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Analysis of Driven Pile Capacity within Pre-Bored Soil

INTRODUCTION

In Louisiana and many other states in the U.S., the pre-boring procedure is a routine practice for large displacement pile driven through hard/stiff cohesive soils. At present, the analysis and design of pre-bored piles relies primarily on local experiences, since the effects of pre-boring on the driving force as well as on the setup and long-term shaft resistances within the pre-bored zone are still largely unclear. Due to the high cost and time involved with field instrumentation and testing on pre-bored piles, the Louisiana Department of Transportation and Development (DOTD) funded this numerical study as a first step to explore the impacts of pre-bore size on the drivability and long-term shaft resistance reduction of piles.

In this research, researchers developed a simplified yet realistic numerical model, which considers a thin horizontal soil disc sufficiently far from the ground surface and the pile base, using the ABAQUS package to investigate the effects of pre-boring on the pile behaviour over different installation and loading stages. Leveraging on the finite element model developed, the long-term shaft resistance reduction factor curves have been generated for typical Louisiana soil strata to provide guidelines for a better design and construction of pre-bored piles in Louisiana. Based on the numerical calculation results, researchers proposed a preliminary protocol, including the site selection, soil properties investigation, and the testing procedure and data collection for future instrumented pile field tests of pre-bored piles in Louisiana. Finally, to facilitate the design of pre-bored piles, researchers developed a set of practical formulas to conveniently predict/evaluate the driving force, setup, and long-term shaft resistances of pre-bored piles. The current research not only reveals the shaft resistance reduction mechanism of pre-bored piles, but also provides a simple and reliable approach to evaluate the driving force and shaft resistance of pre-bored piles, which will be helpful and beneficial for geotechnical and construction engineers involved with the design and installation of the pre-bored pile foundations in Louisiana.

OBJECTIVE

The main objective of this project was to develop a general numerical approach, using the ABAQUS finite element program, to evaluate the reduction factor of shaft resistance for pre-bore piles pertaining to the long-term capacity. Reduction factor curves were generated for various combinations of pre-bore size and soil conditions, with the aim of their incorporation into the current pile analysis and design software through directly lowering the α or β coefficient involved to determine the pile capacity in Louisiana soil involving pre-boring. Another objective of this research was to develop practical formulas that could be used for design and construction of pre-bored piles in Louisiana.

METHODOLOGY

Researchers developed a finite element model (FEM) that integrates the entire process from pile installation through subsequent consolidation to pile loading using the ABAQUS package to investigate the effects of pre-boring on the pile behaviour over different installation and loading stages. The FEM model stuck to a (representative) thin horizontal soil disc sufficiently far from the ground surface and the pile base and simplifying the pre-bored pile problem, in each of the stages involved, to a one-dimensional situation yet still capturing the overall two-dimensional feature of the problem considered. Leveraged on the developed numerical model, researchers thoroughly

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investigated the changes in the stress state of the surrounding soils due to the pile installation and loading to reveal the long-term shaft resistance reduction of the pre-bored piles.

Researchers explored the impacts of the size of pre-drilled holes on the long-term shaft resistance reduction of pre-bored piles in three representative Louisiana soils by using the developed finite element model. Long-term shaft resistance factor curves and shaft resistance reduction factor curves were generated for these typical soil strata, which may provide guidelines for better design and construction of pre-bored piles in Louisiana. Based on the numerical calculation results, researchers proposed a preliminary protocol, including the site selection, soil properties investigation, and the testing procedure and data collection for future instrumented pile field tests of pre-bored piles in Louisiana.

Researchers developed practical formulas, based on some essential findings of the numerical study, to evaluate the driving force, setup, and long-term shaft resistance of pre-bored piles. The proposed practical formulas properly take the size of the pre-drilled hole, the installation effects, and the consolidation of the soil, as well as the shearing of the soils adjacent to the pile into consideration, and hence is capable of yielding satisfactory predictions when compared with the more comprehensive finite element numerical results. The proposed formulas provide a simple and reliable approach to evaluate the driving force and the shaft resistance of pre-bored piles, which will be helpful and beneficial for geotechnical and construction engineers involved with the design and installation of the pre-bored pile foundations in Louisiana.

CONCLUSIONS

The major conclusions of this study can be summarized as follows:

1. The reduction of the pile tip resistance due to pre-boring is the primary cause for the driving force reduction. However, the driving force reduction is irrelevant to the shaft resistance as the soil immediately reaches the critical state once the pre-drilled hole has been expanded. The magnitude of the driving force reduction decreases with increase in the overconsolidation ratio, residual friction angle, and with the pile slenderness.
2. The setup and long-term shaft resistance factor decrease significantly with the increase of the overconsolidation ratio. While the influences of the coefficient of earth pressure at rest on the driving force, setup, and long-term shaft resistance of pre-bored piles are nearly negligible.
3. For the typical hole size of $a_{p,pre}/a_p$ = 80% that is commonly recommended in the practice of Louisiana, the shaft resistance reduction factor R_{qs} falls in the range of 0.50-0.78 for the typical Louisiana soils.

RECOMMENDATIONS

1. A reasonable design of the size of the pre-bored hole should balance the cost of pile installation and the long-term load carrying capacity to achieve the goal of economic design. The numerical results show that the shaft resistance increases more significantly than the driving force when the size of the pre-drilled hole decreases. Hence, it is recommended that $a_{p,pre}/a_p$ = 70% or a slightly smaller size of the pre-drilled hole be considered for pre-bored piles in Louisiana in order to reduce the total cost of the pile constructions, if the drivability allows.
2. The protocol for field pile loading tests, which provides essential guidelines for the selection of sites and appropriate pre-bored hole sizes, soil properties investigation, and the testing procedure and data collection is recommended for implementation in future field tests for further investigation of the reduction mechanism of pre-bored piles as well as calibration/validation of the numerical results.
3. The simplified design formulas developed for the practical purpose to predict/evaluate the driving force, setup, and long-term shaft resistances of pre-bored piles under different soil conditions, after calibrations with the future field tests, may be recommended for potential applications in the convenient design of pre-bored piles in Louisiana.