**TC250/SC7/EG4: Numerical Methods**

**(draft) Final Report** **2014**

# Decisions/outcomes

# Which clauses in the current EN 1997-1 and -2 are relevant to your EG's topic of interest?

2.4 Geotechnical design by calculation

2.4.1 General

2.4.1 (5) The calculation model may consist of any of the following:

— an analytical model;

— a semi-empirical model;

— a numerical model.

2.4.1 (12) Numerical methods can be appropriate if compatibility of strains or the interaction between the structure and the soil at a limit state are considered.

2.4.1 (13) Compatibility of strains at a limit state should be considered. Detailed analysis, allowing for the relative stiffness of structure and ground, may be needed in cases where a combined failure of structural members and the ground could occur. Examples include raft foundations, laterally loaded piles and flexible retaining walls. Particular attention should be paid to strain compatibility for materials that are brittle or that have strain-softening properties.

2.4.1 (14) In some problems, such as excavations supported by anchored or strutted flexible walls, the magnitude and distribution of earth pressures, internal structural forces and bending moments depend to a great extent on the stiffness of the structure, the stiffness and strength of the ground and the state of stress in the ground.

2.4.1 (15) In these problems of ground-structure interaction, analyses should use stress-strain relationships for ground and structural materials and stress states in the ground that are sufficiently representative, for the limit state considered, to give a safe result..

[Spread foundations] 6.5.2.2 (6) Analytical methods are often not applicable to the design situations described in 6.5.2.2(3)P, 6.5.2.2(4)P and 6.5.2.2(5). Numerical procedures should then be applied to determine the most unfavourable failure mechanism.

[Overall stability] 11.5.1 (3) When choosing a calculation method, the following should be considered:

— soil layering;

— occurrence and inclination of discontinuities;

— seepage and pore-water pressure distribution;

— short- and long-term stability;

— creep deformations due to shear;

— type of failure (circular or non-circular surface; toppling; flow);

— use of numerical methods.

[Overall stability] 11.6 (3) Since the analytical and numerical methods available at present do not usually provide reliable predictions of the deformation of a natural slope, the occurrence of serviceability limit states should be avoided by one of the following:

— limiting the mobilised shear strength;

— observing the movements and specifying actions to reduce or stop them, if necessary.

# Which of those clauses should remain unchanged in the next edition of Eurocode 7?

2.4.1 all clauses except (12).

6.5.2.2 (6)

11.5.1 (3)

11.6(3)

# Which of those clauses should be deleted from the next edition of Eurocode 7? And why?

None.

# Which of those clauses should be changed in the next edition of Eurocode 7? What changes should be made? And why?

2.4.1 (12) Add cross-reference to new section on numerical methods

# What new clauses should be added on your topic in the next edition of Eurocode 7? And why?

The implementation of many aspects of the current Eurocode 7 using numerical methods is unclear. Since numerical methods are being increasingly used in geotechnical design, there is a need to include more information on how to implement Eurocode 7 using these tools. A new section is required in Eurocode 7 with several clauses covering numerical methods, entitled “Numerical methods” and it needs to be placed in a non-structure-specific area, such as in Section 5 “Geotechnical Analysis” of the proposed restructured EN1997-1. Appropriate values of partial factors for the proposed design approaches to be considered for incorporation into the revised EN1997-1 are also given below.

The clauses marked \* could be cross-referenced or repeated in some form in the sections covering pile and anchor design.  
  
The new clauses should cover at least the following areas (clause-type language has deliberately been avoided to give the Project Teams freedom to prepare the clauses from scratch) [explanatory notes are provided in square brackets]:

**General**

1. Definition of *numerical methods*: analytical methods involving numerical approximation and which satisfy both equilibrium and compatibility requirements. They include finite element, finite difference, boundary element and discrete (distinct) element analysis methods and beam-spring approaches.
2. There are some advantages to performing geotechnical design using numerical methods which include simultaneous checking for limit states in multiple forms, checking SLS and ULS with one analysis model and more accurate simulation of ground behaviour and soil-structure interaction.
3. Users of numerical methods software should be able to demonstrate that they hold the appropriate level of competency according to defined levels such as the COGAN scheme or similar. [Numerical methods place particularly high demands on the competency of users and benchmark exercises have shown that many errors arise from users having a lack of competency. Therefore more emphasis on competency is required than the general level described in EN1990 and EN1997-1 §1.3(2) assumptions “appropriate skill and experience” and EN1990 §2.1(7) “due skill and care”. The COGAN scheme ([www.cogan.eu.com](http://www.cogan.eu.com)) specifically addresses this need and its Competency Tracker which could be used to demonstrate competency in geotechnical numerical analysis will continue to be maintained by the independent body NAFEMS.]
4. An assessment will be made of the degree to which a numerical model and its input parameters (characteristic values) provide an accurate representation of the real world case being simulated [i.e. validation].
5. Due to the complexity of numerical methods, there are many influences on their prediction of limit states. Should consider the sensitivity of limit state prediction to these influences, including:
   * discretization of geometry
   * initial stress states
   * preceding construction stages
   * boundary conditions
   * drainage conditions
   * constitutive behaviour (e.g. stiffness, dilatancy, yield criteria, flow rules)
   * strength and stiffness of structural elements

**SLS**

1. Improved predictions of deformations may be achieved by considering, for example, non-linear stress- and strain-dependent stiffness or creep behaviour.
2. In order to check that serviceability limit states are sufficiently unlikely to be exceeded, cautious estimates of the strength, stiffness and initial stress state of the ground should be used in numerical analyses, complying with the definition of characteristic values of material properties in 2.4.5.2. If a “most probable” estimate of deformations is also required, best estimate values of parameters should be adopted.

**ULS**

1. Design approach is a mandatory dual application of input factoring (IFA) and output factoring (OFA) approaches (see table below). Design structural forces shall be the largest value obtained from the two approaches. Geotechnical failure shall be verified by IFA, except axially loaded piles and anchors (see below). [IFA and OFA dual approach mandatory with IFA intended to check adequate safety against multiple forms of possible geotechnical failures in one operation and OFA intended to obtain design values of structural forces, however structural forces from IFA should also be checked for any cases when structural forces are higher when ground is weaker than expected. For axially loaded piles and anchors where resistances are typically measured directly by testing or obtained by direct design methods from in situ tests, either use OFA (see para. 2) or IFA on resistances (see para. 3).] [The existing EC7 requires resistance factoring approach for countries selecting DA2 but it is very difficult to calculate geotechnical resistance and factor it in many situations using numerical methods and many countries chose to take outputs from “characteristic” numerical analyses and check resistance independently. While it is proposed to still allow this (see next paragraph), this group believes that the mandatory IFA + OFA factoring proposed makes best use of the available technology because it provides a straightforward check on the multiple geotechnical failure forms that can be predicted by the analysis model.]
2. In addition to IFA to check on multiple geotechnical failure forms, specific geotechnical failure forms may be checked by comparing analysis outputs with separately calculated resistance values by numerical methods or other methods. All partial factors should be as specified for non-numerical methods when verifying ULS in this way. [This approach or the one below is mandatory for axially loaded piles and anchors where resistances are typically measured directly].\*
3. Geotechnical resistances as input parameters: certain geotechnical resistances may be available as input parameters in some software and the factors applied should achieve be the resistance factors for non-numerical methods. Satisfactory prediction of design values of resistance should be validated, e.g. by simulation of full-scale tests. \*
4. IFA may either be performed with design values from the start and throughout all the construction stages of an analysis or with characteristic values during sequential construction stages with dedicated adjunct stages used only to change to design values at appropriate stages (staged factoring). [Staged factoring has the advantage that each sequential construction stage is arrived at with characteristic values so stress states and hence predicted behaviour should be more appropriate. It also has the advantage of allowing IFA to be applied as an adjunct to a “characteristic” OFA analysis rather than analyzing the whole construction sequence twice for IFA and OFA. The OFA-ULS and SLS analyses could also be the same in cases where the characteristic values and geometry are the same for SLS and ULS. The advantage of factoring at the start is that it requires no modification of existing software and is quicker to apply]. Staged factoring of material strength can be performed by a one-step reduction for basic constitutive models but check stress paths or by stepwise strength reduction procedure in the analysis software with an appropriate change to the analysis formulation. Strength reduction may be continued beyond partial factor value to find most critical failure mechanism. Ground strength reduction should be combined with structural element strength reduction to identify critical failure mechanisms of combined geotechnical and structural failures, while structural resistance should still be verified also by OFA.
5. Partial factors on strength should be applied to the strengths (drained, undrained, etc) computed by the constitutive model taking into account all influences on the computed strength. [There are many influences on the computed strength (such as stress state, discretization, stiffness, dilatancy) so the partial factors should not be regarded as merely applicable to phi, c’ and cu. Advanced constitutive models may have strength parameters other than phi and c’.]

Structural elements: project team to consider interfaces with other structural Eurocodes, in particular for potential verification of limit states in numerical models of soil-structure interaction.

Factoring ground stiffness: project team to consider whether a reduction in ground stiffness should be included in ULS calculations in cases where strength is not the critical parameter (eg stiff clays) in short term situations.

## ‘Basic’ partial factors for persistent, transient and accidental design situations for GEO/STR ultimate limit states

|  |  |  |  |
| --- | --- | --- | --- |
|  | | Numerical methods | |
| Approach | | IFA | OFA |
| ***Partial factors on actions (from EN 1990) including importance factor KFI*** | | | |
| Unfavourable permanent | γG,n | 1.0 | 1.0 |
| Unfavourable variable | γQ,n | 1.3/1.0 | 1.1/1.0 |
| Favourable perm. | γG,fav,n | 1.0 | 1.0 |
| ***Partial factors on ground parameters including importance factor KMI*** | | | |
| Drained strengthA | γϕ,n | 1.25/1.1 | 1.0 |
| Undrained strengthB | γcu,n | 1.4 |
| Unconfined strengthC | γqu | 1.4 |
| Weight density | γγ,n | 1.0 | |
|  | | | |
| ***Partial factors on effects of actions including importance factor KEI*** | | | |
| PermanentD | γEG | 1.0 | 1.35/1.0 |
| VariableD | γEQ |

The table above is intended for the complete verification of GEO/STR ULSs by numerical methods. If the characteristic outputs of numerical methods of analysis are used to verify ULSs by other methods, then the partial factors for non-numerical methods should be used.

Where two values are given (e.g. 1.3/1.0), choose the value according to the design situation (persistent and transient or accidental).

NOTE A: should be regarded as a factor on the computed drained shear strength taking account of secondary effects (e.g. stiffness, dilatancy) and a factor on the drained strength predicted by advanced constitutive models using yield criterion other than basic Mohr-Coulomb.  
NOTE B: should be regarded as a factor on the computed undrained shear strength taking account of secondary effects, particularly when using effective stress strength parameters (e.g. pore pressure prediction, stiffness, dilatancy) and a factor on the computed strength predicted by advanced constitutive models using yield criterion other than basic Mohr-Coulomb or Tresca.  
NOTE C: should be regarded as a factor on the computed unconfined strength taking account of secondary effects (e.g. stiffness, dilatancy) and a factor on the unconfined strength predicted by advanced constitutive models using yield criterion other than basic Tresca.  
NOTE D: factors on effects of actions apply to structural effects (e.g. bending moments, shear forces, etc.) and geotechnical effects (e.g. pile axial load, anchor load).  
The factors shaded in peach are defined in EN 1990 (and are outside of SC7’s control).

To obtain design values of resistance, use the partial factors shown for non-numerical methods.

# Active membership

|  |  |  |
| --- | --- | --- |
| Name | Position\* | Country |
| **Markus Herten** |  | Germany |
| **Michael Kavvadas** |  | Greece |
| **Kirsi Koivisto** |  | Finland |
| **Anders Kullingsjö** |  | Sweden |
| **Andrew Lees** | Convenor & Secretary | Cyprus |
| **César Sagaseta** |  | Spain |
| **Helmut Schweiger** |  | Austria |
| **Manole Serbulea** |  | Romania |
| **Bruno Simon** |  | France |
| **Brian Simpson** |  | UK |
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