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Application of numerical modelling in Next Generation of Eurocode 7

Application de la modélisation numérique dans la prochaine génération de l'Eurocode 7

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ABSTRACT: The Next Generation (NG) of Eurocodes are currently being drafted and scheduled to be rolled out in later part of 2027. The existing code does not cover the use of numerical modelling in geotechnical design although its use for serviceability limit state assessment and even for ultimate limit state (ULS) design has gone on for many years. The draft document will provide some guidance on the use of numerical modelling for ULS design of geotechnical structures. Clause 8.2 in Part 1 of this new draft code covers the recommended procedure for the application of numerical modelling in ULS design of geotechnical structures. This paper describes the evolution of the use of numerical modelling in geotechnical design and the recommended procedure included in this new code. A comparison is also made on the consequences of this procedure on the existing design approaches currently implemented in the existing code.

RÉSUMÉ: La prochaine génération d'Eurocodes est en cours d'élaboration et devrait être déployée durant l'année 2027. Le code actuel ne couvre pas l'utilisation de la modélisation numérique dans la conception géotechnique, bien que son utilisation pour l'évaluation de l'état limite de service et même pour la conception de l'état limite ultime (ELU) se poursuivent depuis de nombreuses années. Le document en cours d'élaboration fournira des indications sur l'utilisation de la modélisation numérique pour la conception ULS des structures géotechniques. L'article 8.2 de la partie 1 de cette nouvelle version du code couvre la procédure recommandée pour l'application de la modélisation numérique dans la conception des structures géotechniques ULS. Cet article décrit l'évolution de l'utilisation de la modélisation numérique dans la conception géotechnique et la procédure recommandée pour être incluse dans ce nouveau code. Une comparaison est également faite sur les conséquences de cette procédure sur les approches de conception existantes actuellement mises en œuvre dans le courant code.

Keywords: Eurocode; numerical modelling; ultimate limit state.

1 INTRODUCTION

The Structural Eurocodes are the current European design standards for buildings and construction works covering a wide range of structural materials and fields of civil engineering. Eurocode 7 (EC7), which is the standard for geotechnical engineering design in Europe, introduces the concepts of limit state design and partial safety factors distinguishing between Serviceability Limit State (SLS) and Ultimate Limit State (ULS).

The development of advanced geotechnical software, together with the introduction of cutting edge and less expensive hardware has resulted in 2D and 3D advanced numerical methods such as Finite Element Method (FEM) being routinely used in the Geotechnical Engineering field. Moreover, the introduction of advanced constitutive models that allows for better simulation of the soil behaviour has resulted in the increasing use of advanced numerical methods in geotechnical engineering to predict deformations and verify against SLS.

Eurocode 7 allows the use of numerical methods for verification against ULS but gives no guidance to the designer in a number of important and practical issues regarding the implementation of the guidance. These issues have triggered an important debate in the geotechnical engineering community over the feasibility of routine use of FEM for ULS checks.

Various concerns were raised in the application of numerical methods in ULS geotechnical design in accordance with EC7 in late 1990s early 2000s, more specifically with the use of finite element modelling.

These include effects of initial stresses, effects of stress history, choice of soil model, when the partial factors are applied and significance of the failure of structural member (Bauduin *et al*. (2000, 2003), Katsigiannis (2017), Simpson and Yazdchi (2003), Yeow (2014, 2022)).

Despite these early concerns, application of numerical methods has been adopted widely by practitioners even with a lack of guidance in its use for ULS design under the existing EC7. The most commonly adopted approach is to undertake the analysis with characteristic ground parameters and subsequently apply partial factor to the structural forces or the *effects of actions*. As the UK adopt Design Approach 1 with the need to undertake two combinations of design assessments, Simpson and Yazdchi (2003), Katsigiannis et al. (2014, 2015) and Yeow (2014, 2015, 2018, 2019 and 2022) used the approach by taking modelling excursion to allow for ULS design with design material properties which allowed the stress state in the ground to be maintained at its characteristic value prior to the introduction of factored or design soil properties.

This paper outlines the approach currently drafted into the next generation (NG) of EC7 for the application of numerical methods in geotechnical design.

2 NUMERICAL MODELLING IN THE NECT GENERATION OF EC 7

The next generation of the Structural Eurocodes are currently being drafted and EC7 is near the stage of final votes in 2024 before finalisation of the documents likely during first half of 2025 for the preparation of nation annexes by individual countries by end of 2025. This paper focuses only on the numerical modelling aspects of the updated EC7 guidance and does not provide any details on other changes introduced to the revised standard.

In the revised standard, numerical models are defined as *calculation models involving numerical approximation to obtain solutions.* These include, but not limited to, finite element, finite difference boundary element, discrete-element and subgrade reaction methods. These models could be used for the verification of limit states including the failure modes and ground movements.

It is worth noting that when using numerical method, verification of specific mode of failure, e.g., sliding, overturning, bearing capacity etc, may not be possible as such approach would produce the most critical deformation and failure mode depending on the geotechnical structure being considered and the ground strength and stiffness of the model.

3 PROCEDURE OF NUMERICAL MODELLING IN THE NEXT GENERATION OF EC7

3.1 Procedure for numerical modelling

The guidance on the procedure for numerical modelling is given in Clause 8.2 of Part 1 of the revised standard. At the time of writing this paper, this clause stipulates that ULS verification of geotechnical structures should be based on the less favourable outcomes given by the:

- input factoring (of material properties):
  - factors on actions γ_F from Verification Case 3 (VC3) and;
  - factors on material γ_M from Set M2;
- output factoring (of the effects of actions):
  - factors on effects-of-actions γ_E from Verification Case 4 (VC4) and;
  - factors on material γ_M from Set M1.

The input factoring is also known as the Material Factor Approach (MFA) in the current code which is still in use in the revised code while the output factoring is the Effects Factor Approach (EFA) in the current code but is no longer used as a term in the next generation of EC7. Clause 8.2 also refers to Table 8.1 which details the above ULS verification procedure. The VC3 and VC4 can be found in Table A1.8 of the revised EN 1990 Eurocode and depending on the type of geotechnical structure, one or both of these verification cases will be recommended in the new code. These two tables are reproduced in Appendix A of this paper for information. It is worth noting that the details in these two tables are defined as National Determined Parameters (NDPs) under the new standard, hence each individual country should be able to make appropriate selection or changes in their National Annex accordingly.

3.2 Ultimate limit state modelling procedure

As discussed above, the next generation of EC7 requires that both input and output factoring combinations are checked when undertake ULS verifications using numerical methods in order to determine the least favourable outcomes to be used for design.

The most straight forward combination is the output factoring approach under VC4 whereby representative values of soil properties (M1) are used to analyse the geotechnical problem and the partial factors are then applied to the output of the model or in this case the effects of actions.

The input factoring procedure under VC3 has two possible methods of applying the material factor M2. These two methods are discussed and compared in depth by Katsigiannis (2017).

In the first method, characteristic values of the parameters are used in the calculations, and at critical discreet stages, the user applies the material factor M2 for the ULS verifications. Such method is also known as the "modelling excursion" approach whereby partial factor M2 on soil properties is applied as and when necessary to invoke the design under VC3.

In the second (i.e. alternative) method, users apply the partial safety factors to the material parameters right from the start of the analysis and the calculations are carried out using the design values of the parameters.

Despite the apparent simplicity of the second method, the recommended method based on the updated standard is to only apply the material factor M2 to the soil properties at critical stages during the construction sequence. The main reason that this method is recommended, is mainly because users can verify against both SLS and ULS by carrying out their design using one numerical analysis model.

Figure 1 shows an example of the ULS design procedures for a retaining wall with multi-stage construction sequence.

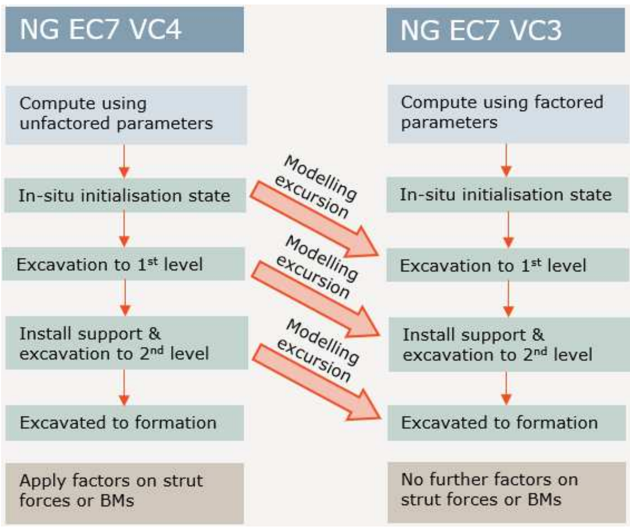

Figure 1. Procedures to undertake ULS verification as per next generation of EC7.

4 COMPARISON WITH CURRENT EC7 APPROACH

For the comparison with the design approaches under the existing EC7 when undertaking design verification using numerical methods, the partial factors published in Section A.3 of Annex A of BS EN1997-1 (2014) are used. No consideration is given of any variations implemented under the National Annex of individual countries.

4.1 Design Approach 1 (DA1)

In accordance with the DA1, ULS design verification of the design under the less favourable of the two combinations of partial factors in the following forms:

- Combination 1 (C1): A1 "+" M1 "+" R1
- Combination 2 (C2): A2 "+" M2 "+" R1

Under DA1 C1, the partial factors are applied to actions or the effects of actions with material factor set to unity, i.e., M1. This is the same with the output factoring (VC4 "+" M1) approach of the revised standard. For DA1 C2, the partial factors are applied to the material properties, i.e., M2, and this is the same with the input factoring (VC3 "+" M2) approach of the revised standard.

Except for pile design in the current standard, the resistance factor R1 is equal to 1.0 for the design of most geotechnical structures. Therefore, the geotechnical design undertaken using DA1 is consistent with the proposed procedures outlined in the revised next generation of EC7 and designers in countries which have adopted DA1 such as the UK, will see little impact on their current established practice when using numerical methods.

4.2 Design Approach 2 (DA2)

DA2 only requires one check based on the following combination:

- Combination: A1 "+" M1 "+" R2

This is similar to the output factoring (VC4 "+" M1) approach of the revised standard with the exception of the application of resistance factor R2 of greater than 1.0. The value of R2 ranges from 1.1 for sliding resistance and earth resistance for slope stability assessment to 1.4 for bearing capacity and earth resistance for retaining structure. However, when undertaking design assessment using numerical analysis, the introduction of a resistance factor to the model is not straight forward as these parameters are not input in the numerical calculations. Therefore, those who used numerical modelling resolve to applying a partial factor on the effects of actions similar to DA1 C1.

Under DA2 there is no verification by applying partial factor to the material properties, i.e., M2. Under conditions whereby input factoring (VC3 "+" M2) approach governs the design, such approach would be unsafe.

Some authors suggest the DA2* approach as an alternative to DA2 for numerical methods (Frank et al., 2004). For retaining wall design, for example, DA2*, requires that the characteristic active earth pressures is used in the analysis while any variable surcharge is factored by γ_G/γ_Q = 1.5/1.35 = 1.1. The passive earth resistances need to be factored by the resistance factor γ_R and the load factor γ_G. The design values of the structural forces are obtained at the end of the analysis, after factoring the outputs by the load factor, γ_G. While the use of DA2* seems to be straightforward for simple methods of analysis such as Limit Equilibrium, factoring the passive earth resistance is not possible in advanced numerical analysis.

Based on the updated EC7 guidance, designers in countries which have adopted DA2 will have to carry out both input and output factoring approaches when using numerical methods, with the combination that gives the most adverse results being critical and governing the design.

4.3 Design Approach 3 (DA3)

DA3 only requires one check based on following combination:

- Combination: (A1* "or" A2†) "+" M2 "+" R3

* on structural actions

† on geotechnical actions

For DA3, the R3 resistance factor is equal to 1.0 hence for geotechnical actions the procedure is similar to input factoring (VC3 "+" M2) approach of the revised standard. For structural actions, however, applying both partial factors on both the actions (A1) and material properties (M2) would be more conservative than input factoring (VC3 "+" M2) approach. While currently under DA3 there is no need for verification with output factoring approach, according to the updated EC7 guidance, designers in countries which have adopted DA3 will have to carry out both input and output factoring approaches when using numerical methods.

5 CONCLUSIONS

The next generation of Eurocodes are currently being drafted to improve the guidance for designers both in the management of safety and risks in design and subsequent execution of construction works. The incorporation of more detailed and consistent guidance on numerical modelling in the revised EC7 will result in numerical methods to be more routinely used for ULS verifications while providing designers who have access to advanced design tools the ability to produce more economical and safer design. However, the use of such tools requires experience, fundamental understanding of the principles of soil mechanics and sound engineering judgement.

The revised EC7 is addressing one of the biggest challenges of the current standard by enabling further harmonization and ease-of-use. This is being achieved with the elimination of the different Design Approaches for numerical methods, effectively recommending all countries to follow the most critical case of the dual factoring approach. This approach seems to provide sufficient levels of safety, rigor and economy and reasonably consistent levels of reliability can be achieved for a wide range of construction problems This harmonization of practice among all countries adopting the Eurocodes definitely represents a major advance over the current version of the standard.

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Appendix A: Table A.1.8 (NG EN 1990 Eurocode) and Table 8.1 (NG EC7 Part 1)

Table A.1.8 (NDP). Partial factors on actions and effects for fundamental (persistent and transient) design situation.

Action or effect				Partial factors γ_F and γ_E for Verification Cases 1 to 4				
Type	Group	Symbol	Resulting effect	Structural resistance	Static equilibrium and uplift		Geotechnical design	
Verification case				VC1[a]	VC2(a)[b]	VC2(b)[b]	VC3[c]	VC4[d]
Formula				(8.4)	(8.4)	(8.4)	(8.4)	(8.5)
Permanent action (G_k)	All [f]	γ_G	unfavourable /destabilizing	$1{,}35k_F$	$1{,}35k_{Fdfdfdf}$	1,0	1,0	G_k is not factored
	Water	γ_{GW}		$1{,}2k_F$	$1{,}2k_F$	1,0	1,0	
	All [f]	$\gamma_{G,\ stb}$	stabilising [g]	not used	1,15 [e]	1,0		
	Water [l]	$\gamma_{GW,\ stb}$			1,0 [e]	1,0		
	All	$\gamma_{G,\ fav}$	favourable [h]	1,0	1,0	1,0	1,0	
Prestressing (P_k)		$\gamma_P{}^k$		-	-	-	-	-
Variable ac Action (Q_k)	All [f]	γ_Q	unfavourable	$1{,}5k_F$	$1{,}5k_F$	$1{,}5k_F$	1.3	γ_Q/γ_G
	Water [l]	γ_{QW}		$1{,}35k_F$	$1{,}35k_F$	$1{,}35k_F$	1,15	1,0
	All	$\gamma_{Q,\ fav}$	favourable	0				
Effects of actions (E)		γ_E	unfavourable	effects are not factored				$1{,}35k_F$
		$\gamma_{E,\ fav}$	favourable					1.0

Notes *a to l* not included here

Table 8.1 (NDP). Procedure for verification of ultimate limit state with numerical models.

			Factoring approach – see 8.2 (1)		
			EFA VC4 + M1	MFA VC3 + M2 (Recommended)	MFA VC3 + M2 (Alternative)
			See 8.2(2), (7) and (8)	See 8.2(2), (3) (4) and (6)	See 8.2(2), (5) and (6)
Construction Stage 1 (CS1)			Step 1 Representative Step	Step 1 Representative Step	Step 1 ---
	Input	Piezometric level or groundwater pressure	Representative Values		Not applicable Go directly to Step 2
		Ground properties	Representative Values		
		Structural element properties	Representative Values		
		External actions	Representative Values		
	Output	Movements	[1]		
		Structural forces	[1]		
			Step 2 ULS Verification Step	Step 2 ULS Verification Step	Step 2 ULS Verification Step
	Input	Piezometric level or groundwater pressure	Design level	Design level	Design level
		Ground properties	Design values by M1 combination	Partial factors M2	Design values by M2 combination
		Structural element properties	Representative values	Representative values	Representative values
		External actions	Design values by VC4 combination	Design values by VC3 combination	Design values by VC3 combination
	Output	Verification of ground failure	See 8.2(7) and 8.2(8)	ULS verified if equilibrium is attained in the ground with no failure of the structure	ULS verified if equilibrium is attained in the ground with no failure of the structure
		Verification of structural failure	Design value (E_d) obtained by applying γ_E to calculate results See 8.2(7) and (8)	Design value (E_d) obtained directly from calculate results See 8.2(6)	Design value (E_d) obtained directly from calculate results
CS2	Continue in the same way through any subsequent stage (CS2, CS3, etc.)				

[1] These output values can be used for SLS verifications

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