JOINT TRANSPORTATION RESEARCH PROGRAM

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Use of Pile Driving Analysis for Assessment of Axial Load Capacity of Piles

Introduction

The dynamic response of a pile during driving is very complex, involving the interactions of the hammer, cushion, pile and soil during application of an impact load. The first analysis aimed at simulating a hammer blow on a pile was published in 1960. A revised, more realistic pile driving analysis was recently developed at Purdue University. Proper modeling of pile driving is important both for planning and inspecting pile driving operations. Reliable estimation of the load capacity of a driven pile based on the ease or difficulty with which the pile is driven allows an inspector to decide when pile driving can be discontinued.

One of the tools used to decide whether an installed pile will have the predicted capacity is the pile driving formula. Pile driving formulas directly relate the pile set per blow to the capacity of the pile, and, due to their simplicity, these formulas have been used often. However, existing formulas have been proposed based on empirical observations and have not been validated scientifically, so some formulas might over-predict pile capacity, while others may be too conservative. In this study we used the more advanced and realistic model developed at Purdue University for dynamic pile driving analysis to develop more accurate pile driving formulas, which consider both soil and pile variability. A review of the Purdue pile driving analysis method and a discussion on selection of model parameters to use in the analysis precedes the application of the analysis to typical soil profiles. Pile driving formulas are developed based on the results of these analyses for five ideal soil profiles: floating piles in sand and clay, end-bearing piles in sand and clay, and piles crossing clay resting on sand.

Well documented case histories of driven piles in Lagrange and Jasper Counties in Indiana are used to validate the proposed pile driving formulas. Comparison of the predictions of proposed formulas with the results of static load tests, dynamic load tests and conventional formulas show that the proposed model is capable of producing more reasonable and accurate predictions of pile capacity based on pile set observations.

Findings

We have developed pile driving formulas by fitting results of a realistic pile driving analysis performed for closed-ended steel pipe piles for five typical cases:

1. Floating piles in sand. The pile driving formula is expressed in this case in terms of five variables: the hammer efficiency, the normalized hammer weight, the normalized hammer drop height, the relative density of the sand and the pile set.
2. End-bearing piles in sand. The pile driving formula in this case is expressed in terms of five variables: the hammer efficiency, the normalized hammer weight, the normalized hammer drop height, the ratio of shaft to base relative density and the pile set.
3. Floating piles in normally consolidated clay. The pile driving formula in this case is expressed in terms of four variables: the hammer efficiency, the normalized hammer weight, the normalized hammer drop height and the normalized pile set.
4. Piles crossing a normally consolidated clay layer and resting on an over-consolidated clay layer. The pile driving formula in this case is expressed in terms of four variables: the hammer efficiency, the normalized hammer weight, the normalized hammer drop height and the normalized pile set.
5. Piles crossing a clay layer and resting on a dense sand layer. The proposed pile driving formula in this case is expressed in terms of five variables: the hammer efficiency, the normalized hammer weight, the normalized hammer drop height, the ratio of shaft relative density to base relative density and the pile set.

Implementation

Up to 80% of Indiana Department of Transportation (INDOT) projects lack the budget to allow dynamic load testing as a means to check the acceptability of driven piles, and therefore pile driving formulas are used. Similar numbers apply to other agencies and, indeed, private companies. Implementation of the results of this research will enable INDOT and other owners or contractors to take advantage of updated and improved pile driving formulas in smaller projects, leading to more economical piling.

Engineers can use the pile driving formulas proposed in this report in their work by following the following steps:

1. based on the soil profile information, decide which of the typical cases applies;
2. based on hammer information, estimate the hammer efficiency, the hammer weight and the hammer drop height;
3. estimate the soil properties to be used based on knowledge of the soil profile;
4. measure the pile set per blow at the end of pile driving;
5. take the value of the observed pile set into the corresponding pile driving formula to calculate the estimated capacity of the pile.

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