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Reliability analysis of pile bearing capacity in clayey soils based on Monte Carlo sampling

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ABSTRACT: Pile foundations are one of the most important foundation systems in geotechnical engineering. The design of pile foundations and the estimation of pile bearing capacity have been improved considerably over the years. However, due to inherent soil uncertainties and disturbances, most theoretical approaches have been mainly based on assumptions and simplifications. Resulting in a wide range of bearing capacity values, different design methods establish the existence of inherent soil variability and model error in bearing capacity prediction. The cone penetration test (CPT) is considered as one of the most useful in situ tests for the characterization of soil. Due to the similarity between the cone and the pile, estimation of pile capacity from CPT data is among its most common applications. This paper proposes a model for predicting the bearing capacity of piles in clayey soils using data that were collected from 62 practical cases of pile loading tests and the corresponding cone penetration tests. The reliability of the proposed model was compared with other methods suggested in the literature. In order to evaluate the reliability of the proposed model, the Monte Carlo sampling method was used. Results show that the proposed model in this research, together with UniCone and Schmertmann methods, have the highest accuracy and reliability.

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1- Introduction

Pile foundations are principally used to transfer the loads from superstructures, through weak, compressible strata into stronger, more compact, less compressible and stiffer soil or rock at depth. In recent years, several theoretical relationships have been proposed to estimate the axial bearing capacity of piles, but due to the nature of soil behavior and the existing uncertainties, it is clear that the results of theoretical relationships are not a reliable method to determine the bearing capacity of the pile. Numerous studies conducted by researchers indicate that there are many uncertainties in estimating the bearing capacity of piles, one of the most important reasons for which can be large changes in soil type and characteristics, as well as measurement errors. Therefore, using relationships based on the results of field experiments is a good solution to solve this problem. Due to the similarities between the cone penetration test and pile loading test, the use of cone penetration test results in determining the pile bearing capacity has received much attention.

In this study, with the help of existing databases of laboratory results of pile loading and the results of the corresponding cone penetration test in clayey soils and using a linear regression probabilistic model, a relationship to determine the pile bearing capacity has been presented.

In this study, three important input parameters were used to construct the model using cone penetration test. Then, the proposed model was compared with other methods of measuring bearing capacity based on the results of the cone penetration test, and it was shown that the proposed model has less uncertainty.

2- Methodology

In this study, using the Rt computer program, which is a powerful tool for constructing and calculating probabilistic models and examining their reliability, a model for predicting the axial bearing capacity of piles in clayey soils was presented. Also, in this study, 62 samples of collected data related to cone penetration test and pile loading test performed in the same soils were used. After performing the analysis in the computer program, each of the model parameters was obtained and the following equation was proposed.

$$Q_u = 0.624\left(f_s . p\, L\right) + 0.69\,(q_c + 0.591\,u_2)A_c \qquad (1)$$

In Equation 1, the first expression represents the frictional resistance of the pile and the second expression represents the resistance of the pile tip and the excess pore water pressure. To ensure the accuracy of the proposed model, further studies similar to the following have been performed.

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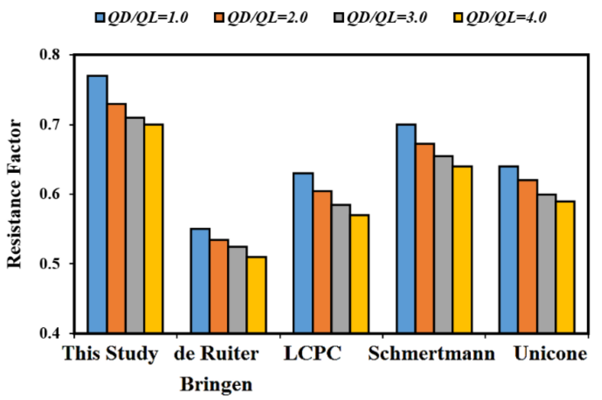

Fig. 1. The value of the resistance factor for the methods and the ratio of dead to live different for

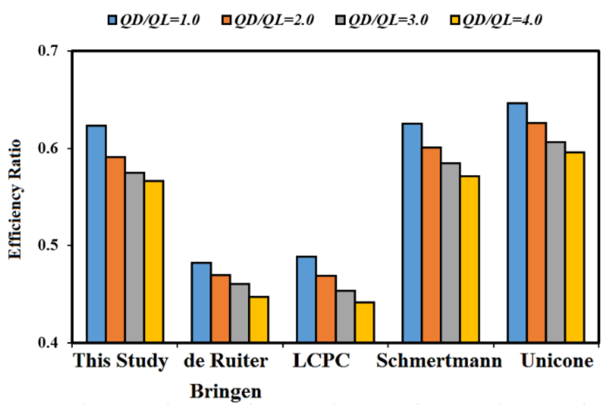

Fig. 3. The efficiency ratio for each method and for different dead to live ratios for

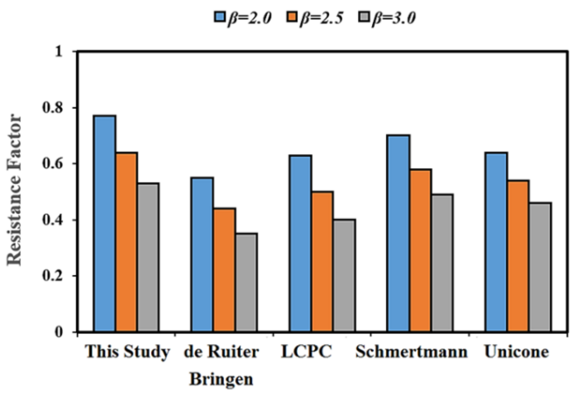

Fig. 2. Resistance factor for different methods and reliability index for

3- Results and Discussion

In order to evaluate the reliability of the axial bearing capacity of the pile in different methods, the reliability analysis was performed using the Monte Carlo sampling method on the collected data.

Limit state function in Equation.2 has been used in Monte Carlo sampling analysis. In this study, load and resistance coefficients in accordance with AASHTO standard have been used.

$$g = \ln \frac{\lambda_R\left(\gamma_{QD}\dfrac{QD}{QL}+\gamma_{QL}\right)}{\varphi\left(\lambda_{QD}\dfrac{QD}{QL}+\lambda_{QL}\right)} \quad (2)$$

“Figure1” shows the value of the resistance factor obtained in different methods for different dead-to-live load ratios and . It is observed that the lower dead load-to-live load ratio, leads to a higher resistance coefficient for a specified reliability index.

Figure 2 shows the sensitivity of the resistance factor to the reliability index for a specified ratio of dead load to live load. It is observed that the higher the value of , or in other words, the lower the probability of failure, leads to the lower resistance factors. The amount of this reduction is obtained to be about 20% in all methods.

In general, a higher resistance factor or a higher reliability index for a method indicates that the method is better. But if one method is too conservative, it can lead to high φ and β values. In this regard, McVay et al. defined a new parameter called the efficiency ratio, which is equal to the ratio of the resistance factor to the bias resistance factor. In fact, this parameter indicates the amount of participated load-bearing capacity in a design for a given reliability. A higher value of this parameter can mean more reliability and more efficiency of that method. Figure 3 shows the efficiency ratios for different methods and the dead-to-live load ratio for . According to this figure, it can be seen that the model presented in this study, with Schmertmann and UniCone methods, is one of the most accurate and reliable methods in estimating the bearing capacity of piles and has higher efficiency ratios.

4- Conclusions

In this study, according to the data collected from the results of pile loading tests and the cone penetration tests, at first, a method was proposed to estimate the axial bearing capacity of piles using a linear regression model; then, the reliability of this method was compared with other common methods in determining the bearing capacity of piles using the results of the cone penetration test. According to the study, it was found that the model proposed in this study had a 29% higher efficiency ratio than the de Ruiter-Bringen method, and 26% more than the LCPC method. This study also showed that the proposed method had the highest efficiency ratio together with the UniCone and Schmertmann methods.

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