

UNDERSTANDING THE CONCEPT OF SAFETY AND RELIABILITY INTRODUCED BY THE 2ND GENERATION EUROCODE 7

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The 2nd generation Eurocode 7 (EC7) has successfully passed the formal vote among the member countries. It is currently in the phase of publication until 2027, accompanied by the development of the National Annexes. Like the present EC7, the next generation EC7 also follows the limit state design principle. Besides the partial factor concept, other reliability-based methods are now explicitly allowed for limit state verification. In addition to this, a framework of mostly qualitative measures is established in EN 1990 (EC0) and EC7, which depend on the geotechnical category assigned to the structure in question, to minimize uncertainties related to insufficient planning in all phases from design to execution and operation, thus, to meet the anticipated reliability. In the numerical verification of limit states with the partial factor method, EC7 allows either the material factor approach or the resistance factor approach combined with the verification cases for actions or effects of actions defined in EC0. Based on selected benchmark examples, it is shown that the calculation results may differ significantly depending on the applied verification procedure and result in different reliability levels if compared to a probabilistic approach.

Keywords: Eurocode 7; geotechnical design; reliability; partial factor concept; geotechnical category.

1. The new Eurocode 7

The 2nd generation EC7 has recently passed the formal vote among the member countries. The following phase of official publication until 2027 is accompanied by the development of the National Annexes. The final withdrawal date of the 1st generation EC7 is the end of March 2028.

The 2nd generation of Eurocodes is entirely reliability-based (JRC, 2024a) and with that also the future EC7. The goal of design is to achieve a sufficient level of reliability of the structure regarding safety, serviceability, and durability. The new EC7 consists of three parts, where the general design rules are defined in part 1, their application to the specific geotechnical structure is the content of part 3, and the ground properties for design are to be derived according to part 2. It is further to be used with the next generation EN 1990-1 (Eurocode 0, EC0), which establishes general design requirements for structural and geotechnical design. EC0 provides provisions on the reliability goals as well as combination and partial factors for actions and the effect of actions to be used. A design following the rules in EC0 and EC7 is assumed to achieve the required reliability level (see EN 1990-1, section 4.1).

In the following, the reliability-based design philosophy established in EC0 and EC7 is introduced. Then, based on two benchmark examples, it is investigated how the implemented design approaches affect the achieved level of reliability compared to a probabilistic analysis.

2. Reliability-based design philosophy

To establish an appropriate level of reliability for a (geotechnical) structure the possible consequences of failure as well as the possible cause and mode of attaining a limit state shall be considered among other aspects. The consequences of failure are addressed by Consequences Classes (CCs) (see Tab. 1, left). Design according to the Eurocodes covers CC1 to CC3, which means that especially for CC4 structures (e.g. flood protection structures, tailing dams, or major harbor structures – see Table 4.3 of EC7) special approaches are necessary, ideally in a risk-informed format (see also EC0, Annex C). EC7 further establishes Geotechnical Complexity Classes (GCC) which consider the uncertainty related to ground and groundwater conditions and the ground-structure interaction. Table 1 shows how they are related to the CCs establishing the Geotechnical Categories (GC).

The future EC7 like the present version follows the limit state design principle. Besides the partial factor concept, other reliability-based methods are now explicitly allowed for limit state verification, but also design by testing or by prescriptive rules and the application of the observational method. A combination of more than one of these approaches may be appropriate in specific design cases.

In the verification of limit states using the partial factor method EC7 allows to use either the material factor approach (MFA) or the resistance factor approach (RFA) combined with verification cases (VC) for actions or effects of actions established in EC0. This concept results in various possible

combinations of partial factors depending on the selected approach which may result in different solutions for the limit state verification which will be addressed in the next sections.

Table 1: Consequence classes (CC) according to Table 4.1 of EC0 (left), Geotechnical Complexity Classes (GCC) according to Table 4.1 of EC7-1(right),and resulting Geotechnical Categories (GC) according to Table 4.2 of EC 7-1 (middle).

Consequence class CC	Indicative qualification of consequences		Geotechnical complexity class GCC			GCC	Complexity	General features
	Loss of human life or personal injury	Economic, social or environmental consequences	GCC 1 lower	GCC2 normal	GCC 3 higher			
CC4 – highest	Extreme	Huge	-	-	-	GCC3	Higher	Complexity: Higher Any of the following apply: considerable uncertainty regarding ground conditions; highly variable or difficult ground conditions; significant
CC3 – high	High	Very great	GC2	GC3	GC3	GCC2	Normal	Complexity: Normal GCC2 applies if GCC1 and GCC3 are not applicable
CC2 – normal	Medium	Considerable	GC2	GC2	GC3	GCC1	Lower	Complexity: Lower All the following conditions apply: negligible uncertainty regarding the ground conditions; uniform ground conditions; low sensitivity to
CC1 – low	Low	Small	GC2	GC2	GC2			
CC0 – lowest	Very low	Insignificant	-	-	-			

However, achieving the required reliability does not only mean the pure numerical verification of limit states. The new EC7, together with EC0, introduces a framework of different, mostly qualitative measures to cope with uncertainties in all phases, from planning and design to execution and operation. These quality measures are defined either in EC0 or in EC7 (see Fig. 1). In EC7, they are all related to the GCs by which the required level of the measure is defined. The quality measures address the determination of design input parameters (including the ground model and representative ground properties), the suitability of design procedures (i.e. the validation of calculation models and interpretation of their results) as well as the prevention of errors in design and execution (mandatory reporting, inspection levels, qualification of personnel, etc.).

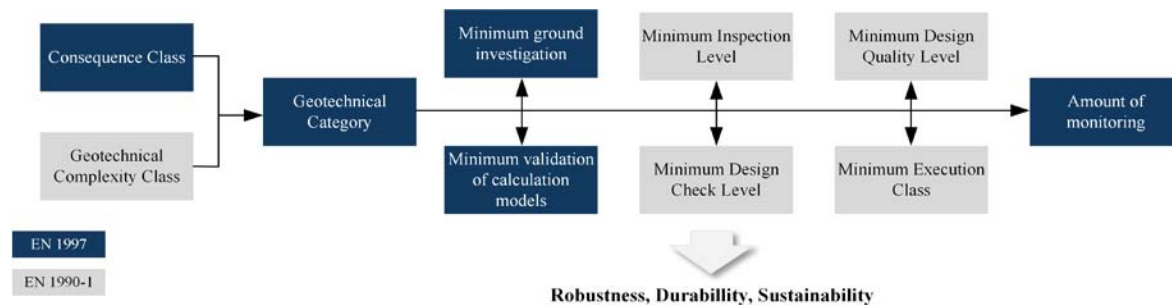


Figure1: Additional quality measures to reach the required reliability.

Important for geotechnical design, e.g., is the definition of a minimum extent of ground investigations according to EC7-2 (extent of investigations) and EC7-3 (investigation depths depending on the type of structure). Besides the minimum extent of ground investigations, EC7 includes specific requirements only for validating the calculation models. The other measures are subject to the National Annexes. Therefore, it is unclear at this stage if and to what extent they will finally be implemented in the design.

3. Design Examples – semi-probabilistic vs. probabilistic design

To illustrate the application of the new EC7 and to compare the partial factor concept with a probabilistic design to assess the achieved reliability level, two design examples from JRC (2024b) have been selected and slightly adapted (see Fig. 2): a gravity wall on silty sand (No. 4 in the report) and a single propped embedded retaining wall (No. 5 in the report). The objective of these examples is to demonstrate the geotechnical design of these structures, ensuring compliance with the requirements according to the 2nd generation of Eurocodes, with a special focus on the ultimate limit state (ULS) where the design resistance, R_d , must be greater than or equal to the design effect of actions, E_d : $E_d \leq R_d$. Both examples are designed using the MFA or the RFA together with the relevant VCs for CC2, i.e., consequence factors $k_M = 1.0$ [-], and $k_F = 1.0$ [-]. For design example No. 4, the necessary base width B and the associated top width b are determined to verify sliding and bearing resistance. For example No. 5 the verification of a sufficient embedment is carried out, and, with this, the necessary embedment depth d is determined for the individual design combinations. For simplicity, a hydrostatic groundwater pressure is considered in this example with no flow around the tip of the wall. The relevant earth pressure distribution for both examples is determined according to EAB (2021) with earth pressure coefficients according to Annex D in EC7-3. The partial factors for a persistent design situation for all possible

combinations according to EC0-1, EC7-1, and EC7-3 relevant to these examples are summarized in Table 2. It should be noted that according to EC7-3, Table 7.2 combination c is not applicable for example No. 5. In addition, the surcharge in this example is assumed to be a permanent load acc. to EAB (2021).

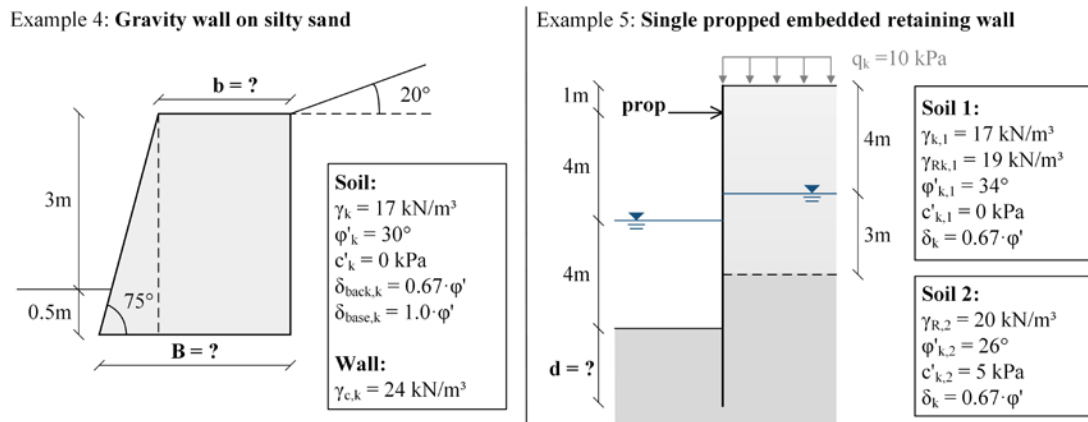


Figure 2: Design examples: a gravity wall on silty sand (left) and a single propped embedded retaining wall (right).

Table 2: Relevant partial factors for the different design combinations.

Partial factors	MFA (a) ^h	MFA (b) ^h	MFA (c) ^{c,h}	RFA (d)	RFA (e)
	VC4 & M1	VC3 & M2	VC1 & M2	VC1	VC4
Actions ³ F	1.00	1.00	1.35 · k _F ^a and 1.2 · k _F ^f or 1.0 ^g	1.35 · k _F ^a and 1.2 · k _F ^f or 1.0 ^g	1.00
Effects of actions ³ E	1.35 · k _F ^a	1.00	1.00	1.00	1.35 · k _F ^a
Material properties ³ M	1.00	1.25 · k _M ^b	1.25 · k _M ^b	1.00	1.00
Resistances ³ R _e	1.00	1.00	1.00	1.10 ^d or 1.40 ^e	1.10 ^d or 1.40 ^e

^aunfavourable permanent action; ^bshear strength parameter in effective stress analysis; ^ccombination not applied to retaining wall; ^dsliding resistance; ^ebearing resistance; ^fpassive earth pressure; ^gpermanent action water; ^hfavourable actions; ^hMFA: both combinations (a) and (b) or single combination (c)

For the probabilistic design of the examples, the target reliability index, ²T_T, has been adopted from Table C.3 of EC0. Accordingly, for structures categorized with CC2, the reliability index is assumed to be ²T_{T, 50-years} = 3.8, corresponding to a probability of failure of approximately P_F H10⁻⁴. The First-Order Reliability Method (FORM, see e.g., JRC, 2024c) is used to assess the structural reliability. A limit state function, g, is established, where g = 1 - μ < 0 indicates a failure state with μ being the degree of utilization defined as μ = E_d / R_d.

The ground properties provided in the design examples have been assumed to be characteristic values. Following EC7-1, the characteristic values should be estimated as either a mean value, if the limit state is insensitive to the variability of the property, or as a 5% or 95% fractile, if the property and its variability significantly impact the limit state verification depending on which of the fractile values has an unfavorable effect on the limit state. Since the shear strength always has a positive effect in the considered limit states, the associated characteristic values are assumed to be 5% fractile values. Means of the underlying distributions have been derived from the 5% fractiles using the z-score. As soil weights are included in both, resistance and load, sensitivity analyses have been carried out to assess which values should be used for the weight densities and whether the limit states are sensitive to the variability of these properties. On this basis, the characteristic values for the weight density are assumed to be mean values, as their variability has shown only little influence on the limit state. Furthermore, information on the variability of soil properties is required to determine the distribution functions and their underlying parameters (mean value and standard deviation). As the original design tasks do not allow any conclusions to be drawn, values for the coefficients of variation (V_X) from Annex A (Table A.1, EC7-1) are used: V_{X,c} = 40% for the effective cohesion, V_{X,tan,ϕ} = 10% for the coefficient of friction tan ϕ', and V_{X,γ} = 7.5% for the weight density γ. The friction angle and weight density are modeled with normal distributions, the cohesion follows a lognormal distribution (see also JRC, 2024c). The underlying distribution functions of the random variables are displayed in Figure 3. Furthermore, a correlation between the shear parameters ϕ and c is considered by a correlation factor of ρ = -0.60, which is within the upper range of the magnitude recommended in the literature (see e.g. JRC, 2024c). In addition, the distribution function of the friction angle in Example 4 must be truncated to avoid friction angles ϕ < 20°, as the formulae for calculating the earth pressure according to EC7-3 are no longer applicable for these cases. With these assumptions, reliability analyses using FORM have been conducted to determine the reliability index for each combination and for the geometrical dimensions derived from MFA and RFA. The results of both analyses are presented and discussed in the following section.

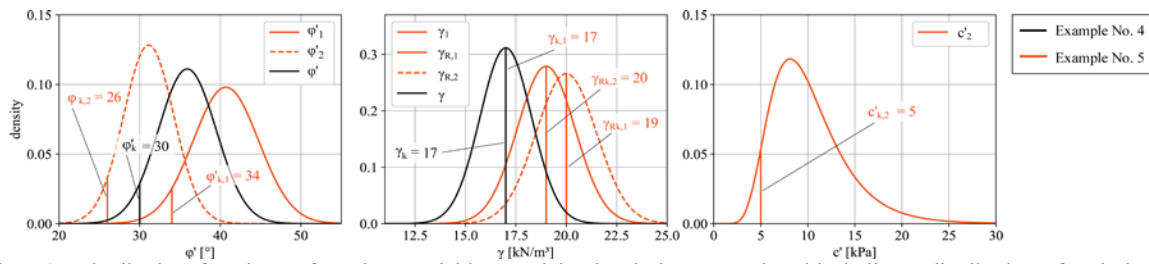


Figure3: Distribution functions of random variables used in the design examples; black lines: distributions for design example No. 4 and orange lines: distributions for design example No. 5.

4. Discussion and conclusion

Table 3 summarizes the required dimensions for both examples, calculated using the design approaches outlined in Table 2, and compares them with the results of the probabilistic design. The results of the RFA cases show consistent findings; however, there are significant differences in the MFA outcomes. Using MFA c requires the largest dimensions for the gravity wall, while MFA a requires the smallest base width. MFA c results in the largest dimensions overall due to reduced shear parameters and increased actions through the use of partial factors. However, MFA c is the only case for achieving the target reliability; all other semi-probabilistic designs do not meet the target reliability. In contrast, for the retaining wall, all designs exceed the dimensions of the probabilistic design, especially in the RFA cases, resulting in probably unnecessarily low failure probabilities compared to the target values specified in EC0-1. Overall, it is difficult to draw a general conclusion on the achieved reliability level. On the one hand, the assumed distributions and variabilities of the random variables may have affected the results, though they represent common recommendations (see JRC, 2024c). On the other hand, the partial factors presented in Table 2 are widely accepted, and the resulting reliability, thus, can also be considered acceptable. The difficulties especially lie in the use of constant partial factors which cannot reflect all design situations covered by EC7. A differentiation of partial factors depending on typical design situations and on the quality of the design input in regard to e.g. the applied calculation model and the available ground information may help to harmonize the reliability level. The MRFA approach, discussed e.g., by Tafur and Ziegler (2021), can be a first step in this direction. However, the analysis also reveals that a more distinct evaluation of the achieved reliability level is only possible with probabilistic analyses where the uncertainties can be explicitly addressed.

Table3: Results from the design using the partial factor method compared to the results from the probabilistic analysis.

			MFA			RFA		Probab. Approach
			a	b	c	d	e	
Example No. 4	Sliding resistance	Required base width B [m]	1.38	1.50	1.91	1.48	1.48	1.81
		Reliability index β	1.28	3.05	4.03	2.99	2.99	3.81
		Failure Probability P_f	0.0997	$1.16 \cdot 10^{-3}$	$2.82 \cdot 10^{-5}$	$1.01 \cdot 10^{-3}$	$1.01 \cdot 10^{-3}$	$3.94 \cdot 10^{-5}$
Example No. 4	Bearing resistance	Required base width B [m]	1.52	1.90	2.33	1.87	1.67	2.26
		Reliability index β	2.02	3.09	3.93	3.02	2.25	3.81
		Failure Probability P_f	0.022	$1.01 \cdot 10^{-3}$	$4.23 \cdot 10^{-5}$	$1.28 \cdot 10^{-3}$	$5.83 \cdot 10^{-3}$	$7.02 \cdot 10^{-5}$
Example No. 5	Required embedment depth [m]		5.44	7.02	not applied	8.40	8.59	4.19
		Reliability index β	4.61	5.29		5.70	5.75	3.80
		Failure Probability P_f	$1.97 \cdot 10^{-6}$	$6.07 \cdot 10^{-8}$		$5.96 \cdot 10^{-9}$	$4.46 \cdot 10^{-9}$	$7.1 \cdot 10^{-5}$

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