

## 2<sup>nd</sup> Generation of Eurocode 7 – Verification of limit states Use of partial factor, testing and prescriptive methods

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**ABSTRACT:** In the 2<sup>nd</sup> Generation of Eurocode 7, the main objective in terms of design is the verification of limit states based on different methods: calculation using the partial factor method or other reliability-based methods; prescriptive rules; testing and Observational Method. Beforehand, the first task is the failure mechanisms identification. Then, the second task is to verify these failure mechanisms considering the various limit states considering the different methods presented previously. In this paper, the objective is to describe these two tasks with the perspective to perform calculation using partial factor method, prescriptive rules and testing. The design strategy of these three methods and the way to account for the uncertainties from the ground and the actions are discussed. The possible interactions between these methods are also mentioned. For example, in a calculation, some very specific verifications can be based on testing when experimental results are available or the use of prescriptive methods considering in a way similar comparable experience and engineering judgement. A special focus is made on the calculation method and two issues are discussed: on the one hand, the calibration and the role of partial factors in line with the use of Resistance Factor Approach or Material Factor Approach as described in Eurocode 0, on the other hand, the use of numerical methods or more advanced numerical methods based on the use of big data or artificial intelligence. For well-established numerical methods such as the finite element method, the various procedures proposed by Eurocode 7 to address safety issues are exposed both for mechanical and hydraulic issues. The verification of serviceability limit states is also addressed.

**KEYWORDS:** Eurocode 7, Design of geotechnical structures, Safety framework, Numerical modelling

### 1 INTRODUCTION

In the 2<sup>nd</sup> Generation of Eurocode 7 (2024a, 2024b and 2024c), one of the main objective in terms of design is the verification of limit states as defined in EN 1990 (2024) based on different methods (see §4.2 in EN 1997): calculation using the partial factor method or other reliability-based methods; prescriptive rules; testing and Observational Method (Figure 1). Beforehand, the first task is the identification of failure mechanisms according to the type of geotechnical structure. Then, the second task is to verify these failure mechanisms considering the various limit states and using the different methods presented previously. In this paper, the objective is to describe these two tasks with the perspective to perform calculations using partial factor method, prescriptive rules and testing. The paper by Schweckendiek (2026) focuses on reliability based methods and the Observational Method.

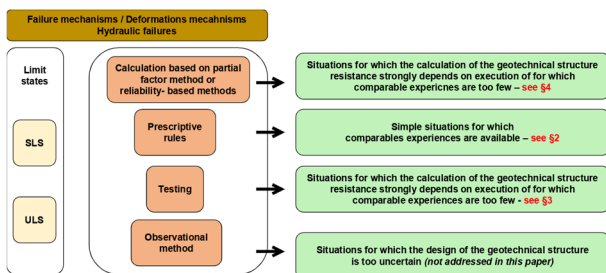


Figure 1. Methods for the verification of geotechnical structures

The design strategy of partial factor methods, prescriptive rules and testing methods and the way to account for the uncertainties from the ground and the actions are discussed. The possible interactions between these methods are also mentioned. For example, in a calculation, some very specific verifications can be based on testing when experimental results are available or the use of prescriptive methods considering, at the same level, similar comparable experience and engineering judgement. A special focus is made on the calculation method and two issues are discussed: on the one hand, the calibration and the role of partial factors in line with the use of Resistance Factor Approach or Material Factor Approach as described in EN 1990

(2024), on the other hand, the use of numerical methods or more advanced numerical methods based on the use of big data or artificial intelligence. For well-established numerical methods such as the finite element method, the various procedures proposed by Eurocode 7 to address safety issues are exposed both for mechanical and hydraulic issues. The verification of serviceability limit states is also addressed.

### 2 PRESCRIPTIVE RULES

Prescriptive rules are only applied for simple situations for which comparables experiences are available and engineering judgement is sure and reliable. They do not need the results of any calculation. They shall be used for a well established set of specific failure mechanisms. It is important to define the limit state states and the design situations that are covered. The way to perform prescriptive rules in each European country is regulated by the National Annex.

In many situations, rules are not applied solely but in conjunction with the other methods especially the partial factor method that is the most commonly used. From another point of view, prescriptive rules allow to check the reliability and the robustness of the design on the base of comparable experiences: precise and correct calculations with appropriate partial factors cannot account for errors and mistakes that have been done during the design.

### 3 TESTING

Testing is used in the situations for which the calculation of the geotechnical structure resistance strongly depends on execution or for which comparable experiences are few. It is important mention that testing allows only to address the resistance uncertainties. Testing is often used for piles, anchors, soil nails or rock bolts. The drilling and the grouting execution is crucial in terms of ground resistances.

As for prescriptive rules, testing methods are not applied solely but in in conjunction with the other methods especially the partial factor method. For example, for piles, testing can be used in order to decrease the ground model and the geotechnical design model uncertainties (Figure 2, see Moormann and Burlon, 2024). Indeed, the bearing pressure at the pile base and

the shaft frictions are deduced considering ground parameters (cohesion, friction angle, cone resistance, net limit pressure, etc.) and the pile technique, which can lead to some uncertainties. Testing results are used to decrease these uncertainties.

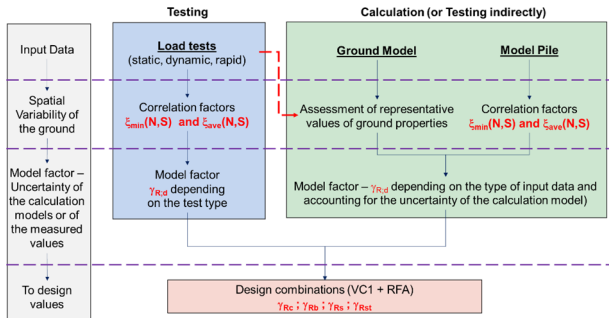


Figure 2. Use of testing method for pile design

## 4 PARTIAL FACTOR METHOD

### 4.1 Principles

The partial factor method is the most commonly used. It is based on the identification of failure and deformation mechanisms regarding the situations for which structural and geotechnical verifications are involved and hydraulic failures regarding the situations for which groundwater flow is involved. Figures 3 and 4 include the main equations that are used for the verification of these failure mechanisms.

For structural and geotechnical verifications, it is important to establish a link between these failure mechanisms and the limit states to check : serviceability limit states (SLS) for quasi-permanent, frequent and characteristic situations, ultimate limit states (ULS) for persistent and transient, seismic and accidental situations. Each design situation is defined by a specific combination of permanent actions, variable actions and where appropriate seismic and accidental actions. The issue about the choice between the four verification cases proposed by EN 1990-1 and the choice between the Resistance Factor Approach (RFA) and the Material Factor Approach (MFA) are only relevant for ULS and persistent and transient combinations.

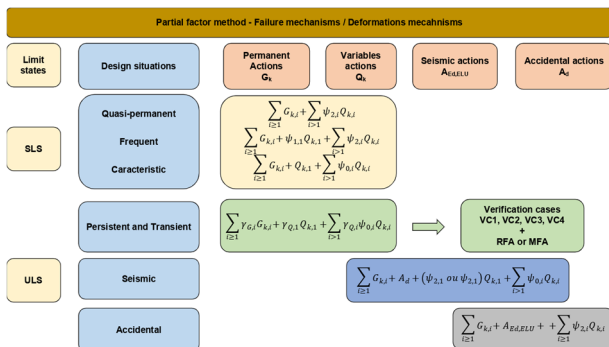


Figure 3. Interactions between failure mechanisms, actions, limit states and design situations

For hydraulic verifications, three situations are considered as presented by Figure 4:

- the first one concerns an equilibrium situation between the gravity and the buoyant force derived from Archimedes' principle. This situation is addressed by considering the verification case VC2 as the internal resistance of the ground and the structures are no involved,
- the second one deals with the equilibrium between the vertical stresses  $\sigma'_v$  and the groundwater pore pressures  $u_d$

and corresponds to a global verification that can be written in a simplified way as following (see equation 8.3 in EN1997-1):

$$\Delta u_d \leq \gamma \sigma'_{v0} \quad (1)$$

where  $\Delta u_d = u_d - u_0$  is the design excess groundwater pressure ( $u_d$  with flow and  $u_0$  without flow),  $\sigma'_{v0}$  is the vertical effective stress and  $\gamma$  a partial factor,

- the third one is related with the design value of the hydraulic gradient  $i_d$  and corresponds to a local verification (see equation 8.4 in EN1997-1):

$$i_d \leq i_{cd} \quad (2)$$

where  $i_{cd}$  is the design value of the critical hydraulic gradient.

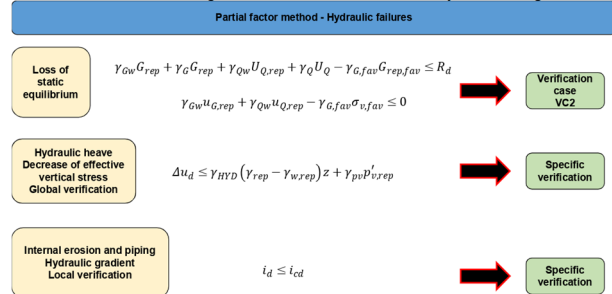


Figure 4. Hydraulic failures

#### 4.1.1 Ground model and Geotechnical Design Model

For geotechnical design, the key issue for the verification of SLS and ULS with their various design combinations is the selection of the representative values of the ground properties based on the derived values presented in the Ground Model. EN 1997-2 (2024b) provides some recommendations regarding both strain and strength parameters included in the Ground Model (GM): the complexity of the models shall be consistent with the available data and the verifications to be carried out.

The selection of the ground parameters (Figure 5) from the derived values presented in the Ground Model (GM) as an output of the Ground Investigation Report (GIR) to generate the representative values that form the basis of the Geotechnical Design Model (GDM) in the Geotechnical Report (GDR) shall consider various aspects: the type of loading, the stress and strain level, the failure mechanism or the coupling effects.

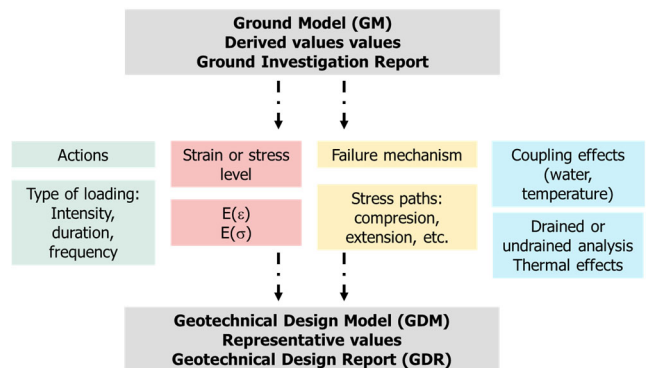


Figure 5. From the Ground Model to the Geotechnical Design Model

Another important issue is the spatial scatter of the ground parameters and two approaches are proposed : the first one based on the engineering judgement provides a nominal value and the second one based on statistical analysis provides a characteristic value  $X_k$  considering a set of  $N$  values:

$$X_k = X_{mean} (1 - k_N V_X) \quad (3a)$$

$$k_N = N_{95} / \sqrt{N} \quad (3b)$$

$$k_N = t_{95,N-1} / \sqrt{N} \quad (3c)$$

Where  $N_{95}$  is the 5% fractile of the Normal law and  $t_{95,N-1}$  is the 5% fractile of the Student law.

At the end, the designer may choose the value considered as the most relevant (or the worst credible value). This choice is clearly affected by the calculation method and the partial factors that are used during the verifications.

#### 4.1.2 ULS verifications for persistent and transient situations

Regarding the actions, the use of partial factors is only relevant for persistent and transient situations. Regarding the way to consider partial factors on actions, on resistances or on strength materials, four verifications cases VC1, VC2, VC3 and VC4 have been defined and interact with two factoring approaches, the resistance factor approach (RFA) and the material factor approach (MFA). VC2 is only used when there is no issue about structural resistance: this verification case corresponds to an equilibrium between actions and resistances. In geotechnical design, as presented after, it is used to account for the situations for which uplift groundwater pressure occurs.

The three other verification cases correspond to some typical design situations. VC1 is used when it is possible to make a clear distinction between actions and resistances, which is possible for foundation design in general: the partial factors are applied on the actions applied at the head of the footings or the pile. VC4 is used when the partial factors are applied on the action effects. In geotechnical design, this verification case is strongly used for retaining wall design. VC3 is used for the design of geotechnical structures when actions and resistances come from the ground weight and its strength properties. RFA is used when the partial factors are applied on the total resistance, for example, the sliding, the bearing capacity, etc. MFA is used when the partial factors are applied on the strength ground properties. Table 1 presents the partial factors used for VC1, VC3 and VC4. Table 2 presents the partial factors used for MFA (EN 1997-1). For RFA, the partial factors are only defined in EN 1997-3 as they depend on the type of geotechnical structures since they may be applied on sliding, bearing capacity or passive earth pressures.

Table 1. Table of partial factor values for verification cases for persistent design situations (where  $k_F$  is a consequence factor)

Type	Resulting effect	VC1	VC3	VC4
Permanent action ( $G_k$ )	unfavourable (all)	$1.35 k_F$	1.0	$G_k$ is not factored
	unfav. (water)	$1.2 k_F$	1.0	
	favourable	1.0	1.0	
Variable action ( $Q_k$ )	unfavourable (all)	$1.5 k_F$	1.3	1.1
	unfav. (water)	$1.35 k_F$	1.15	1.0
Effects of action ( $E$ )	unfavourable	$\gamma_E$ is not applied		$1.35 k_F$
	favourable			1.0

Table 2. Table of partial factor values for material sets for soil and fill (where  $k_M$  is a consequence factor)

Ground property	M1	M2
Shear strength in effective stress analysis ( $\tau_F$ )	1.0	$1.25 k_M$
Coefficient of peak friction ( $\tan\phi'_p$ )	1.0	$1.25 k_M$
Peak effective cohesion ( $c'_p$ )	1.0	$1.25 k_M$
Coefficient of friction at critical state ( $\tan\phi'_{cs}$ )	1.0	$1.1 k_M$
Shear strength in total stress analysis ( $c_u$ )	1.0	$1.4 k_M$

#### 4.2 Use of RFA and MFA

EN 1997-3 (2024c) defines for each geotechnical structure the verifications cases (VC1, VC3 and VC4) and the factoring approaches to select, between RFA and MFA. The selection

between VC1, VC3 and VC4 on the one hand and RFA or MFA on the other hand is defined by each European country and depends on the national experience: the calculation methods commonly used, the evaluation of ground properties, the safety level commonly accepted. For each specific geotechnical structure, Eurocode 7 defines possible combinations between VC1, VC3 and VC4 or RFA and MFA. In each European country, one of these combinations is applied. Regarding partial factors, Eurocode 7 provides a set reflecting the main trend in Europe but some countries may use values of partial factors that are different. Table 3 illustrates the combination of the various verification cases with the factoring approaches RFA or MFA.

Table 3. Verifications cases and resistance/material factor approaches

Verifications Cases	Type of geotechnical limit state				
	Rupture and Excessive deformation		Static equilibrium and uplift	Hydraulic failure	
	MFA	RFA	MFA and/or RFA	—	
1	$\gamma_Q > \gamma_G > 1.0$ $\gamma_G = 1.35 (1.2) ; \gamma_Q = 1.5$	X	X	Specific verifications: -effective stress variations -hydraulic gradients	
2	$\gamma_Q > \gamma_G > 1.0$ $\gamma_G = 1.0 ; \gamma_Q > 1.0$	—	—		X
3	$\gamma_G = 1.0 ; \gamma_Q > 1.0$	X	—		—
4	$\gamma_E > 1.0 ; \gamma_Q > 1.0$	—	X		—

#### 4.3 Use of numerical Modelling

##### 4.3.1 Principles for ULS in persistent and transient situations

In the second generation of the Eurocodes partial factors on actions  $\gamma_F$  and action effects  $\gamma_E$  are grouped in four Verification Cases (VC1 to VC4) in EN 1990 (2024) for all types of structures and are partly listed in Table 1. (The tables in this paper contain considerable simplifications and omissions, refer to the tables in EN 1990, EN 1997-1 and EN 1997-3 for all details, Smith and Walter, 2023).

For geotechnical structures, partial factors on material strength parameters  $\gamma_M$  and resistances  $\gamma_R$  are supplied in EN 1997-1 if they are valid for all types of geotechnical structures, and in EN 1997-3 if they are specific for certain types of geotechnical structures. Partial factors on material strength parameters are listed and grouped in sets M1 and M2 in EN 1997-1 and are partly listed in Table 2.

Whether partial factors on material strength parameters (Material Factor Approach, MFA) or partial factors on resistances (Resistance Factor Approach, RFA) are used, the choice of the Verification Case and of set M1 or M2 and suggested values for partial factors on resistances are specified in EN 1997-3 for the different types of geotechnical structure. National standards bodies may modify these specifications, including the values of the partial safety factors.

For soils and rocks, geotechnical verifications are more complex than for structural elements: the stress state is known but it is impossible to define the limit stresses and even less the limit forces that implicitly result from the integration of the constitutive law: it is only possible to say that the stresses are limited by a yield surface which can possibly evolve due to hardening mechanisms.

Regarding this situation, a specific procedure is given in EN 1997-1 for numerical methods. Two approaches are mainly described and the more unfavourable of the two governs the design (Figure 6), currently without a distinction between different types of geotechnical construction:

- Input factoring using VC3 and M2,
- Output factoring using VC4 and M1.

These approaches are given to facilitate the straightforward use, and to take full advantage of the power of numerical methods. However, it is also clear that design check outcomes may differ if using factors for numerical methods compared to using factors for specific design calculation methods as listed in EN 1997-3. EN 1997-3 allows to perform ULS verifications by focusing on specific failure mechanisms: geotechnical resistances may be calculated by numerical models by forcing geotechnical structures to fail by particular mechanisms (Figure 6).

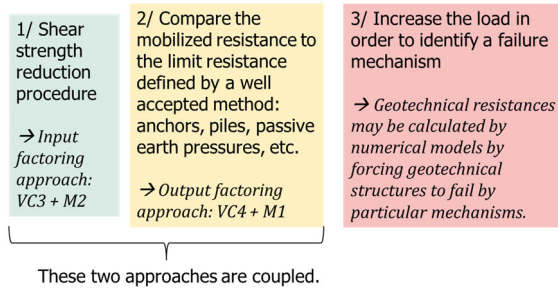


Figure 6. Input, output and forcing particular mechanisms

#### 4.3.2 Input factoring

This approach is now mainly based on the use of shear strength reduction procedures that are fully available in many softwares. EN 1997-1 recommends:

- (i) to reach the value  $\gamma_M=1.25$  to check the geotechnical verifications. This value may be modified by the national standard bodies,
- (ii) to check the structural forces that are obtained from this calculation with strength reduction to  $\gamma_M$  without or with the use of elastoplastic structural elements. When elastoplastic structural elements are used, the forces into the structural elements are implicitly limited by the strength parameters of the elements. Regarding the strength reduction, at this stage, it is performed only on strength parameters ( $c'$  and  $\phi'$  or  $c_u$ ); strain parameters such the Young modulus, the shear modulus or the bulk modulus should not be factored. Research and development about this issue would be interesting and useful for the geotechnical design with numerical models.

For each phase, the calculation is performed with representative values of the loads and the ground properties. Each phase can be used for SLS verifications (ignoring the results with strength reduction). The calculations can be organised according to Figure 7.

Instead of using a strength reduction procedure, the shear strength parameters can also be reduced ab initio or after previous steps with representative values of the strength parameters. One has to keep in mind that these variants can result in different displacements and different forces on the structural elements.

#### 4.3.3 Output factoring

For each phase, the calculation is performed with representative values of the loads and the ground properties. Using VC4, the representative values of the action effects are multiplied by 1.35 in order to obtain the design values.

When it is possible, the mobilized resistance can be calculated and then evaluated and compared to the ultimate resistance determined by a separate calculation where closed-form or theoretical solutions are known.

In the case of a retaining wall for which a subgrade reaction approach is used, Figure 8 presents the typical results.

In the case of piles or anchors, it is possible to calculate the mobilized axial resistance and compare it to a full-scale test or another calculation performed by the traditional calculation procedures based on  $c_u$ , CPT or PMT values as described in Annex D of EN 1997-3.

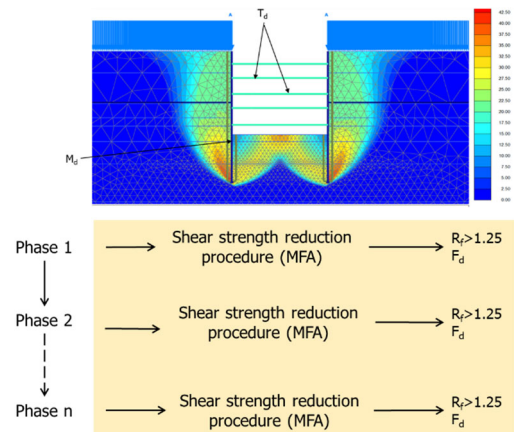


Figure 7. Input factoring with shear strength reduction procedure

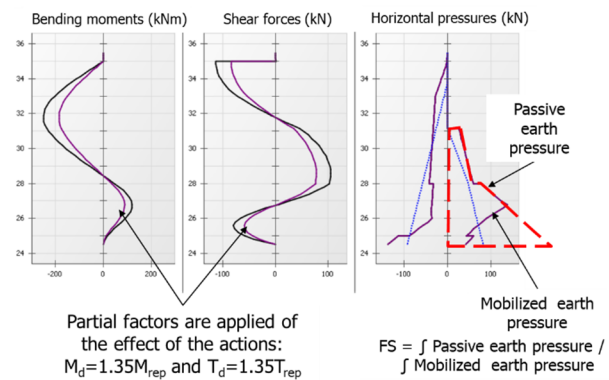


Figure 8. Output factoring with subgrade reaction methods

#### 4.3.4 Coupling input and output factoring approaches

Input and output factoring approaches can be combined in the same calculation as proposed by Figure 9.

These two approaches can be performed alone depending on the type of geotechnical structures. For example, checking the earth pressure mobilization by the finite element method is not straightforward, so in the current practice it is rarely done when effects of actions are factored. When dual factoring is used, the passive resistance is factored by MFA as the strength properties are reduced.

The design values of the structural forces  $F_d$  correspond to the more unfavourable of the two values.

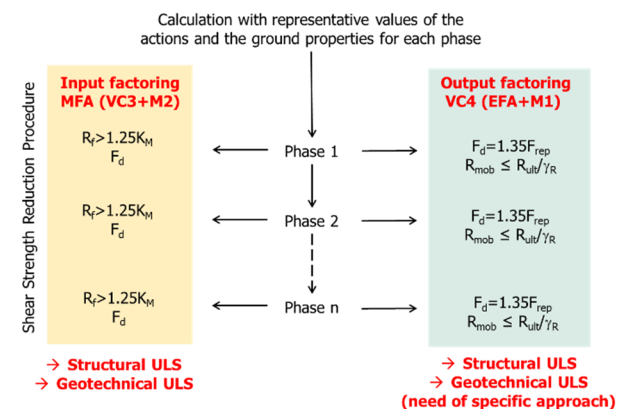


Figure 9. Coupling of input and output factoring

#### 4.3.5 Identifying particular mechanisms

Identifying particular failure mechanisms is sometimes very useful especially for the design of foundations. Two options can be performed:

- Option 1: calculate the ultimate resistance  $R_{ult}$  by means of a numerical method and check that:  $1.35G + 1.5Q \leq R_{ult}/\gamma_R$ . For example, as shown in Figure 10, the ultimate resistance  $R_{ult}$  is obtained by forcing a bearing capacity mechanism taking into account the load inclination directly. This procedure allows to account for load and eccentricity effects in a more straightforward way than the classical methods.
- Option 2: Increase the load to show that no failure mechanism occurs:  $\alpha \cdot V < R_{ult}$  (with low settlements) and  $\alpha$  can be written as:  $\alpha = (1.35 \text{ to } 1.5) \cdot \gamma_R$  then:  $(1.35 \text{ to } 1.5) \cdot \gamma_R \cdot V \leq R_{ult} \leftrightarrow 1.35G + 1.5Q \leq R_{ult}/\gamma_R$ .

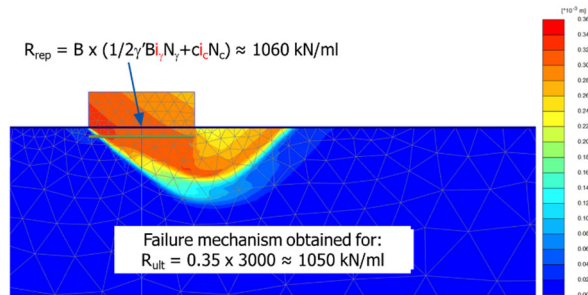


Figure 10. Forcing specific particular mechanisms (with option 1)

#### 4.3.6 Hydraulic verifications

The example taken from a paper published by Pane et al. (2015) (Figure 11) illustrates that the two hydraulic verifications (see equations 1 and 2) are antagonist:

- without wells, the hydraulic flow arrives at the bottom of the excavation: the hydraulic gradient is low but as all the layer thickness is affected by the hydraulic flow, the vertical effective stresses increase very slowly, which is very disadvantageous for the mobilization of the passive earth pressure. The reduction of the vertical effective stresses is large in comparison to the initial one,
- with wells, the hydraulic flow arrives at the bottom of the wells: the hydraulic gradient is higher in the at the base of the embedded retaining wall but the upper part of the ground is not affected by the hydraulic flow. In average, the vertical effective stresses are higher than previously, which is advantageous for the mobilization of the passive earth pressure. The reduction of the vertical effective stresses is not so large in comparison to the initial one.

These calculations do not require any partial factors as input, which simplifies the analysis (the worst case hydraulic conditions are adopted).

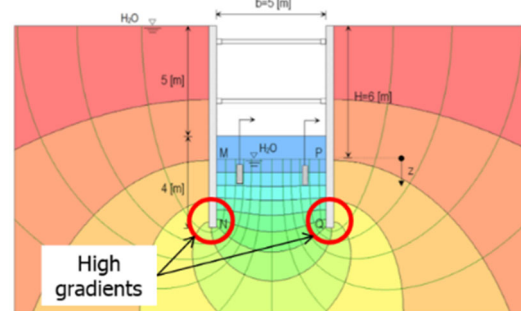
### 5 CALIBRATION OF PARTIAL FACTORS

The calibration of partial factors is rarely discussed in Eurocode 7 as the selection of partial factor values are under the responsibility of each European country. Moreover, the partial factors of the Verification Cases VC1, VC2, VC3 and VC4 are defined in EN 1990-1. Eurocode 7 is in charge of partial factors in line with strengths and resistances.

For resistances or strengths, the national values do not only reflect reliability issues but account for national practices that include the ground investigation techniques, the approaches to select derived and representative values, the calculation methods, the execution procedures and the geological, environmental and climatic features. The costs, the

maintenance, the robustness and the sustainability are other issues to consider. Regarding all these parameters, it is very difficult to really understand the differences in terms of partial factor values between European countries. Even if partial factors are used for the verification of ULS, it is never clear to know if a part of the partial factors does not concern some serviceability issues and is not used to address time effects and delayed displacements.

Moreover, as already precised, the partial factor design approach can be used in conjunction with testing and prescriptive measures.



Pane et al., 2015  
(Hydraulic Heave Failure in EC7:  
Suggestions for Verification)

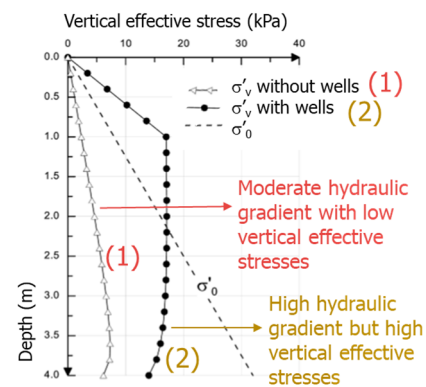


Figure 11. Hydraulic verifications

### 6 OTHER 'MODERN' APPROACHES

In the next years, some 'modern' approaches based on the use of a huge amount of data and artificial intelligence tools will be available. This type of approaches will be able to provide the representative values of ground parameters and a first draft of the construction to be designed.

Regarding the ground parameters, these new procedures will not change the current philosophy and the designer will remain the one who will guarantee the selection of the representative values. These procedures will permit to analyse a large amount of data very fastly but, in practice, it will not alter the role of the designer. The identification of the measured values that are not correct due to some errors is another problem which is very difficult to handle.

Regarding the artificial intelligence for the design, probably, it will be only an help for the designer to identify the solutions that are not in line with some other available comparable experiences. Whatever the next evolution, computing has already undergone immense changes in the 50 years between 1975 and 2025, and engineering has been able to adapt to these changes. Well implemented, they enable us to deal with singular cases and better understand the behaviour of geotechnical structures.

Huge parametric studies or iterative procedures to optimize geotechnical structures seem to be two more possible directions. In this case, the structure of EN 1997-1 is already appropriate.

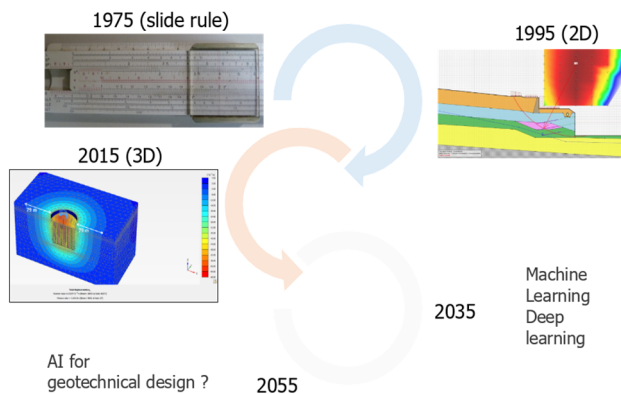


Figure 12. Evolution of computing and numerical modelling

## CONCLUSIONS

This paper has tried to present how partial factor, testing prescriptive methods are presented and used within the second generation of Eurocode 7. The identification of the failure or deformation mechanisms is the key issue since it obliges to think about the way to obtain the representative values of ground properties considering the type of loading or the stress and strain level. Hydraulic failures are addressed in a specific way. The introduction of numerical modelling has obliged to define a specific safety framework.

All these concepts keep the 2nd generation of Eurocode 7 very robust and reliable regarding the various future evolutions especially those in line with the emergence of artificial intelligence tools.

## ACKNOWLEDGMENTS

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