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Evaluation of Compressive Bearing Capacity of Long Offshore Steel Piles Driven in the Persian Gulf

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ABSTRACT: Long-driven steel piles are widely used in the foundation of fixed offshore oil and gas extraction platforms due to the existence of physical limitations, heavy loads and weak shallow seabed soil layers. There are different methods to determine the pile bearing capacity, including static analysis, using the results of in-situ tests, as well as static and dynamic pile loading tests. In recent years, the in-situ cone penetration test has considerably been developed in the design of offshore piles owing to its high accuracy, continuous recoding across the depth, and similarity to pile. Additionally, the application of in-situ tests for pile design is of great interest due to difficulties in obtaining undisturbed soil samples at sea. The dynamic pile load test is also considered as an alternative and economical way to the static pile load test, particularly in offshore environments. In this paper, for the first time, a comprehensive data bank, including soil engineering parameters derived from laboratory and in-situ tests as well as field measurements obtained from dynamic pile tests in short, medium, and long-term conditions, is developed for the Persian Gulf - South Pars field. Afterward, fourteen methods, including four offshore static analysis methods and ten direct methods based on cone penetration test results, are selected and applied to estimate the axial compressive bearing capacity of steel pipe piles driven in the studied area. The results obtained from different methods are compared with the results of dynamic pile tests at three mentioned times and evaluated using the statistical criteria. According to the findings of the conducted statistical analyses, the lowest precision and prediction quality are provided in the four static analysis methods compared to the CPT-based methods for the developed data bank. The values of pile total ultimate bearing capacity obtained from the static analysis methods are on average 70%, 63%, and 35% higher than the corresponding values measured by the dynamic pile tests in short, medium, and long-term conditions, respectively.

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1- Introduction

Over the past years, the pile foundation of offshore platforms installed in the Persian Gulf has usually been designed based on the American Petroleum Institute (API) method as an available and common standard procedure. According to the data recorded from the piling process of the offshore projects in the Persian Gulf region and the experiences gained from the installation of these platforms, it is generally found that the results of the API method do not match the field measurements resulted from the pile dynamic tests conducted in this area. In some cases, significant differences are observed between the predicted and measured values [1]. This mismatch can cause numerous difficulties during the piling process and installation of offshore platforms. It can even pose risks to these structures against applied loads in the long term condition and during operation.

By reviewing the literature, it is revealed that so far, no comprehensive research works have been carried out to determine the bearing capacity of offshore piles in Iran. Hence, the authors have decided to take a step towards evaluating the different offshore static analyses as well as CPT-based methods for predicting the bearing capacity of offshore piles in the Persian Gulf region. For this purpose, the results obtained from the different methods are compared to those of pile dynamic tests and subsequently, the methods with better predictive quality and higher reliability are selected.

2- Methodology

In this research, for the first time, a comprehensive data bank including soil engineering parameters, CPTu results at the vicinity of piles, and the results of pile dynamic loading tests at different time intervals is developed for the Persian Gulf region - South Pars field [2, 3]. This data bank contains more than 5000 geotechnical data derived from laboratory and in-situ tests, the information of 8 CPTu performed adjacent to 22 piles, along with the measurements of 28 dynamic pile tests at short, medium and long term conditions. In this study, two

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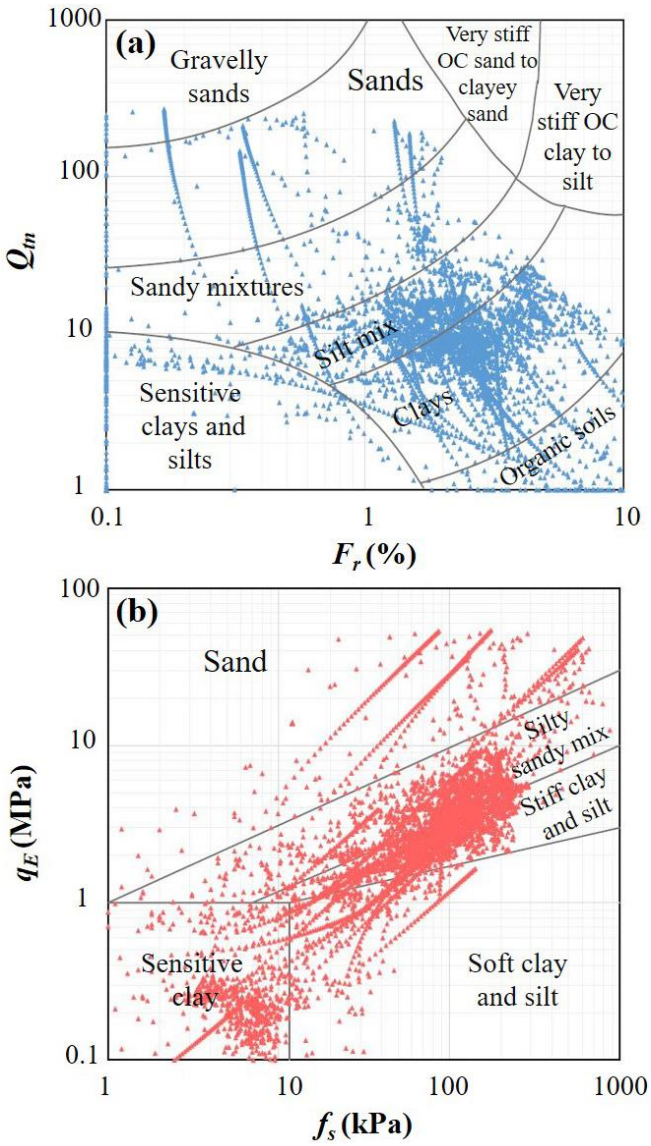

Fig. 1. Soil classification using (a) Rabertson (1990), and (b) Eslami & Fellenius (2004) charts.

methods, Robertson (1990) and Eslami & Fellenius (2004), have been used for soil classification using CPTu results [4, 5]. As shown in Figure 1, more than 94% of the marine sediments in the studied area are fine-grained soils. According to the consolidation curves obtained from the oedometer tests, reaching on average 50 and 90% consolidation degrees takes about 3.5 and 83.5 days, respectively. It is worth noting that the short-term bearing capacity of a pile is the value measured immediately after the pile driving. At the same time, the medium-term bearing capacity corresponds to the consolidation degree of 40 to 50%. Finally, the long-term bearing capacity of a pile is realized when 90% of the consolidation process is completed. Accordingly, out of 28 dynamic tests performed on the piles, the bearing capacity of 22 cases has been measured immediately after driving (short term), 5 cases from a few hours to 10 days (medium-term), and one case after 263 days (long term).

In the present study, 4 offshore static analysis methods, including American Petroleum Institute (1993), Kolk and Velde (1996), Jardine et al. (2005) and Karlsrud et al. (2005), 8 direct methods based on CPT results comprising Aoki & Velloso (1975), Clisby et al. (1978), Schmertmann (1978), de Ruiter & Beringen (1979), Phillipponat (1980), Tumay & Fakhroo (1982), Bustamante & Gianeselli (1982), and Price & Wardle (1982), as well as 2 direct methods using CPTu results, consisting of Eslami & Fellenius (1997) and Niazi & Mayne (2016) are employed [6].

Seven statistical criteria are used to evaluate the bearing capacity of piles based on the model parameter (Qp/Qm) in short, medium and long term conditions. Statistical criteria include arithmetic mean (μ), Square Root of Sum of Squares (SRSS), Coefficient of Variation (CV), coefficient of determination (R2), 50% and 90% cumulative probabilities, and 20% accuracy level obtained from normal logarithmic and histogram distribution diagrams for corresponding ratio. Finally, the radar charts are utilized to score the methods and select the superior one. The better performance of the method leads to a higher Area Ratio (AR) which is closer to 100.

3- Results and Discussion

According to the statistical criteria, the best prediction of the shaft, base, and total ultimate resistances in long-term conditions are obtained in Eslami & Fellenius (1997), Price & Wardle (1982) and again Eslami & Fellenius (1997) methods, respectively. Additionally, the lowest scattering and, therefore the best performance is observed in Schmertmann (1978) and Tumay & Fakhroo (1982) methods for shaft resistance prediction, Price & Wardle (1982) and Clisby et al. (1978) methods for base resistance prediction, and Bustamante & Gianeselli (1982) method for total ultimate resistance prediction in short and medium-term conditions, respectively. In this respect, the radar charts related to each method for estimating the short and medium-term total ultimate bearing capacities are presented in Figures 2 and 3, respectively.

4- Conclusion

According to the performed statistical analyses, the following conclusions can be drawn:

- Comparing to the results of the dynamic pile tests, the shaft resistance values obtained from the offshore static analysis methods are largely over-predicted in short, medium and long-term conditions. In this respect, the magnitudes of shaft resistance derived from these methods are on average 87%, 71%, and 38% higher than the corresponding values measured by the dynamic pile tests in short, medium, and long-term conditions, respectively. Therefore, assuming the "conservative performance" of the static analysis methods, which is common in the technical literature, is not correct at least for clayey soils. Consequently, it is recommended to apply the term "uncertainty" for the performance of these methods. However, the values of base resistance are accurately estimated by the offshore static analysis methods, particularly in the long-term condition.

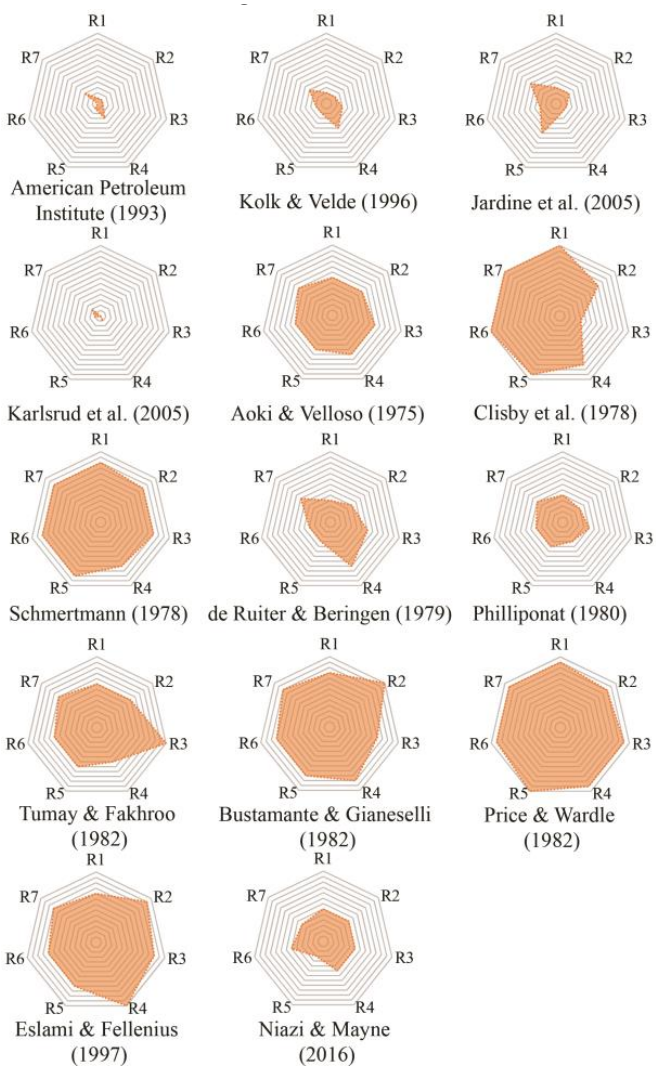

Fig. 2. Radar chart related to each method for estimating the short term total ultimate bearing capacity of piles.

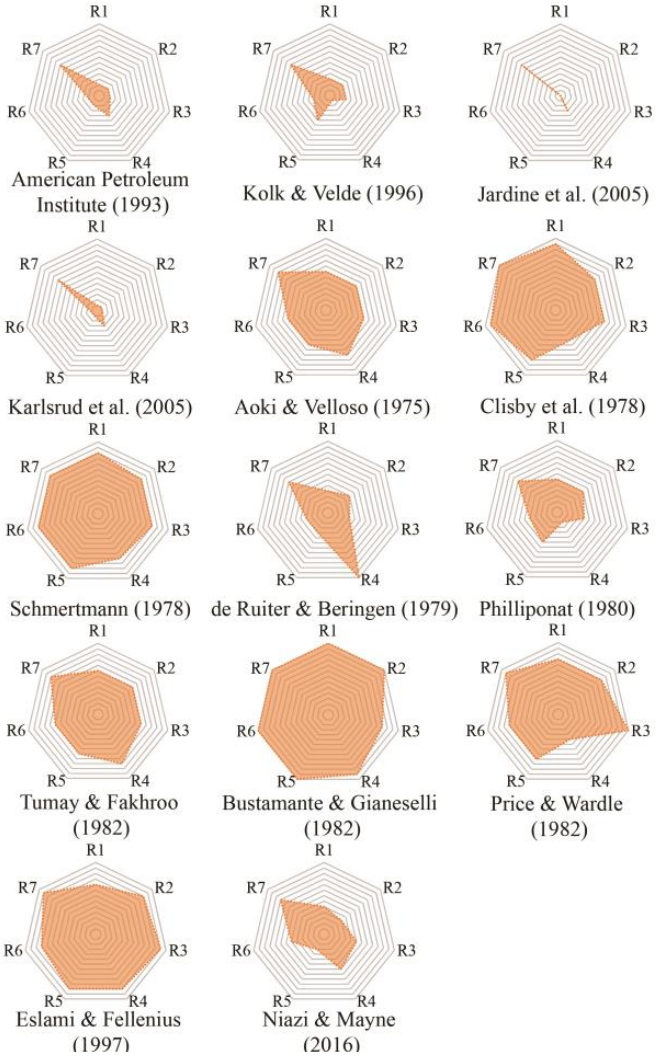

Fig. 3. Radar chart related to each method for estimating the medium term total ultimate bearing capacity of piles.

- The CPT- and CPTu-based methods predict the shaft resistance with less scattering and higher accuracy than the static analysis methods. The precision level as well as the prediction quality of the direct methods based on the mechanical CPT equipment in estimating the long-term bearing capacity of piles are lower than those of direct methods based on the electrical CPTu device. The main reason is attributed to the fact that, unlike the electrical CPTu device, the mechanical CPT equipment is not able to measure the pore water pressure during cone penetration and applies the total stresses to determine the pile bearing capacity.

- So far, no comprehensive study has been conducted on determining the bearing capacity of offshore piles in Iran. The results of the current investigation can be used by researchers and specialists involved in the field of geotechnical engineering to minimize the potential risks of Iran's offshore projects, especially in the Persian Gulf region.

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