Recommended Resistance Factors for LRFD of Drilled Shafts in Iowa

tech transfer summary

Regional resistance factors for drilled shafts have been developed and recommended in this project to improve the reliability and cost effectiveness of bridge foundations.

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RESEARCH PROJECT TITLE
Verification of LRFD Resistance Factors for Drilled Shafts Using Field Tests

SPONSORS
Iowa Department of Transportation
(InTrans Project 14-512)

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Objective

The primary objective of this research was to utilize an expanded version of the Drilled SHAft Foundation Testing (DSHAFT) database that was developed for Iowa to develop and recommend refined regionally calibrated resistance factors for the design of drilled shafts.

Background

The Federal Highway Administration (FHWA) mandated the use of the Load and Resistance Factor Design (LRFD) approach for designing foundations for all federally funded bridges since October 1, 2007. Given the limitations of the American Association of State Highway Transportation and Officials (AASHTO) specifications for LRFD of drilled shafts and the potential benefits of a regional calibration, preliminary regional resistance factors for drilled shafts of highway bridges in Iowa were calibrated by the researchers prior to this (Ng et al. 2014).

Research Description

The general calibration framework detailed by Allen (2005) was primarily used to achieve the objective of this study. The available load test data were categorized based on the type of geomaterial along the side and at the base of the shafts.

For side resistance, a segmental approach was adopted in this categorization process so that resistance factors could be calibrated for individual geomaterial types and corresponding resistance prediction methods. Various resistance predictions methods were examined in the calibration.

Resistance biases were calculated at two strength criteria for each category. The strength criteria considered were the 1-inch and the 0.05D (where D is the shaft base diameter) for top displacements.

For side resistance, two approaches, the local approach and the global approach, were used to calculate the resistance biases. In the local approach, the resistance biases were calculated for each individual shear zone in a given test shaft; in the global approach, shear zones of the same geomaterial category were combined to produce a single resistance bias.

The actual side and tip resistances needed to calculate the resistance biases for a given test shaft were determined using load test strain gauge data and t-z analysis.

The statistical characteristics of the resistance biases were then determined. Using probability plots and histograms of the actual resistance biases and those of theoretical distributions, the lognormal distribution was found to be the most suitable distribution type.

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Summary and Key Findings

Using the first order second moment reliability method, the resistance factors were calibrated at the Strength I limit state (dead load and live load only) to achieve a target reliability of 3.0.

The statistical characteristics of the resistance bias and resulting resistance factor for side resistance were significantly influenced by the approach used in calculating the resistance bias. The global approach resulted in lower variability in side resistance prediction as indicated by the lower coefficients of variation (COVs). Consequently, the global approach led to higher resistance and efficiency factors compared to the local approach.

While the resistance factors calibrated using the local approach did not show any improvements over AASHTO (2017), recommended values (with the exception of the resistance factor for side resistance prediction in cohesive intermediate geomaterial [IGM] at 5%D using the O'Neill and Reese 1999 modified α-method), the global calibration approach led to a substantial increase.

The resistance factors for side resistance prediction calibrated using the load test data from Iowa only are shown in Figure 1 and Figure 2, and their respective efficiency factors in Figure 3 and Figure 4.

The figures indicate that the prediction methods considered in the calibration are more accurate at estimating the side resistance of several geomaterial layers than that of just a single or couple of layers.

Two methods were considered for side resistance prediction in cohesionless soil and rock. When the global approach is used, the calculated efficiency factors show that the O'Neill and Reese (1999) β-method and the Kulhway et al. (2005) method are the most economical for Iowa.

The calibrated resistance factors for tip resistance prediction are presented in Figure 5 and Figure 6 for cohesive IGM and rock, respectively.

Four additional prediction methods were considered in the calibration in addition to those recommended by AASHTO.

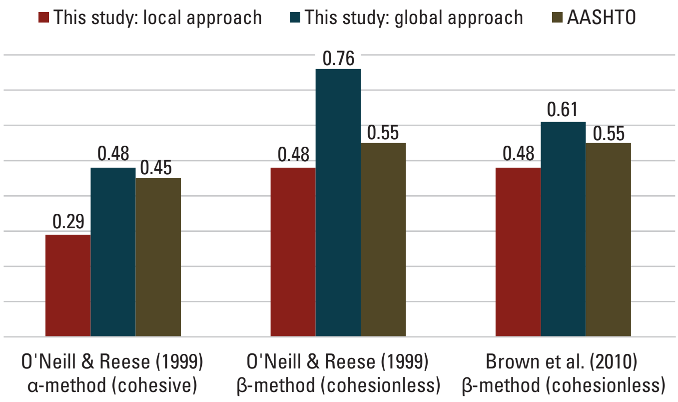

Figure 1. Resistance factors for side resistance prediction in cohesive and cohesionless soil at 1-inch strength criterion

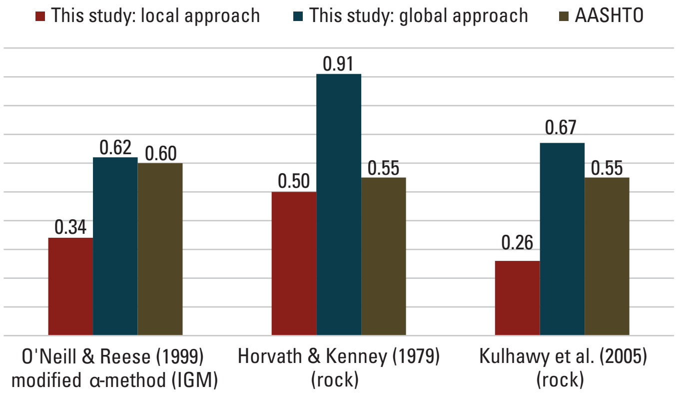

Figure 2. Resistance factors for side resistance prediction in cohesive IGM and rock at 1-inch strength criterion

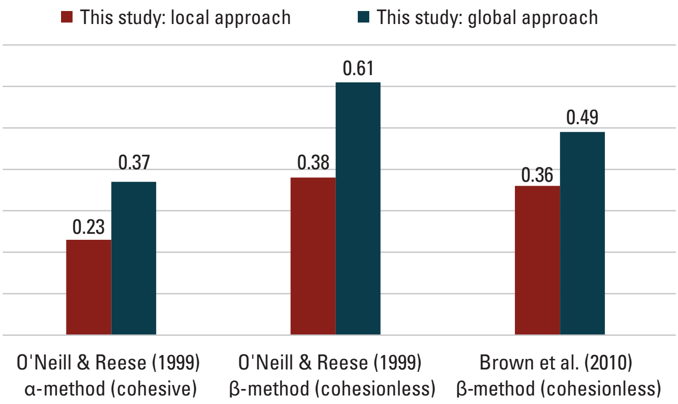

Figure 3. Efficiency factors for side resistance prediction in cohesive and cohesionless soil at 1-inch strength criterion

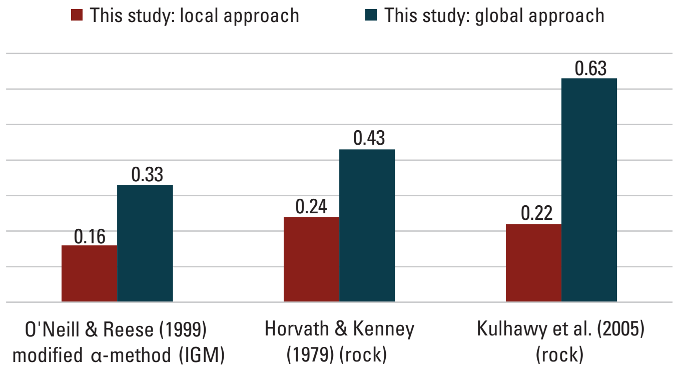

Figure 4. Efficiency factors for side resistance prediction in cohesive IGM and rock at 1-inch strength criterion

As shown in the figures, the calibration did not result in any improvements for both methods recommended by AASHTO, including the O'Neill and Reese (1999) and the Carter and Kulhawy (1988) methods for cohesive IGM and rock, respectively. The efficiency factors of the methods were also calculated and are shown in Figure 7 and Figure 8.

The values indicate that the O'Neill and Reese (1999) and the Sowers (1976) methods are the most economical for tip resistance prediction in cohesive IGM and rock, respectively. The lack of load test data for tip resistance in soil prevented the appropriate statistical characterization of the resistance bias and the calibration of resistance factors for cohesive soil and cohesionless soils.

Implementation Readiness/ Recommendations

This work resulted in refined regionally calibrated resistance factors for the design of drilled shafts in Iowa. The resistance factors recommended for implementation are given in Table 1. The factors were rounded to the nearest 0.05.

For tip resistance prediction in cohesive and cohesionless soil, the values recommended by AASHTO are recommended for the time being until additional load test data can be obtained and used to develop regional values. Note, however, that AASHTO recommended values were established using a strength criterion corresponding to a top displacement of 0.05D. In accordance with AASHTO recommendations, the recommended values should be reduced by 20% when a single drilled shaft is to be used to support a bridge pier.

To ensure the selected target reliability (i.e., 3.0), the recommended resistance factors must be used in accordance with the resistance components, geomaterials, and prediction methods used in the calibration. When a static load test is performed, the resistance factor provided by AASHTO is recommended.

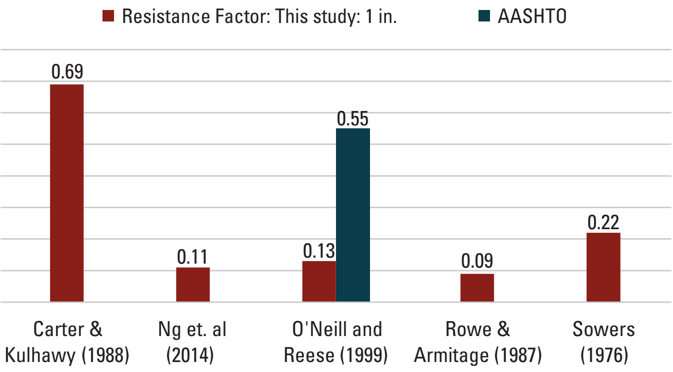

Figure 5. Resistance factors for tip resistance prediction in cohesive IGM at 1-inch strength criterion

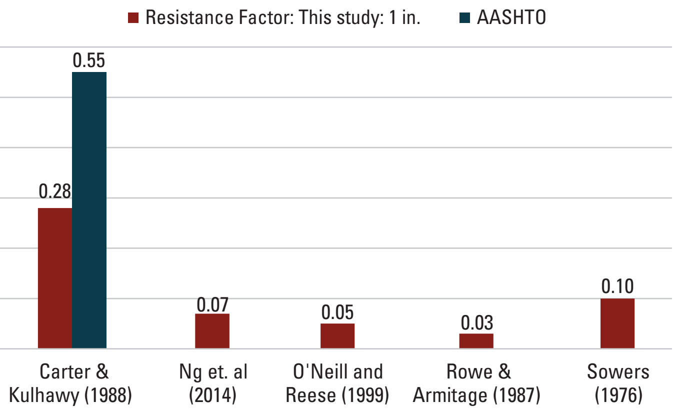

Figure 6. Resistance factors for tip resistance prediction in rock at 1-inch strength criterion

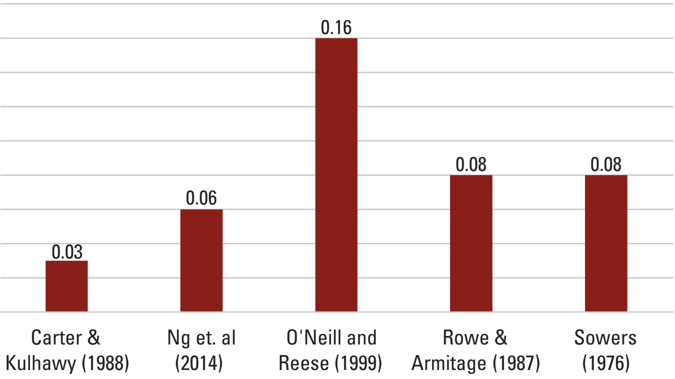

Figure 7. Efficiency factors for tip resistance prediction in cohesive IGM at 1-inch strength criterion

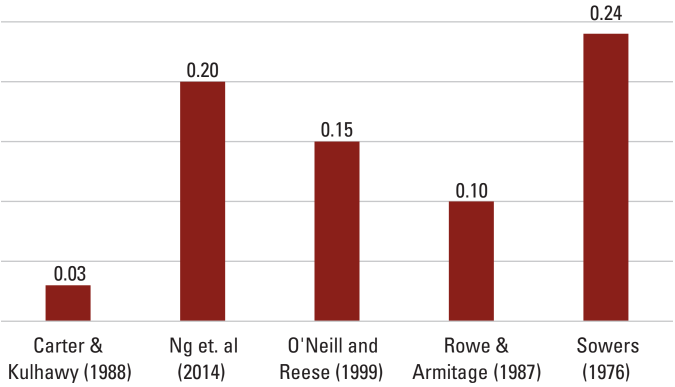

Figure 8. Resistance factors for tip resistance prediction in rock at 1-inch strength criterion

Table 1. Recommended resistance factors based on 1-inch strength criterion

Resistance Component	Geo Material	Analytical Method	Resistance Factors for $\beta T = 3.00$, φ(a)
Side Resistance	Cohesive soil	α-method by O'Neill and Reese (1999)	0.50
	Cohesionless soil and IGM	β-method O'Neill and Reese (1999)	0.75
	Cohesive IGM	O'Neill and Reese (1999)	0.60
	Rock	Kulhawy et al. (2005)	0.65
End Bearing	Cohesive soil	Total Stress method by O'Neill and Reese	0.40(b)
	Cohesionless soil and IGM	Effective stress method by Reese and O'Neill (1989)	0.50(b)
	Cohesive IGM	O'Neill and Reese (1999)	0.15
	Rock	Sowers (1976)	0.10
All	All	Static Load Test	0.70(c)

(a) – If a single drilled shaft is used to support a bridge pier, the resistance factors should be reduced by 20%
(b) – Adopted from AASHTO (2017) corresponding to 5% of diameter for top displacement criterion
(c) – Maximum resistance factor recommended in AASHTO was adopted

Implementation Benefits and Future Research

The regional resistance factors for drilled shafts that were developed and are recommended through this research aim to improve the reliability and cost effectiveness of bridge foundations in Iowa. The results of this work could also help other states.

Adoption of these recommendations brings the state into compliance with the FHWA-mandated use of the LRFD approach for designing foundations for all federally funded bridges in Iowa and provides a more efficient LRFD design procedure than the nationally recommended resistance factors. The next project has been funded and started, with the following plan, to verify the recommendations from this project:

- Continuously increase the regional drilled shaft test data in the DSHAFT database
- Conduct detailed soil and rock investigations at demonstration shaft locations beyond the typical standard penetration test (SPT)
- Verify the recommended resistance factors by performing controlled O-cell load tests in Iowa and make appropriate revisions
- Ensure that any future load tests are conducted to large displacements or complete geotechnical failure
- Develop and recommend regional resistance factors for end bearing in cohesive and cohesionless soils as additional data become available
- Using adequate data from load tests performed in Iowa, develop state-specific drilled shaft design methods that further increase drilled shaft design efficiency

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