# Implementing Eurocode 7 to achieve reliable geotechnical designs

Trevor ORR
*Trinity College Dublin, Ireland*

**Abstract.** This paper examines how the different measures to achieve safe and reliable geotechnical designs are implemented in Eurocode 7. These measures include: the use of the concept of geotechnical categories of take account of the complexity of geotechnical designs, procedures for managing the design and execution processes, requirements for the selection of characteristic parameter values, and recommended partial factor values associated with the three Design Approaches. How the consequences and reliability classes, set out in the head Eurocode, EN 1990, are implemented in Eurocode 7 for geotechnical designs is also examined. In additions, the paper presents the results of surveys to investigate how Eurocode 7 is being adopted in the different European countries and the experiences in some of those countries with its implementation.

**Keywords.** Eurocode 7, geotechnical design, partial factors, reliability, consequences classes, implementation

## 1. Introduction

In 1975 the European Commission decided to prepare set of technical rules for the design of construction works. The objectives of this program included the elimination of technical obstacles to trade and the harmonization of technical specifications within Europe. Arising from this, 10 Eurocodes consisting of 58 parts have been prepared and published by CEN, the European Committee for Standardization, with EN 1997: Eurocode 7 Geotechnical Design, consisting of two parts. One of the purposes of the Eurocodes is to serve as reference documents to prove compliance of building and civil engineering works with the essential requirements for mechanical resistance and stability and safety in case of fire set out in European Construction Products Directive, 89/106/EEC of 21$^{st}$ December 1988 (CPD), which has now been replaced by the Construction Products Regulations (CPR) of the European Parliament and Council adopted on 20$^{th}$ January 2011. These essential requirements are performance based and specify that building and construction works must be fit for their intended use, account being taken of economy and subject to normal maintenance. These requirements have been implemented in the EU countries through national building regulations, which refer to the Eurocodes as demonstrating compliance of a structural or geotechnical design with the building regulations and hence with the Construction Products Directive. Eurocode 7 has now been implemented in most European countries, but the way it has been implemented in each country through the National Annexes has differed to some extent. The reasons why Eurocode 7 has been implemented differently in each country are because of different design traditions, different soil and climatic conditions, and, most importantly, because each country is responsible for setting the level of safety and reliability required for its structures.

## 2. Eurocode 7 and reliability

The head Eurocode, EN 1990 Basis of design (CEN, 2002) provides the design method adopted in all the Eurocodes, including Eurocode 7 for geotechnical design (CEN, 2004), which is the limit state concept used in conjunction with the partial factor method. EN 1990 {2.1(1)P}, where the { } brackets refer to the paragraph in the code, states that "*a structure shall be designed and executed in such a way that it will, during its intended life, with appropriate degrees of reliability and in an economical way:*

- *Sustain all actions and influences likely to occur during execution and use, and*
- *Remain fit for the use for which it is required.*"

(Note that an action is a set of forces (loads) or an imposed deformation or acceleration). As shown by the first bullet point above, the aim of the Eurocodes is to design structures that have appropriate degrees of reliability. Reliability is defined in EN 1990 {1.5.2.1.7} as "*the ability of a structure or structural member to fulfill the specified requirements, including the design working life, for which it has been designed, and it is noted that reliability is usually expressed in probabilistic terms.*"

Calgaro (2011) notes that structural reliability covers four aspects: safety, serviceability, durability and robustness. He explains that robustness is the ability of a system to resist damage while maintaining its important functions and that robustness is not limited to physical structures but robustness principles can also be applied to management systems to reduce the effects of unknown risks. This is in accordance with EN 1990 {2.1(1)P} which states that "*the required reliability of geotechnical designs shall be achieved by design in accordance with EN 1990 and EN 1997-1 together with appropriate execution and quality management measures*". An application rule {2.2(5)} in EN 1990 on reliability management says "*the required levels of reliability relating to structural resistance and serviceability can be achieved by suitable combinations of the following:*

– *Preventative and protective measures*"

An example in the case of geotechnical design is the placing of foundations at appropriate depth to avoid damage due to frost heave

– "*Measures relating to design calculations*"

Examples given are the representative values of actions and the choice of partial factors

– "*Measures relating to quality management*"

Examples given are measures aimed to reduce errors in design and execution of the structure, and gross human errors

– "*Other measures relating to other design matters*"

These include: the basic requirements, the degree of robustness (structural integrity), the durability, including the choice of design working life, and the extent and quality of preliminary investigations of soils and preliminary investigations, the accuracy of the mechanical models used, and the detailing.

- "*Efficient execution, e.g. in accordance with execution standards referred to in EN 1990 to EN 1999*
- *Adequate inspection and maintenance according to procedures specified in the project documentation."*

Since soil is a natural material, not manufactured, the reliability of geotechnical designs does not just depend on selecting appropriate partial factor values and calculation models but depends on ensuring that all aspects of the design, from geotechnical investigations to execution, are carried out appropriately. This is reflected in the form and the content of Eurocode 7, which provides a limit state framework for geotechnical design based on the application of partial factors to characteristic parameters, but does not provides any calculation models in the core text; instead it provides a design system that includes many of the measures listed above to achieve the required reliability level. Hence Eurocode 7 is not the same as the Eurocodes for manufactured materials, which are generally more prescriptive, being based on agreed calculation models and specified material parameters. The measures to achieve reliability included in Eurocode 7 are:

1. <u>The need for good communication</u>. One of the assumptions in Eurocode 7, which is given in {1.3(2)}, that is particularly pertinent to the reliability of geotechnical designs is that there is "*adequate continuity and communication between the personnel involved in data collection, design and construction.*" Eurocode 7 aims to achieve compliance with this assumption through requiring, as a principle {2.8(1)P}, the preparation of a Geotechnical Design Report which, according to {2.8(4)P}, shall include a plan of supervision and monitoring that clearly identifies "*items which require checking during construction or which require maintenance after construction*". Furthermore, it requires that items which have been checked "shall be recorded in an addendum to the Report" and {2.8(6)P} requires that "*an extract of the Geotechnical Design Report containing the supervision, monitoring and maintenance requirements for the completed structure, shall be provided to the owner/client*".
2. <u>The need to identify the complexity of a geotechnical design</u>. In order to establish the minimum requirements for the extent and content of geotechnical investigations, calculations and construction control checks, Eurocode 7 requires {2.1(8)P} that "*the complexity of each geotechnical designtogether with the associated risks shall be identified*". Hence Eurocode 7 requires that a risk assessment, as discussed in the next section, is carried out.
3. <u>Many lists are provided of items to be considered or taken into account in design</u>. Examples include the different limit states that need to be considered for any particular design situation, for example the ultimate limit states for spread foundations in {6.2(1)P} and for pile foundations in {7.2(1)P}.
4. <u>A special definition for the characteristic value of a geotechnical parameter</u>. Since soil is a natural material, not manufactured, and since its properties need to be determined, rather than specified, the definition of the characteristic value of a geotechnical parameter is given in Eurocode 7 {2.4.5.2(2)P} as the value selected "*as a cautious estimate of the value controlling the occurrence of the limit state*". This definition differs from the general, statistical definition of the characteristic value of structural material

given in EN 1990 {1.5.4.1 and 4.2(3)} as the 5% fractile value attained in a hypothetical unlimited test series The Eurocode 7 definition demonstrates that selecting characteristic geotechnical parameter values is part of the design process and makes it clear that how they are selected is important for ensuring the reliability of geotechnical designs. Although it is not anticipated that statistical methods will normally be used to select characteristic values for geotechnical designs, EN 1997-1 {2.4.5.2(11)} states that "*if statistical methods are used, the characteristic value should be derived such that the calculated probability of the occurrence of a worst value governing the occurrence of the limit state under consideration is not greater than 5%*".

5. The importance of relevant experience. The important of having and using relevant experience is stressed throughout EN 1997-1. For example, in relation to the selection of characteristic values of geotechnical parameters, Eurocode 7 {2.4.5.2(1)} states that the selection "*shall be based on results and derived values from laboratory and field tests, complemented by well-established experience*". Eurocode 7 {1.5.2.2} defines comparable experience as "*documented or other clearly established information related to the ground being considered in design, involving the same types of soil and rock and for which similar geotechnical behavior is expected, and involving similar structures. Information gained locally is considered is considered to be particularly relevant*". How to assess the personnel who have the relevant experience and are appropriately qualified to carry out a geotechnical design is discussed in Section 3.

Soil has the following features that have caused Eurocode 7 to differ from the other Eurocodes codes for manufactured material; it is (a) a natural material; (b) composed of 2 or 3 phases; (c) non homogeneous and highly variable; (d) frictional; (e) dilatant; (f) ductile; (g) compressible and with a low shear stiffness; and (h) non-linear with a complex stress-strain behavior. These features have affected the way in which the limit state method in EN 1990 has been adopted for geotechnical design in Eurocode 7, resulting in Eurocode 7 having requirements for geotechnical investigations, a special definition for the characteristic value of geotechnical parameters, reduced partial factors on permanent actions, and an emphasis on serviceability limit states (Orr, 2011).

Simpson (2011) has examined the features affecting the reliability of geotechnical designs and noted the following five features of the designer's situation: (a) his specific knowledge of the site; the ground conditions and their possible variability; (b) the importance of extreme variations in the parameters causing failure; (c) the large number of variables usually involved in as design situation; (d) the need for robustness, i.e. providing adequate margins for secondary actions that are not related to the primary parameters, including moderate human errors; and (e) the significance of human errors. The execution and quality management measures included in Eurocode 7 address most of the features identified by Simpson as affecting the reliability of geotechnical designs.

## 3. Design complexity and Geotechnical Categories

The first stage in achieving geotechnical designs to Eurocode 7 that have the appropriate degree of reliability is to assess the complexity of the design. According to

Eurocode 7 {2.1(8)}, this involves establishing "*the minimum requirements for the extent and content of geotechnical investigations, calculations and construction control checks ... together with the associated risks*". The factors that need to be considered when assessing the level of risk in a geotechnical design can be divided into the geotechnical hazards, which include:

- The ground conditions
- Groundwater situation
- Regional seismicity, and
- Influence of the environment.

and the vulnerability factors, which include:

Table 1. Geotechnical Categories, geotechnical complexity and risk (Orr and Farrell, 1999)

| Geotechnical Category (GC) | GC1 | GC2 | GC3 |
|---|---|---|---|
| | Geotechnical Complexity and Risk Levels | | |
| *Geotechnical hazards* | *Low* | *Moderate* | *High* |
| Ground conditions | Known from comparable experience to ne straightforward. Not involving soft. Loose or compressible soil, loose fill or sloping ground | Ground conditions and properties can be determined from routine investigations and tests | Unusual or exceptionally difficult ground conditions requiring non-routine investigations and tests |
| Groundwater situation | No excavations below water table, except where experience indicates this will not cause problems | No risk of damage without prior warning to structures due to groundwater lowering or drainage. No exceptional water tightness requirements | High groundwater pressures and exceptional groundwater conditions, e.g. multilayered strata with variable permeability |
| Regional seismicity | Areas with low or very low earthquake hazard | Moderate earthquake hazard where seismic design code (EC8) may be used | Areas of high earthquake hazard |
| Influence of the environment | Negligible risk of problems due to surface water, subsidence, hazardous chemicals, etc. | Environmental factors covered by routine design methods | Complex or difficult environmental factors requiring special design methods |
| *Vulnerability* | *Low* | *Moderate* | *High* |
| Nature and size of the structure and its elements | Small and relatively simple structures or construction, insensitive structures in seismic areas | Conventional types of structures with no abnormal risks | Very large or unusual structures involving abnormal risks. Very sensitive structures in seismic areas |
| Surroundings | Negligible risk of damage to or from neighboring structures or services and negligible risk for life | Possible risk of damage to neighboring structures or services due, for example, to excavations or piling | High risk of damage to neighboring structures or services |
| *Geotechnical risk* | *Low* | *Moderate* | *High* |

- The nature and size of the structure and its elements, and
- The surroundings.

Eurocode 7 offers {2.1(10)} the concept of three geotechnical categories, referred to as Geotechnical Categories 1, 2 and 3 (GC1, GC2 and GC3), as a means to take account of the different levels of complexity in geotechnical design. The use of these categories is not a principle requirement but they provide a framework for categorizing the different levels of risk in geotechnical design. The distinction between the categories only lies in the level of expertise required and in the nature and extent of the geotechnical investigations and calculations to be carried out, as shown in Table 1 (Orr and Farrell, 1999). Hence to achieve the required reliability of geotechnical designs involving different categories, Eurocode 7 does not provide for any variation in the partial factor values but rather requires that greater attention is given to the quality of the investigations and design calculations.

Having assessed the complexity and level of risk of a geotechnical design, and the,

Table 2. Geotechnical Categories, minimum requirements, expertise required and examples of designs (Orr and Farrell, 1999)

| | Geotechnical Categories | | |
|---|---|---|---|
| | GC1 | GC2 | GC3 |
| Geotechnical investigations and tests | Qualitative investigations, including trial pits | Routine investigations involving borings, filed and laboratory tests | Additional moresophisticated investigations and laboratory tests |
| Design procedures and calculations | Prescriptive measures and simplified design procedures, e.g. design bearing resistance based on experience or published presumed bearing pressures. Stability or deformation calculations may not be necessary | Routine calculations for stability and deformations based of design procedures in Eurocode 7 | More sophisticated analyses |
| Expertise required | Personnel with appropriate comparable experience | Experienced qualified personnel | Experienced geotechnical specialist |
| Examples of structures | - Simple 1 and 2-storey structures and agricultural buildings having maximum design column loads of 250kN and maximum wall load of 100kN/m<br>- Retaining walls and excavation supports where ground level difference does not exceed 2m<br>- Small excavations for drainage and pipes | Conventional types of:<br>- Spread and pile foundations<br>- Walls and other retaining structures<br>- Bridge piers and abutments<br>- Embankments and earthworks<br>- Ground anchors and other support systems#<br>- Tunnels in hard non-fractured rock | - Very large buildings<br>- Large bridges<br>- Deep excavations<br>- Embankments on soft ground<br>- Tunnels in soft and highly permeable ground |

geotechnical category, if this is being used, the next stage is to establish the minimum requirements for the geotechnical investigations, design procedures and calculations related to the categories and these are presented in Table 2 from Orr and Farrell (1999). Therefore, as noted in Section 3, achieving the minimum requirements is dependent on having and using appropriate experience and therefore on the personnel involved in all aspects of a geotechnical design being appropriately qualified and having appropriate skill and experience. Hence Eurocode 7 assumes that all aspects of geotechnical designs are carried out by appropriately qualified and experienced personnel as it states in {1.3(2)} that:

"– *Data required for design are collected, recorded and interpreted by appropriately qualified personnel*
– *Structures are designed by appropriately qualified and experienced personnel*
– *Execution is carried out ... by personnel having the appropriate skill and experience*".

Eurocode 7 does not define what is meant by people having appropriate qualifications, skill and experience. This will depend on the nature of the project and the ground conditions and has been left for national determination. Simpson and Driscoll (1998) state that to work in a particular category, a designer must be competent to judge that the situation is not more complex than allowed within that category. An indication of the sort of person who may be competent for the different categories is shown in Table 2 A formal measure to address this issue and identify those with appropriate qualifications, skills and experience has been taken in the UK by the Institution of Civil Engineers, together with the Geological Society and the Institute of Materials, Minerals and Mining, by the establishment of a Register of UK Ground Engineering Professionals (RoGEP).

## 4. Ultimate limit states, Design Approaches and partial factors

Eurocode 7 {2.4.7.1(1)P} lists the following five different ultimate limit states, each with a set of partial factors, that the designer needs to verify are not exceeded:

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

Eurocode 7 provides in Annex A only four sets of partial factor values for use in calculations to check that none of these five ultimate limit states is exceeded since the same set is used for both STR and GEO. The reliability of geotechnical design calculations depends on the characteristic values provided for the actions, on the characteristic values selected for the geotechnical parameters, as described in Section 2, and on the partial factor values adopted and on the calculation model used. The partial material and resistance factors in Eurocode 7 cover uncertainty in the calculation model as well as uncertainty in the material strength o resistance

When verifying STR and GEO ultimate limit states, partial factors may be applied either to material properties or to resistances using one of three Design Approaches (DA): DA1 with two Combinations, in Combination 1 partial factors are only applied to the actions while, in Combination 2, partial factors are applied to the variable actions and the soil parameters; DA2 with partial factors applied to both the actions and the resistances rather than to the soil parameters; DA3 with partial factors are applied to both the actions and the soil parameters in a single calculation. Using the most recent information that was available to the author, the Design Approach or Approaches adopted in the 31 CEN member states are shown in Table 3, where the countries are represented by their conventional abbreviations. Although Table 3 is a simplification of the actual situation in some countries, it shows that, while some countries have adopted DA1 for all designs, most countries have adopted DA2 for spread foundations, pile foundations structures and retaining structures, and DA3 for slopes. Some countries allow either of two Design Approaches for all designs, while two countries, the Czech Republic and Ireland, allow the use of any one of the three Design Approaches for all designs. Also some countries that have adopted DA2 are using DA3 for numerical analyses.

Table 3.Design Approaches adopted by 31 CEN Member States

<table>
<tr><th>Design type</th><th>No or incomplete answers</th><th>DA1</th><th>DA2</th><th>DA2*</th><th>DA3</th><th>DA1, DA2 or DA3</th></tr>
<tr><td rowspan="2">Spread foundations</td><td rowspan="2">BG, CR, E, IS, LV, MT</td><td rowspan="2">B, IT, LT, PT, RO, UK</td><td>EST. F</td><td>A, EST, D, GR, H, IT, PL, SK, SLO</td><td rowspan="2">CH, DK, F**, NL, NO, S</td><td rowspan="2">CZ, IRL</td></tr>
<tr><td colspan="2">CY, L, SF</td></tr>
<tr><td>Pile foundations</td><td>BG, CR, E, IS, LV, MT</td><td>B, IT, LT, PT, RO, UK</td><td colspan="2">A, CH, CY, D, EST, F, GR, H, IT, L, PL, SF, SK, SLO, SWE</td><td>DK, F**, NL, NO, S</td><td>CZ, IRL</td></tr>
<tr><td>Retaining structures</td><td>BG, CR, E, IS, LV, MT</td><td>B, IT, LT, PT, RO, UK</td><td colspan="2">A, CH, CY, D, EST, F, GR, H, IT, L, PL, SF, SK, SLO</td><td>A**, DK, F**, NL, NO, S</td><td>CZ, IRL</td></tr>
<tr><td>Slopes</td><td>BG, CR, E, IS, LV, MT</td><td>B, EST, IT, LT, PT, UK</td><td colspan="2">F</td><td>A, CH, CY, D, DK, F**, GR, H, IT, L, NL, NO, PL, RO, SF, SK, SLO, S</td><td>CZ, IRL</td></tr>
<tr><td>Total</td><td>6</td><td>6</td><td colspan="2">1 - 15</td><td>5 - 18</td><td>2</td></tr>
</table>

* Partial action factor applied to action effect rather than to the actions

** For numerical analyses

The EN versions of the Eurocodes, including Eurocode 7, contain recommended values for the partial factors. The recommended partial factor values for STR/GEO ultimate limit states in persistent and transient design situations, except those for bored piles, CFA piles and prestressed anchorages, are presented in Table 4. Eurocode 7 {2.4.8(2)} states that the partial factors for serviceability limit states should normally be taken equal to 1.0. However, each CEN member state retains the exclusive competence and responsibility for setting the safety levels of works constructed in its state in order to take account of different design traditions, different regulatory systems and different environmental conditions. For this reason the selection of the particular Design Approach (DA) and the values of partial factors and other parameters in the Eurocodes, referred to as Nationally Determined Parameters (NDP), for use in each country have been left for national choice. These NDPs are published in National Annexes (NA) that accompany the full texts of the Eurocodes, which are published, unchanged, as national standards in each country; for example in Ireland the Eurocodes are published as Irish Standards. CEN and the European Commission would like more harmonization regarding the Design Approaches and partial factor values and hence an Evolution Group of CEN TC250/SC7, the CEN sub-committee responsible for the development of Eurocode 7, is investigating ways to reduce and simplify the number of Design Approaches and the number of NDPs.

## 5. Partial factor calibration

The numerical values of the partial factors given in the Eurocodes to achieve the required reliability level assume that appropriate levels of workmanship and quality management apply. EN 1990 {C3(2)} states in an Informative Annex that the numerical values of the partial factors can be determined either:

– On the basis of calibration to a long experience of building tradition, or

– On the basis of statistical evaluation of experimental data and field observations, and this should be carried out within the framework of a probabilistic reliability theory.

Table 4. Recommended partial factor values for STR and GEO ultimate limit states

| Parameter | Symbol | Design Approaches | | | | |
|---|---|---|---|---|---|---|
| | | DA1 | | DA2 | DA3 | |
| | | DA1.C1 | DA1.C2 | | Structural actions | Geotechnical actions |
| *Partial factors on actions ($\gamma_F$) or the effects of actions ($\gamma_E$)* | | | | | | |
| Permanent unfavorable action | $\gamma_G$ | 1.35 | 1.0 | 1.35 | 1.35 | 1.0 |
| Permanent favorable action | $\gamma_G$ | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Variable unfavorable action | $\gamma_Q$ | 1.5 | 1.5 | 1.5 | 1.5 | 1.3 |
| Variable favorable action | $\gamma_Q$ | 0 | 0 | 0 | 0 | 0 |
| Accidental action | $\gamma_A$ | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| *Partial factors for soil parameters ($\gamma_M$)* | | | | | | |
| Angle of shearing resistance (this factor is applied to tanϕ') | $\gamma_{\tan\phi}$ | 1.0 | 1.25 | 1.0 | 1.25 | |
| Effective cohesion | $\gamma_{c'}$ | 1.0 | 1.25 | 1.0 | 1.25 | |
| Undrained shear strength $c_u$ | $\gamma_{cu}$ | 1.0 | 1.4 | 1.0 | 1.4 | |
| Unconfined strength $q_u$ | $\gamma_{qu}$ | 1.0 | 1.4 | 1.0 | 1.4 | |
| Weight density of ground $\gamma_{c'}$ | $\gamma_\gamma$ | 1.0 | 1.0 | 1.0 | 1.0 | |
| *Partial resistance factors ($\gamma_R$)* *Spread foundations, retaining structures and slopes* | | | | | | |
| Bearing resistance | $\gamma_{R;v}$ | 1.0 | 1.0 | 1.4 | 1.0 | |
| Sliding resistance | $\gamma_{R;h}$ | 1.0 | 1.0 | 1.1 | 1.0 | |
| Earth resistance, incl. slopes | $\gamma_{R;e}$ | 1.0 | 1.0 | 1.4 | 1.0 | |
| *Pile foundations – Driven pile ($\gamma_R$)* | | | | | | |
| Base resistance | $\gamma_b$ | 1.0 | 1.3 | 1.1 | 1.0 | |
| Shaft resistance (compression) | $\gamma_s$ | 1.0 | 1.3 | 1.1 | 1.0 | |
| Total combined (compression) | $\gamma_t$ | 1.0 | 1.3 | 1.1 | 1.0 | |
| Shaft in tension | $\gamma_{s;t}$ | 1.25 | 1.6 | 1.15 | 1.1 | |

EN 1990 also notes that the recommended partial factor values in the Eurocodes and also the values published in the National Annexes have mostly been chosen on the basis of calibration with experience, i.e. with practices which have proven to be reliable, and not on the basis of probabilistic methods. However, if a statistical approach is adopted, EN 1990 states {C3(3)} that the partial factors for ultimate limit states should be calibrated such that the reliability levels of representative structures are as close as possible to the target reliability index. The target reliability indexes, i.e. $\beta$ values, given in EN 1990 {C6(1)} for ultimate and serviceability limit states are 4.7 and 2.9 corresponding to 1-year probabilities of failure, $P_f$ of $1\text{x}10^{-6}$ and $2\text{x}10^{-3}$, respectively. It is anticipated that, when sufficient statistical data are available, semi-probabilistic and full-probabilistic design methods will be used for code calibration purposes and for the further development of the Eurocodes.

## 6. Reliability differentiation and management

Reliability differentiation occurs first between ultimate and serviceability limit states. Higher levels of reliability are required for ultimate limit states, which are concerned with structural failure and hence risk to human life, compared with serviceability limit

Table 5.Consequences classes and associated reliability classes

| Consequences class | CC1 | CC2 | CC3 |
|---|---|---|---|
| Description | **Low** consequence for loss of human life , *or* economic, social or environmental consequences **small or negligible** | **Medium** consequence for loss of human life, economic, social or environmental consequences **considerable** | **High** consequence for loss of human life *and* economic, social or environmental consequences **very great** |
| Examples of buildings or civil engineering works | Agricultural buildings where people do not normally enter (e.g. storage buildings), greenhouses | Residential and office buildings, public buildings where consequences of failure are medium (e.g. an office building) | Grandstands, public buildings where consequences of failure are high (e.g. a concert hall) |
| Reliability class | RC1 | RC2 | RC3 |
| $\beta$ | 4.2 | 4.7 | 5.2 |
| $P_f$ | $10^{-5}$ | $10^{-6}$ | $10^{-7}$ |

states, which involve excessive deformations of structures. The required higher levels of reliability are achieved through the use of partial factors greater than unity for ultimate limit states and partial factors equal to unity in deformation calculations for serviceability limit states.

EN 1990 {B1(2)} offers the following procedures for managing and differentiating the reliability of structures with regard to ultimate limit states:

- The introduction of classes based on the assumed consequences of failure and on the exposure of the construction works to hazard. The bases of these classes are similar to the bases of the Eurocode 7 geotechnical categories, referred to in Section 3, where the vulnerability of the structure and the surroundings correspond to the consequences of failure.
- A procedure for differentiating between various types of construction based on the quality levels of the design supervision and inspection during execution.

The classes referred to in the first bullet point above are three consequences classes (CC) and three reliability classes (RC). The consequences classes relate to the consequences of failure or malfunction of the structure with regard to the consequences for loss of human life and the economic, social and environmental consequences. These range from low for CC1, through medium for CC2, to high for CC3, as shown in Table 5 together with the examples given in EN 1990 {B3.1(1)}. The consequences classes as defined in EN 1990 differ from the Eurocode 7 geotechnical categories in that they focus only on the consequences of failure, i.e. on the vulnerability factors in Table 1, and do not refer to the hazards related to the ground conditions that contribute to the complexity of geotechnical designs.

Eurocode 7 introduces a further method for reliability differentiation, not given in EN 1990, that is based on the design situation. Design situations are related to the duration of the action and defined in EN 1990 {1.5.2.2} as sets of physical conditions representing the real conditions occurring during a certain time interval for which the design will demonstrate that relevant limit states are not exceeded. The following four design situations are given in EN 1990:

- Transient design situation that is relevant during a period much shorter than

Table 6. Partial factor values in Austrian NA for different consequences classes and design situations

| Common soil parameters[a] | Symbol | Partial material factor values $\gamma_M$ for consequences classes | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | CC 1 | | | CC 2 | | | CC 3 | | |
| | | Design Situation(BS) | | | Design Situation(BS) | | | Design Situation(BS) | | |
| | | BS 1 | BS 2 | BS 3 | BS 1 | BS 2 | BS 3 | BS 1 | BS 2 | BS 3 |
| Effective angle of friction[b] | $\gamma_{tan\varphi'}$ | 1.10 | 1.05 | 1.00 | 1.15 | 1.10 | 1.05 | 1.30 | 1.20 | 1.10 |
| Effective cohesion | $\gamma_{c'}$ | 1.10 | 1.05 | 1.00 | 1.15 | 1.10 | 1.05 | 1.30 | 1.20 | 1.10 |
| Weight density | $\gamma_{\gamma'}$ | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Undrained shear strength | $\gamma_{cu}$ | 1.20 | 1.15 | 1.10 | 1.25 | 1.20 | 1.15 | 1.40 | 1.30 | 1.20 |
| Uniaxial compressive strength | $\gamma_{qu}$ | 1.20 | 1.15 | 1.10 | 1.25 | 1.20 | 1.15 | 1.40 | 1.30 | 1.20 |

[a] Certain failure mechanisms according to ONORM EN 1997-1:2006, 11.5.2 (for example a block on an inclined surface) require other safety elements

[b] This value is applied to tan$\varphi'$

the design working life of the structure and has a high probability of occurrence, e.g. temporary conditions during construction or repair {1.5.2.3}

- Persistent design situation that is relevant during a period of the same order as the design working life of the structures corresponding to normal use {1.5.2.4}
- Accidental design situation involving exceptional conditions of the structure or its exposure, including fire, explosion, impact or local failure {1.5.2.5}
- Seismic design involving exceptional conditions of the structure when subjected to a seismic event {1.5.2.7}.

Eurocode 7 {2.4.7.1(2)P} states that the recommended partial factor values are for transient and permanent design situations. More severe value should be used in cases of abnormal risk or exceptionally difficult ground or loading conditions, while less severe values may be used for temporary structures or transient situations, where the likely consequences justify it. For accidental design situations, Eurocode 7 {2.4.7.1(3)} states that the partial factors for actions or the effects of actions should be 1.0, while the partial factors for resistances should be selected according to the particular circumstances of the accidental situation.

Example of CEN member states that have introduced reliability differentiation involving consequences classes and design situations are Austria and Germany. The different partial material factor values for the three consequences classes given in the Austrian NA for the design of slopes and anchorages are related to the design situation (BS) and shown in Table 6. The highest partial factor values are given for persistent design situations, BS 1, intermediate values for transient design situations, BS 2, and lowest values for accidental situations, BS 3. In the German Handbook, the partial action factor values are related to the design situation for persistent, transient and accidental situations, BS-P, BS-T and BS-A, for all types of geotechnical designs as shown in Table 7. As in the case of the Austrian partial material factors, the highest partial action factors are for the persistent design situation, BS-P.

Greece is considering introducing, in a revised version of its NA, reliability classes with different partial material/resistance factors for each reliability class in order to provide less severe partial factor values than the recommended values for temporary structures and transitory design situations.

In France, a form of reliability differentiation has been introduced that does not

Table 7. Partial action factor values in German Handbook to Eurocode 7 for different design situations

| Action | Partial action factor values $\gamma_F$ for design situation | | | |
|---|---|---|---|---|
| | Symbol | BS-P (persistent) | BS-T (transient) | BS-A (accidental) |
| Unfavorable permanent action | $\gamma_G$ | 1.35 | 1.20 | 1.00 |
| Favorable permanent action | $\gamma_{G, inf}$ | 1.00 | 1.00 | 1.00 |
| Unfavorable permanent earth pressure | $\gamma_{G, EO}$ | 1.20 | 1.10 | 1.00 |
| Unfavorable variable action | $\gamma_Q$ | 1.50 | 1.30 | 1.10 |
| Favorable variable action | $\gamma_Q$ | 0 | 0 | 0 |

involve changes to the partial factor values but links the consequences classes to the geotechnical categories and hence to the level and quality of the geotechnical investigations and design calculations as shown in Table 8. This form of reliability differentiation is similar to the quality management differentiation outlined in EN 1990 {B4} and {B5}, based on the three levels of supervision during design, DSL1, DSL2 and DSL3, and the three levels of inspection during construction, IL1, IL2 and IL3, that are related to the three reliability levels, as shown in Table 9. These are linked to the minimum requirements in the geotechnical categories for design procedures and calculations and for the expertise involved given in Table 2.

Table 8. Linkage in France of geotechnical categories to consequences classes, site conditions and basis for design

| Geotechnical category | Consequences class | Site conditions | Basis for design |
|---|---|---|---|
| GC1 | CC1 | Simple and known | Experience and qualitative investigations |
| GC2 | CC1 | Complex | Site investigations and design |
| | CC2 | Simple or complex | |
| GC3 | GC3 | Simple or complex | Site investigations and detailed design |

Table 9. Design supervision and inspection levels and minimum requirements

| Design Supervision Level | Characteristics | Minimum recommended requirements for checking of calculations, drawing and inspections |
|---|---|---|
| DSL1 relating toRC1 | Normal supervision | Self-checking: Checking performed by person who has prepared the design |
| DSL2 relating to RC2 | Normal supervision | Checking by different persons than those originally responsible and in accordance with the procedure of the organization |
| DSL3 relating to RC3 | Extended supervision | Third party checking: Checking performed by an organization different from that which has prepared the design |
| **Inspection Levels** | **Characteristics** | **Requirements** |
| IL1 relating toRC1 | Normal inspection | Self inspection |
| IL2 relating to RC2 | Normal inspection | Inspection in accordance with the procedures of the organization |
| IL3 relating to RC3 | Extended inspection | Third party inspection |

## 7. Experiences with the application of Eurocode 7

Following the implementation of Eurocode 7 and the other Eurocodes in 2010, a series of Workshops was held as part of the XV ECSMGE in Athens in 2011 to share experiences with the application of Eurocode 7. A report on these Workshops has been prepared by Orr (2012). The Workshop presentations showed the different ways in which Eurocode 7 is being implemented in ten countries, not only with different Design Approaches, as shown in Section 4, but also with other differences introduced to improve the reliability of geotechnical designs, such as consequences classes as shown in Section 6.

Prior to the XV ECSMGE, a questionnaire with the following questions was circulated to geotechnical engineers in some countries to obtain information about the experiences of applying Eurocode 7 in their countries:

1. *Do you find Eurocode 7 easy to use?*
2. *Do you use it for all geotechnical design situations?*
3. *Does it provide enough detail? If not, what more detail would you like?*
4. *Do you as the geotechnical designer choose the characteristic value or does the ground investigation report provide you with a characteristic value?*
5. *Are you confident choosing characteristic soil strengths?*
6. *Are you happy with the partial factor values in your National Annex (NA) and confident of the safety of the resulting designs?*

The responses received to the questions above revealed that:

- While initially engineers found Eurocode 7 more difficult to use than existing standards, once used to it they now find it easy to use and are generally happy with it and are confident in the safety of the designs obtained.
- Eurocode 7 is generally used for all geotechnical designs, although in some countries, such as Ireland and the UK, it is not used for some designs, such as for the design of ground anchors.
- Many countries do not think it provides enough information and hence have considered it necessary to produce supporting national documents and standards with additional non-conflicting complementary information (NCCI), such as calculation models.
- In most countries the characteristic values of geotechnical parameters are selected by the designer. However in some countries, mainly for legal reasons, the characteristic values are selected by the person who carries out the geotechnical investigation.
- Many engineers said they would like more guidance on how to select the characteristic values of geotechnical parameters.
- Most engineers are happy with the partial factor values adopted in their National Annexes.

The presentations on Eurocode 7 during the Workshops in Athens revealed that, in addition to different Design Approaches being adopted in the different countries, many differences still remain in the way pile resistances are determined. Most countries have introduced model factors in the design of piles to increase the level of safety above that provided by the recommended partial factors so that the overall factor of safety is close to that used previously and to ensure that the occurrence of an SLS as well as a ULS is sufficiently unlikely.

## 8. Conclusions

The aim of the Eurocodes is to design structures that have the required level of reliability. The various reliability measures given in EN 1990 have been adopted in an appropriate manner in Eurocode 7 in order to achieve reliable geotechnical designs. This has meant that, compared with the other Eurocodes for manufactured materials, Eurocode 7 focuses more on the management of the design process than on the details of the design calculations and provides no calculation models in the core text, only in Informative Annexes. Lists of factors to be considered and taken into account during the different aspects of a geotechnical design, from geotechnical investigations to design calculations, execution procedures and maintenance, are given. Due to the different conditions and traditions in the European countries, different Design Approaches and different partial factors have been adopted. Many countries have adopted model factors to increase the overall factors of safety for pile designs so that they are closer to those used previously. The survey of experiences with the implementation of Eurocode 7 has revealed that engineers, once they are familiar with Eurocode 7, are generally happy with it and do not have much difficulty using it. However they would like more guidance on its use and hence many countries have updated or are updating their national standards to provide complementary non-conflicting information.

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