PUTTING RESEARCH TO WORK

BRIEF

Improved Field Methods for Estimating Pile Bearing Capacities

In order to provide support for Wisconsin's bridges and other structures, the concrete-encased cast-in-place piles or steel piles that serve as their foundations must be installed into the ground. Engineers need to predict a pile's axial capacity during construction, which is based on the resistance of the pile during installation. If actual pile capacity differs from predicted pile capacity, then either the piles may not be installed deep enough to meet desired safety levels, or the piles may be driven too deep, which wastes time, labor and materials.

For many years, WisDOT has used an Allowable Stress Design procedure and a field pile bearing capacity prediction method called the modified Engineering News-Record formula. This EN-Wisc formula incorporates a factor of safety; it estimates a "safe bearing load" for a pile to ensure structural effectiveness. However, this methodology can lead to variable capacity predictions.

AASHTO has revised its bridge design specifications to include Load and Resistance Factor Design procedures to increase bridge structural reliability. These procedures use a dynamically calculated resistance factor to modify pile designs. This resistance factor is based on the calibration of predicted pile capacities versus actual pile capacities. Responding to AASHTO recommendations, WisDOT has revised its foundation design practices to include calibration of resistance factors based on local conditions. WisDOT engineers realized that if the EN-Wisc formula were retained with its corresponding resistance factor, the result would be a significant increase in the number and/or length of piles driven on Wisconsin construction projects.

What's the Problem?

In transitioning from ASD procedures to LRFD procedures, WisDOT needed to calibrate the dynamic formula to local conditions, and engineers wanted to explore other formulas that would lead to an increase in the resistance factor. FHWA and other organizations have provided evidence and encouragement for state DOTs to migrate away from the EN formula to the FHWA-modified Gates formula, a dynamic formula that provides greater predictive accuracy regarding pile bearing capacity.

However, WisDOT needed to be able to quantitatively define the behavior and limitations of this dynamic formula. For example, there is evidence that the modified Gates formula may be applicable only over a limited range of pile capacity. Furthermore, WisDOT needed a clear quantitative comparison of predictions made with the modified Gates and EN-Wisc formulas, along with other dynamic formulas, to better assess the impact that the transition will have on the practice and economics of design and construction of driven pile foundations.

Research Objectives

This project sought to use the results of static load tests and Pile Driving Analyzer tests to compare the accuracy and precision of several dynamic formulas that have been developed to predict axial pile capacity using driving resistance. These formulas include the current EN-Wisc formula, the FHWA-modified Gates formula (and a corrected version of this formula), and formulas developed by Washington State DOT and the University of Illinois.

Methodology

Investigators compared the pile bearing capacities predicted by each formula with actual capacity data; these comparisons were drawn from two databases of driven steel piles. The first database combined several smaller national studies conducted from 1964 to 2007, totaling 156 tests. The second database, provided by WisDOT, included tests on 316 piles from several locations around the state. Only a few of these records included static load test results, but there were several cases in which Pile Driving Analyzer tests with CAPWAP (Case Pile Wave Analysis Program) analyses were conducted on re-strikes; these measurements provide reasonable estimates of the actual pile capacity.

Investigator

"In transitioning to LRFD procedures, retaining the current method for predicting capacity was going to be expensive, with a lot more piling going into the ground. Using more accurate methods will save the state money."

–James H. Long
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Investigators evaluated different dynamic formulas for predicting the actual bearing capacity of a driven pile in order to improve procedures for constructing deep bridge foundations.

In these comparisons, investigators found that the FHWA-modified Gates formula overpredicted pile capacity for small loads and underpredicted capacity for loads greater than 750 kips, so they created and tested a "corrected" FHWA-Gates formula. This modification factors in the specific pile type, pile hammers and soil in predicting construction pile capacity.

Investigators also performed analyses to compare the impact of changing from EN-Wisc to a more accurate predictive formula, and of incorporating LRFD specifications into the design process.

Results

In comparing the various dynamic formulas to the results of static load tests or PDA/CAPWAP analyses, investigators found that the corrected FHWA-Gates and WSDOT formulas tended to be the most effective predictors of pile capacity. The EN-Wisc formula generally underpredicted capacity and was the least precise.

The WSDOT formula exhibited a slight tendency to overpredict capacity, but was very precise. It predicted capacity well across the range of capacities, whereas the predictions of the corrected FHWA-Gates formula, which was more precise and accurate, did not correlate as well for piles with a lower axial capacity (less than 200 kips).

This study also generated resistance factors for each of the dynamic formulas; these are used in LRFD design when determining how to incorporate pile bearing capacity predictions into pile driving practices. These factors can be used in place of the AASHTO derived factors, which tend to be more conservative.

Investigators found that the impact of moving to LRFD procedures on required foundation capacity can be mitigated by replacing EN-Wisc with a more accurate formula, such as the corrected FHWA-Gates formula or the WSDOT formula.

Further Research and Implementation

An implementation project is under way to incorporate the results of this project, including a more precise dynamic formula with corresponding resistance factors, into the Wisconsin Bridge Manual by developing design values, guidance and tools that work to support LRFD procedures. This implementation project will help ensure that WisDOT foundation designs predict pile capacity as accurately as possible, leading to structures that are both safe and cost-efficient.

This brief summarizes Project 0092-07-04, "Comparison of Five Different Methods for Determining Pile Bearing Capacities," produced through the Wisconsin Highway Research Program for the Wisconsin Department of Transportation Research Program, 4802 Sheboygan Ave., Madison, WI 53707.

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Project Manager

"As part of the transition from Allowable Stress Design to Load and Resistance Factor Design, WisDOT needed to evaluate the precision of the various dynamic formulas used to determine pile bearing capacities."

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