Development of Preliminary Load and Resistance Factor Design of Drilled Shafts in Iowa

tech transfer summary

This project has established a framework to define total vertical load resistance of drilled shafts using performance-based failure criteria and developed preliminary Load and Resistance Factor Design (LRFD) resistant factors for use in Iowa.

Background

Despite possessing several advantages, drilled shafts are used infrequently in Iowa. The soil conditions in several regions of the state are ideal for using this foundation option. The reasons for the limited use of drilled shafts can be attributed to the following:

- Lack of a formal process for selection of appropriate foundation types, especially in evaluating the advantages of drilled shafts over driven piles
- Limited design guidelines and details for drilled shafts in the Iowa Bridge Design Manual
- Absence of standard construction inspection checklists for drilled shafts

Furthermore, the resistance factors for drilled shafts recommended in the American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) Bridge Design Specifications (2010) were determined based on a general national database that does not reflect local design and construction practices and the regional soil conditions.

Research Objectives

The primary objective of this research was to use the recently established Drilled SHAft Foundation Testing (DSHAFT) database to develop preliminary LRFD resistance factors for the design and construction of drilled shafts in Iowa.

Research Description

A literature review on current design and construction practices for drilled shafts used by the Iowa Department of Transportation (DOT) and 10 neighboring DOTs, as well as other relevant documents, was conducted to ensure an understanding of current drilled shaft design and construction practices.

The LRFD framework recommended in the AASHTO specifications was adopted to determine regionally calibrated resistance factors for drilled shafts. Preliminary LRFD resistance factors were developed using the recently established DSHAFT drilled shaft load test database (http://srg.cce.iastate.edu/dshaft/), which included 41 drilled shaft tests performed in 11 states. LRFD resistance factors (φ) were calibrated following the probability-based reliability theory. Among the various methods, the modified first-order second moment (FOSM) method, which is simple to use and provides comparable results to other more complex

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The Bridge Engineering Center (BEC) is part of the Institute for Transportation (InTrans) at Iowa State University. The mission of the BEC is to conduct research on bridge technologies to help bridge designers/owners design, build, and maintain long-lasting bridges.

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methods, was selected to determine resistance factors for total resistance (R) and side resistance (R_s) as well as end bearing resistance (R_p) for four different geomaterials (i.e., clay, sand, intermediate geomaterial/IGM, and rock).

To illustrate the potential success of using drilled shafts in Iowa, the design procedures of drilled shaft foundations were examined and the advantages of drilled shafts over driven piles were assessed in two case studies.

Key Findings

Resistance factors for each resistance component (i.e., side resistance, end bearing, and total resistance) and each geomaterial type were determined based on the following failure criteria:

- Maximum measured load reported in the load test reports
- 1-in. top displacement
- 5% of shaft diameter for top displacement

The table in this summary summarizes the recommended regionally calibrated resistance factors based on the 1-in. top displacement criterion.

To determine measured total resistances corresponding to the performance-based failure criteria, three improved procedures are proposed for three different shaft load-test failure types (i.e., Cases A, B, and C) to generate and extrapolate equivalent top load-displacement curves. This was necessary because the O-cell test does not usually fully mobilize both the side resistance and end bearing (as shown in the figure in this summary), unless multiple O-cells are used, which is prohibitively expensive.

Case A refers to tests in which side resistance is fully mobilized but end-bearing is not, while Case B refers to the opposite case in which only the end bearing is fully mobilized. In Case C, neither the side resistance nor the end bearing are fully mobilized.

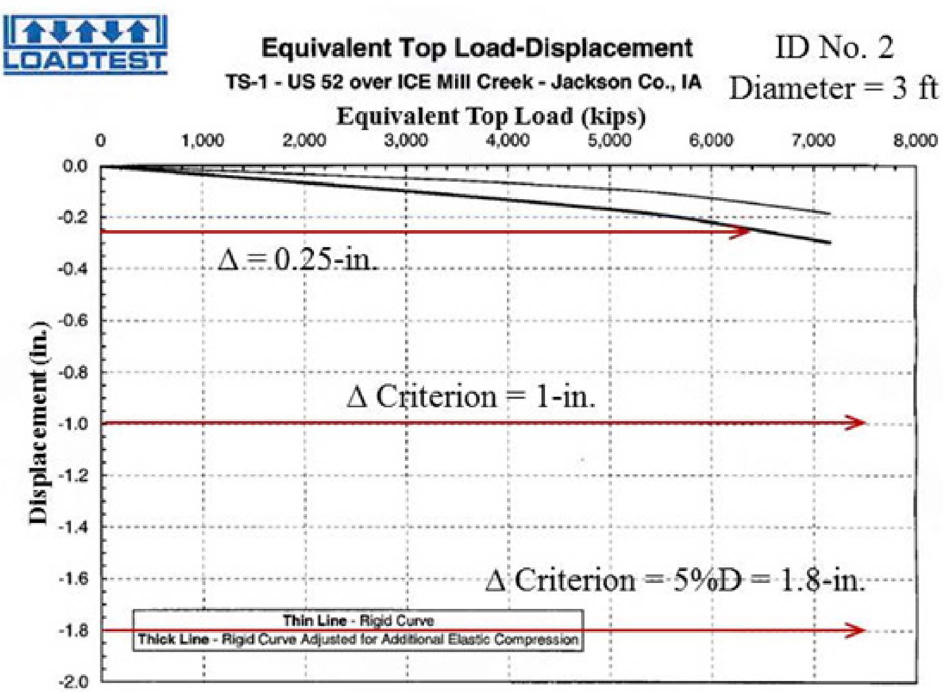
Compared to the resistance factors recommended in the National Cooperative Highway Research Program (NCHRP) reports and from AASHTO (2010), regional calibration produces higher resistance factors and efficiency factors, except for the side resistance components in clay and sand.

Comprehensive tables and figures, as well as summaries of the major outcomes of the research, are provided in the final report for this project. An example is shown in the table in this summary.

Implementation Readiness and Benefits

The following notable benefits to the bridge foundation design were attained in this phase of the project:

- A preliminary LRFD design procedure for drilled shafts was established to ensure a uniform design of bridges across Iowa
- The cost-competitiveness of drilled shafts was demonstrated as an alternative deep foundation solution in Iowa
- Regionally calibrated resistance factors were developed for drilled shafts in Iowa, reflecting local design and construction practices and regional soil conditions



Calculated equivalent top load-displacement curve from an O-cell test

Recommended resistance factors based on 1-in. top displacement criterion

Resistance Component	Geo-Material	Analytical Method	Resistance Factors for $\beta_T = 3.00$, φ(a)
Total Resistance	All	A combination of methods depending on the subsurface profile	0.60
Side Resistance	Clay	α-method by O'Neill and Reese (1999): Section 2.3.2	0.45(b)
	Sand	β-method by Burland (1973) and O'Neill and Reese (1999): Section 2.3.3	0.55(b)
	IGM	Eq. (2-11) for cohesive IGM and Eq. (2-14) for cohesionless IGM by O'Neill and Reese (1999): Section 2.3.4	0.60
	Rock	Eq. (2-16) by Horvath and Kenney (1979): Section 2.3.5	0.55
End Bearing	Clay	Total Stress method by O'Neill and Reese (1999): Section 2.4.2	0.40(b)
	Sand	Effective stress method by Reese and O'Neill (1989): Section 2.4.3	0.50(c)
	IGM	Proposed method described in Section 2.4.5 and Table 3.4 for cohesive IGM and Eq. (2-22) for cohesionless IGM by O'Neill and Reese (1999): Section 2.4.4	0.55(d)
	Rock	Proposed method described in Section 2.4.5 and Table 3.4	0.35(e)
All	All	Static Load Test	0.70(f)

(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 (2010) corresponding to 5% of diameter for top displacement criterion

(c) Reduce from 0.76 to 0.50 so that the resistance factor of the end bearing component is smaller than that of the side resistance component

(d) Reduce from 0.64 to 0.50 so that the resistance factor of the end bearing component is smaller than that of the side resistance component

(e) Resistance factor of 0.50 can be used if pressuremeter method following the Canadian Geotechnical Society (1985) is used as the analytical method

(f) Maximum resistance factor recommended in AASHTO was adopted

Recommendations for Future Research

- Continuously increase the regional drilled shaft test data in the DSHAFT database
- Conduct detailed soil and rock investigations
- Verify drilled shaft resistance factors by performing controlled O-cell load tests in Iowa and make appropriate revisions
- Increase the number of O-cell load tests of drilled shafts in clay and rock materials
- Verify the proposed procedures for generating the equivalent top load-displacement curves

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