pile-CPT methods in addition to the developed combined pile-CPT method were implemented into the LPD-CPT program for friendly use by Louisiana engineers to design PPC piles utilizing CPT technology.

CONCLUSIONS

- The results of statistical evaluation criteria demonstrated that the best performed pile-CPT methods in order are: LCPC, ERTC3, Probabilistic, UF, Philipponnat, De Ruiter and Beringen, CPT2000, UWA, and Schmertmann methods.
- The results of MultiDimensional Unfolding (MDU) evaluation criteria revealed the same best performed pile-CPT methods with highest rankings similar to the statistical analysis criteria.
- The results of LRFD reliability analysis in terms of resistance factor and efficiency were consistent with the previous criteria in which the LCPC, ERTC3, Probabilistic, UF, Philipponnat, De Ruiter, methods with the highest rankings
- Dividing the pile database into four categories based on soil type showed that increasing the sand contribution to pile capacity causes overprediction in pile capacity, which means less accuracy and reliability in estimations of pile-CPT methods in sandy soils.
- A combined pile-CPT method was developed, which demonstrated significant improvement in accuracy of estimating the ultimate pile capacity.
- The developed machine learning (ML) models based on ANN and GBT outperformed the top-performed pile-CPT methods in all evaluation criteria.

RECOMMENDATIONS

- It is recommended to start using the top-performed pile-CPT methods that were implemented in the LPD-CPT software on the design of piles in new bridges and other infrastructure.
- It is recommended to start using the modified Schmertmann method instead of the original Schmertmann method for design of piles in bridges and other infrastructures.
- It is recommended to start using the combined pile-CPT method that is implemented in the LPD-CPT software on the design of piles in new bridges and other infrastructure and compare the results with the top-performed direct pile-CPT methods.
- It is recommended to start exploring the potential benefits of using ML models for estimating the ultimate pile capacity from CPT data, and compare the results with the top-performed direct pile-CPT methods.