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Calibration of Region Specific Gates Pile Driving Formula for LRFD

INTRODUCTION

The Louisiana Department of Transportation and Development (DOTD) uses a variation of the Federal Highway Administration (FHWA) Gates formula, hereinafter referred to as the DOTD pile driving formula, to verify the long term ultimate pile capacity with blow counts obtained during end-of-initial-driving (EOID) per the 2006 Louisiana Standard Specifications for Roads and Bridges, Section 804.10. The DOTD pile driving formula is typically used on smaller projects where static load tests and dynamic monitoring are not practical.

The resistance factor for load and resistance factor design (LRFD) specified by the current American Association of State Highway and Transportation Officials (AASHTO) design guide for the FHWA Gates Formula is 0.40. However, DOTD uses a resistance factor equal to 0.50 for designs using static equilibrium methods. The goal of this study is to develop pile driving formulas using a regional pile load test database and calibrate the LRFD resistance factors that have the same reliability index and probability of failure that is being used in static equilibrium methods.

OBJECTIVE

The objectives of this project are to evaluate and, if necessary, develop new pile driving formulas based on the generic Gates formula using a regional Louisiana database with pile types and local soil conditions encountered in Louisiana. LRFD resistance factors associated with each pile driving formula will be calibrated for values of the reliability index and probability of failure appropriate for redundant foundation systems. Another important objective of this research is to geographically organize historical pile load testing records for use in this study as well as for future enhancement of DOTD's geotechnical information database.

METHODOLOGY

This research study includes a literature review to provide background information regarding the basis and use of pile driving formulas within state Departments of Transportation (DOTs) across the United States. The literature review emphasizes LRFD implementation of pile driving formulas and efforts to modify and establish LRFD resistance factors based on regional experience and load tests. A pile load test database was compiled using 804 piles installed and load tested on 194 DOTD projects. The database also includes information about the pile driving equipment used and the field driving resistance observed at end-of-initial-driving (EOID) and beginning-of-restrike (BOR). Static and dynamic (i.e., Case Pile Wave Analysis Program or CAPWAP) load tests are included in the database.

Based on the gathered pile load test and restrike data, the bias of the DOTD pile driving formula was calculated. New DOTD pile driving formulas for pile capacity verification were developed using pile driving blow counts recorded at EOID or BOR. The new pile driving formulas were developed using a multivariate regression

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to recalibrate the FHWA Gates Formula to reduce the mean and standard deviation of the bias values. Updated values of the LRFD resistance factor for the DOTD pile driving formula and the new DOTD modified pile driving formulas were calculated using the Monte Carlo Simulation (MCS) method for the Strength I limit state with a reliability index (β_T) of 2.33 as recommended for pile groups in AASHTO specifications. Recommendations for implementing the new pile driving formulas and LRFD resistance factors are presented along with a benefit-cost assessment associated with the implementation.

CONCLUSIONS

The current DOTD pile driving formula that uses blow counts obtained at EOID was found to have a median bias of measured-to-predicted capacity of 1.23 and a corresponding resistance factor of 0.65, which is higher than the AASHTO default resistance factor of 0.40 for the same pile driving formula. The new EOID DOTD Modified Gates pile driving formula has a median bias of measured-to-predicted capacity of 1.07 and corresponding resistance factor of 0.60. There is uncertainty in the magnitude of pile setup that may not be captured in all of the pile load tests; therefore, it is prudent to select a resistance factor of 0.50 for the EOID Modified Gates pile driving formula. Because the proposed EOID Modified Gates pile driving formula is a more accurate pile driving formula, the adoption of this new pile driving formula will result in more cost effective foundations that will meet the reliability target index without excessive conservatism associated with the current pile driving formula and the AASHTO resistance factor.

Pile setup curves have been evaluated using the Skov Denver model with pile setup factor obtained from a limited amount of pile setup data. The results indicate that it is important to evaluate the ultimate pile capacity from pile restrikes performed after EOID. To mitigate the deficiencies in the current practice of not using ultimate pile capacities based on BOR resistance, pile driving formulas were developed to evaluate ultimate pile capacity from restrikes for two soil types having distinct pile capacity setup characteristics within the state.

The benefit-cost ratio of implementing the findings of this study is between 3.5 and 6 within the first year of implementation of the improved DOTD pile driving formulas and updated LRFD resistance factors. Furthermore, the economic benefits continue in following years after the implementation of this study.

RECOMMENDATIONS

The long-term ultimate pile bearing capacity can be computed using the recommended pile driving formulas. The pile driving formula that should be used is dependent on the time at which the pile bearing capacity verification is being performed. If the pile bearing capacity is verified at EOID, then the recommended EOID DOTD Modified Gates pile driving formula should be used. If pile bearing capacity is not achieved at EOID, pile restrikes can be performed after EOID to evaluate the nominal pile bearing capacity after pile setup has occurred by using the recommended BOR Modified Gates pile driving formulas dependent on the soil conditions at the site.

It is recommended that the criteria for the hammer approval method and the wave equation method be revised to "The required number of hammer blows for pile verification of the nominal resistance at either EOID or BOR shall be from 36 to 110 blows per foot." In order to reduce the potential for pile damage during pile installation or during pile restrikes, the pile driving approval should also include criteria to prevent pile driving stresses during pile installation or pile restrikes to exceed the allowable values indicated in Subsection 804.08(g) of the standard specifications.

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