

# How the second generation of Eurocode 7 is progressing?

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**ABSTRACT:** The second generation of Eurocode 7 is now being drafted. The formal votes are now in progress. The main modifications discussed and agreed by the technical committee in charge EN 1997 are presented. Some important issues to be discussed are highlighted. Various aspects of the geotechnical engineering are addressed: ground investigation, safety of geotechnical structures, monitoring, etc.

## 1 INTRODUCTION

Since 2015, Eurocode 7, like the other Eurocodes, has entered its effective revision phase. The work is being carried out by six project teams (PT) under the responsibility of the technical committee in charge of Eurocode 7 (TC 250/SC7). Eurocode 7 now includes three parts: general rules, geotechnical investigations and calculation of geotechnical structures (slopes, cuttings and embankments; shallow foundations; deep foundations; anchorages, soil reinforced with nails, geotextiles, bolts and reinforced earth; soil improvement). High tunnels and dams are not dealt with directly.

The six project teams (PTs) that have made or will be making contributions cover the following topics:

- PT1: drawing up the principles for harmonising and organising the text,
- PT2: drafting of part 1 of Eurocode 7,
- PT3: drafting of part 2 of Eurocode 7,
- PT4: drafting of the chapters of Eurocode 7 relating to slopes, shallow foundations, deep foundations and ground improvement,
- PT5: drafting of the chapters of Eurocode 7 relating to supports, tie rods and ground improvement,
- PT6: making the three parts of the Eurocode consistent with each other and with the other Eurocodes, then inserting rock mechanics and dynamic and cyclic loads into the various parts.

For the purposes of this article, it is only appropriate to focus on Parts 1 and 2, for which the broad outlines of the texts have been stabilised. The content of Part 3 is briefly presented only.

An important point to highlight is the strong interaction with Eurocode 0 that now clearly includes geotechnical design since its title is (Figure 1): '*Basis of structural and geotechnical design*'.

## 2 EUROCODE 7 – PART 1 (PREN 1997-1)

The first objective of the revision of Eurocode 7 is to introduce two new topics: rock mechanics, so as to treat soil and rock on the same level, and dynamic loading (excluding seismic loading) and cyclic loading.

As far as rock mechanics is concerned, the work underway suggests that this field will be covered extensively and will make it possible to apply the Eurocodes to geotechnical projects in rocky ground, which is not currently the case. Numerous definitions have been proposed to describe rock masses from a geometric or mechanical point of view. The specific behavioural characteristics of rocks are also addressed.

For dynamic and cyclic loads, the aim is simply to present certain recommendations for taking account of this type of load.

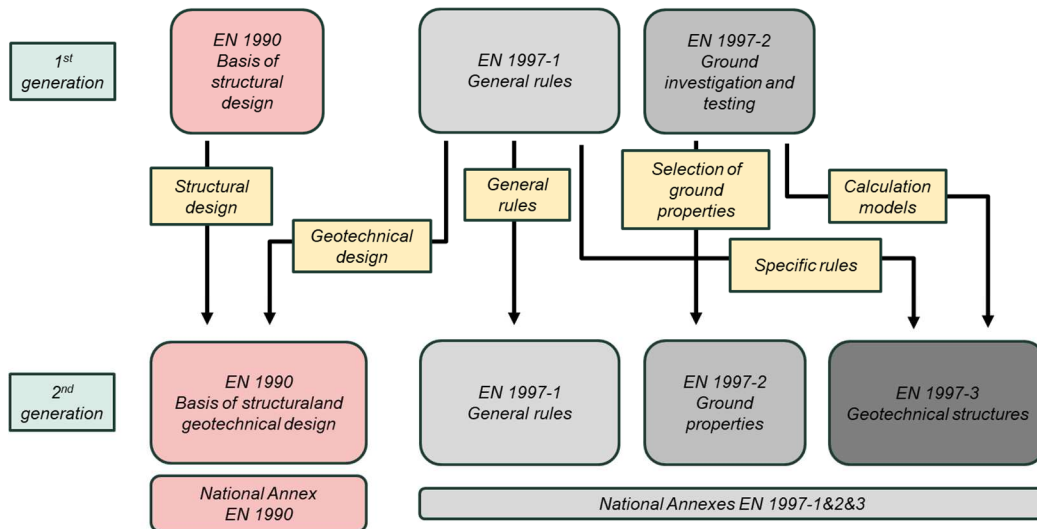


Figure 1. From the 1<sup>st</sup> generation to the 2<sup>nd</sup> generation of Eurocode 7

### 2.1 Geotechnical categories

The geotechnical category allows countries that so wish to define a minimum program of geotechnical investigations, as well as variable levels of control, monitoring or qualification (the latter aspect would only be applied in countries where personal qualifications exist). The geotechnical category is defined as a combination of the consequence class of a structure (which reflects its importance in terms of human, social and economic risks) and the geotechnical complexity class, which represents all the geotechnical uncertainties of the site under consideration (heterogeneity of the ground, atypical behaviour, etc.). Figure 2 below summarises the links between these different concepts.

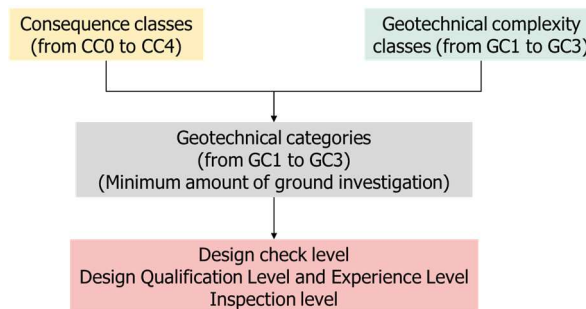


Figure 2. Consequence class, geotechnical complexity class and geotechnical category

### 2.2 Verification procedures

As in the previous version of Eurocode 7, four procedures are proposed for the justification of geotechnical structures. These procedures include :

- calculation methods based on the application of partial coefficients,
- prescriptive methods,
- methods based on tests,
- the observational method.

### 2.3 Ground model and geotechnical design model

The ground model (GM) and the geotechnical design model (GDM) together form a new concept that better describes the way in which knowledge of the ground relative to a site should be

synthesized. The ground model (GM) is a conceptual model for representing the ground independent of the structure to be built, while the geotechnical design model (GDM) incorporates the various interactions to be considered in relation to the geotechnical structure to be designed. The geotechnical model is described in part 2 of Eurocode 7 and includes the derived values of the ground properties. The geotechnical design model includes representative values of the ground properties that take into account both the spatial uncertainty of the ground properties and the deformation or failure mechanism to be considered. Emphasis has been placed on the reliability of the data incorporated into these geotechnical models: it is important to remember that the results of a calculation have a lesser worth than the assumptions used to obtain them.

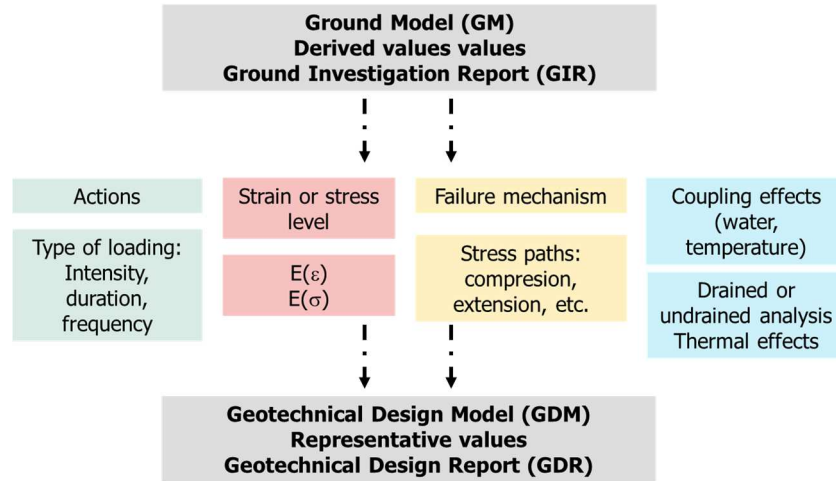


Figure 3. From the Ground Model to the Geotechnical Design Model

#### 2.4 Representative values of ground properties

The problem of determining property values for land is now presented by considering two types of values:

- 'nominal' values, which are based on expert judgement backed up by comparable experience ;
- 'characteristic values, based on the calculation of a conservative average value that is 95% reliable. Within a layer of soil considered to be homogeneous, this value is obtained using the following equations:

$$X_k = X_{mean} - k_N \sigma = X_{mean} (1 - k_N \cdot V) \quad (1)$$

$$X_k = e^{Y_{mean} - k_N \sigma} = e^{Y_{mean} (1 - k_N \cdot V)} \quad (Y = \ln X) \quad (2)$$

$$k_N = \frac{t_{95, N-1}}{\sqrt{N}} \text{ et } V = \frac{\sigma}{X_{mean}} \quad (3)$$

with:  $X_{mean}$  the arithmetic mean,  $\sigma$  the standard deviation,  $V$  the coefficient of variation,  $N$  the number of values considered and  $t_{95, N-1}$  the 5% fractile of Student's law with  $N-1$  degrees of freedom.

The two procedures can be implemented in parallel and the choice between these two values is left open. The aim is to obtain a representative value to which partial coefficients can be applied if required.

#### 2.5 Safety concepts

The concepts of calculation approaches have been abandoned and have given way to two main ways of approaching the safety of geotechnical structures:

- the first consists of weighting geotechnical resistances (Resistance Factor Approach - RFA): this is the approach commonly used for the justification of deep foundations, for which partial factors are applied to the terms of bearing capacity, resistance to sliding, etc. It also covers approaches aimed at expressing the level of safety as the ratio between the mobilisable resistance and the mobilised resistance,

- the second consists of weighting the intrinsic properties of resistance to shear (Material Factor Approach - MFA): this is the approach commonly used to justify the slope stability, where partial factors are applied to cohesion and the friction angle.

With the exception of some very specific structures, such as slopes, the choice between the two approaches is left to each country or project. In fact, depending on the calculation method and the calculation parameters used, the two weighting approaches may have their benefits and drawbacks.

These approaches to the safety of geotechnical structures shall be combined with load combinations that indirectly reflect the old calculation approaches. Classically, these load combinations consist of applying partial coefficients :

- either on the permanent actions  $\gamma_G$  and on the variable actions  $\gamma_Q$ ,
- or on the effects of actions  $\gamma_E$ .

It is thus possible to draw up the following table for different failure mechanisms: those relating to geotechnical and structural limit states, those relating to equilibrium limit states (i.e. limit states involving neither the strength of the ground nor the strength of the supported structure), and those relating to water-related limit states.

It is important to note that calculation approach 3 has formally disappeared. The concept of geotechnical actions that derived from it has nevertheless been retained, but with a more flexible definition: it refers to actions reflecting the interaction between a structure and the ground; for example, active earth pressure, negative friction or water pressures.

Table 1. Safety approaches

Verification Cases		Type of geotechnical limit states			
		<i>Rupture and Excessive deformation</i>		<i>Static equilibrium and uplift</i>	
		MFA	RFA	MFA and/or RFA	
VC1	$\gamma_Q > \gamma_G > 1.0$	X (old DA1-1)	X (old DA2)		Specific verifications: - total stresses, - hydraulic gradients.
VC2	$\gamma_Q > \gamma_G > 1.0$ $\gamma_G = 1.0 ; \gamma_Q > 1.0$			X	
VC3	$\gamma_G = 1.0 ; \gamma_Q > 1.0$	X (old DA1-2)			
VC4	$\gamma_E > 1.0 ; \gamma_Q > 1.0$		X (old DA2*) EFA		

## 2.6 Water levels

The question of the choice of water levels led to the definition of different levels, as shown in Figure 2, which is quite similar to that used in France. The figure does not refer to the water level but to the piezometric level in a homogeneous layer of ground (geotechnical unit).

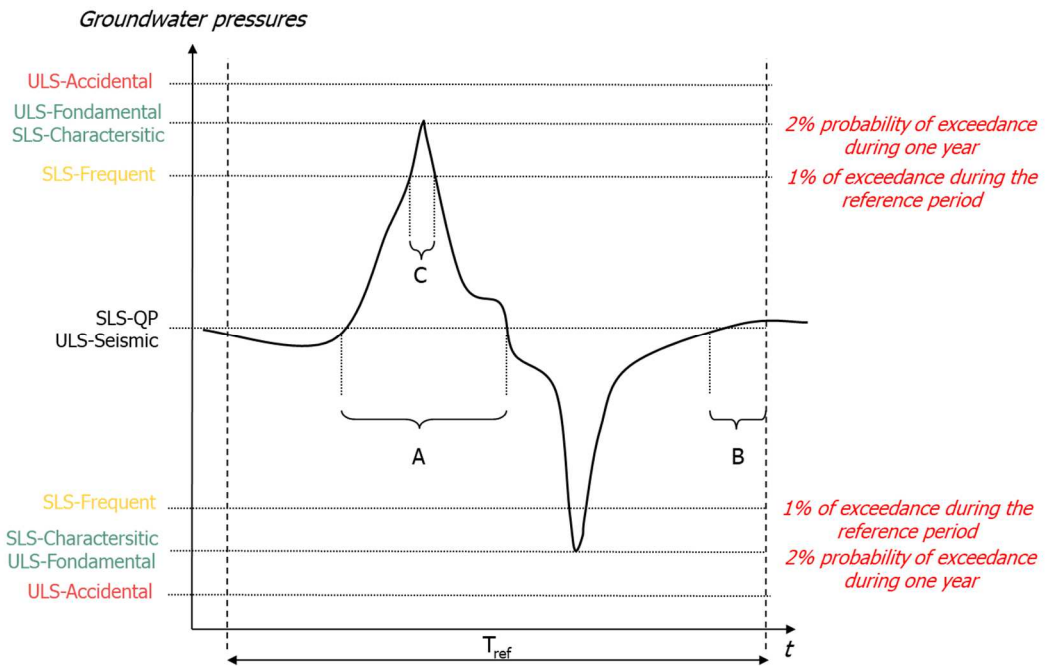


Figure 4. Selection of groundwater or piezometric levels

## 2.7 Hydraulic failures

Two failure mechanisms are presented in prEN 1997-1:

- the first one is related with the design value of the hydraulic gradient  $i_d$  and corresponds to a local verification (see equation 8.4 in prEN1997-1):

$$i_d \leq i_{cd} \quad (4)$$

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

- 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 prEN1997-1):

$$\Delta u_d \leq \gamma \sigma'_{v0} \quad (5)$$

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 example taken from a paper published by Pane et al. (2015) (Figure 5) illustrates these two verifications are antagonist:

- without wells, the hydraulic flow arrives at the bottom of the excavation: the hydraulic gradient is low but as all the layer width 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).

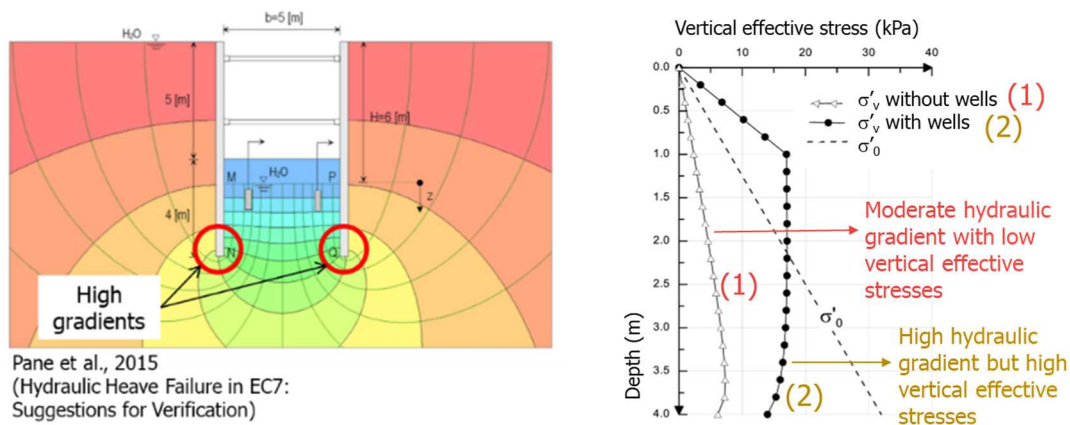


Figure 5. Hydraulic verifications

## 2.8 Numerical methods

A specific procedure is given in prEN 1997-1 for numerical methods. Two approaches are mainly described and the more unfavorable of the two governs the design (Figure 3), 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 prEN 1997-3. prEN 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 3).

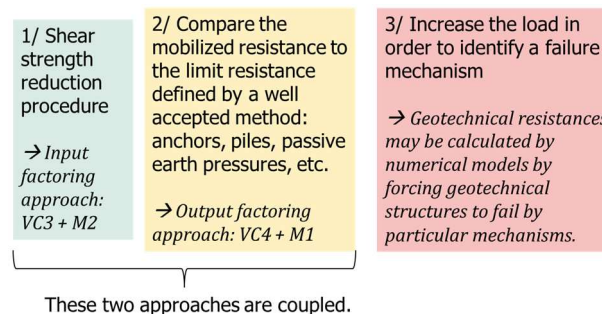


Figure 6. Input, output and forcing particular mechanisms

### 2.8.1 Input factoring

This approach is now mainly based on the use of shear strength reduction procedures that are fully available in many software. prEN 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 body,
- (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.

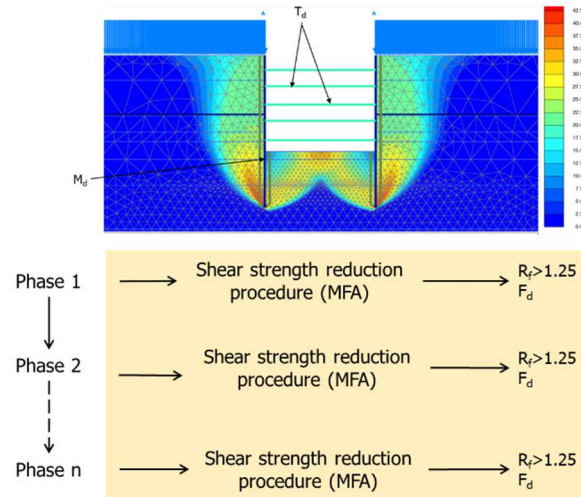


Figure 7. Input factoring with shear strength reduction procedure

### 2.8.2 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 prEN 1997-3.

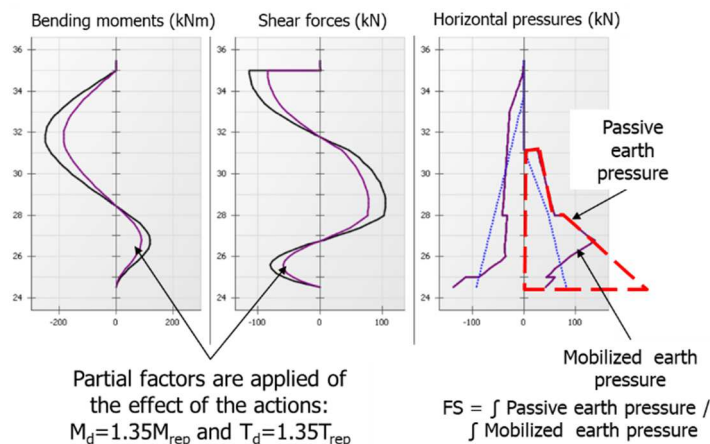


Figure 8. Output factoring with subgrade reaction methods

### 2.8.3 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.

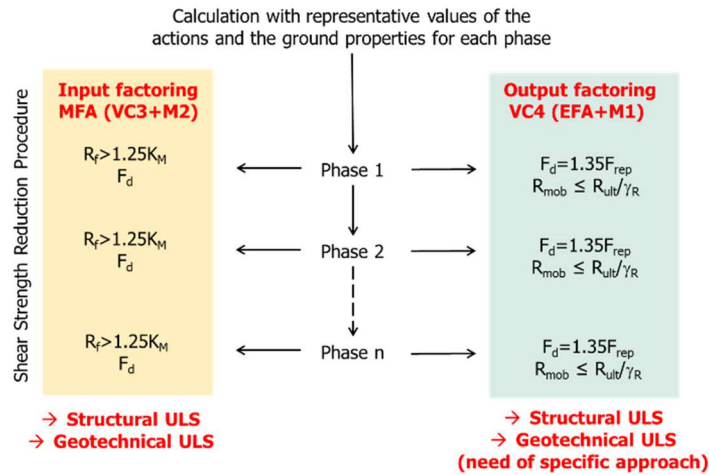


Figure 9. Coupling of input and output factoring

### 2.9 Dynamic and cyclic loads

Some criteria have been identified to make the distinction between cyclic and dynamic loads as shown in Figure 10. For cyclic effects, simplified rules for shallow and deep foundations have been proposed to identify when Eurocode 7 is relevant:

- Domain 1: cyclic analysis is not useful,
- Domain 2: simplified cyclic analysis (degradation of soil properties – adjust model factors),
- Domain 3: specific methods (not described in EN 1997).

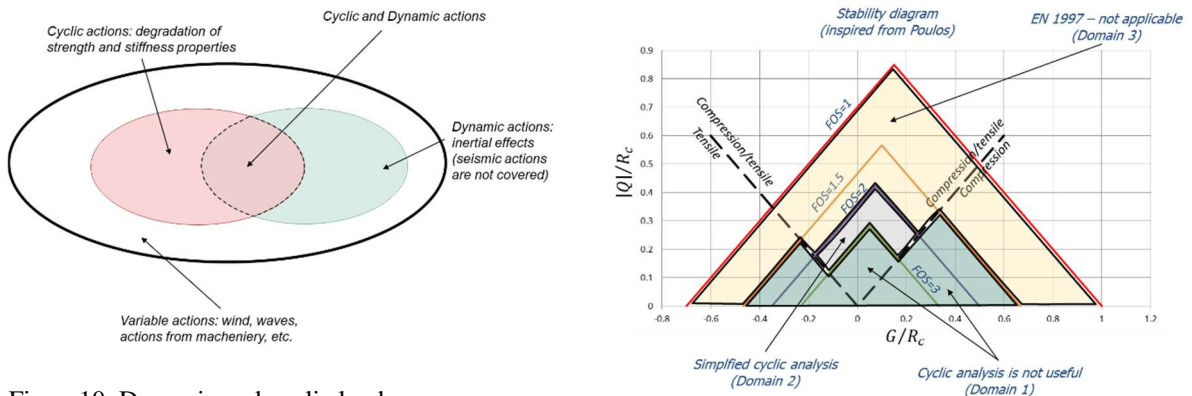


Figure 10. Dynamic and cyclic loads

### 2.10 Execution and reporting

A chapter of Eurocode 7 - Part 1 is dedicated to various topics relating to the execution of geotechnical works: supervision of works, inspection of works, monitoring of works, particularly with regard to instrumentation plans, and maintenance of geotechnical structures.

Finally, the last chapter describes the structure of a geotechnical report, with the main stages of a project and a graduated approach to taking geotechnical risks into account.

## 3 EUROCODE 7 – PART 2 (PREN 1997-2)

### 3.1 *Structure of Part 2*

The structure of the text has been completely changed compared with the previous version of Eurocode Part 2, which was organised around aspects relating to the organisation of a geotechnical investigation campaign and the different types of geotechnical tests carried out in the laboratory or on site. From now, Eurocode 7 - Part 2 is organised around the presentation of the mechanical, hydraulic and thermal properties of soils and rocks. The first chapter is nevertheless dedicated to the construction of the ground model, emphasising the need to integrate geological, hydrogeological, geotechnical and geomechanical aspects. The aim is to provide a conceptual model of the ground.

Specific developments on shear properties and deformation moduli are then presented. For shear properties, the simplest failure criteria for soils and rocks are described. For deformation moduli, their variation with the level of deformation is presented. The presentation of these different parameters is intended to be compatible with the use of numerical methods involving complex behaviour laws with non-linear elasticity and plastic mechanisms with strain hardening. Nevertheless, it is not intended to favour any particular calculation code: only the principles are presented. A chapter on the consideration of seismic, dynamic and cyclic loading is also included to complement the aspects of Eurocode 7 Part 1 relating to dynamic and cyclic loading.

### 3.2 *Derived values*

One of the key points of Eurocode 7 - Part 2 is the concept of derived values. This term refers to the mechanical, hydraulic or thermal properties obtained from geotechnical tests in the laboratory or on site. The way in which these properties are obtained may be more or less direct, depending on the parameter being sought. For example, cohesion and friction angle are parameters derived from the stress paths measured during a shear test. The interpretation of the tests is linked to the limit states to be considered when the structure to be designed is defined. The use of correlations is also highlighted insofar as they are validated on comparable experiments.

## 4 EUROCODE 7 – PART 3 (PREN 1997-3)

Eurocode 7 - Part 3 is currently being drafted. This part is organized around various chapters dealing with the following geotechnical structures: slopes, shallow foundations, deep foundations, retaining structures, anchors, reinforced soils both for soils and rocks, ground improvement, control of groundwater. The aim is to provide calculation methods for each of these geotechnical structures, enabling Eurocode 7 - Part 3 to be applied directly without the need for national standards. The harmonization work to be carried out is colossal, as each country has acquired its own experience over the course of its history, influenced more by its geology and professional organization (influence of public authorities, procurement methods, insurance systems, etc.) than by genuine technical and scientific choices.

## 5 CONCLUSION

The drafting work on Eurocode 7 is entering its final phase. Formal votes for Parts 1 and 2 have been positive. European countries can now start the drafting of their national annexes. Some discussions will be planned to harmonize the way of implementing national practices in these annexes. Background reports and guidelines published of the JRC (Joint Research Center of the European Commission) will be available to help the designer in the use of the now Eurocode 7. Formal vote for Part 3 is planned for the end of 2024. For geotechnical structures that were already well described in the 2005 version, the changes may appear minor: however, it will be necessary to anticipate them. Structures that were given little or no consideration in 2005 will need to be read more carefully, as the changes in approach could be more significant. The changes presented will not radically alter the way in which geotechnical structures are designed, but they will nonetheless bring about changes in certain National practices that it is prudent to anticipate.

However, a review of the revision of Eurocode 7 should not be concluded without mentioning the action being taken as part of the revisions of the other Eurocodes, so that they take better account of the specific features of geotechnical structures.

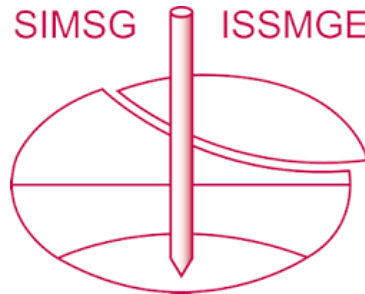
## 6 ACKNOWLEDGEMENTS

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