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Calibration of Resistance Factors for Load and Resistance Factor Design to Establish Value for Site Characterization

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Abstract

New design guidelines were developed from a comprehensive site characterization research program for the Missouri Department of Transportation (USA) as “state specific” load and resistance factor design specifications. The new guidelines include resistance factors calibrated as a function of the variability and uncertainty in design parameters to provide designers with explicit means to quantify the potential value of site characterization activities and make more rational decisions regarding the type and scope of site characterization activities. The paper introduces procedures for developing the resistance factors and demonstrates the usefulness of the calibrated resistance factors. Simulations were performed to mimic designs using different quantities of measurements from “state of the art” site investigations at rock and soil sites with high and low site variability, respectively. The results show that the percentage of designs achieving the target reliability steadily increases with more measurements. The percentage of under reliable cases is practically independent of the number of measurements and the design models used. The percentage of designs achieving the target reliability is greater for the rock site when adopting the calibrated resistance factors. Generally, the percentage of designs achieving target reliability heavily depends on the quantity of measurements acquired from site characterization and the site variability.

Keywords: Site characterization, Load and Resistance Factor Design (LRFD), Site variability, Reliability

1 Introduction

Resistance factors are usually adopted for design to account for variability and uncertainty in the resistance component. Many design specifications, such as the national code developed by the American Association of State Highway and Transportation Officials in USA (AASHTO, 2012), adopt constant resistance factors that collectively address variability and uncertainty in design input parameters,

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variability and uncertainty in design models, and variability and uncertainty attributed to construction. Designs developed using such constant resistance factors may not achieve consistent levels of reliability or may be excessively costly (Loehr et al., 2015; Ching et al., 2012). Use of constant resistance factors practically precludes the potential to achieve consistent reliability because it restricts means to effectively account for differences in the variability and uncertainty of geotechnical design parameters across a broad range of sites and projects. Use of constant resistance factors also diminishes the apparent value of site characterization activities that might be used to reduce uncertainty in geotechnical design parameters. The reliability of designs is largely dependent on the variability and uncertainty in design parameters, which in turn, is heavily influenced by site variability and the quantity and quality of site characterization activities. Therefore, several LRFD design methods adopt resistance factors that depend on the variability and uncertainty in geotechnical design parameters (Phoon et al., 2000; Fenton et al., 2008; Loehr et al., 2013).

A comprehensive research program was recently completed to develop "state specific" load and resistance factor design (LRFD) guidelines (MoDOT, 2011) that represent an improvement over current AASHTO LRFD design specifications. The state design guidelines were developed to provide procedures that more precisely and consistently achieve target reliability in design by implementing resistance factors that depend on the variability and uncertainty in design parameters. The procedures for calibrating resistance factors as a function of the variability and uncertainty in design parameters for spread footings on rock and soils at different target probabilities of failure is introduced, followed by analyses to illustrate the effectiveness of using those calibrated resistance factors for design at sites with different site variability and with different quantities of measurements.

2 Calibration of Resistance Factors for Spread Footing Design

Resistance factors were calibrated for design of spread footings under $\phi = 0$ conditions at the strength limit state. The load and resistance factor design criterion can be written such that the factored bearing resistance equals or exceeds the factored loads:

$$\varphi \cdot R_n \cdot A \geq \gamma \cdot Q_n \quad (1)$$

where φ is the resistance factor, R_n is the nominal unit bearing resistance, and A is the footing area. The factored load, $\gamma \cdot Q_n$, for the appropriate strength limit state is taken to be a combination of dead and live loads:

$$\gamma \cdot Q_n = \gamma_{DL} \cdot Q_{DL} + \gamma_{LL} \cdot Q_{LL} \quad (2)$$

where, γ_{DL} is a load factor for dead load, Q_{DL} is the nominal dead load, γ_{LL} is a load factor for live load, and Q_{LL} is the nominal live load. Values for load factors were taken as $\gamma_{DL} = 1.25$ and $\gamma_{LL} = 1.75$ (AASHTO, 2012). The dead and live load components were assumed to follow normal distributions with representative mean values (μ_{DL} and μ_{LL}) and coefficient of variation (CV_{DL} and CV_{LL}) values (Kulicki et al., 2007):

$$Q_{DL} \sim \text{Normal}(\mu_{DL} = 4.5\ MN, CV_{DL} = 0.12) \quad (3)$$

$$Q_{LL} \sim \text{Normal}(\mu_{LL} = 2.2\ MN, CV_{LL} = 0.10) \quad (4)$$

Resistance factors were calibrated for spread footing designs to achieve target reliabilities established by the Missouri Department of Transportation for structures located on different classes of roadways (Huaco et al., 2012). The different classes of roadways/bridges considered include bridges on