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Practical use of the concept of geotechnical categories in rock engineering

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ABSTRACT

The aim of the paper is to show how Eurocode 7: Geotechnical Design Part 1: General Rules (EC7) could be developed in order to be in accordance with practise in rock engineering and construction. A main feature is the geological uncertiantis, which imply that a risk based approch should be used. The use of Geotechnical Category (GC) has therefore to be improved by (1) combining the consequences of a failure to the geological uncertainties before excavation, and (2) combining the consequences to the ground quality found after excavation. Three GC classes are needed to properly use the GC in rock construction.

The paper further describes how GC influences the design, which design method to be applied. It also outlines the types of control, inspection and supervision to be applied in the various GC classes during various stages of a project. An example is presented showing how GC can be determined at various stages of a rock construction.

1. Introduction

In 1975, the Commission of the European Community promoted an action program in the field of civil works construction to harmonize the rules for design and construction. The European Committee for Standardization approved in 2002 the standard EN1990:2002 "Basis of Structural design" with the objective to establish the principles and requirements for the safety, serviceability and durability of structures.

The standard for geotechnical design EN 1997-1:2004, which is a part of EN1990, was given the name Eurocode 7: Geotechnical Design Part 1: General Rules (EC7). Approved in 2004, it has been given the status of national standard in all European countries from 2010. There is, however, a debate on whether the standard can be directly applied on rock engineering issues like foundations, slopes, cuttings and underground openings. This paper provides suggestions on how the Eurocode could be developed an interpreted in order to be in accordance with rock engineering practice. The objective is to show how investigation, design, control and monitoring can be related to geotechnical risks and their classification into geotechnical categories. The paper also shows the design tools suitable for various geotechnical categories.

2. Basis of geotechnical design and rock mechanics

A general base for design is that the prevailing uncertainties should be covered by the safety margin of the designed structure. The size of the safety margin (reliability index) is related to the consequences of failure. More severe consequences will require higher margins. This implies that the design ought to be carried out with a method based on reliability and probability. Modern codes like EN1990: 2002 *Basis of structural design* are based on such thoughts. In the code, three different consequence classes are defined, and to each class a minimum value for reliability index is recommended with the intention of keeping a constant risk level.

The design of underground openings in rock has been discussed in many papers and textbooks such as those by Hoek and Brown (1980), Bieniawski (1984, 1989) and Palmstrom and Stille (2015).

As for all other engineering structures, and as stated in modern building codes, such as the European codes (EN 1990: 2002 *Basis of structural design* and EN 1997-1:2004 *Geotechnical design*), the design goals in rock must include structural resistance, durability and serviceability. The environmental impacts from construction and usage of the structure are to be acceptable. The main differences between structural and geotechnical design is the building material. In structural design, materials are man-made with well-defined properties. In geotechnical design, the soil and rock material is as given by nature with larger variation and uncertainties in properties. As stated above, the actual geological conditions will be revealed only upon excavation. This implies that the final design cannot be carried out in advance. In rock mechanics, the terms preliminary and final design are used to describe the time-related procedures required to obtain adequate information of the ground and the adapted design.

Structural resistance and serviceability as well as environmentally acceptable impacts are defined by ultimate or serviceability limit states.

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Adequate reliability of the structure shall be achieved. Durability is a part of this issue, but is related also to working life and maintenance. These factors require consideration at all stages of the design, and the design process should be transparent and the design work is traceable. This is facilitated if the design is carried out in accordance with accepted rules or standards. Further, rock design is based on the use of structural elements like steel bolts and concrete linings in interaction with the rock mass to improve stability. Compatibility with standards for structural design will then be required.

The two main types of structures related to rock engineering are underground openings and rock slopes. The environmental impacts are often due to spoil disposal, the effect on the groundwater changes in the surroundings and of the vibrations from the construction works and from usage. The structures and impacts can be classified as both temporary and permanent. The measures used during constructions to satisfy given requirements are in many cases governing for the permanent design.

In rock engineering, all these different issues are described as different design situations. The design situation has to be used in broad sense for describing issues related both to temporary and to permanent structures, including impacts as well as local and total stability.

In Eurocode, the design situation is classified according to the type of loads: persistent (normal use), transient (temporary), accidental (exceptional) or from impact of seismic events.

The basic requirements set up in EN 1990, should in the opinion of the authors to be redefined and be met by:

- adequate investigation of prevailing materials (ground conditions);
- appropriate choice of design tool;
- appropriate design situation and stages;
- suitable construction methods; and
- specified control procedures for design, construction and usage relevant to the particular project.

3. Main features in geotechnical design

3.1. Geological uncertainties

Geological uncertainties are related to the assessment of the geological and geotechnical conditions. They include incomplete knowledge of the actual geological conditions as well as poor accuracy in terms of properties and geometries. The geological uncertainties are related to the limited extent of ground investigations and also that the basis for rock mechanics and rock engineering are largely empirical. This implies that the geological uncertainties will decrease during excavation as the actual geology is revealed. The nature of many rock excavation projects implies that the level of confidence in the estimated ground conditions can be low based on the pre-investigation, especially in complex geological formations.

Muir Wood (1994) argues that geology is the prime source of uncertainty in geotechnical engineering. Unidentified features of the ground may lead to unexpected behaviour (incompleteness), secondly: identified features may not be expressible in quantified terms or to some degree unknown (system uncertainty) and thirdly: there may be a failure in communication between parties (human factors).

3.2. Ground conditions and behaviour types

Rock mechanics and soil mechanics form the scientific basis for geotechnical engineering. The properties of soils can be determined in laboratory tests with reasonable accuracy and application of established theories and design methods give good predictions of prototype behaviour.

In rock mechanics, the interaction of the blocks that form a rock mass dominates its behaviour. The randomness of the joints (joint direction and strength) within each joint set makes it difficult to characterise the mechanical behaviour of the rock mass. Laboratory testing has limited application due to scale effects. The assessment of properties in rock mechanics is therefore empirically based (based on observation of rock behaviour). This implies generally larger uncertainties of mechanical properties of rock masses than for soil materials. Rock masses can behave in different ways depending on the rock mass properties and applied stresses. Different behaviours require the application of different methods of assessment and design. Therefore it is necessary to understand the actual type of behaviour, as a prerequisite for estimating of rock support and other evaluations.

Behaviour type is an important concept in rock mechanics (Terzaghi, 1946; Hoek et al., 1995; Martin et al., 1999; Schubert et al., 2004; Palmstrom and Stille, 2015). They can be put into three groups: gravity driven, stress induced and water influenced. These phenomena are in not mutually exclusive and can therefore occur at the same time at any location.

A list of behaviour types is shown in Table 2. Depending on the geology, some types can be regarded as local instability, while in other situations they may influence on the total stability. Some will only prevail during excavation, others may only influence on the permanent stability.

3.3. Risks and consequences

3.3.1. Risks in rock engineering

Risk is in engineering defined as the combination of consequences of failure and the probability of failure and emanate from the underlying uncertainties. Geological uncertainties are dominant in rock engineering. Hazard is defined as potential source of undesirable consequences.

Risk management can be defined (ISO 31000) as handling such uncertainties that might prevent the objectives of the project from being obtained. The objectives can be expressed as the quality of the result, which means that implied or stated needs are fulfilled (IS0 9000). Projects may fail in many ways. Some issues like assessments of strength of structure material are so well known that they are not normally defined as involving any risks although they have to be controlled. However, all issues controlled during the work can have associated risks. Thus, the standard quality control work is part of risk management.

Risk in rock engineering includes many different issues and types of hazards. General aspects have been given by many authors, e.g. Blockley (1994) and Stille (2017). Guidelines have been elaborated by Eskensen et al. (2004).

Geotechnical risks are risks associated with geology as it affects the behaviour of permanent structures and their construction. Mitigation of these risks is a significant factor in cost and schedule control on all major engineering projects, see Hoek and Palmieri (1998). The resistance, durability and serviceability of the permanent tunnel structure are issues, which are to be handled in the design comparable with other building projects. However, stability issues and environmental impact during construction have also to be covered of the design work and can give consequences comparable with failure of permanent structures.

Geotechnical uncertainties can be split into two categories related to the sources. The first category is related to uncertainties from assessment of actual geological conditions. Example of this type of uncertainties is the limitations of observations of the geology ahead of the tunnel front at the time of construction. The second type is related to the uncertainties from estimation of ground properties of observed geology. Even if detailed assessments of the geological conditions is possible from mapping of excavated rock surfaces there remains uncertainties of the mechanical properties to be used in the deign.

Geotechnical risks can managed in different ways. The epistemic nature of the uncertainties implies that further information about the geological conditions can reduce the uncertainties. This may be achieved by additional geological investigations in the preconstruction