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A review on the current use of RBD in Geotechnical Design practice in view of the next Eurocode 7

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Abstract: In course of the evolution of the next Eurocode 7 CEN TC 250/SC7 Task Group C3 is developing a guideline on reliability-based methods for geotechnical design and assessment. As part of this work, a survey was prepared to identify best practices and examples that could be used for illustration in the guidelines. Beside this, information on possible benefits and limitations of using reliability-based methods in the engineering practice were requested from the participants. The survey was distributed in summer 2021 among the international geotechnical community. The results reveal that the main benefits are seen in the identification and visualization of uncertainties and risks as well as in the possibilities for design and cost optimization. However, as major limitations an often insufficient data basis but generally a lack of acceptance on the side of the clients and an insufficient knowledge on the side of possible practitioners were identified. Consequently, clear guidance on how to use reliability-based methods and how to implement them in decision processes are needed. The TG C3 guideline therefore is a step in the right direction. On the other hand, integrating methods of reliability analysis in the engineering education already at an early stage is also considered to be important.

Keywords: reliability-based design; Eurocode 7; survey; guideline

1 Introduction

Currently, the next generation of Eurocode 7 (prEN 1997) is being developed by CEN TC 250/SC7. The new code will be much more linked to Eurocode 0 (prEN 1990) compared to its current version and with that, generic principles of reliability-based design (RBD) already adopted in structural design will be implemented into geotechnical design as well. One apparent consequence is that the verification of limit states by reliability-based methods (RBM) will be explicitly allowed within the safety framework provided by EN 1990 as an alternative to the partial factor method.

To promote the use of RBM in the geotechnical design practice a guidance for (full probabilistic) reliability-based verification of limit states within the safety concept of the Eurocodes is currently being established by TC250/SC7 Task Group C3 'Reliability-based methods' (TG C3, 2022). The main objectives of these guidelines are, among others, to provide recommendations for the selection of target reliability values, methods and tools for geotechnical reliability analysis and to give guidance for modeling uncertainties involved in geotechnical design. In these guidelines, best-practices and recommendations shall be presented supplemented by suitable examples illustrating how to apply these methods in the engineering practice.

Along with the work on the guidelines, a survey has been prepared and distributed within the international geotechnical community to evaluate the existing experience on using reliability-based (probabilistic) methods in research and practice. The main purpose of this survey was to identify possible case studies for the aforementioned guidelines. Another aim was to reflect the potentials and benefits but also the challenges and limitations of applying reliability-based design methods from the viewpoint of practicing engineers. The latter aspect is subject of the present paper. After a short introduction of the design and safety philosophy of prEN 1990 and prEN 1997 as well as an overview on the aforementioned guidelines, the results of the questionnaire are presented and discussed in light of the practical use of RBM within limit state design.

2 Reliability based design in the context of the next Eurocode 7

2.1 Structure and design philosophy of prEN 1997

The next Eurocode 7 (prEN 1997) will comprise three instead of two parts. Part 1 contains general rules whereas part 2 provides regulations for planning, execution and reporting of ground investigations as well as rules for developing the ground model and determining derived values of ground properties. Part 3 finally defines specific requirements for the design and verification of geotechnical structures, reinforcing elements and measures for ground improvement and groundwater control.

The target level of reliability to be maintained by design according to prEN 1997 is defined in EN 1990-1 where the concept of reliability is introduced to structural *and* geotechnical design. The term 'reliability' covers the safety, serviceability and durability of a (geotechnical) structure over its entire service life and is the common basis for all Eurocodes. According to JRC (2022), reliability in a narrow sense 'refers to the way uncertainties are dealt with in design and assessment by the use of partial factors or more advanced probabilistic methods'. Hence, prEN 1997, which adopts limit state design, can also be interpreted to be reliability-based. According to the concept of this code, the required level of reliability shall be achieved by following the regulations in prEN 1997 with prEN 1990-1 not only on design and verification, but also those on quality control, reporting, supervision, monitoring and maintenance. PrEN 1997 further allows the verification of limit states by one or more of the following methods:

- Calculation using the partial factor method *or other reliability-based methods*
- Prescriptive rules
- Testing
- Observational method

For the design by calculation, the regulations in part 3 are based on the partial factor method and the verification of ultimate and serviceability limit states. However, with the regulation above, RBM are explicitly introduced as an equal alternative. Moreover, it is stated that, if the uncertainty in ground properties is too large to ensure the level of reliability required by EN 1990-1, limit states should not be verified using the partial factor method alone. In such a case, the application of, e.g. the observational method in a reliability-based framework could be a possible solution (see e.g. Spross, 2016).

PrEN 1997 will be supplemented by several guidelines on common topics. These guidelines are currently being prepared by TC250/SC7 Task Groups C1–C4 and cover the following topics:

- Task Group C1 – "From derived to design value"
- Task Group C2 – "Assembling the Ground Model"
- Task Group C3 – "Reliability based methods"
- Task Group C4 – "Implementation of Design during Execution"

The authors of this paper are members of Task Group (TG) C3 "Reliability based methods" which is developing the guideline 'Reliability-based methods for geotechnical design and assessment' introduced in the next section.

2.2 Guideline on reliability-based methods for geotechnical design and assessment

As outlined before the next generation Eurocode 7 will explicitly allow the use of RBM as an alternative to limit state design with the partial factor method. However, such methods are not yet established in the geotechnical design practice. Therefore, the main objectives of the guideline are:

- to explain the reliability-based safety concept of the Eurocodes in relation to geotechnical design and assessment according to EN 1990 and EN1997;
- to provide recommendations for target reliability values;
- to describe methods and tools for geotechnical reliability analysis;
- to provide guidance for modelling the uncertainties involved with geotechnical analysis, including typical statistics for ground properties and model uncertainties;
- to describe how to derive partial factors for different service life durations;
- to formulate best-practices and provide examples.

Figure 1 shows a flow chart indicating the procedure to perform RBD. The structure of the guideline follows this flow chart and recommendations will be included for the different analysis steps supplemented by examples illustrating the different methods and procedures. Additionally, selected case studies will be provided in an Annex showing a full RBD performed according to the flow chart and adopting the recommendations from the guidelines.

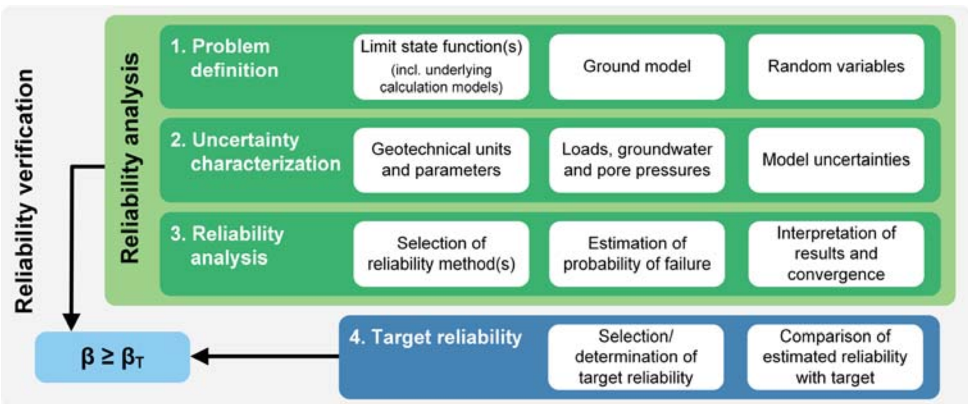

Figure 1. Flowchart of reliability verification based on the introduced guideline (TG C3, 2022).

In the course of the work on the guideline, it was decided to conduct a survey among the geotechnical engineering community in order to identify suitable case studies for the Annex. However, during the development of the survey it quickly became clear that additional information could be generated on the subject of application of probabilistic methods and reliability analysis. This information does not include theoretical basics, but rather subjective assessments of participants in dealing with these methods. Yet, for this reason, such information was considered a valuable input for the guidelines. The concept and the major results of the survey are presented in the following section.

3 Survey on the use of RBD in the engineering design practice

3.1 Aim and concept

The survey with the title *"Application of probabilistic methods in geotechnical research and practice"* was created and conducted with the open source online survey application LimeSurvey. The survey was divided into three sections. The first section asked questions about the participant's background. Information such as the country of residence, kind of institution and the task in it as well as the academic background were requested. Further, the general section asked whether and where the participant has gained knowledge or experience of probabilistic methods and their application prior to or during their work in geotechnical engineering. Participants who had experiences in probabilistic methods moved to the questions in the second section. Otherwise, this section was skipped and the participant was passed to the third section. In the second section, further questions were asked about the applied probabilistic methods such as the field of application as well as the methods and software tools used. In addition, the participants were asked to give an assessment of the advantages and limitations of RBM. In the third section, participants who had no application experience so far were asked about the reasons for this. Finally, participants who could provide a potentially interesting application example for the guideline were asked for their contact details in order to be able to ask for further details at a later stage.

From the European TG C3, the survey was sent out worldwide. Potential users of RBM, such as planning engineers and university members, but also various national societies and organizations from geotechnical science and practice were addressed. The survey ran from June to September 2021 and 329 responses from across the world have been received. From these responses, 133 were completed and could be used for further evaluation.

3.2 Survey results

3.2.1 General information

This section provides a brief overview of the participants' backgrounds. First, the participants were asked about the country in which they work. Although this does not initially allow any conclusions on the use of RBD, it does give an impression of the reach of the survey. Table 1 provides an overview of the countries mentioned and the corresponding number of participants per country. Although the survey was prepared and distributed by TG C3 as a CEN committee, it also reached people in non-CEN member countries. However, the survey was mainly answered by people in CEN member states, in particular by participants in Germany, Spain and the Netherlands.

Table 1. Overview of the countries in which participants work and number of participants per country; in italics: non-CEN Members.

Country	Number
Germany	64
Spain	25
Netherlands	11
Switzerland	9
France, Ireland, UK	5
Austria	4
Portugal, *USA*	3
Canada, *China,* Finland, Italy, *Japan*, Norway	2
Argentina, Belgium, *Brazil*, *Chile*, Cyprus, Czech Republic, *India*, *Iran,* Luxembourg, *Peru*, Poland, Romania, *Russia*, Sweden, *Taiwan*, *Vietnam*	1

The next two questions asked about the kind of institution the participants work in and their function or tasks there. Figure 2a first shows the classification into planning offices, universities, construction companies, authorities, research institutes and regulatory bodies. Others are, e.g., software companies, doctoral students and laboratory services. While almost half of the participants work in an engineering office and another quarter at universities, the functions and tasks are obviously more evenly distributed. The various functions within the institutes can be seen in Figure 2b. The functions listed under 'Others' include e.g. software development and studies. Particularly interesting was the finding that of the participants from engineering or planning offices about 74% already have experiences with probabilistic methods, whereas 87% of participants from universities used RBM.

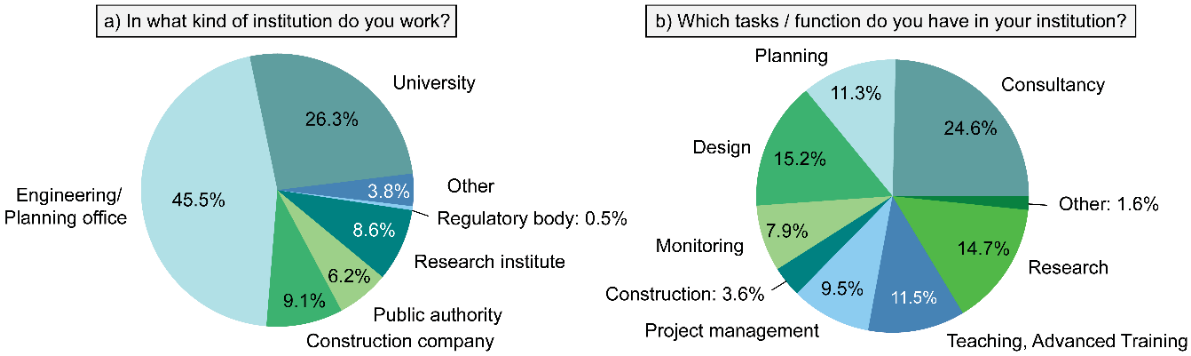

Figure 2. Overview of a) the kind of institutions in which participants work and b) their functions or tasks in the institution.

In the further course, the participants were asked about their (academic) background. As can be seen very clearly in Figure 3a, the majority of the participants (almost 75%) are civil engineers of whom 65% stated that they had already used RBM. Geologists and geoscientists were represented by over 20%, whereas only 2-3% each stated mathematics or "other" (e.g. mining engineering, physics and political science) as their background. In addition, the participants were asked where they had gained experience and knowledge in RBM. As can be seen in Figure 3b, about one third already have expericene in university classes during their studies (probably civil engineering studies, cf. Figure 3a). However, a significant proportion with each approx. 23% only gained expericnce with the application of RBM during their doctoral thesis or in self-studies. Another ~ 13% learned by advanced training.

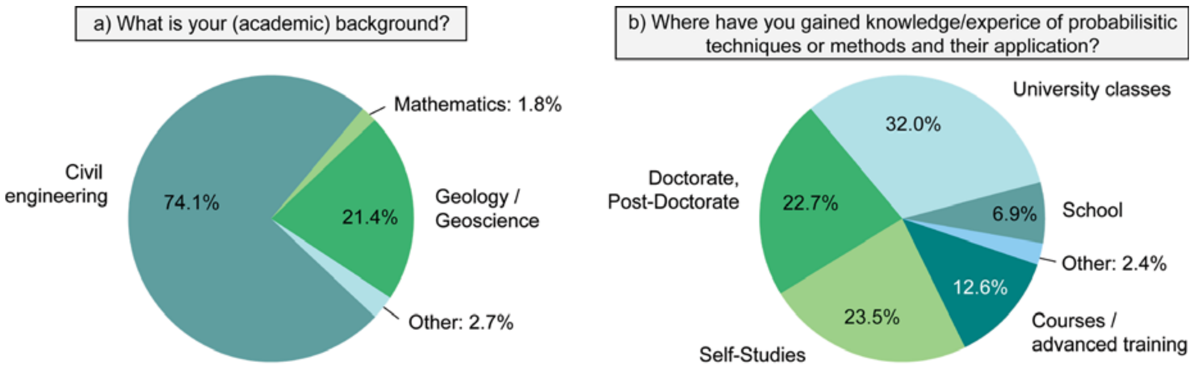

Figure 3. a) (Academic) background of participant and b) context in which participants have gained knowledge or experience on probabilistic methods and their application. Multiple answers were possible.

3.2.2 Area and purpose of application

The fields of application shown in Figure 4 correspond to clauses in prEN 1997-3 where rules for design and verification are provided for the specific geotechnical structures. The fields that are grouped under 'Others' are, e.g., offshore foundations, abandoned mining and tunneling, i.e. fields which are not covered by prEN 1997. It can be seen in Figure 4, that probabilistic methods and reliability studies are not limited to individual structures, but are used in all fields of geotechnical design. Nevertheless, there are some fields where RBM is used more frequently. In particular, these include slopes, cuttings and embankments, ground properties and retaining structures. Pile foundations and spread foundations also account for a significant proportion with around 10% of the mentions.

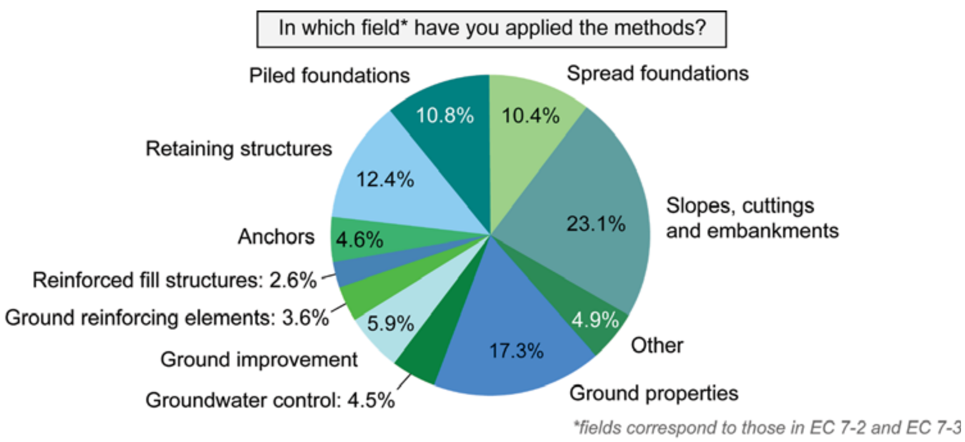

Figure 4. Fields in which participants applied RBM; multiple responses were possible.

3.2.3 Applied methods and objectives of application

In the first question on the applied methods, the participants were asked which methods and procedures in probabilistic design and reliability analysis they had used. Based on the answers, methods for describing uncertainties and reliability analysis methods can be differed. The results show that for reliability analysis mainly Monte Carlo simulations are used whereas the First-Order-Reliability-Method (FORM) was ranked next. Other more specific methods such as importance sampling or subset simulation were also mentioned often, while the First-Order-Second-Moment (FOSM) seems to be used less frequently. Moreover, many participants also mentioned basic statistical techniques, e.g. distribution functions or correlations. All methods will be covered by the TG C3 guidelines.

In the second question to this topic, the participants should outline the main objectives of applying RBM in their projects and the answers were again grouped into categories. From this, three main application objectives could be identified with reliability assessment and determination of uncertainties stated most frequently. Another objective of application was risk assessment and risk management. Additionally, RBM were used in the evaluation and optimization of costs and materials within the design process, but also in the assessment of existing structures.

3.2.4 Limitations of application

The answers to the question "*Where is an application of RBM not an option and why?*" can be summarized in nine categories. An overview of how often a category was mentioned can be seen in Figure 5. One reason with a larger number of votes describes an application as not useful if there is an insufficient data basis or if there are no comparable cases (3: not enough data). Further, many participants voted not to apply RBM to standard structures (2: simple design), because the effort is not worth it, as RBMs are complex, expensive and time-intensive.

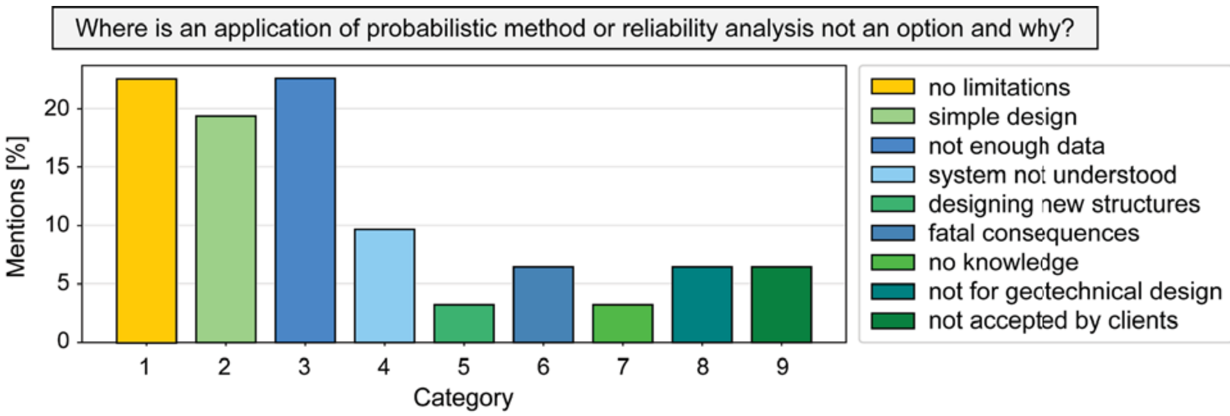

Figure 5. Classification of the answers to the question "Where is an application of probabilistic methods or reliability analysis not an option and why?" into nine categories.

At the same time, however, a similar number of participants see no limitations to the use of RBM in geotechnical design (1: no limitations) and consider its application particularly useful when a complex or important structure is involved. Furthermore, some participants see no possibility for application if a system is not fully understood or describable (4: System not understood), in the design of new structures (5: Designing new structures) or even fundamentally in geotechnical design as such (8: not for geotechnical design). In addition, some participants indicated that they do not recommend the use of RBM if a failure of the structure is associated with fatal consequences for humans and the environment (6: fatal consequences). Further, probabilistic methods should be used only when a planning engineer is trained in using the methods and interpreting the results (7: no knowledge). The last reason against applying RBM is the lack of acceptance (9: not accepted), e.g. by clients or politicians, which can also be a reason for resorting to the partial safety factor concept instead of RBM.

4 Discussion of results

The survey gives an overview of the application fields, objectives and common methods related to the use of RBM in geotechnical design. However, it also appears that opinions on the use of probabilistic methods as well as the perceived advantages and limitations of the methods vary widely and seem to depend on the (academic) background of the participants or on their functions within their institutions or even only on personal attitude to this topic. While, e.g. some see no limitations and recommend their application for complicated tasks with a small database, others see no application exactly there. According to the survey results, clear advantages of RBD are the objective identification, evaluation, assessment and visualization of uncertainties and risks in geotechnical design. Another important aspect is to understand the sensitivity of input parameters to the safety and the integrity of the structure for which probabilistic methods provide a consistent mathematical framework. Another major benefit of probabilistic design is the possibility to communicate risks to clients or other decision makers on a quantifiable and comprehensive basis. All this allows optimized designs by preventing over-conservative approaches.

On the other side, main key points were identified, which are obviously major limitations preventing a broader use of RBM in the geotechnical design practice. First, RBM are generally believed to be too expensive, time consuming and therefore not reasonable to be implemented especially in standard design projects. Further, a major argument against the application is the supposed insufficient data basis, which inevitably raises the question of when the available data in geotechnical design is considered sufficient. In this regard, the assessments made seem subjective to some degree. In addition, RBM serve especially for the quantification of uncertainties in the design process; in view of available methodologies such as Bayes Statistics a small data basis should therefore not a priori represent an obstacle and especially then reliability analysis can be considered an alternative or complementary to the partial safety factor concept. The next aspect concerns the design task itself; here, the character of the considered problem plays a major role. Reservations exist where a problem is not fully understood or cannot sufficiently be described in the context of limit state design. This applies especially to problems that cannot easily be divided into separate limit states or where it is unclear which limit states do exist and whether all limit states are considered.

Another point concerns the level of understanding and acceptance of this type of analysis and the corresponding results involved with RBD. In design practice clients, project partners and/or inspection engineers may not accept such methods as not being verifiable or because they do not understand the meaning of failure probabilities and cannot deal with an existing risk. In this regard, the semi-probabilistic methods are easier to understand and - which is most important - they suggest absolute safety or, in other words, a probability of failure of zero, if the limit states are verified based on the partial factor method with pre-defined partial factors. It often seems not to be understood that partial factors are also based on certain target reliabilities and that absolute safety does not exist. However, also the agreement on target reliabilities on a project-specific basis also requires an in-depth understanding of this design philosphy.

An obvious solution to handle these problems is to increase the knowledge not only of those applying RBM but also of those who have to assess the results in decision-making processes. This is important to avoid misunderstanding and misinterpretation of results, which may have fatal consequence. A lack of understanding in this regard can be perceived as an additional source of uncertainty, which is hard to define. As discussed by, e.g., Baecher (2017), many geotechnical engineers are intuitive in Bayesian thinking in their daily work but in regard to RBD people often adhere to the frequentist form of statistical thinking which is not useful expect in narrowly defined problems. Hence, this finally leads to the crucial aspect of how to achieve an adequate state of knowledge to apply RBM. Since not every university graduate has a doctorate or does self-studies, more opportunities must be created to learn the application and interpretation in the university education but also by advanced training, which is especially importet for enigeers with other acadmic backgrounds, e.g. universities of applied science.

5 Conclusions

A survey was conducted in the course of the TC250/SC7 TG C3 work on guidelines for reliability-based design in the context of the next Eurocode 7 to evaluate the status of RBM in the engineering practice. The results show that RBM are already applied in geotechnical design especially in cases with complex boundary conditions. The fields of application range from assessing ground properties to the design of slopes, cuttings and embankments or retaining structures and cover most geotechnical structures included in prEN 1997.

Despite major benefits of RBM such as objective uncertainty and risk assessment, clear limitations were identified that may prevent a broader use. Beside the often addressed insufficient data basis or a high complexity, a major obstacle seems to be a lack of knowledge and acceptance among the people involved in the design. Hence, there is a strong need for clear guidance on using reliability-based methods, how to interpret the results and implement them in decision-making processes. Nevertheless, there seems to be a broad and growing interest in probabilistic methods and RBD. Thus, the TG C3 guidance may help to close this gap and to further advance the introduction of reliability analysis into the geotechnical engineering practice.

Acknowledgments

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