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Limit States Design Based Codes for Geotechnical Aspects of Foundations in Canada

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EXTENDED ABSTRACT

The geotechnical engineering profession in Canada, and elsewhere throughout the world, is in the process of incorporating limit states design into codes of practice for geotechnical design aspects of foundation engineering. Primary benefits of the use of limit states design are that it provides a consistent design approach between structural and geotechnical engineers, as well as providing a rational and consistent framework for design and risk management of design uncertainty. This paper describes the needs and objectives for limit states design in Canada, and its development in codes; identifies and describes the primary Canadian Codes; discusses the role of the Canadian Foundation Engineering Manual and other authoritative references related to these Codes; discusses some of the experiences and challenges encountered in practice during implementation and application of limit states design; and outlines ongoing and proposed code development work, and associated future directions and research needs. The importance of understanding fundamental principles, effective communications between structural and geotechnical engineers, education and training is emphasized. All of these components will be required for successful implementation and acceptance of limit states design for geotechnical aspects of foundation engineering.

Limit states design, based on a factored strength approach similar to that of the European practice, for geotechnical aspects of foundations was first introduced into Canadian engineering practice in the early 1980s. However, this initial introduction did not get off to a good start because factored strength concepts were not well accepted by geotechnical engineers; it also generated a fair amount of confusion and controversy because the promised economy of design was not achieved. Canadian geotechnical practitioners felt that it was not logical or rational for strength parameters to be reduced (factored) to reflect weaker "artificial" soils and then use them directly in the same equations for calculating design resistances. In the early 1990s, an overall factored resistance approach, based on a Load and Resistance Factor Design (LRFD) format, was proposed for limit states design based codes. Subsequently, a LRFD format for foundations became a mandatory requirement in the 2000 edition of the Canadian Highway Bridge Design Code (CHBDC) and in the 2005 edition of the National Building Code of Canada (NBCC). Nevertheless, confusion continues to exist concerning the objectives of limit states design as engineering practitioners in Canada struggle to undergo the transition from traditional working (allowable) stress design to design based on limit states (LRFD) concepts.

The primary structural codes in Canada are the NBCC, the CHBDC and the Canadian Offshore Structures Code. These codes involve the interaction of structural and geotechnical engineers; they generally apply to the design and construction of foundations, retaining walls and other buried structures. There is no national code document for aspects in which geotechnical engineers do not normally interact with structural engineers. The current geotechnical state-of-practice in Canada does not use limit states design concepts to design slopes, earth embankments, dams and other earth structures. The code requirements are normally written as performance requirements and are based on scientific or technical principles. The codes avoid standardizing certain methods or procedures of design and construction. For example, the NBCC (2005) is published in an Objective-Based Code format where each code requirement is linked to the four basic objectives of Safety, Health, Accessibility (in particular for persons with disabilities), and Fire and Structural Protection of Buildings. Although some countries are striving to establish Performance-Based Codes, the NBCC code developers are of the opinion that current building science knowledge is inadequate to write a "true" (as per their perspective) Performance-Based Code, and that the measures to verify performance

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are not yet adequately in place. It is anticipated that it will be many years before a true Performance-Based Code format exists in the NBCC and other Canadian Codes. The current implementation of an Objective-Based Code format in NBCC (2005) is considered to be an initial step in this regard.

There appears to be a general lack of understanding, communication, education and training concerning the fundamental principles and intent of limit states (LRFD) design. In the LRFD format, it is important to note that the load and resistance factors are interrelated to each other. The values of the load and resistance factors depend on the target reliability index that the design is to achieve, the variability of the parameters that affect loads and resistances, and the statistical definition of their characteristic values. For consistent and rational design in practice, the selection of a given characteristic value for geotechnical resistance needs to be made in the same manner as that used to derive the specified geotechnical resistance factor. The mean or a "cautious estimate" of the mean value for the affected volume of ground (zone of influence) is generally considered to be appropriate for the characteristic value and the basis of the load/resistance factors derivation (calibration). The quantification of "cautious estimate" has not been formalized completely; there may be a need to establish an unambiguous quantitative definition for it.

In general, practicing geotechnical engineers who have completed limit states design for foundations do not object to the use of the NBCC and CHBDC specified geotechnical resistance factors for shallow foundations. However, some of the specified resistance factors for deep foundations are considered to be too low. In particular, it is felt that static pile load tests are being unduly penalized by the specified resistance factor of 0.6. There appears to be support for the use of a value of 0.7, which is also under consideration by the AASHTO Bridge Code. A review of the geotechnical resistance factors is anticipated to be part of new code development work, including an assessment of the influence of class (level of detail) of geotechnical site characterization. In addition, effects such as subsurface variability, construction quality control, and previous site and construction experience would be interrogated to account for specific knowledge that an engineer has and can be utilized in design. Although it is generally recognized that site investigation, test dependent and knowledge-based resistance factors have merit, the approach for both the CHBDC and NBCC was to keep the design process simple, at least during the initial stages of transition between working (allowable) stress design and limit states design. It was felt that it is more important that the fundamental principles of limit states design for foundations be conveyed to and understood by geotechnical practitioners. The initial transition should be as gradual and smooth as possible. Providing a myriad of partial factors that cover a large range of methods used in practice may not be conducive to better understanding and acceptance of limit states design (LRFD) by geotechnical engineers. Refinements and level of sophistication and details can come later when more experience with limit states design for foundations has been gained. Without the "test" of designs in practice, there can be no substantive verification of appropriate numerical values of geotechnical resistance factors.

Assessment of appropriate partial factors for serviceability limit states has not received the same kind of attention and scrutiny as applied to ultimate limit states. Currently the specified factor is 1.0 in the NBCC and CHBDC. The effects of sampling disturbance and other effects will need to be considered carefully. It is anticipated that partial factor values of both less than and greater than 1.0 may be a result of the assessment of partial factors for serviceability.

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Risk Assessment in Rock Engineering

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SUMMARY

Risk assessment in rock engineering is based on the formal identification of uncertainties and on their assessment and possible modification in the context of risk analysis and management. The best way to include uncertainty in the engineering design process is through the use of the basic structure of decision making under uncertainty which progresses from information collection, to deterministic and probabilistic modeling to end up with risk assessment and related decisions. These decisions, i.e. risk management range from accepting the risk as is to modifying it.

Before applying this decision making process to rock engineering, it is necessary to be clear as to what criteria engineering structures have to fulfill: safety, susceptibility, economics and aesthetics and, particularly, to identify the relevant sources of uncertainty. In rock engineering, the most important sources are inherent spatial variability, measurement/estimation errors and model uncertainties.

In information collection, one needs to determine the relevant parameters and associated uncertainties (distributions) through appropriate sampling procedures. Specifically, potential biases have to be avoided and corrected for. Also, one needs to relate the sample to the sample population and, most importantly, to the target population, the latter usually requiring judgement. The result of information collection are state-of-nature models, which express the natural variability. Stochastic fracture pattern models are examples.

In the deterministic modeling, phase one relates parameters to outcomes, i.e. predicted performance. The performance can be related to stability, deformation, flow or economic aspects (or combinations). In rock engineering, such performance is related to the typical problems of slope stability, foundation performance, flow and tunneling. An important aspect of the deterministic phase is the concluding sensitivity analysis, which is used to identify the parameters having the greatest effect on the results. Usually only these parameters will be varied in the probabilistic phase.

Probabilistic modeling is entirely analogous to the deterministic one but now the relevant parameters and their uncertainties (distributions) are propagated through the model. Hence, the state of nature models mentioned earlier provide the required input. An important issue specifically related to rock engineering is the treatment of fracture persistence, i.e. the fact that fractures and intact rock are interspersed; which has a significant effect on rock mass performance. The probabilistic approach allows one to rationally solve "the persistence problem". Probabilistic models are also well suited to deal with uncertainties affecting economics such as the cost and time to build a tunnel.

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In the final phase, one combines the uncertain performance from the probabilistic phase with its consequences; this combination is the risk. When doing this one has to be aware of the fact that a particular performance does not always have a consequence, another uncertain aspect usually called vulnerability. Also, consequences can be expressed in form of cost or, better, in form of utilities. Risk management can then be used to modify the risk through active actions which change the probability of unsatisfactory performance, or passive actions which change the consequences or the vulnerabilities.

Determining and using uncertainties in predictions have a long tradition in rock engineering. Hence, quite a few procedures and models are available. It is, however, most important to put all this in the context of the decision making structure as was done here.