Some aspects of soil-structure interaction according to Eurocode 7
'Geotechnical design'

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ABSTRACT

Eurocode 7 on 'Geotechnical design' is now actively being implemented throughout Europe. In particular, Part 1 devoted to the 'General rules' (Part 1) has been published in 2004 and National Annexes are presently being prepared (2006). After describing shortly the history of the development of Eurocode 7, and giving the main contents of the documents, some aspects of particular interest to the soil-structure interaction modelling are described: design approaches (DA1, DA2 and DA3) for ULS verifications in persistent and transient design situations, SLS verifications and allowable movements of foundations.

1. INTRODUCTION

The Structural Eurocodes are design codes for buildings, bridges and other civil engineering structures. They are based on the Limit State Design (LSD) approach used in conjunction with a partial factor method. They consist of 10 sets of standards: 'Eurocode: Basis of structural design' (EN 1990) and Eurocodes 1 to 9 (EN 1991 to EN 1999; EN is for 'European Norm')

Eurocodes 2, 3, 4, 5, 6 and 9 are 'material' Eurocodes, i.e. relevant to a given material (reinforced concrete, steel, etc.). EN 1990 (Basis of design), Eurocode 1 (Actions), Eurocode 7 (Geotechnical design) and Eurocode 8 (Earthquake resistance) are relevant to all types of construction, whatever the material.

Eurocode 7 should be used for all the problems of interaction of structures with the ground (soils and rocks), through foundations or retaining structures. It allows the calculation of the geotechnical actions on the structures, as well the resistances of the ground submitted to the actions from the structures. It also gives all the prescriptions and rules of good practice for conducting the geotechnical part of a structural project or, more generally speaking, a purely geotechnical project.

Eurocode 7 consists of two parts:
EN 1997-2 Geotechnical design - Part 2: Ground investigation and testing (2005)
In this paper, only Eurocode 7 – Part 1 on 'General rules' is mentioned.

The development of Eurocode 7 – Part 1 has been strongly linked to the development of EN 1990: 'Eurocode: Basis of structural design' (CEN, 2002) and the format for verifying ground-structure interaction problems is, of course, common to both documents.

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After describing shortly the history of the development of Eurocode 7, and giving the main contents of the document, this Paper comments some aspects directly linked to soil-structure interaction, without recalling all the principles of LSD and of the partial factor method used.

2. DEVELOPMENT OF EUROCODE 7 AND MAIN CONTENTS

2.1. History and implementation

The first Eurocode 7 Group, in charge of drafting a European standard on geotechnical design, was created in 1981. It was composed of representatives of the National Societies for Geotechnical Engineering of the 10 countries forming the European Community at that time. A first model code on general rules for geotechnical design (corresponding to Eurocode 7-Part 1) was published in 1990.

In 1990, the task of drafting design codes for buildings and civil engineering works was transferred to the Comité Européen de Normalisation (CEN, European Committee for Standardization) and CEN/TC 250 (Technical Committee 250) in charge of all the ‘Structural Eurocodes’ was created. In particular, SC 7, Sub-Committee 7, is in charge of Eurocode 7 on ‘Geotechnical design’. Note that CEN is composed of the national standard bodies of a number of European countries (in February 2006, 29 countries are members, i.e. 25 countries of EU, plus 3 countries of EFTA, plus Romania; 5 countries are affiliates).

In 1993, SC 7 adopted the ENV 1997-1 pre-standard: ‘Geotechnical design - Part 1: General Rules’. It was clear, at that time, that (much) more work still needed to be done before reaching a full European standard (EN) acceptable to all members of CEN. An important fact helped in obtaining a positive vote for the conversion into an EN (May 1997). It was the recognition by CEN/TC 250 that geotechnical design is unique and cannot be considered to be the same as other design practices needed in the construction industry. The models commonly used vary from one country to the other and cannot be harmonised easily, simply because the geologies are different and form the rationale for the so-called ‘local traditions’... This recognition is confirmed by a resolution taken by TC 250 (Resolution N 87, 1996): ‘CEN/TC 250 accepts the principle that ENV 1997-1 might be devoted exclusively to the fundamental rules of geotechnical design and be supplemented by national standards’.

The work for the conversion of ENV 1997-1 into EN 1997-1 ‘Geotechnical design – Part 1: General rules’ was performed from 1997 to 2003. The positive vote on the versions in the 3 working languages of CEN (English, French and German) was obtained in 2004 (the vote was nearly unanimous: 26 countries out of 28 expressed a positive vote). CEN finally published Eurocode 7 – Part 1 (EN 1997-1) in November 2004 (CEN, 2004).

The publication of a Eurocode Part by each national standardisation body with its National Annex (in the official language(s) of the country) has to be completed within two years after publication by CEN. The role of the National Annex is to indicate the decisions corresponding to the so-called "Nationally Determined Parameters (NDPs)". The National Annex can also give a ‘normative’ status to one or to several of the ‘informative’ Annexes, i.e. it (they) will be mandatory in the corresponding country.

As mentioned above, each country is also free to supplement the general rules of Eurocode 7 by national application standards, in order to specify the calculation models and design rules to be applied in the country. Whatever their contents they will have to respect in all aspects the principles of Eurocode 7.

The ‘legal’ status of standards/norms is different in each country and the regulatory bodies of the various countries have an important role to play for the implementation of the Eurocodes. A ‘Guidance Paper’ has been elaborated by the European Commission to co-
ordinate the implementation of the Eurocodes into the national regulations. (CE, 2003a). The European Commission has also issued a strong recommendation to the Member States inviting them to adopt the Eurocodes in their regulations (CE, 2003b).

2.2 Contents of the document

Eurocode 7 - Part 1: 'General rules' is a rather general document giving only the principles for geotechnical design inside the general framework of LSD. These principles are relevant to the calculation of the geotechnical actions on the structural elements in contact with the ground (footings, piles, basement walls, etc.), as well as to the deformations and resistances of the ground submitted to the actions from the structures. Some detailed design rules or calculation models, i.e. precise formulae or charts are only given in informative Annexes. Eurocode 7 – Part 1 includes the following sections (CEN, 2004):

Section 1 General
Section 2 Basis of geotechnical design
Section 3 Geotechnical data
Section 4 Supervision of construction, monitoring and maintenance
Section 5 Fill, dewatering, ground improvement and reinforcement
Section 6 Spread foundations
Section 7 Pile foundations
Section 8 Anchorages
Section 9 Retaining structures
Section 10 Hydraulic failure
Section 11 Overall stability
Section 12 Embankments

A number of Annexes are included. They are all informative, except for Annex A which is 'normative' (i.e. mandatory). They are the following:

Annex A (normative) Partial and correlation factors for ultimate limit states and recommended values
Annex B Background information on partial factors for Design Approaches 1, 2, 3
Annex C Sample procedures to determine limit values of earth pressures on vertical walls
Annex D A sample analytical method for bearing resistance calculation
Annex E A sample semi-empirical method for bearing resistance estimation
Annex F Sample methods for settlement evaluation
Annex G A sample method for deriving presumed bearing resistance for spread foundations on rock
Annex H Limiting values of structural deformation and foundation movement
Annex J Checklist for construction supervision and performance monitoring

Annex A is important, as it gives the partial factors for ULS in persistent and transient design situations ('fundamental combinations'), as well as correlation factors for the characteristic values of pile bearing capacity. But the numerical values for the partial or correlation factors given in Annex A are only recommended values. These values can be changed in the National Annex. All other Annexes are informative (i.e. not mandatory in the normative sense). Some of them, though, contain valuable material which can be accepted, in the near future, by most of the countries.
3. SOME ASPECTS OF SOIL-STRUCTURE INTERACTION

3.1. General

It can be argued that the whole of Eurocode 7 is devoted to soil-structure interactions, as its first role is to provide the geotechnical rules for the structures designed with the so-called system of 'Structural' Eurocodes (see Introduction above).

From the viewpoint of the structure, Eurocode 7 provides the principles for determining the geotechnical actions (noted P in Figures 1 to 3 in section 3.2 below, where only vertical equilibrium is considered). The geotechnical (P) and structural (G and Q) actions and the "reactions" from the ground (noted E), in turn, allow to check the resistance and/or the deformation of the structural element in contact with the ground. From the viewpoint of the ground, Eurocode 7 deals not only with the geotechnical actions on the structural element (P), but also with the deformations of the ground and its resistances (R) corresponding to the "reactions" (E). The "reactions" (E) are the forces provided by the ground, which equilibrate both the structural actions (G and Q) and the geotechnical actions on the structure (P) (E = -V in Figures 1 to 3). The values of the resistances of the ground correspond to the limiting values for the "reactions" in ultimate limit states verifications (ULS), i.e. E ≤ R must be satisfied.

This assumes that the loads on the structural element have been determined previously. Soil-structure interaction studies, in the pure sense, aim precisely at determining the loads and the displacements of the structural elements in contact with the ground. They take into account, of course, both the stiffness of the ground and the stiffness of the structure (see, for instance, Frank, 1991). Most often they use numerical methods (finite element method, load transfer functions, etc). The way to apply numerical methods in geotechnical engineering is not really the subject of Eurocode 7. Nevertheless, it comprises a large number of recommendations relevant to their use. It can even be noted that many of the requirements of Eurocode 7 are not practicable without recourse to numerical modelling, e.g. those relevant to the determination of the displacements of foundations.

In the following, the approaches advocated by Eurocode 7, for the ultimate limit state (ULS) verifications are described (i.e. sets of partial factors to be used for G, Q, P and R). The requirements for serviceability limit state (SLS) verifications and allowable movements of foundations, which are relevant to the displacements of foundations, are also considered.

3.2. ULS verifications

The ultimate limit states (ULS) to be checked are defined, in the following manner, by Eurocode 7 – Part 1, consistently with ‘Eurocode: Basis of structural design’ (CEN, 2002) (clause 2.4.7.1 in EN 1997-1):

‘(1)P Where relevant, it shall be verified that the following limit states are not exceeded:

- loss of equilibrium of the structure or the ground, considered as a rigid body, in which the strengths of structural materials and the ground are insignificant in providing resistance (EQU);
- internal failure or excessive deformation of the structure or structural elements, including footings, piles, basement walls, etc., in which the strength of structural materials is significant in providing resistance (STR);
- failure or excessive deformation of the ground, in which the strength of soil or rock is significant in providing resistance (GEO);
- loss of equilibrium of the structure or the ground due to uplift by water pressure (buoyancy) or other vertical actions (UPL);
– hydraulic heave, internal erosion and piping in the ground caused by hydraulic gradients (HYD).

**NOTE:** Limit state GEO is often critical to the sizing of structural elements involved in foundations or retaining structures and sometimes to the strength of structural elements.’

The ultimate limit states should be verified for the combinations of actions corresponding to the following design situations (see EN 1990, CEN, 2002):  
- permanent and transient (the corresponding combinations are called 'fundamental');  
- accidental;  
- seismic (see also Eurocode 8 - Part 5, i.e. EN 1998-5).

The design values of the actions and the combinations of actions are defined in EN 1990 (partial factors $\gamma$ for the actions and factors $\psi$ for the accompanying variable actions).

For the soil-structure interaction, STR and GEO are the relevant ultimate limit states (in the case of foundations submitted to uplift by vertical forces, UPL must also be checked). For STR/GEO, EN 1997-1 writes (clause 2.4.7.3.1(1)P) : '... it shall be verified that

$$E_d \leq R_d \quad (2.5)$$

where: $E_d$ is the design value of the effects of all the actions, $R_d$ is the design value of the corresponding resistance.'

The debate about the format for checking the STR and GEO ultimate limit states was relevant to the persistent and transient design situations. This debate follows from the formulation in the pre-standard ENV 1997-1 which inferred that STR and GEO had to be checked for two formats of combinations of actions, i.e. for Cases B and C, as they were called at that time. B was aimed at checking the uncertainty on the loads coming from the structure, and C the uncertainty on the resistance of the ground. Some geotechnical engineers were in favour of this double check, as others preferred having to use only one single format of combinations of actions (for more details, see, for instance, Frank and Magnan, 1999).

The consensus reached opened the way to three different Design Approaches (DA 1, DA 2 and DA 3). The choice is left to national determination, i.e. each country can state in its National Annex, the Design Approach(es) to be used for each type of geotechnical structure (spread foundations, pile foundations, retaining structures, slopes or overall stability).

The three Design Approaches are the following (clause A1.3.1 in EN 1990):  
‘(5) Design of structural members (footings, piles, basement walls, etc.) (STR) involving geotechnical actions and the resistance of the ground (GEO) should be verified using one of the following three approaches supplemented, for geotechnical actions and resistances, by EN 1997: 

Approach 1: Applying in separate calculations design values from Table A1.2(C) and Table A1.2(B) to the geotechnical actions as well as the other actions on/from the structure. In common cases, the sizing of foundations is governed by Table A1.2(C) and the structural resistance is governed by Table A1.2(B);  
Note: In some cases, application of these tables is more complex, see EN 1997.

Approach 2: Applying design values from Table A1.2(B) to the geotechnical actions as well as the other actions on/from the structure;  

Approach 3: Applying design values from Table A1.2(C) to the geotechnical actions and, simultaneously, applying partial factors from Table A1.2(B) to the other actions on/from the structure. Note: The use of approaches 1, 2 or 3 is chosen in the National annex.’

Tables 1 and 2 give, in a simplified manner, the recommended values for buildings taken from Tables A1.2(B) and A1.2(C) of EN 1990 (CEN, 2002). The recommended values given may also be modified by National decision. Note that, for continuity with the ENVs, the sets of partial factors are noted 'Set B' and 'Set C'.

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Table 1 – Recommended values for partial factors for actions STR/GEO (Set B).

<table>
<thead>
<tr>
<th>Action</th>
<th>Symbol</th>
<th>Value</th>
<th>Eq. (6.10)</th>
<th>Eq.(6.10a)</th>
<th>Eq.(6.10b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent actions</td>
<td>γGsup</td>
<td>1.35</td>
<td>1.35</td>
<td>1.15(2)</td>
<td></td>
</tr>
<tr>
<td>- unfavourable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- favourable</td>
<td>γGinf</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Variable actions</td>
<td>γQ</td>
<td>1.50</td>
<td>1.5ψ₀</td>
<td>1.50</td>
<td></td>
</tr>
<tr>
<td>- unfavourable</td>
<td></td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- favourable</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

(1) all permanent actions from one source are multiplied by γGsup or by γGinf.
(2) value of ξ is 0.85, so that 0.85γGsup = 0.85 × 1.35 ≅ 1.15.

Note 1: choice between Eq. 6.10 or Eqs 6.10a and 6.10b, is by National decision.
Note 2: γQ and γQ may be subdivided into γg and γq and the model uncertainty factor γSd. γSd = 1.15 is recommended.

Table 2 – Recommended values for partial factors for actions STR/GEO (Set C).

<table>
<thead>
<tr>
<th>Action</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent actions</td>
<td>γG,sup</td>
<td>1.00</td>
</tr>
<tr>
<td>- unfavourable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- favourable</td>
<td>γG,inf</td>
<td>1.00</td>
</tr>
<tr>
<td>Variable actions</td>
<td>γQ</td>
<td>1.30</td>
</tr>
<tr>
<td>- unfavourable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- favourable</td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

In other words, Design Approach 1 (DA1) is the double check procedure coming from the ENV 1997-1 (B+C verification). Design Approaches 2 (DA 2) and 3 (DA 3) are new procedures using a single format of combinations of actions. DA 2 is elaborated with ‘resistance factors’ for the ground (RFA), as DA 3 makes uses of ‘material factors’ for the ground (MFA).

Whatever the Design Approach selected, it is to be noted that STR and GEO ULS are checked with the same values of partial factors, i.e. with the same combinations of actions.

Two important remarks should be made at this point:
- with regard to the choice between Eq. 6.10 or Eqs 6.10a and 6.10b of EN 1990 (see table 2 for set B), Eurocode 7 only mentions Eq. 6.10 (table A.3 in the note to paragraph A.3(1)P of Annex A in EN 1997-1). This derives from the fact that there is no experience on the use of Eqs 6.10a et 6.10b in geotechnical engineering…
- for DA 2 and DA 3, the partial factors can be applied either on the actions or on the effects of the actions (they are noted γF and γE, respectively). This is relevant to the factors of set B and set C (unfavourable variable actions).

Table 3 gives the link between Sets B and C and the corresponding sets of factors for geotechnical actions and resistances: Sets M1 and M2 for material properties (e.g. shear strength parameters c', φ', c_u, etc.) and Sets R1, R2, R3 and R4 for total resistances (e.g. bearing capacity, etc.). These sets are defined in Annex A of Eurocode 7 – Part 1. As mentioned above, Annex A also gives their recommended values which may be set differently by the National Annex. Note that the recommended values for the partial factors γM on material properties in Set M1 are always equal to 1.0.
Table 3 – STR/GE\' limit states. Partial factors to be used according to EN 1997-1

<table>
<thead>
<tr>
<th>Design Approach</th>
<th>Actions on/from the structure</th>
<th>Geotechnical Resistances</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>B and M1</td>
<td>M1 and R1</td>
</tr>
<tr>
<td>2</td>
<td>C and M2</td>
<td>M2 and R1 or M1 and R4*</td>
</tr>
<tr>
<td>3</td>
<td>B and M1</td>
<td>M1 and R2</td>
</tr>
</tbody>
</table>

*for piles and anchorages

Figures 1, 2 and 3, as well as their captions, illustrate the situation for each of the three Design Approaches. On these figures, index 'd' indicates a design value with a partial factor \( \gamma \) different from 1.0 and index 'k' indicates a value equal to the characteristic value. The values recommended by EN 1997-1 are used and, for simplicity, only vertical equilibrium is considered and only unfavourable actions have been shown in these figures.

In DA 1, the first format (combination 1, former case B) applies safety mainly on actions, while the factors on resistances have recommended values equal to 1.0 (Sets M1 and R1) or near 1.0 (Set R1 in the case of axially loaded piles and anchorages); in the second format imposed by DA 1 (combination 2, former case C), the shear strength parameters are always factored for the calculation of geotechnical actions and sometimes factored for the calculation of resistances (Set M2); in the case of axially loaded piles and anchorages, the total resistance is directly factored by applying Set R4. In DA 2, safety is applied both on the actions (Set B) and on the total ground resistance (Set R2). In DA 3, safety is applied both on the actions (Set B for the actions coming from the structure and Set M2 for the properties of the ground acting on the structure, i.e. for the geotechnical actions) and on the geotechnical resistances (Set M2 for the elementary properties; the recommended values for Set R3 for the total geotechnical resistance is always equal to 1.0, except for piles in tension and anchorages for which they are equal to 1.1).

\[
\begin{align*}
G_d &= \gamma_G \cdot G_k = 1.35 \cdot G_k \\
Q_d &= \gamma_Q \cdot Q_k = 1.50 \cdot Q_k \\
G_a &= \gamma_G \cdot G_k = 1.35 \cdot G_k \\
q_d &= \gamma_Q \cdot q_k = 1.50 \cdot q_k \\

\gamma_d = \gamma_q = 1.30 \cdot Q_k \\
\phi_d' = \phi_k', c_d' = c_k' \\
P_{Q,d} = P_0(\phi'_d, c_d', q_d) \\
P_{G,d} = \gamma_G \cdot P_0(\phi'_d, c_d') = 1.35 \cdot P_0(\phi'_d, c_k') \\
V_d = \Sigma V_{G,d} + \Sigma V_{Q,d} \\
E_{v,d} \leq R_{v,d} &= R_v(V_d, H_d, \phi'_d, c'_d)/\gamma_{R_v} \\
&= R_v(V_d, H_d, \phi'_k, c'_k)/1.0
\end{align*}
\]

\[
\begin{align*}
\text{Figures 1, 2 and 3, as well as their captions, illustrate the situation for each of the three Design Approaches. On these figures, index 'd' indicates a design value with a partial factor } \gamma \text{ different from 1.0 and index 'k' indicates a value equal to the characteristic value. The values recommended by EN 1997-1 are used and, for simplicity, only vertical equilibrium is considered and only unfavourable actions have been shown in these figures.}
\end{align*}
\]

In DA 1, the first format (combination 1, former case B) applies safety mainly on actions, while the factors on resistances have recommended values equal to 1.0 (Sets M1 and R1) or near 1.0 (Set R1 in the case of axially loaded piles and anchorages); in the second format imposed by DA 1 (combination 2, former case C), the shear strength parameters are always factored for the calculation of geotechnical actions and sometimes factored for the calculation of resistances (Set M2); in the case of axially loaded piles and anchorages, the total resistance is directly factored by applying Set R4. In DA 2, safety is applied both on the actions (Set B) and on the total ground resistance (Set R2). In DA 3, safety is applied both on the actions (Set B for the actions coming from the structure and Set M2 for the properties of the ground acting on the structure, i.e. for the geotechnical actions) and on the geotechnical resistances (Set M2 for the elementary properties; the recommended values for Set R3 for the total geotechnical resistance is always equal to 1.0, except for piles in tension and anchorages for which they are equal to 1.1).

\[
\begin{align*}
G_d &= \gamma_G \cdot G_k = 1.00 \cdot G_k \\
Q_d &= \gamma_Q \cdot Q_k = 1.30 \cdot Q_k \\
G_a &= \gamma_G \cdot G_k = 1.00 \cdot G_k \\
q_d &= \gamma_Q \cdot q_k = 1.30 \cdot q_k \\

\gamma_d = \gamma_q = 1.30 \cdot Q_k \\
\phi_d' = \phi_k', c_d' = c_k' \\
P_{Q,d} = P_0(\phi'_d, c_d', q_d) \\
P_{G,d} = \gamma_G \cdot P_0(\phi'_d, c_d') = 1.00 \cdot P_0(\phi'_d, c'_d) \\
V_d = \Sigma V_{G,d} + \Sigma V_{Q,d} \\
E_{v,d} \leq R_{v,d} &= R_v(V_d, H_d, \phi'_d, c'_d)/\gamma_{R_v} \\
&= R_v(V_d, H_d, \phi'_k, c'_k)/1.0
\end{align*}
\]

**Figure 1** – Design Approach 1 - Combination 1 (left), Combination 2 (right) (after Frank, et al., 2004).
Figure 2 – Design Approach 2 – Factoring the actions at the source (left), factoring effects of actions (right; Design Approach DA2*) (after Frank, et al., 2004).

Figure 3 – Design Approach 3 (after Frank, et al., 2004).

More details on the use of the three Design Approaches for persistent and transient situations are given, for instance, in Frank et al. (2004).

Figures 1 to 3 also show some specific features of geotechnical design compared to structural design:
- some geotechnical actions depend on the ground resistance (e.g. earth pressures against retaining walls; downdrag on piles);
- some geotechnical resistances, on the other hand, depend on the actions (e.g. bearing capacity of shallow foundations under eccentric or inclined loads).

Thus, actions and resistances, cannot always be completely separated.

With regard to the design values for accidental situations, Eurocode 7 only states that (clause 2.4.7.1 in EN 1997-1): ‘(3) All values of partial factors for actions or the effects of actions in accidental situations should normally be taken equal to 1.0. All values of partial
factors for resistances should then be selected according to the particular circumstances of
the accidental situation.
NOTE The values of the partial factors may be set by the National annex.'

3.3. Verification of serviceability limit states (SLS)

The main discussions during the development of Eurocode 7 were about the format for
verifying ULS in permanent and transient situations. However, the verification of
serviceability limit states (SLS) is an issue equally important in contemporary geotechnical
design. This issue is fully recognised by Eurocode 7 which indeed often refers to
displacement calculations of foundations and retaining structures, while common geotechnical
practice mainly sought so far to master serviceability by limiting the bearing capacity or by
limiting the shear strength mobilisation of the ground to relatively low values.

The verification of SLS in the real sense proposed by Eurocode 7 (prediction of
displacements of foundations) is certainly going to gain importance in the near future. For the
time being, it is an aspect which is too often neglected in common geotechnical practice.

Eurocode 7 - Part 1 repeats the formulation of EN 1990 (clause 2.4.8, EN 1997-1) :
'(1)P Verification for serviceability limit states in the ground or in a structural section,
element or connection, shall either require that:

\[ E_d \leq C_d \]  \hspace{1cm} (2.10)

or be done through the method given in 2.4.8(4).

(2) Values of partial factors for serviceability limit states should normally be taken equal
to 1.0.

NOTE The values of the partial factors may be set by the National annex.'

with \( E_d \) the design value of the effect of actions and \( C_d \) the limiting value (serviceability
criterion) of the design value of effect of actions. At the same time, Eurocode 7 introduces
immediately the possibility to keep the traditional approach mentioned above (clause 2.4.8) :
'(4) It may be verified that a sufficiently low fraction of the ground strength is mobilised to
keep deformations within the required serviceability limits, provided this simplified approach
is restricted to design situations where:
— a value of the deformation is not required to check the serviceability limit state;
— established comparable experience exists with similar ground, structures and application
method.'

This clause is to be linked to the one dealing with the design methods of spread
foundations (paragraph 6.4(5)P in EN 1997-1) :
'(5)P One of the following design methods shall be used for spread foundations:
— a direct method, in which separate analyses are carried out for each limit state. When
checking against an ultimate limit state, the calculation shall model as closely as possible
the failure mechanism, which is envisaged. When checking against a serviceability limit
state, a settlement calculation shall be used;
— an indirect method using comparable experience and the results of field or laboratory
measurements or observations, and chosen in relation to serviceability limit state loads so
as to satisfy the requirements of all relevant limit states;
— a prescriptive method in which a presumed bearing resistance is used (see 2.5).'

Indeed, the indirect method 'chosen in relation to serviceability limit state loads'
comes to applying the traditional method of designing the bearing capacity of spread
foundations, i.e. a simple calculation comparing the applied loads for serviceability limit
states to a limit load divided by a global factor of safety high enough (usually around 3). Of
course, as indicated in Eurocode 7, this can only be valid if there is no need to assess the settlement of the foundation and if conventional structures with well known ground conditions are dealt with.

Paragraph 2.4.8(2) of Eurocode 7 – Part 1, reproduced above, indicating that partial actors for SLS are normally taken equal to 1.0 (in other words that the design values of the various quantities are taken equal to their characteristic values), applies to the actions in the characteristic, frequent or quasi-permanent combinations (see EN 1990), as well as to the geotechnical properties, such as the modulus of deformation. It should be noted that, for determining the differential settlement for instance, sets of lower characteristic values and upper characteristic values can be chosen in order to take account of the ground variability.

With regard to the use of the combinations of actions for SLS, EN 1990 provides (in editorial notes) some guidelines which are summarised in table 5 (clause 6.5.3 in EN 1990)

Table 4 – Recommended combinations of actions for checking serviceability limit states SLS

<table>
<thead>
<tr>
<th>Combination of actions</th>
<th>Use according to EN 1990</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristic</td>
<td>Irreversible limit states</td>
</tr>
<tr>
<td>Frequent</td>
<td>Reversible limit states</td>
</tr>
<tr>
<td>Quasi permanent</td>
<td>Long term effect and appearance</td>
</tr>
</tbody>
</table>

When applying equation 2.10 of Eurocode 7 - Part 1 (see paragraph 2.4.8(1)P reproduced above), it appears that the frequent and quasi-permanent combinations should be recommended; on the contrary, in the case of the alternative method allowed by 2.4.8(4), the characteristic (or 'rare') combination should be used, because the experience gained in the past was rather for loads near this type of combination.

The last general paragraph in Eurocode 7 – Part 1 about SLS, deals again with the 'displacement approach'. It states that (clause 2.4.8 in EN 1997-1):

'(5)P A limiting value for a particular deformation is the value at which a serviceability limit state, such as unacceptable cracking or jamming of doors, is deemed to occur in the supported structure. This limiting value shall be agreed during the design of the supported structure.'

The application of these general clauses is detailed further down in Eurocode 7 - Part 1 for each geotechnical structure (in the Sections for spread foundations, pile foundations, retaining structures, overall stability and embankments). It is interesting to note that the document insists several times on the difficulty to predict displacements with accuracy (in the present state of geotechnical engineering knowledge, of course!).

3.4 Limiting values of displacements of foundations

The knowledge of limiting allowable displacements of foundations is a subject of prime importance, even though it is not often explicitly addressed. These limiting values depend primarily on the nature of the supported structure, but it has also been a point of interest for geotechnical engineering for a long time, as well (a summary of data collected for buildings and bridges is given e.g. by Frank, 1991).

The limiting values of movements of foundations is the subject, in particular, of clause 2.4.9, as well as of Annex H (informative) of Eurocode 7 – Part 1. It is noted that clause 2.4.9 contains 4 rather strong principles, i.e. paragraphs (1)P to (4)P. The first one says:

'(1)P In foundation design, limiting values shall be established for the foundation movements. NOTE Permitted foundation movements may be set by the National annex.'
Furthermore, it seems that not only SLS are concerned (see above) but also ULS… (because movements of foundations can trigger an ULS in the supported structure).

Eurocode 7 lists a number of factors which should be considered when establishing the limiting values of movements. It is important that these limiting values are established in a realistic manner, by close collaboration between the geotechnical engineer and the structural engineer. If the values are too much severe, they will usually lead to uneconomical designs.

Figure 5 defines the parameters used to quantify movements and deformations of structures. This figure, originally due to Burland and Wroth (1975) is reproduced in Annex H of Eurocode 7 – Part 1.

Figure 4 – Definitions of foundation movements and deformations of structures (CEN, 2004, after Burland and Wroth, 1975).

Annex H (informative) quotes the following limits after Burland et al. (1977):
- for open framed structures, infilled frames and load bearing or continuous brick walls: maximum relative rotations between about 1/2000 an about 1/300 to prevent the occurrence of a SLS in the structure;
- for many structures, a maximum relative rotation $\beta = 1/500$ is acceptable for SLS and $\beta = 1/150$ for ULS;
- for normal structures with isolated foundations, total settlements up to 50 mm are often acceptable.
These values can serve as a guide, in the absence of other indications on the limiting values for the deformations of the structures.

4. CONCLUSION

The implementation of the 'Structural' Eurocodes in the various countries will prove to be very important for the whole construction industry. Eurocode 7 is devoted to all the geotechnical aspects of structural design. It is meant to be a tool no only to help European geotechnical engineers speak the same technical language, but also a necessary tool for the dialogue between geotechnical engineers and structural engineers.

It is felt that Eurocode 7 will promote research, in particular in the field of soil-structure interactions. One of the great challenges of contemporary geotechnical engineering is precisely the development of rational methods for predicting the movements of foundations, in order to design safe and more economical structures.

5. REFERENCES


