Second Generation of Eurocode 7 and Approach to Partial Factors When Using FEM

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ABSTRACT: The second generation of Eurocode 7 will be implemented in October 2027. For geotechnical engineers, the main change is not only the organisation of Eurocode 7, but also the emphasis on the use of ground model (GM) and geotechnical design model (GDM) in the geotechnical design process. GDM is used, among other things, as a source for the use of numerical modelling in geotechnical design. Although numerical modelling has been used for geotechnical structure design using the ultimate limit state (ULS) and the serviceability limit state (SLS) for a long time, the current Eurocode does not provide the designer any guidance on a number of important and practical issues related to the use of numerical methods for the verification of limit sates. This deficiency is eliminated by the second generation of Eurocode 7. The article briefly describes the use of GM and GDM and presents how numerical models are implemented in the second generation of Eurocode 7. It also summarises the steps in creating a numerical model of a geotechnical problem in relation to the available data.

1. INTRODUCTION

The development of the second generation of Eurocode 7 has reached its final stage and it will be implemented in practice from October 2027. For geotechnical engineers, the main change is not only the organisation of Eurocode 7 into three parts, but also the fact that the revised Eurocode 1990 ed. 3 of 2024 (CSN EN 1997-0 ED.3 2024) has taken over a significant part of the current EN 1997-1. In the new generation of Eurocode 7 (hereinafter EC7), there are two different models. The ground model, including geology, presentation, and evaluation of test results, and the geotechnical design model serve as the basis for the design of the structure. All data and information regarding ground and groundwater for the GM area must be recorded and included in the Ground Investigation Report (GIR). However, the selection of design parameters is already part of the next step, which is the creation of the GDM. Based on the GDM, it is possible to create a numerical model that is a simplified representation of the assumed reality suitable for a specific numerical analysis.

When the first generation of Eurocode 7 was introduced, the use of numerical methods was in its beginnings, and in practice 2D analysis clearly dominated, providing limited information for geotechnical design. This situation was also reflected in the fact that numerical models were not sufficiently implemented by the first generation of Eurocode. In EC7, numerical models are defined as calculation models that involve numerical approximation to obtain a solution. The recommended procedures for the use of numerical modelling for the design of geotechnical structures are given in Article 8.2 of Part 1 of EC7. Thus, engineering practice today has useful and applicable recommendations for the use of numerical methods for the design of geotechnical structures based on ultimate limit states (ULS) and serviceability limit states (SLS).

2. GROUND MODEL

The term Ground model is defined in EC7 Part 1: 3.1.6.6 as: ‘site-specific outline of the disposition and character of ground and groundwater based on the results of ground investigations and other available data’. In EC7 Part 2: 4.1 Foundation soil investigation and testing, it is further stated: ‘A ground model shall comprise the geological, hydrogeological, and geotechnical conditions at the results of the site, based on the ground investigation.' (ČSN EN 1997-1 ED.2 2025, ČSN EN 1997-2 ED.2 2025). It is therefore obvious that the GM is connected to the specific structure(s) and the phases of its/their construction and therefore the zones of influence (ZOI). It is essential for the success of any project that the scope of the GM is appropriate to the given project, foundation soil, and groundwater conditions.

During the process of building a ground model and determining derived values, several sources of uncertainty arise (e.g., with geological conditions, knowledge of the history of the site, spatial heterogeneity, determination of the ZOI, etc.), and care must be taken to minimise these uncertainties. Not only for the purpose of minimising errors in the GM, the CEN/TC250/SC7 working group has developed a guideline describing in detail the creation of a ground model and obtaining derived values of ground properties (Garin et al., 2024).

3. GEOTECHNICAL DESIGN MODELS

The term geotechnical design model is defined in EC7 as a conceptual site representation derived from a ground model for the verification of each appropriate design situation and limit state. Guidance on the content of a GDM is given in Chapter 12 and Annex B.4.2 EC7-1. The model is intended to include representative values of ground properties of geotechnical units (the data sources used to determine the representative value shall be stated), specification of geometry, and groundwater conditions. Annex B.4.2 EC7-1 specifies the requirements for a GDM. The GDM is thus the result of a review of the information available in the GIR and GM, including reconnaissance of the site and its surroundings, subgrade investigation, laboratory testing, and groundwater investigation. Representative values included in the GDM are assessed according to EC7, taking into account the accuracy achieved in the ground investigation, the extent of the investigation, and the level of risk for the specific geotechnical structure.

4. APPLICATION OF NUMERICAL MODELLING IN THE NEW GENERATION OF EUROCODE 7

Various approaches to the application of the finite element method for ULS verification in geotechnical design emerged with the application of the first generation of Eurocodes into practice at the beginning of the 21st century. The differences in approach mainly concerned the influence of initial stresses, the choice of a soil constitutive model (the Mohr-Coulomb model clearly prevailed), the application of partial factors, and the determination of structural element failure. The greatest discussion among experts dealt with the application of partial factors.

Brinkgreve and Post described the application of partial factors in the design of a sheet pile wall anchored at one level in PLAXIS (Brinkgreve and Post, 2015). Bauduin et al. (2003) also discussed the use of Eurocode 7 limit states in the design of a sheet pile wall. Katsigianis et al. (2015) described the use of Eurocode 7 in the application of various material models. Simpson (2007,2013) discussed the application of Eurocode 7 in numerical models. Schweiger solved the application of Eurocode 7 in the numerical analysis of tunnels (Schweiger 2010, Schweiger, Marcher, and Nasekhian 2010). Some authors have proposed the DA2* approach as an alternative to DA2 for numerical methods (EAB 2006, Frank et al. 2004, Barták and Pruška 2015). Despite the lack of guidance in the first generation of Eurocode 7, numerical methods for design using ULS have been widely used after some initial uncertainties. Of the approaches proposed, the most common is the analysis with characteristic soil parameters and the subsequent application of a partial factor for the effects of loads or structural forces.

EC7 describes the implementation of partial coefficients in numerical methods for:

-(i) Verification of ULS with application of partial coefficients at input and output. Both approaches are described in terms of their choice and implementation.

- (ii) SLS verification is important when choosing a material model in accordance with the GDM. Representative values of ground properties must take into account all situations based on the derived values presented in the GM.

4.1 ULS VERIFICATION

Eurocode 1990 ed. 3 of 2024 (CSN EN 1997-0 ED.3 2024) introduces four verification cases (VC1 to VC4) for all types of structures, which use partial factors for loads γ_F and load effects γ_E. According to EC7, Part 1, Article 8.2, the ULS verification of geotechnical structures should be based on the less favourable results given by:

- applying partial factors to the input (input factoring – MFA material factor approach) using:

- partial factors for load γ_F from verification case 3 (VC3) and;

- partial factors on material properties γ_M for the set M2.

This approach is based primarily on the use of shear strength reduction, which is possible with various software. There are two possible ways of applying partial factors. The first method performs the calculation with representative values and only in the ULS verification phases applies partial factors γ_M from the set M2. EC7 recommends this method due to the possibility of performing SLS and ULS assessments using a single numerical analytical model. The second method applies partial factors γ_M from the set M2 to the ground properties right from the start of the analysis. If the reduction of the strength parameters does not lead to significant stress redistribution, additional plasticity, and unbalanced forces, the critical state will not be verified.

- applying partial factors to the output (output factoring – RFA resistance factoring approach) using:

- partial factors for load effects γ_E for verification case 4 (VC4) and;

- partial coefficients on material properties γ_M for the set M1.

This is a direct combination, where the calculation is performed with representative values of the soil properties and the partial coefficient γ_E from the set M1 is applied to the model output (load effects). This approach of applying partial factors to loads and bearing capacity is equivalent to the LRFD approach, which is used, for example, in the USA. Its application is suitable for the use of nonlinear material models, large displacements, analysis of progressive failure, creep, shrinkage, or interaction of the structure and soil. It is worth mentioning that when using load redistribution in this approach, the partial factors for load effects are applied to the bearing capacity side, i.e., to the strength properties of the structure. It is logical that if the solved problem does not contain any structural elements (e.g., stability of an unsecured slope, notch, etc.), verification of the application of partial factors to the results of the problem does not make sense. The ULS verification procedures are detailed in Table 8.1 in EC7. The partial factors for sets VC3 and VC4 are given in CSN EN 1997-0 ED.3 (2024), and the partial factors for sets M1 and M2 are given in CSN EN 1997-1 ED.2 (2025). It is important that the parameters in these sets are defined as Nationally Determined Parameters (NDPs).

The new Eurocodes also allow for the verification of both limit states using a numerical model containing more than one geotechnical structure (complex or continuous methods). However, when modelling complex problems, it is often not clear which of the above approaches is critical, and it is necessary to check with both approaches, as stated e.g. by Lees (2019).

4.2 SLS VERIFICATION

The SLS verification allows the assessment of the structure with regard to its functioning under normal use, the comfort of people, and the appearance of the building. When verifying this limit state, these assessments necessarily require the choice of a material model in accordance with the GDM and the failure mechanism (considering the stress paths), taking into account the range and frequency of the loads. The complexity of the numerical models must be in accordance with the available data and the verifications carried out, even for coupled numerical tasks (consolidation, thermomechanical analysis, etc.). The representative values of the soil properties must take into account all these situations based on the derived values presented in the GM. The main problem is therefore the selection of the foundation soil to determine the representative values of the GDM. The determination of some parameters and recommendations regarding both stress and strength are provided by Eurocode 1997-2.

5. STEPS IN NUMERICAL MODEL DEVELOPMENT

Below is an overview of the steps for a numerical model development in accordance with the new generation of Eurocode 7 (Fig. 1 shows a schematic representation of a general 2D task in relation to actual and calculated settlements):

- Definition of the geotechnical problem, specific design situations, construction phases, assessment requirements (limit states, failure mechanism, etc.).
- Derivation of an FEM computational model from the GDM. The FEM model exemplifies a simplified representation of the layers and geometry while maintaining the properties that affect stability and deformation. The groundwater conditions in the model reflect the critical design situations. Determination of the size of the modelled area and boundary conditions. Selection of a representative profile for 2D analysis.
- Selection of a material model and the type of task. The material model should be selected in accordance with the type of the given material, the stress state and the required accuracy (e.g., Mohr-Coulomb model, HS model, Cam clay, Hoek Brown, etc.). The type of task is 2D or 3D version and the solution method – axisymmetric task, deformation, or stress analysis.
- Determination of representative values of soil properties, taking into account their variability, assessed volume, influence of the area of effect, or failure mode.
- Selection of a method of application of partial factors (input factoring, output factoring, etc.). The numerical model must clearly show which parameters are adjusted by partial factors and why.
- Modelling of construction phases and the influence of time. A realistic construction process should be modelled, taking into account gradual activation/deactivation, consolidation, creep (if relevant), and changes in groundwater.
- Performing ULS and SLS verification. Limit values must be defined prior to performing the FEM analysis.
- Performing sensitivity analysis and verifying model reliability. Explicitly recommended in EC7.
- If required, the numerical model can be used as a basis for a monitoring forecast.
- Preparation of documentation for a geotechnical design report (GDR). The report should include: description and assumptions of the numerical model, derivation of parameters, method of model verification, results and their plausibility check, and limitations of the model.

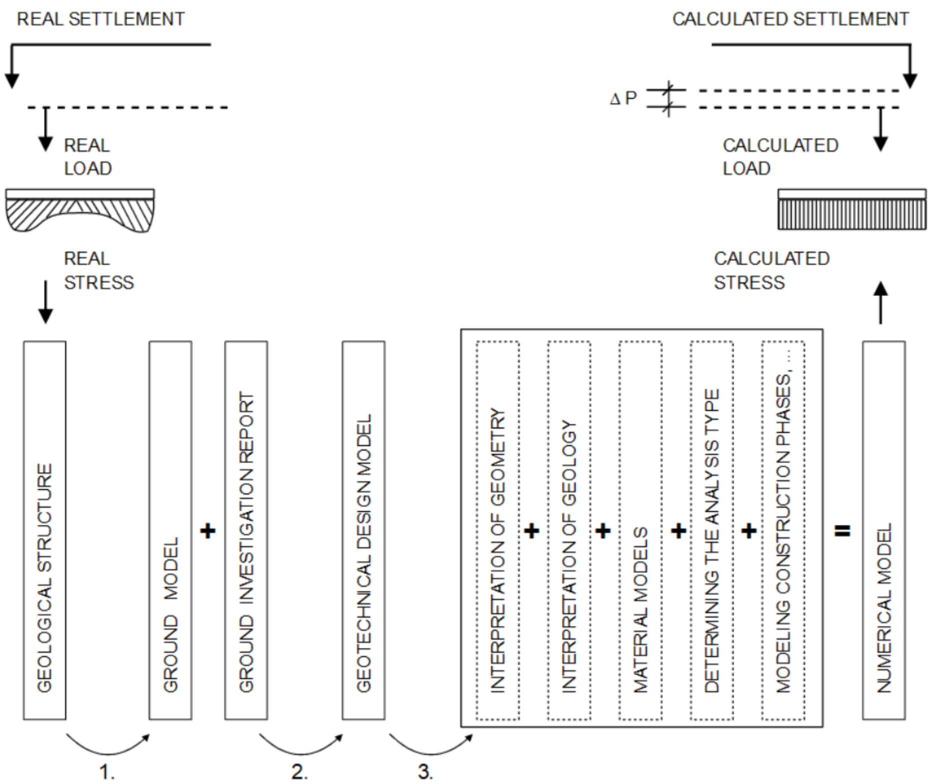

Figure 1: Steps in developing a numerical model

6. CONCLUSION

The second generation of Eurocode 7 provides designers with rules for the use of numerical methods for the verification of ULS and SLS in geotechnical design based on the use of partial factors, which is a huge step forward compared to the first generation. These rules are based on current practices used by designers and allow the use of nonlinear material models for both soil and supporting elements. It allows for standard analysis based on properties reduced from the beginning (input factoring) with partial factors from the VC3 set (CSN EN 1990: 2024) and the M2 set (CSN EN 1997-1: 2025) or based on the application of partial factors to the effects of action during subsequent processing of the results (output factoring) with partial factors from the VC4 set (CSN EN 1990: 2024) and the M1 set (CSN EN 1997-1: 2025). The new Eurocodes also allow for the verification of both limit states using a numerical model containing more than one geotechnical structure (complex or continuous methods). However, when modelling complex problems, it is often not clear which of the above approaches is critical; it is necessary to check with both approaches, as stated, e.g., by Lees (2019).

Although the above text may suggest that the choice of partial factors is crucial to ensure the meaningfulness of a numerical model, there are a number of other important factors that affect the safety (and economics) of design using numerical methods. It is important for the designer to understand the difference between behaviour prediction, serviceability limit state (SLS) analysis, and ultimate limit state (ULS) verification. For the verification of structural elements, the design forces should be compared with the design resistances calculated using other Eurocodes. Another factor is the use of advanced material models (e.g. Hoek-Brown, Hardening soil) and the application of partial coefficients (EC7 does not provide any specific instructions). And last but not least, the creation of the numerical model itself, based on the data in the GDM and the GIR (simplification of soil layers and geometry, level of conservatism in the assumptions of representative parameters, etc.)

The development of the second generation of Eurocodes has led to significant improvements over the first generation. However, from the perspective of tunnels and underground structures, it is only applicable to excavation-constructed works. The process of standardization of tunnels is still ongoing and the first conclusions made by the expert group of the Joint Research Centre (JRC) of the European Commission are published in two reports (JRC 2019, 2022). In cooperation with the JRC, the members of CEN TC250/SC7 have also published a set of guidelines and further elaboration of the requirements set out in EC7 (JRC 2024a, 2024b, 2024c). The above publications, together with the guidance on numerical modelling in the revised EC7, provide designers with the opportunity to use numerical methods to produce more economical and safer designs. However, the use of numerical methods also requires experience, a basic understanding of soil mechanics principles, and sound engineering judgement.

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