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On the Cautious Estimation of Characteristic Soil Strength for Axial Pile Capacity

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Assuming perfect knowledge of soil strength and prescribing load factors for loads, we calibrate the necessary requirement for the material factor on characteristic soil strength by tuning a reliability analysis to meet a prescribed target failure probability. Keeping this calibrated material factor unchanged, the reliability analysis is repeated with the stochastic model for soil strength altered to include statistical uncertainty owing to limited soil data. A reduced "cautious" value of the characteristic soil strength is determined such that the failure probability resulting from the new analysis is maintained equal to the target. Based on this reduced value, the minimum confidence level needed for characteristic value estimation is interpreted.

INTRODUCTION

Assuming perfect knowledge of soil strength and prescribing load factors for loads, we calibrate the necessary requirement for the material factor on characteristic soil strength by tuning a reliability analysis to meet a prescribed target failure probability. Keeping this calibrated material factor unchanged, the reliability analysis is repeated with the stochastic model for soil strength altered to include statistical uncertainty owing to limited soil data. A reduced "cautious" value of the characteristic soil strength is determined such that the failure probability resulting from the analysis is maintained equal to the target. Based on this reduced value, the minimum confidence level needed for characteristic value estimation is interpreted. Using soil strength for prediction of axial pile capacity as an example, this paper outlines a procedure for reliability-based calibration of the minimum confidence needed when estimating characteristic soil strength, defined as the mean value, with confidence for use in offshore pile design.

Design codes commonly require the characteristic soil strength for axial pile capacity to be estimated with caution or conservatism; i.e., in statistical terms, it has to be estimated with confidence. This study is concerned with a reliability-based calibration of the minimum confidence level needed for such estimation when a specific definition of characteristic strength is given, here the mean value. Capitalizing on existing load and resistance models for an example pile from the literature, the study demonstrates an approach to characteristic strength estimation that will render an incentive to obtain more soil strength data and thereby give credit to the geotechnical designer who opts to test more.

A second-order reliability analysis of the example pile is carried out. With an assumption of perfect knowledge of the soil strength and with prescribed load factors for permanent and environmental loads, the necessary requirement for the material factor on the characteristic soil strength is calibrated by tuning the reliability analysis to meet a prescribed target failure probability.

With the calibrated material factor kept unchanged, the reliability analysis is repeated, now with the stochastic model for soil strength altered to include statistical uncertainty owing to limited soil data. A reduced "cautious" value of the characteristic soil strength is determined such that the failure probability resulting from the analysis is maintained equal to the target. Capitalizing on the properties of the Student's t distribution, this value is converted into the minimum confidence level needed for characteristic value estimation. Results are presented for target annual failure probabilities in the range from 10^{-5} to 10^{-4}.

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KEY WORDS: Characteristic value, pile capacity, model uncertainty, probabilistic analysis, code calibration, confidence estimation.

BACKGROUND

In the geotechnical design of axially loaded piles, the characteristic value of the soil strength as a function of depth is used in conjunction with a capacity prediction model and a material factor to determine the design capacity. A number of different capacity prediction models exist; see, for example, Ronold et al. (2012) and Lacasse et al. (2013).

The characteristic value of the soil strength is usually defined in the design standard that is used for the geotechnical design of the pile, and the definition is usually some objective measure in the probability distribution of the strength, for example, the mean value or some lower-tail quantile. Sometimes the design standard also provides requirements for the estimation of the characteristic soil strength with caution and conservatism, i.e., in statistical terms, estimation with confidence, such as when the estimation is to be based on statistical methods and limited data. Requirements for the material factor to be used in the geotechnical pile design are also given in the design standard, and these requirements are specific for the specific definition of characteristic soil strength employed by the standard.

NORSOK G-001 (NORSOK, 2004) specifies that the characteristic value of soil strength to be selected for use in design shall be a "conservatively assessed mean value" (p. 12). This implies that the definition of the characteristic value is the mean value and that the assessment of this characteristic value shall be conservative; i.e., in statistical terms, it has to be estimated with confidence. NORSOK N-001 (NORSOK, 2010) has similar wording for characteristic soil strength, but neither NORSOK G-001 nor NORSOK N-001 specifies any particular requirement regarding which confidence shall be used for the conservative estimation. Note that the referenced NORSOK standards are developed by the Norwegian petroleum industry to ensure adequate safety, value adding, and cost effectiveness. NORSOK standards are, as much as possible,