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When is the observational method in geotechnical engineering favourable?

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ABSTRACT

The observational method in geotechnical engineering is an acceptable verification method for limit states in Eurocode 7, but the method is rarely used despite its potential savings. Some reasons may be its unclear safety definition and the lack of guidelines on how to establish whether the observational method is more favourable than conventional design. In this paper, we challenge these issues by introducing a reliability constraint on the observational method and propose a probabilistic optimization methodology that aids the decision-making engineer in choosing between the observational method and conventional design. The methodology suggests an optimal design after comparing the expected utilities of the considered design options. The methodology is illustrated with a practical example, in which a geotechnical engineer evaluates whether the observational method may be favourable in the design of a rock pillar. We conclude that the methodology may prove to be a valuable tool for decision-making engineers' everyday work with managing risks in geotechnical projects.

1. Introduction

In geotechnical engineering, much construction work is performed under significant uncertainty. Nevertheless, the acceptability of structural performance must be verified. The relevant limit states are typically verified before construction has started with either deterministic or probabilistic calculation methods. However, when the structural behaviour is particularly hard to predict, geotechnical engineers may apply an approach known as the observational method, which was first defined by Peck [1]. In the 1980s, a similar approach known as "active design" was successfully applied in Sweden [2]. Today, the observational method is—with some modifications from Peck's original version—an acceptable verification method for limit states in Eurocode 7 [3], which is the European standard for the design of geotechnical structures.

The benefit of applying the observational method instead of a conventional design approach is its potential for savings in time and money, while continuously maintaining safety [1]. The essence of the method includes preparing (1) a preliminary design based on what is known at the time, (2) a monitoring plan for verifying that the structure behaves acceptably during construction and (3) a contingency action plan that is put into operation if defined limits of acceptable behaviour are exceeded. To be successful, the preliminary design must be chosen such that it avoids the use of costly and time-delaying contingency actions with sufficiently high probability. Over the years, successful applications of the observational method and discussions thereof have been reported [4–17].

However, the above examples seem to be exceptions: despite the potential savings, the observational method is not common practice, at least not in accordance to its formal definition. In fact, in a symposium arranged by the Institution of Civil Engineers for a special issue of Geotechnique on the observational method, it was found that further clarification of how to apply the method properly was needed, in particular, with respect to safety aspects [18]. Therefore, the concerns reported by Powderham [19] regarding uncomfortably low safety margins may not be surprising, especially as the advantage of the method is to allow less conservative designs than other design approaches. Recently, Harrison [20] and Bozorgzadeh and Harrison [21] identified a need for further elaboration of the observational method in Eurocode 7 for rock engineering applications. On this topic, Spross et al. [22] highlighted that Eurocode 7 does not explicitly require any safety margin for the completed structure, which may lead to an arbitrary safety at best and unknown safety at worst. In addition, there is currently no general guideline for establishing when the observational method is more favourable than other available conventional design methods.

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In this paper, we challenge the unclear definition of the observational method by suggesting that design with this method should be made under a reliability constraint. Based on this constraint, we propose a probabilistic optimization methodology that aids the decision-making engineer in choosing between the observational method and conventional design. The methodology suggests an optimal design after comparing the expected utilities of the considered design options. The methodology also addresses an application problem in the observational method [11,22]: how to satisfy the Eurocode 7 requirement "[to show] that there is an acceptable probability that the actual behaviour will be within the acceptable limits" [3]. Here, the "acceptable probability" refers to the probability of not needing to put contingency actions into operation.

The paper is structured as follows. The methodology is first presented in general terms. Its applicability is then shown with an illustrative example, in which two available design options of a rock pillar are analysed to find the more favourable one. Finally, the importance of the suggested reliability constraint and its relation to the limits of acceptable behaviour are discussed. In addition, remarks are made on the practical difficulties of applying the methodology in more complex cases.

2. Applied definition of the observational method

When the observational method is referred to in geotechnical engineering, there is sometimes confusion about its meaning. Some use the term for any design that is mainly based on observations, while others use it only for designs following a strict definition [18]. We have the latter view, and this paper follows the definition in Eurocode 7 [3]. This definition is quoted below, in which "P" indicates principles that must not be violated:

(1) "When prediction of geotechnical behaviour is difficult, it can be appropriate to apply the approach known as 'the observational method', in which the design is reviewed during construction.

(2) P The following requirements shall be met before construction is started:
   - acceptable limits of behaviour shall be established;
   - the range of possible behaviour shall be assessed and it shall be shown that there is an acceptable probability that the actual behaviour will be within the acceptable limits;
   - a plan of monitoring shall be devised, which will reveal whether the actual behaviour lies within the acceptable limits. The monitoring shall make this clear at a sufficiently early stage, and with sufficiently short intervals to allow contingency actions to be undertaken successfully;
   - the response time of the instruments and the procedures for analysing the results shall be sufficiently rapid in relation to the possible evolution of the system;
   - a plan of contingency actions shall be devised, which may be adopted if the monitoring reveals behaviour outside acceptable limits.

(3) P During construction, the monitoring shall be carried out as planned.

(4) P The results of the monitoring shall be assessed at appropriate stages and the planned contingency actions shall be put into operation if the limits of behaviour are exceeded.

(5) P Monitoring equipment shall either be replaced or extended if it fails to supply reliable data of appropriate type or in sufficient quantity."

3. Bayesian decision framework for the observational method

The proposed methodology is based on classic Bayesian decision analysis, which assumes that the optimal decision maximizes the expected utility [23,24]. Bayesian decision analyses generally include four phases (Fig. 1): (1) a decision to perform an experiment or measurement, e, (2) an outcome, z, of the performed e, (3) a decision to take an action, a, based on z, and (4) the occurrence of an event, θ. Bayesian decision analyses have previously been shown to be useful in geotechnical engineering [25–29], and van Baars and Vrijling [30] have briefly discussed how such analyses can be applied together with the observational method. The decision analysis in this paper includes reliability assessments and Bayesian updates to prior assumptions of relevant parameters with measurements; each aspect is discussed in the following subsections.

3.1. Limiting the observational method with a target reliability

In general, the performance of a structure consisting of j components may be described by the combination of their limit state functions $G_j(\mathbf{X})$, where $\mathbf{X}$ is a vector containing all relevant basic variables. On a component level, the event of unsatisfactory performance (hereafter denoted "failure", F, for simplicity) is defined as $F_j = \{G_j(\mathbf{X}) \leqslant 0\}$, and its complementary event—i.e., the event of satisfactory performance—is $\bar{F}_j$. A measure of the probability of failure of the complete system, p_F, is given by the multidimensional integral

$$p_F = \int_{\Omega} f_{\mathbf{X}}(\mathbf{x}) \mathrm{d}\mathbf{x}, \tag{1}$$

where $\mathbf{x}$ is the realization of $\mathbf{X}$, $f_{\mathbf{X}}(\mathbf{x})$ is the joint probability density function of $\mathbf{X}$, and Ω is the region for the failure event, defined by

$$\Omega \equiv \bigcup_k \bigcap_{j \in c_k} \{G_j(\mathbf{X}) \leqslant 0\}. \tag{2}$$

This formulation of the failure region implies that the structure is seen as a system of j components, and failure of the structure occurs when some combination c_k of these components fails [31]. The p_F is frequently presented in terms of the reliability index, β, given by

$$\beta = -\Phi^{-1}(p_F), \tag{3}$$

where Φ^{-1} is the inverse of the standard normal distribution function.

Using a conventional design method, the suggested design of the structure should, prior to its realization, meet an acceptance criterion, which is usually defined by a design code. For probabilistic design, the criterion is defined by a target probability of failure, p_{FT}, such that $p_F^{\{0\}} \leqslant p_{FT}$, where the superscript $\{0\}$ indicates that the assessment is based on prior information, e.g., from pre-investigations and engineering judgement.

From a probabilistic view, the "realization" implies that the built structure is one realization of many possible outcomes [32]. The realization causes the aleatoric uncertainties of the structural

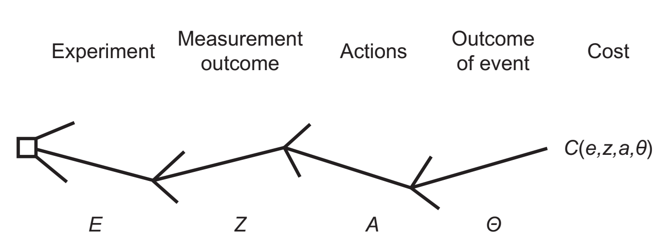

Fig. 1. General decision tree.