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Limit States Design of Deep Foundation

Introduction

Foundation design consists of selecting and proportioning foundations in such a way that limit states are prevented. Limit states are of two types: Ultimate Limit States (ULS) and Serviceability Limit States (SLS). ULSs are associated with danger, involving such outcomes as structural collapse. SLSs are associated with impaired functionality, and in foundation design are often caused by excessive settlement. Reliability-based design (RBD) is a design philosophy that aims at keeping the probability of reaching limit states lower than some limiting value. Thus, a direct assessment of risk is possible with RBD. This evaluation is not possible with traditional working stress design. The use of RBD directly in projects is not straightforward and is cumbersome to designers, except in large-budget projects. Load and Resistance Factor Design (LRFD) shares most of the benefits of RBD while being much simpler to apply. LRFD has traditionally been used for ULS checks, but SLS's have been brought into the LRFD framework recently (AASHTO 1998).

Load and Resistance Factor Design (LRFD) is a design method in which design loads are increased and design resistances are reduced through multiplication by factors that are greater than one and less than one, respectively. In this method, foundations are proportioned so that the factored loads are not greater than the factored resistances.

In order for foundation design to be consistent with current structural design practice, the use of the same loads, load factors and load combinations would be required. In this study, we review the load factors presented in various LRFD Codes from the US, Canada and Europe. A simple first-order second moment (FOSM) reliability analysis is presented to determine appropriate ranges for the values of the load factors. These values are compared with those proposed in the Codes.

For LRFD to gain acceptance in geotechnical engineering, a framework for the objective assessment of resistance factors is needed. Such a framework, based on reliability analysis is proposed in this study. Probability Density Functions (PDFs), representing design variable uncertainties, are required for analysis. A systematic approach to the selection of PDFs is presented. Such a procedure is a critical prerequisite to a rational probabilistic analysis in the development of LRFD methods in geotechnical engineering. Additionally, in order for LRFD to fulfill its promise for designs with more consistent reliability, the methods used to execute a design must be consistent with the methods assumed in the development of the LRFD factors. In this study, a methodology for the estimation of soil parameters for use in design equations is proposed that should allow for more statistical consistency in design inputs than is possible in traditional methods.

The primary objective of this study is to propose a Limit States Design method for shallow and deep foundations that is based on a rational, probability-based investigation of design methods. In particular, Load and Resistance Factor Design is used to facilitate the Limit States Design methodology. Specifically, the objectives of the study are to 1) provide guidance on the choice of values for load factors; 2) develop recommendations on how to determine characteristic soil resistances under various design settings; 3) develop resistance factors compatible with the load factors and the method of determining characteristic resistance.

Findings

This research was able to develop a systematic framework for the assessment of resistance factors for geotechnical LRFD. Several steps comprise this framework: a) the design equations are identified; b) all variables showing in the design equation are decomposed to identify all component quantities; c) probabilistic models for the uncertain quantities are developed using all available data; d) reliability analysis is used to determine the limit state values corresponding to a set of nominal design values at a specified reliability index; e) resistance factors are determined algebraically from the corresponding nominal and limit state values.

In order for LRFD to fulfill its promise for designs with more consistent reliability, the methods used to execute a design must be consistent with the methods assumed in the development of the LRFD factors. In this study, a methodology for the estimation of soil parameters for use in design equations is proposed to allow for more statistical consistency in design inputs than is possible in traditional methods. This methodology, called the conservatively assessed mean (CAM) method, is defined so that 80% of the measured values of a specific property are likely to fall above the CAM value. We were able to show that the CAM procedure tends to stabilize the reliability of design checks completed using particular *RF* values even when the uncertainty of the soil at a site is different from that assumed in the analysis.

The primary objective of this study is to propose a LRFD method for shallow and deep foundations that is based on a rational, probability-based investigation of design methods. Since resistance factor values are dependent upon the values of load factors used, a method to adjust the resistance factors to account for code-specified load factors is presented. Resistance factors for ultimate bearing capacity are then computed using reliability analysis for shallow and deep foundations both in sand and in clay, for use with both ASCE-7 (1996) and AASHTO (1998) load factors. The various considered methods obtain their input parameters from the CPT, the SPT, or laboratory testing.

Finally, designers may wish to use design methods that are not considered in this study. As such, the designer needs the capability to select resistance factors that reflect the uncertainty of the design method chosen. A methodology is proposed in this study to accomplish this task, in a way that is consistent with the framework.

Implementation

The resistance factor results of this study could be used to develop future LRFD codes for geotechnical design. As a first step towards implementation, Purdue University and INDOT are organizing a workshop to educate designers on the principles and application of the resistance factors and their associated design methods. This workshop will form the basis for INDOT designers to explore the use of these methods in support of code development. It is important to note that in order for LRFD to fulfill its promise for designs with more consistent reliability, the soil investigation forming the basis of a geotechnical design must be consistent with the interpretation methods assumed in the development of the LRFD factors. Thus, the concept of the CAM method must be implemented as the first component of the LRFD methodology. The implementation of the CAM method would not require additional efforts than those already common in soil investigations. It is easily applied and is demonstrated in the design examples in this study report.

In summary, the key areas of implementation are

- to hold a workshop on LRFD to introduce geotechnical engineers to the application of LRFD to foundations
- the use of the Conservatively Assessed Mean procedure to improve the repeatability of soil property assessments

the shift to the use of factored loads and resistance factors in the assessment of design resistances for foundations.

Contacts

For more information:

Prof. Rodrigo Salgado
Principal Investigator
School of Civil Engineering
Purdue University
West Lafayette IN 47907
Phone: (765) 494-5030
Fax: (765) 496-1364
E-mail: rodrigo@ecn.purdue.edu

Indiana Department of Transportation
Division of Research
1205 Montgomery Street
P.O. Box 2279
West Lafayette, IN 47906
Phone: (765) 463-1521
Fax: (765) 497-1665

Purdue University
Joint Transportation Research Program
School of Civil Engineering
West Lafayette, IN 47907-1284
Phone: (765) 494-9310
Fax: (765) 496-7996