TU Delft

Delft University of Technology

Document Version
Final published version

Citation (APA)
Schweckendiek, T., & Korff, M. (2026). 2nd generation of Eurocode 7 – verification of limit states: Reliability-based methods and the Observational Method. In J. Pistrol, D. Adam, & H. F. Schweiger (Eds.), *Proceedings of the 21st ICSMGE* (pp. 6853-6856). Article 771 ÖGG. https://doi.org/10.53243/ICSMGE2026-771

Important note
To cite this publication, please use the final published version (if applicable).
Please check the document version above.

Copyright
In case the licence states “Dutch Copyright Act (Article 25fa)”, this publication was made available Green Open Access via the TU Delft Institutional Repository pursuant to Dutch Copyright Act (Article 25fa, the Taverne amendment). This provision does not affect copyright ownership.
Unless copyright is transferred by contract or statute, it remains with the copyright holder.

Sharing and reuse
Other than for strictly personal use, it is not permitted to download, forward or distribute the text or part of it, without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license such as Creative Commons.

Takedown policy
Please contact us and provide details if you believe this document breaches copyrights.
We will remove access to the work immediately and investigate your claim.

This work is downloaded from Delft University of Technology.

Proceedings of the 21st ICSMGE, Vienna, Austria, 14 – 19 June 2026. Pistrol, Adam & Schweiger (eds.)
Published by: ÖGG, Austrian Society for Geomechanics, Salzburg, Austria, ISBN 978-3-9503898-4-5
https://doi.org/10.53243/ICSMGE2026-771

2nd generation of Eurocode 7 – verification of limit states: Reliability-based methods and the Observational Method

Timo Schweckendiek[1,2], Mandy Korff[1,2]
[1]Deltares, Delft, Netherlands, timo.schweckendiek@deltares.nl
[2]Delft University of Technology, Delft, Netherlands

ABSTRACT: In the 2nd Generation of Eurocode 7, the verification of limit states is based on different methods: calculation using the partial factor method or other reliability-based methods; prescriptive rules; testing and Observational Method. The design of each geotechnical structure thus needs to identify and verify limit states regarding both ultimate and serviceability issues, considering one of these methods. This paper lays out novel elements in the 2nd Generation of Eurocode 7, specifically addressing reliability-based methods and the Observational Method. The possible combined use of both methods is also discussed. For example, the Observational Method is particularly amenable for probabilistic treatment, since the ability to quantitatively incorporate monitoring data, such as measured deformations, is a strong advantage of probabilistic reliability methods through the use of Bayesian updating. Both, reliability-based design and assessment as well as the Observational Method promise great potential, providing alternatives to the most commonly used partial factor method, where verifications with the latter either lead to infeasible or uneconomic designs. For both, greater effort is required compared to conventional designs. Therefore, we would expect applications rather for non-standard structures or design situations.

KEYWORDS: Eurocode 7, verification, limit states, reliability-based methods, observational method.

1 INTRODUCTION

1.1 *2nd generation Eurocode 7*

The Second-Generation Eurocodes will be published during the period 2023 to 2027 and will fully replace the current codes by 2028, when the first-generation Eurocodes will be withdrawn. In the 2nd-Gen Eurocodes, the design of geotechnical structures is spread across four standards: EN 1990 for the basis of geotechnical design and three parts of EN 1997 for specific aspects of geotechnical design, as shown in Figure 1.

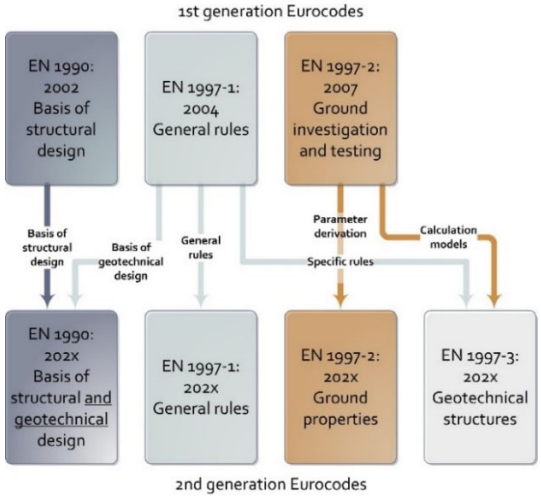

Figure 1. New structure of Eurocodes for geotechnical design and assessment

1.2 *Objectives*

The objectives of this paper are the following:

- To lay out novel elements in the 2nd generation Eurocode 7 for both reliability-based methods and the observational method.
- To discuss the implications for practical design and assessment.
- To highlight new opportunities.

For practical applications illustrating the opportunities we will make reference to readily published examples.

1.3 *Limit state design*

The 2024 version of EN1997-1 describes limit state design, as testing the two principal design criteria: the ultimate limit state (ULS) and serviceability limit state (SLS). The ULS and SLS design criteria mean in simplified form that the Resistance should be larger than the Load, when they are equal the Limit State has been reached. Since both Resistance and Load are uncertain, the probability of Resistance being smaller than Load needs to be assessed and compared with a target probability of failure, which depends on the consequences of failure of the structure.

This can be achieved using a reliability-based method or with the Observational Method (and for completeness, EN1997-1 also allows verification by Testing or by Prescriptive rules, but these are not part of this paper).

1.4 *Relevant changes*

In terms of reliability-based design and assessment (RBDA) the major change has been that EN 1997-1:2024 now lists reliability-based methods as an option for the verification of limit states, and therefore, as an alternative for the partial factor method. While the 2nd generation EN 1997 series does not contain any more detailed provisions, JRC (2024a) was published as a dedicated guidance document to guidance for (full probabilistic) reliability-based verification of limit states for geotechnical structures within the safety concepts of the Eurocodes. Furthermore, EN 1990:2024 Annex C provides the fundamentals of reliability approaches, and JRC (2024b) details the reliability backgrounds and safety concept underlying the entire Eurocode series.

As for the observational method (OM), relevant changes in OM clauses are concentrated in EN1997-1. The main change is that Eurocode 7 now offers the observational method as one of four methods to verify sufficient safety with respect to limit states and on the same level as the most used partial factor method. Further changes are described in Chapter 3 of this paper.

2 RELIABILITY-BASED VERIFICATION

The principles and practical application of the reliability-based verification of limit states for both design and assessment of geotechnical structures are laid out in JRC (2024a). The sections below provide a concise overview.

2.1 *Uncertainties and principles*

Geotechnical design and assessment involve massive uncertainties not only in the ground model and properties, but also in groundwater conditions, actions and last but not least the calculation models used in the verification of limit states (Figure 2).

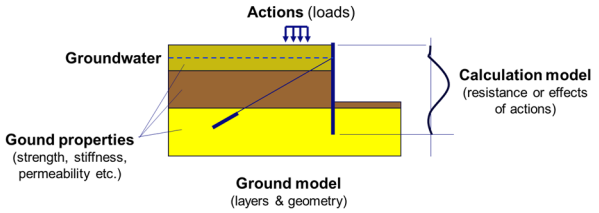

Figure 2. Uncertainties in geotechnical limit state verifications

Reliability-based methods can be used as an alternative to the partial factor method. In the partial factor method uncertainties are covered through the use of representative values and partial factors resulting in design values. In reliability based verification, uncertainties are explicitly addressed using probabilistic modelling. The uncertainties in ground properties, for example, are captured by using random variables ($\boldsymbol{X}$) which are characterised by probability distributions ($f_{\boldsymbol{X}}(\boldsymbol{x})$). The probability of failure is then defined as the probability of exceeding the limit state (defined through the limit state function $g(\boldsymbol{x})$):

$$P_f = \int_{g(\boldsymbol{x})<0} f_{\boldsymbol{X}}(\boldsymbol{x})\, d\boldsymbol{x} \qquad (1)$$

The reliability index is a measure of the probability of (non-) failure (Φ^{-1} is the inverse standard Gaussian probability function):

$$\beta = \Phi^{-1}(1 - P_f) \qquad (2)$$

JRC (2024a) describes how the partial factor method (also called 'semi-probabilistic') is related to the concept of reliability.

2.2 *Reliability methods*

There are numerous methods published in the literature for determining P_f and β. The guidelines JRC (2024b) provide an overview of the ones with most practical experience, and give recommendations for choosing a method based on the problem characteristics (Figure 3).

The main issues are computation time of the model used for limit state verification (due to the large number of computation runs needed), and the 'complexity' of the model (non-linearity, noise etc.).

2.3 *Reliability requirements*

The reliability index β obtained from the reliability analysis needs to be greater than the required (or target) reliability index β_T:

$$\beta \geq \beta_T \qquad (3)$$

The main reference for reliability requirements is given in EN 1990 through the following table (Figure 4).

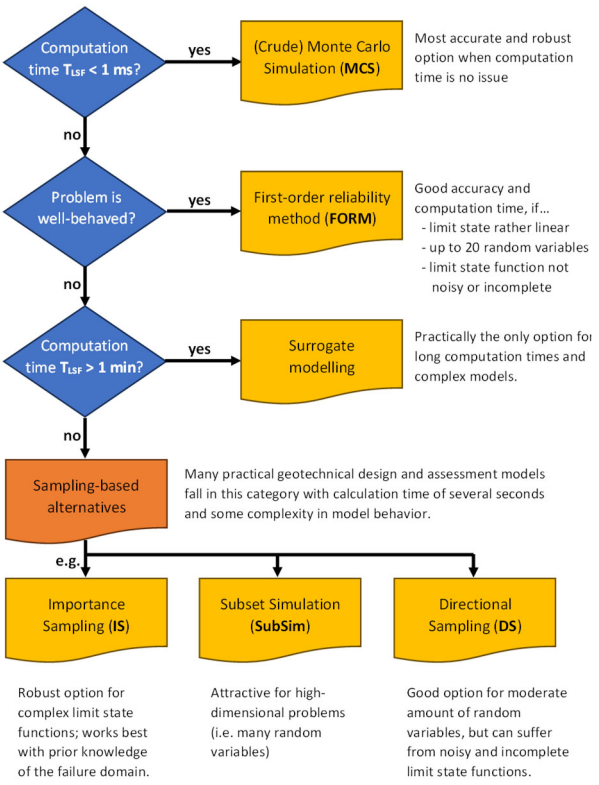

Figure 3. Guidance for the selection of reliability methods (from JRC, 2024a)

Consequence class[a]	1-year reference period β	50-year reference period	
		β	$P_{f,50}$
CC3	5,2	4,3	~ 10^{-5}
CC2	4,7	3,8	~ 10^{-4}
CC1	4,2	3,3	~ 10^{-3}

Figure 4. Target reliability values for reliability index (ULS) for different consequence classes according to EN 1990-1 Table C.3.2

There are a number of considerations when choosing an appropriate reliability index value such as consequence class, reference period, structural system behavior, design vs. assessment etc. The guideline JRC (2024a) provides practical recommendations and give an international perspective by comparing with reliability requirements in other international design guidelines or codes of practice.

3 OBSERVATIONAL METHOD

3.1 *Principles*

EN1997-1 Paragraph 4.7 details verification by the Observational Method with the following clauses repeated here:

"(1) When using the Observational Method to verify limit states, a range of different design variants (including corresponding Geotechnical Design Models) shall be established, covering all foreseeable relevant ground responses and ground–structure interactions.

(2) If monitoring of the relevant ground responses and ground–structure interactions does not allow detection of incipient failures, the Observational Method shall not be used.

(3) A contingency plan shall be prepared that defines contingency measures to be applied when actual behaviour violates acceptance criteria or threshold values.
(4) Contingency measures shall include methods for preventing immediate failure, and instructions for selecting a prepared design variant that covers the actual ground response and ground–structure interaction.
(5) Ultimate and serviceability limit states shall be verified for each design variant.
(6) Execution specifications shall be prepared for each design variant.
(7) There shall be sufficient design variants to allow replacement of the current design variant by one matching the observed behaviour of the structure when the threshold value is reached.
(8) An Inspection Plan and a Monitoring Plan shall be devised to check the assumptions against the specified acceptance criteria and threshold values for each design variant.
(9) The design shall be adapted to the evaluated results in (8) by application of the contingency plan."

The second generation thus is more explicit than the first generation in the need to make and report different design variants, and for each of them a contingency plan, inspection plan and monitoring Plan. At the same time, ULS and SLS need to be verified for each Design Variant, which requires a careful look at the meaning of ULS and SLS for each design variant.

3.2 *Verifications*

EN1997 issues users of the Observational Method verification approach to make several design variants that describe "the anticipated behaviour of the geotechnical structure, given that the relevant ground properties lie in a predefined range". EN1997 clause 4.3.2.1 states that representative values shall be determined for each limit state; these should be linked to the predefined range mentioned here.

For each Design Variant, threshold values and acceptance criteria should be defined, that "with an appropriate safety margin define the point at which contingency measures are applied to avoid exceeding the limiting value" (threshold value) or describe "the acceptable variations of material, ground and geometrical properties expressed as tolerances to avoid exceeding the serviceability criteria or the ultimate limit state" (acceptance criteria).

In practice the amount of Design Variants and value ranges and criteria linked to them need to be carefully considered as there is a tradeoff between design effort and potential benefit.

3.3 *Inspection and monitoring plan*

A new distinction is made in the second generation between inspection and monitoring. Both are required for every project, with or without OM. Inspection refers to "measures or activities during execution to check the compliance of the execution with the execution specification and the validity of the design assumptions in relation to encountered ground conditions at the site". Monitoring refers to "measurement or observation of the behaviour of the ground or structure to check compliance with the serviceability criteria and to check that the execution complies with the design assumptions and execution specifications".

Monitoring shall be rapid enough to capture potential changes and also management and communication procedures need to be sufficiently fast. For the application of the OM this has been a prerequisite ever since it was first established.

3.4 *Contingency measures*

Essential for the verification by the Observational Method is the use of contingency measures described in a contingency plan. Paragraph 10.6 reports on contingency plans: "(1)…the Contingency Plan shall address foreseeable ground responses and ground-structure interactions and give contingency measures appropriate for each design variant. (2) The Contingency Plan shall be activated if threshold values or acceptance criteria for the current design variant are exceeded."

EN1997 also specifies the use of a Geotechnical Construction Record for all structures that for the OM includes the encountered scenarios at site and the measures implemented, with justification.

3.5 *Discussion*

When designing a structure and verifying limit states with the Observational Method according to the second generation Eurocodes, the main design principles of the original OM of Ralph Peck, and the most common application forms in current practice (CIRIA 185) can remain intact, while changes have to be made in the terminology (Monitoring and Inspection) and also in the extent to which alternative options (Design Variants) are described. The derivation of representative values requires careful consideration of the ranges that are linked to each design variant, otherwise the benefit of the use of the Observational Method will quickly vanish due to high costs. On the other hand, the additional requirement of the 2nd generation Eurocodes to make a Supervision, Inspection and Monitoring Plan and Construction Record, might reduce the step towards a a-priori use of the OM, potentially resulting in increased safety for projects while economically attractive.

The combined use of reliability-based methods and the Observational Method may be a next step forward, also providing options for ULS (and SLS) verifications during the construction phase, which are otherwise not clearly specified in EN1997.

4 COMBINED USE

In the 2nd-generation Eurocode 7, reliability-based methods and the Observational Method are treated separately. However, probabilistic approaches can be tremendously beneficial when implementing the Observational Method, and help to overcome some common challenges. Below we elaborate on a few examples.

4.1 *Risk-based intervention thresholds*

A key application of the combined use of reliability-based methods and the OM is the use of reliability-based thresholds for verifying structural safety. As detailed by Spross & Johansson (2017) and Spross & Gasch (2019), it is possible to establish threshold values by equating the conditional probability of failure related to the threshold exceedance to the target failure probability. The threshold represents the point at which the reliability requirement for the construction phase is no longer met. Conceptually, the use of such thresholds ensures that the structure maintains the desired level of reliability throughout construction. Monitoring thus becomes a verification tool, enabling less conservative designs compared to traditional approaches, while still ensuring safety through probabilistic control, and through accounting for potential interventions. Spross & Johansson (2017) demonstrated this approach for slope stability, where rainfall-induced pore pressure increases were monitored and compared against reliability-based thresholds to determine the need for emergency stabilization.

Since the target reliability index values provided in EN1990 Annex C were established for the ultimate use of the structure, not the construction phase, it may also be beneficial to use dedicated reliability requirements derived for the underlying safety requirements referring to risk to life or economic considerations as explained in JRC (2024b). In that case the OM would essentially be a form or risk-based design in the sense that the consequences of failure are explicitly quantified.

4.2 *Bayesian updating with monitoring*

Bayesian updating enhances the Observational Method by incorporating monitoring data in a probabilistic way to update the reliability of the structure. This approach is inherently iterative: the posterior distribution obtained at one stage of the project serves as the prior for the subsequent stage. As the project progresses, this continuous refinement enables increasingly informed decision-making. Note that the aim of a reliability analysis normally is to estimate the probability of failure, while in case of Bayesian updating for the OM, it is to draw samples in the accepted (failure) domain. Researchers have used this approach to include additional site investigation data in reliability analysis. Duvvuru Mohan et al (2019) showed for example a case of updating a slope analysis with additional CPTs. The application of monitoring data during the project execution is a bit more rare. De Wolf et al (2021) showed the possibilities and impracticalities of inferring monitoring data for a deep excavation. Also, Liu et al. (2024) developed a Bayesian-based slope digital twin model and used slope monitoring data and past performance records to optimize the selection of slope hydraulic model for updating the statistical information of soil properties.

Ultimately, having reduced uncertainties in (ground) properties, and hence the structural performance of a geotechnical structure, also results in information on the as-built reliability, due to the additional information taken into account. Often, the as-built reliability will be higher than the design reliability, leading to an increase in capacity and residual service life (for structures subject to material degradation).

4.3 *Probability of contingency measures*

Reliability-based approaches are probabilistic and as such allow for quantifying the probability that threshold values are exceeded, i.e. that contingency measures will be activated or needed. In tunnel construction through soft soils, for instance, the probability of requiring face pressure adjustments or ground improvement can be estimated based on prior data and updated as excavation progresses. This probabilistic insight supports better planning and resource allocation.

Likewise, the probability of exceeding deformation threshold values can be assessed a-priori (design stage) and can then be adjusted during construction (with Bayesian updating), as described for a deep excavation by De Wolf et al (2021).

4.4 *Cost-benefit analysis*

Furthermore, reliability can be explicitly linked to the cost of design interventions, facilitating risk-informed choices through Bayesian decision theory. By estimating the expected cost of contingency measures and comparing it to the cost of more conservative designs, engineers can inform decisions on whether to opt for the OM, or optimize interventions. In foundation engineering, for example, the decision to pre-install deep foundations versus monitoring and installing them only if settlement exceeds a threshold can be evaluated using Bayesian decision theory. This was explored by Löfman & Korkiala-Tanttu (2022), who showed how expected utility can guide the selection of design strategies that balance safety and cost.

5 CONCLUSION

Both, RBDA and the OM promise great potential for the design and assessment of geotechnical structures by providing alternatives to the most commonly used partial factor method, where verifications with the latter either lead to infeasible or uneconomic designs. For both, greater effort is required compared to conventional designs. Therefore, we would expect applications rather for non-standard structures or design situations. It would be greatly beneficial if successful (and failed) applications of these approaches in geotechnical projects are reported in case histories.

6 ACKNOWLEDGEMENTS

The authors wish to thank the authors of JRC 2024a and members of TC206 on OM for the fruitful discussions on the topic.

7 REFERENCES

Nicholson, D., Tse, C.-M. and Penny, C. (1999). The Observational Method in ground engineering: principles and applications (R185). CIRIA

EN1997-1:2024 Eurocode 7: Geotechnical design – Part 1: General rules. CEN/TC 250/SC 7/WG 1 “Evolution of 1997 series”.

JRC Technical Report (2024a). Reliability-based verification of limit states for geotechnical structures, Schweckendiek, T. editor, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2760/1342542, JRC139408.d.

JRC Technical Report (2024b). Vrouwenvelder, T., Dimova, S., Sousa, L., Marková, J. et al. ‘Reliability background of the Eurocodes‘ Publications Office of the European Union, Luxembourg.

De Wolf, W. J., Korff, M., van Seters, A., & van Dalen, J. H. (2021). Bayesian inference for deep excavations. In Geotechnical Aspects of Underground Construction in Soft Ground, IS-CAMBRIDGE 2022) 529-535 https://doi.org/10.1201/9780429321559-69

Duvvuru Mohan, V., Vardon, P., Hicks, M., & van Gelder, P. (2019). Uncertainty Tracking and Geotechnical Reliability Updating Using Bayesian Networks. In J. Ching, D.-Q. Li, & J. Zhang (Eds.), Proceedings of the 7th International Symposium on Geotechnical Safety and Risk (ISGSR 2019), pp. 631-636. Article IS3-5. https://doi.org/10.3850/978-981-11-2725-0-IS3-5-cd

Liu,X, Wang,Y., Koo, R.C., Kwan, J.S. (2022). Development of a slope digital twin for predicting temporal variation of rainfall-induced slope instability using past slope performance records and monitoring data. Eng Geol, 308 (2022), Article 106825

Löfman, M., & Korkiala-Tanttu, L. (2022). Observational method applied to the decision optimizing of foundation method in Kujala Interchange on silty clay subsoil. In E. Tutumluer, S. Nazarian, I. Al-Qadi, & I. I. A. Qamhia (Eds.), Advances in Transportation Geotechnics IV - *Proceedings of the 4th International Conference on Transportation Geotechnics* Volume 3 (pp. 739-751). Springer. https://doi.org/10.1007/978-3-030-77238-3_56.

Spross, Johan, and Stefan Larsson (2021). ‘Probabilistic Observational Method for Design of Surcharges on Vertical Drains’, Géotechnique, Vol. 71, No 3, pp. 226–238.

Spross, J.; Bergman, N. & Larsson, S. (2021): Reliability-Based Verification of Serviceability Limit States of Dry Deep Mixing Columns. DOI: 10.1061/(ASCE)GT.1943- 5606.0002458.