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Eurocode 7 and its latest developments

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ABSTRACT: Eurocode 7 on geotechnical design consists of two Parts: General rules (Part 1) and Ground investigation and testing (Part 2). Their conversion into full European Standards (ENs) has now been completed. The contents and main principles of the two parts of Eurocode 7 are described and it is shown how they fit into the concept of limit states in the system of the ten structural Eurocodes. Some aspects of particular interest are presented, such as ultimate limit state verifications in persistent and transient design situations. The Eurocode gives a number of options which have to be decided by the national standards bodies, such as three design approaches for the verification of geotechnical ultimate limit states in persistent and transient situations and the values of the partial factors. On the one hand, this is of course a shortcoming for a code but, on the other hand, it constitutes an openness which makes adoption of the code attractive not only in Europe but also world-wide. However, in future, further harmonization will be necessary to improve the competitiveness of the construction industry. The evaluation of questionnaires on which of the three design approaches for the verification of geotechnical ultimate limit states and which values of the partial factors have been selected in the Member States is presented. It shows that there is great potential for the harmonization of geotechnical design in Europe which must be investigated by research to support and prepare the next steps of further standardization.

1 INTRODUCTION

The system of Structural Eurocodes includes the 10 following multi-part standards (EN for ‘European Norm’):

- EN 1990 Eurocode: Basis of structural design
- EN 1991 Eurocode 1: Actions on structures
- EN 1992 Eurocode 2: Design of concrete structures
- EN 1993 Eurocode 3: Design of steel structures
- EN 1994 Eurocode 4: Design of composite steel and concrete structures
- EN 1995 Eurocode 5: Design of timber structures
- EN 1996 Eurocode 6: Design of masonry structures
- EN 1997 Eurocode 7: Geotechnical design
- EN 1998 Eurocode 8: Design of structures for earthquake resistance
- EN 1999 Eurocode 9: Design of aluminium structures

The Structural Eurocodes are design codes for buildings and civil engineering works. They are based on the Limit State Design (LSD) approach used in conjunction with a partial factor method. Except for EN 1990, all Eurocodes are subdivided into several parts. Eurocodes 2, 3, 4, 5, 6 and 9 are ‘material’ Eurocodes, i. e. relevant to a particular material. 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 consists of two parts:

- Eurocode 7: Geotechnical design - Part 1: General rules (EC 7-1)
- Eurocode 7: Geotechnical design - Part 2: Ground investigation and testing (EC 7-2)

EC 7-1 was ratified by the CEN Members States and published by CEN in November 2004 when the two-year calibration period started during which each National Standards Body (NSB) has to write its

National Annex (NA) to EC 7-1. The NA makes EC 7-1 operable and serves as a link between EC 7-1 and the national standards. After the calibration period and a further 3-year coexistence period EC 7-1 will become mandatory in all EU Member States in around 2010. National standards covering the same items as EC 7-1 will then have to be withdrawn.

In May 2006, EC 7-2 was unanimously ratified by the CEN Members and will be implemented in the EU Member States by the same procedure and a similar timetable. A National Annex has to be written to make EC 7-2 operable and to provide a link to the national standards covering additional items for ground investigation and testing. For the history of EC 7 see SCHUPPENER & FRANK (2006).

2 CONTENTS OF EUROCODE 7

2.1 Part 1: General rules

EC 7-1 (CEN, 2004) includes sections

- on the basis of geotechnical design of different types of foundations and earthworks including spread foundations, pile foundations, anchorages, retaining structures and embankments, on hydraulic failure and overall stability as well as
- on geotechnical data, supervision of construction, monitoring and maintenance, on fill, dewatering, ground improvement and reinforcement.

It should be used for all the problems involving the interaction of structures with the ground (soils, rocks and groundwater) through foundations or retaining structures. It addresses not only buildings but also bridges and other civil engineering works. It permits the calculation of the geotechnical actions on the structures, as well the resistances of the ground subjected to the actions from the structures. It also includes all the provisions and rules for good practice required to conduct the geotechnical side of a structural design properly or, more generally speaking, to carry out a purely geotechnical project.

EC 7-1 is a rather general document – an umbrella code - giving only the principles for geotechnical design within the general framework of Limit State Design (LSD). These principles are relevant to the calculation of the geotechnical actions on structures (buildings and civil engineering works) and to the design of the structural elements themselves in contact with the ground (footings, piles, basement walls, etc.). Detailed design rules or calculation models, i. e. precise formulae or charts, are only given in informative Annexes. The main reason is that the parameter assessment and design models in geotechnical engineering differ from one country to another and it was not possible to reach a consensus, especially when many of these models still need to be calibrated and adapted to the LSD approach.

That is why Annex A only gives recommended values for the partial factors for verifications of the Ultimate Limit State (ULS) in persistent and transient design situations ('fundamental combinations') as well as correlation factors for the characteristic values of pile bearing capacity. The actual values may be set by the Member States in the NA. Moreover, EC 7-1 has provided the option of three alternative design approaches for the verification of geotechnical ultimate limit states in persistent and transient design situations (“fundamental combinations”).

2.2 Part 2: Ground investigation and testings

The role of EC 7-2 (CEN, 2006), which is devoted to laboratory and field testing, is primarily to cover the planning of the tests, their evaluation and, finally, the derivation of values of geotechnical parameters which are the basis for the characteristic values to be determined by EC 7-1 as input to design models. It complements the requirements of EC 7-1 in order to ensure safe and economic geotechnical designs. It provides the link between the design requirements of EC 7-1, in particular the section on geotechnical data, and the results of a number of laboratory and field tests. It does not cover the standardization of the geotechnical tests themselves. (Another Technical Committee (TC) on Geotechnical investigation and testing has been created by CEN specifically to address this matter (TC 341)). In this respect, the role of EC 7-2 is to elaborate on the application of the test results which serve as input to characteristic values for design, referring to the detailed rules for test standards covered by TC 341. EC 7–2 includes sections on

- planning of ground investigations,

- soil and rock sampling and groundwater measurements,
- field tests in soils and rocks,
- laboratory tests on soils and rocks and
- the ground investigation report.

EC 7-2 also includes a number of informative Annexes with examples of methods to determine derived values of geotechnical parameters and coefficients commonly used in design. Some of these annexes give guidance on the use of the sample calculation models in the annexes of EC 7-1. Although the Annexes are informative, they present a clear picture of the approaches existing in Europe for the use of field or laboratory test results in the design of geotechnical structures. For details see SCHUPPENER & FRANK (2006).

3 PROVISIONS FOR THE IMPLEMENTATION IN THE MEMBER STATES

Under the Public Procurement Directives of the European Commission (EC, 2004), it will be mandatory for the Member States to accept designs to the EN Eurocodes. Therefore, EN Eurocodes will become the standard technical specifications for all public works contracts. It will not be mandatory to design to the EN Eurocodes in a particular Member State, but a designer proposing to use alternative design standards will have to demonstrate that the alternative is technically equivalent to an EN Eurocode solution.

Three basic principles that have to be adhered to when harmonizing European standards have been set out by the European Commission in Guidance Paper L - Application and use of Eurocodes (2003a). The principles are as follows:

- Eurocodes must be introduced in all EU Member States by the National Standards Bodies.
- National standards in the technical fields in which European standards exist must be withdrawn after a transitional period but
- national standards in the technical fields not covered by European standards are permitted as long as they do not conflict with the Eurocodes.

The three language versions of Eurocode 7: Geotechnical design - Part 1: General rules (EC 7-1) were published by CEN Management Centre in November 2004. This is the official Date of Availability and from now on the European Member States have a period of two years - known as the National Calibration Period - in which to prepare the national versions of EC 7-1. These will comprise

- a national title page and national foreword,
- the full text of the Eurocode with all annexes and
- a National Annex.

The National Annex (NA) is needed as a link between the Eurocode and the national standards of the Member States. One of the most important principles for drafting and implementing the Eurocodes is stated in clause 2.1 National Provisions for the structural design of works of Guidance Paper L:

> *2.1.1 The determination of the levels of safety of buildings and civil engineering works and parts thereof, including aspects of durability and economy, is, and remains, within the competence of the Member States.*

That is why the Eurocodes only state recommended values of the partial factors; the actual values may be set by the Member States in the NA. Moreover, Guidance Paper L states that the national competence to determine the level of safety may also comprise the use of alternative design methods (see 2.1.2). EC 7-1 has made use of this option of alternative design approaches for the verification of geotechnical ultimate limit states (GEO). To make EC 7-1 operational in the Member States, the NA will therefore

- define the values of the partial safety factors,
- select the national design approaches and
- draw up specifications on the use of the informative annexes of EC 7-1.

Then there are two more important rules for writing a national annex. Guidance Paper L also stipulates the following:

> *2.3.4 A National Annex cannot change or modify the content of the EN Eurocode text in any way other than where it indicates that national choices may be made by means of Nationally Determined Parameters.*

That is why the foreword of each Eurocode includes a list of those paragraphs in which national choice is allowed. No other changes or modifications are permitted:

> *2.1.6 National Provisions should avoid replacing any EN Eurocode provisions, e.g. Application Rules, by national rules. ... When, however, National Provisions do provide that the designer may deviate from or not apply the EN Eurocodes or certain provisions thereof, then the design will not be called "a design according to EN Eurocodes.*

To make EC 7-1 operational in the Member States, the National Annex will therefore

- give specifications on the use of the informative annexes of EC 7-1,
- define the values of the partial safety factors and correlation factors,
- select the national design approaches for different geotechnical structures and
- give references to national standards.

National standards will still be used as EC 7-1 is an umbrella code; however, the national standards have to be adapted to the format of the Eurocodes.

As a result of these basic provisions, we will have the following hierarchy of Eurocodes as illustrated in Figure 1 for Germany and its national DIN-standards for waterway engineering: At the top of the hierarchy, we have the Eurocode: Basis of design and Eurocode 1: Actions on structures with several parts and annexes. They are the basis for structural design all over Europe.

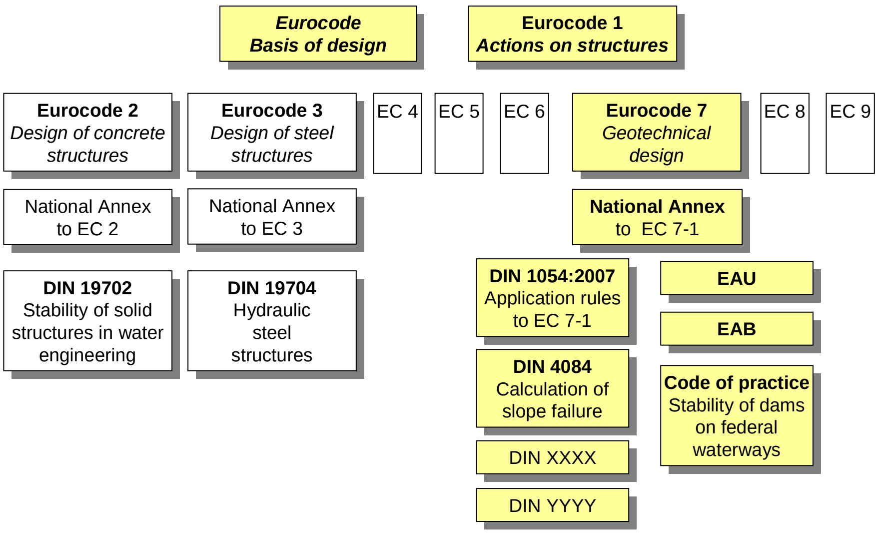

Fig.1 Future hierarchy of standards in Germany illustrated for waterway engineering

All other Eurocodes refer to these two Eurocodes: from EC 2: Design of concrete structures to Eurocode 9: Design of Aluminium structures. Most of the Eurocodes are more or less umbrella codes. So a design cannot be performed using Eurocodes alone as the values for the partial factors are recommended values, for example. Moreover, most of the ECs only give options for design procedures. So every country must decide on its own safety level and decide which DA must be used in the various verifications. That is why we need national annexes (NA). The special application of the Eurocode in each member state is laid down in the NAs. Thus the NAs make the Eurocodes operable in every Member state. In future, the Member States will still be permitted to have national standards as long they do not compete or conflict with Eurocodes or general provisions. So the national annexes will also act as an interface between the Eurocodes and national standards.

4 PROCEDURES OF ULS VERIFICATIONS OF EUROCODE 7

4.1 General

The ultimate limit states (ULS) to be checked are defined in the following manner by Eurocode 7 – Part 1 and are consistent 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.’

Thanks to the Eurocodes, a single format will be used for the mathematical analysis of the ultimate limit states throughout the construction sector in Europe in future. Accordingly, for any section in a structure, structure-soil interface or the soil, it will have to be verified that the design value of the effects of actions, E_d, never exceeds the design bearing capacity or the design resistances, R_d, i.e.:

$$E_d \leq R_d \tag{1}$$

There has to be a clear-cut distinction between the effects of actions and resistances in order for the general limit state equation (1) to be applied. Such a distinction can be made without much difficulty in other fields of structural engineering. However, in geotechnical engineering, there are many cases in which it is not possible to make a clear-cut distinction between the effects of actions and the resistances. For instance, the action of the active earth pressure also depends on the shearing resistance or the shear strength in the failure surface of the active sliding wedge. In other cases, the resistance of the soil depends on the magnitude of the action. For instance, the sliding resistance is governed by the magnitude of the effect of the action due to the vertical component of the bearing pressure resultant.

Additional problems concerning the application of equation (1) are caused by the fact that there are two entirely different ways of introducing the partial safety factors in geotechnical engineering, as described below.

- On the one hand, the design values, E_d and R_d, of the geotechnical effects of actions and resistances can be determined by what is known as the method of factored shear parameters (MFA: 'material factor approach') . In this method, the 'material' partial factors are applied to the characteristic shear parameters, φ'_k and c'_k. Thus the design value of the effective coefficient of friction, $\tan \varphi_d$, is determined by dividing the characteristic coefficient of friction, $\tan \varphi'_k$, by the partial factor for friction, γ_φ. Similarly, the design cohesion, c'_d, is obtained by dividing the characteristic cohesion, c'_k , by the partial factor for cohesion, γ_c, i.e.:

$$\tan \varphi'_d = \tan \varphi'_k / \gamma_\varphi \tag{2}$$

$$c'_d = c'_k / \gamma_c \tag{3}$$

The design values of the geotechnical actions and resistances, E_d and R_d, to be used in the limit state equation (1) are then determined with the design values of the shear parameters, φ'_d and c'_d.

- On the other hand, there is the method of factored actions and resistances (RFA: 'resistance factor approach'). In this method, the characteristic values of the actions, effects of actions and resistance of the soil, F_k, E_k and R_k respectively, are determined using the characteristic values of the shear parameters, φ'_k and c'_k. The design values of the geotechnical effects of actions, E_d, (stresses, internal forces and moments) and the resistances are then obtained by applying the partial factors for the geotechnical effects of actions and resistances, γ_E and γ_R, to the characteristic values, i.e.:

$$E_d = E_k / \gamma_E \tag{4}$$

$$R_d = R_k / \gamma_k \tag{5}$$

The different ways of introducing the partial factors into the calculation explained above are the principle reason why Eurocode 7 - Part 1 offers three different methods of verifying GEO ultimate limit states for persistent and transient situations. The choice of design approach can be determined nationally by each National Standards Body. Yet different design approaches can be used to verify different limit states. The numerical values of the partial factors to be applied in a given design procedure can also be determined nationally and must be specified in the National Annex to EC 7-1.

The three design approaches of Eurocode 7 - Part 1 differ in the way in which they distribute the partial factors between geotechnical actions and resistances (see Table 1). The concept of partial factors differentiates between the partial factors on actions or effects of actions and those on the resistances. As regards the actions and effects of actions, a distinction is made between actions coming from the structure and actions coming from the ground.

Table 1 Recommended value of partial factors for persistent and transient situations for the design of shallow foundations and slopes in accordance with Annex A of Eurocode 7 - Part 1

Design Approach		Actions or effects of actions of the structure	Actions or effects of actions of the ground	Resistance of the ground
DA 1	Comb. 1	$\gamma_G = 1.35$; $\gamma_{G,inf} = 1.00$; $\gamma_Q = 1.50$		$\gamma_R = \gamma_{\varphi'} = \gamma_{c'} = \gamma_{cu} = 1.0$
	Comb. 2	$\gamma_G = 1.00$; $\gamma_Q = 1.30$	$\gamma_{\varphi'} = \gamma_{c'} = 1.25$; $\gamma_{cu} = 1.40$; $\gamma_R = 1.0$	
DA 2, DA 2*		$\gamma_G = 1.35$; $\gamma_{G,inf} = 1.00$; $\gamma_Q = 1.50$		$\gamma_{R;e} = \gamma_{R;v} = 1.40$; $\gamma_{R;h} = 1.10$ $\gamma_{\varphi'} = \gamma_{c'} = \gamma_{cu} = 1.0$
DA 3		$\gamma_G = 1.35$; $\gamma_{G,inf} = 1.00$; $\gamma_Q = 1.50$	$\gamma_{\varphi'} = \gamma_{c'} = 1.25$; $\gamma_{cu} = 1.40$; $\gamma_R = 1.00$	

γ_G: partial factor for unfavourable permanent actions,
$\gamma_{G;inf}$: partial factor for favourable permanent actions
γ_Q: partial factor for unfavourable variable actions (for favourable variable actions $\gamma_Q = 0$)
$\gamma_{R;e}$: partial factor for passive earth pressure
$\gamma_{R;v}$: partial factor for ground bearing resistance
$\gamma_{R;h}$: partial factor for resistance to sliding

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.'

Although the verification of serviceability limit states (SLS) is a issue of equal importance in contemporary geotechnical design it gave rise to only a few difficult discussions, unlike the ultimate limit states, when Eurocode 7 was drawn up. That is why the issue of SLS will probably will not play an important part in future discussions on further harmonization.

4.2 Design Approach DA 1

In Design Approach DA 1, two combinations of partial factors have to be investigated. Combination 1 aims to provide safe design against unfavourable deviations of the actions from their characteristic values. Thus, in Combination 1, partial factors greater than 1.0 are applied to the permanent and variable actions from the structure and the ground. The recommended factors are: γ_G = 1.35 for unfavourable permanent actions, $\gamma_{G;inf}$ = 1.00 for favourable permanent actions and γ_Q = 1.50 for variable actions. The factors are the same as those used in other fields of structural engineering and they are consistent with those specified in EN 1990: Basis of structural design. By contrast, the calculations for the ground resistance are performed with characteristic values, i.e. the partial factors γ_φ, γ_c and γ_{cu}, which are all set at 1.00, are applied to the shear parameters; the partial factor for the ground resistance, γ_R, is also 1.00.

Combination 2 of Design Approach DA 1 aims to provide safe design against unfavourable deviations of the ground strength properties from their characteristic values and against uncertainties in the calculation model. It is assumed that the permanent actions correspond to their expected values and the variable actions deviate only slightly from their characteristic values. Thus, the partial factors $\gamma_{\varphi'}$, $\gamma_{c'}$ and γ_{cu} with numerical values of 1.25 or 1.40 are applied to the characteristic values of the ground strength parameters while the characteristic values of the permanent actions from the structure (with γ_G set at 1.00) are used in this verification. The partial factors are applied to the representative values of the actions and to the characteristic values of the ground strength parameters at the beginning of the calculation. Thus the entire calculation is performed with the design values of the actions and the design shear strength.

Of the two combinations, the one resulting in the larger dimensions of the foundation will be relevant for designs according to Design Approach DA 1. More details on the use of the three Design Approaches are given in FRANK ET AL. (2004), for instance.

*4.3 Design Approaches DA 2 and DA 2**

In Design Approach DA 2, only one verification is ever required unless different combinations of partial factors for favourable and unfavourable actions need to be dealt with separately in special cases. In DA 2, the partial factors applied to the geotechnical actions and effects of actions are the same as those applied to the actions on or from the structure, i. e. γ_G = 1.35, $\gamma_{G;inf}$ = 1.00 and γ_Q = 1.50. The partial factors given in Table 1 are recommended for the ground resistances.

There are two ways of performing verifications according to Design Approach DA 2. In the design approach referred to as “DA 2” by FRANK ET AL. (2004), the partial factors are applied to the characteristic actions right at the start of the calculation and the entire calculation is subsequently performed with design values. By contrast, in the design approach referred to as “DA 2*” by FRANK ET AL. (2004), the entire calculation is performed with characteristic values and the partial factors are not introduced until the end when the ultimate limit state condition is checked. As characteristic internal forces and moments are obtained in the calculation, the results can generally also be used as a basis for the verification of serviceability.

4.4 Design Approach DA 3

Similarly, only one verification is required for Design Approach DA 3. The partial factors applied to the actions on the structure or coming from the structure are the same as those used in Design Approach DA 2. However, for the actions and resistances of the ground, the partial factors are not applied to the actions and resistances but to the ground strength parameters, φ′, c′ or cu instead. The recommended values for $\gamma_{\varphi'}$, $\gamma_{c'}$ and γ_{cu} are 1.25 and 1.40. The partial factors are applied to the representative values of the actions at the beginning of the calculation and to the characteristic values of the ground strength parameters. Thus, in Design Approach DA 3, the entire calculation is performed with design values of the actions and the design shear strength.

5 STATE OF IMPLEMENTATION AND DECISIONS ON THE DESIGN APPROACHES OF EC 7-1 BY THE EUROPEAN MEMBER STATES

5.1 General

Questionnaires were sent to the Member States in 2005 and 2006 to collect information about the stage that had been reached in the implementation of EC 7-1, the drafting of the National Annex and the selection of the partial factors and design approaches. The questionnaire circulated in 2006 was more detailed in so far as the selection of the design approaches and the numerical values of the partial factors was linked to practical examples. The examples were taken from geotechnical design examples prepared for the International Workshop on the Evaluation of EC 7-1 held in Trinity College, Dublin on 31st March and 1st April 2005 (ORR, 2006). The aim of the questionnaire was

– to stimulate the discussion on problems of implementing and applying EC 7-1 in the European Member States and
– to support and discuss with the Joint Research Centre (JRC) of the European Commission the next steps in their mandate to contribute to the implementation, harmonization, international promotion and further development of the Eurocodes.

The questionnaires were sent to the National Standards Bodies of the Member States of the European Union and to the affiliated Member States of CEN. Not all were returned by January 2007. Some of them were not filled in completely as some Member States had not concluded their decision-making process on which design approaches and partial factors to use in geotechnical verifications. Other questionnaires contained quite detailed explanations and reports on the discussions. The following sections can therefore only give an overview of the most important aspects of the implementation of EC 7-1 reached by January 2007.

5.2 GEO ultimate limit states

The decisions of the Member States with respect to the selected design approaches for the GEO ultimate limit states are presented in Table 2 (The names of the countries have been abbreviated using the vehicle country identification codes). The design approaches had to be stated for the design of

– a shallow foundation where the ground bearing capacity and sliding failure had to be verified;
– a pile foundation for bored and driven piles based on soil parameter values and pile load tests;
– a retaining structure of an anchored sheet pile quay wall - design of embedment depth - and
– a road embankment constructed over soft clay where the maximum height had to be determined based on an analysis of the slope stability.

Table 2 Selection of Design Approach in the European Member States (as at January 2007)

Design example	No/incomplete answers from	Design approach of EC 7-1				
		All DAs	DA 1	DA 2	DA 2*	DA 3
Shallow foundation		IRL	B, UK, P, LT, I, RO	F, SK, I SF, L	D, A, E, PL SLO, GR	CH, NL, DK
Piles	N, CZ, M, S, EST, LV, CY, IS, H, BG	IRL	B, UK, P, LT, I, RO	F, SK, CH, SF, D, A, E, NL, SLO, PL, DK, GR, L		NL
Retaining structures		IRL	B, UK, P, LT, I, RO	F, SK, CH, SF, D, A, E, SLO, PL, GR, L		NL, DK
Slopes		IRL	B, UK, P, LT, I	F,E		NL,F,SK,CH,SF, D,A, PL, DK, SLO, GR, L, RO
Total:	10	1	5-6	2 - 13		2 – 13

One Member State has decided to admit all three design approaches. Five countries have decided to use Design Approach DA 1 in all GEO ultimate limit states. Between 11 and 13 Member States have made design approaches DA 2 and DA 2* mandatory for shallow foundations, piles and retaining structures whereas two or three have chosen Design Approach DA 3. However, almost all Member States that have selected Design Approach DA 2 or DA 2* for shallow foundations, piles and retaining structures have decided that Design Approach DA 3 will be mandatory for slope stability, except for Spain. In most cases, the use of DA 3 for slopes is in effective similar to that of Combination 2 in DA 1.

The partial factors for the three design approaches recommended in Annex A of EC 7-1 are presented in the first line of each design example in Tables 3, 4 and 5. The second line shows the Member States and their choice of partial factors if they differ from the recommended values.

There are no great deviations from the recommended values of the partial factors for the verification of pad foundations (see Table 3) when the design approaches DA 1 and DA 2 are adopted. However, the variance in partial factors is greater for Design Approach DA 3. The Netherlands reduces almost all factors except the factor on the cohesion intercept c´ in terms of effective stresses; Switzerland reduces the factor on the effective angle, φ´, of shearing resistance but increases the factor on the cohesion intercept, c´. Switzerland even uses a factor of $\gamma_{G,fav}$ = 0.80 for favourable permanent actions.

Table 3 Selection of partial factors for GEO limit states for pad foundations

Design example	DA 1: recommended factors MS: Differing values	DA 2: recommended factors MS: Differing values	DA 3: recommended factors MS: Differing values
Example 2: Pad foundation, verification of ground bearing capacity	C.1: γ_G = 1.35; $\gamma_{G,fav}$ = 1.0; γ_Q=1.50 C.2: γ_G= 1.0; γ_Q= 1.30; γ_φ= 1.25; $\gamma_{c'}$= 1.25, γ_{cu}= 1.40;	γ_G=1.35; $\gamma_{G,fav}$=1.0; γ_Q=1,5, $\gamma_{R;v}$ = 1,4	γ_φ= γ_c=1.25;γ_{cu}=1.40;γ_Q= 1.3, structure: γ_G= 1.35; $\gamma_{G,fav}$= 1.0; γ_Q=1.5
	IRL: C.1: γ_{cu} = 1.25 B: C.2: γ_Q = 1.10 LT: $\gamma_{G,fav}$ = 0.90; I: C.1: γ_G = 1.5, $\gamma_{G,fav}$ = 1.3; C.2: $\gamma_{G,fav}$ = 1.0, γ_G = 1.3; γ_c= 1.4, $\gamma_{R,v}$ =1.8;	E: global Factor $\gamma_{R;v}$ = 3.0, F: $\gamma_{R;v}$ = ? I: γ_G =1.5,$\gamma_{G,fav}$ =1.3, $\gamma_{R,h}$=1.1 L, SK undecided	CH: γ_φ= 1.2; γ_c= 1.5;γ_{cu}= 1.5; structure: $\gamma_{G,fav}$= 0.8 NL: γ_φ=1.15, γ_c=1.6; γ_{cu}=1.35; structure: $\gamma_{G,fav}$= 0.90; DK: γ_φ= 1.2; γ_c= 1.2, γ_{cu}= 1.8; structure: γ_G = 1.2 / 1.0; $\gamma_{G,fav}$= 1.0 / 0.9
Example 2: Pad foundation, verification of sliding resistance	C.1: $\gamma_{G;unfav}$=1.35; $\gamma_{G,fav}$=1.0; γ_Q=1.50 C.2: γ_G= 1.0; γ_Q= 1.30; $\gamma_{\varphi'}$= $\gamma_{c'}$= 1.25, γ_{cu}= 1.40;	$\gamma_{G;unfav}$= 1.35; $\gamma_{G,fav}$=1.0; γ_Q= 1.50, $\gamma_{R;h}$ = 1.10	γ_φ= γ_c=1.25; γ_{cu}=1.40;γ_Q= 1.30, structure:γ_G= 1.35; $\gamma_{G,fav}$=1.0; γ_Q=1.5
	B: C.2: γ_Q = 1.10 I: C.1: γ_G = 1.5, $\gamma_{G,fav}$ = 1.3, C.2: γ_c= 1.4, $\gamma_{G,fav}$ = 1.0, $\gamma_{R;h}$ = 1.1 LT: $\gamma_{G,fav}$ = 0.90;	IRL: $\gamma_{R;h}$ = 1.40 E: global factor $\gamma_{R;h}$ = 1.5 F: $\gamma_{R;h}$ = ? L, SK undecided	CH:γ_φ=1.2; structure:$\gamma_{G,fav}$ = 0.8 NL: γ_φ=1.15, γ_c=1.6; γ_{cu}=1.35; structure: $\gamma_{G,fav}$ = 0.90; DK: γ_φ= 1.2; γ_c= 1.2, γ_{cu}= 1.8; structure: γ_G = 1.2 /1.0; $\gamma_{G,fav}$= 1.0 / 0.9

C.1: Combination 1 of DA 1, C.2: Combination 2 of DA 1,
γ_G : partial factor for unfavourable permanent actions,
$\gamma_{G;fav}$: partial factor for favourable permanent actions
γ_Q : partial factor for unfavourable variable actions (for favourable variable actions γ_Q = 0)
$\gamma_{R;e}$: partial factor for passive earth pressure on the side of the shallow foundation
$\gamma_{R;v}$: partial factor for ground bearing resistance
$\gamma_{R;h}$: partial factor for resistance to sliding
γ_φ : partial factor for the angle of shearing resistance
γ_c : partial factor for the effective cohesion
γ_{cu} : partial factor for the undrained shear strength

Approaches DA 1 and DA 2 were chosen for pile design by all Member States except the Netherlands (see Table 4). No Member State adopted the recommended values for bored piles without alteration and five Member States have not yet decided on the values of the partial factors. The situation is more homogeneous for the design of driven piles derived from pile load tests as the tests give a more reliable basis for the design.

Table 4 Selection of partial factors for GEO limit states in pile foundations

Design example	DA 1: recommended factors	DA 2: recommended factors	DA 2: recommended factors
	MS: Differing value	MS: Differing value	MS: Differing value
Example 3: foundation with bored piles – design of the pile length from soil parameter values	C.1: γ_G =1.35; γ_Q=1.50; γ_b=1.25; γ_s= 1.0; γ_t= 1.15; C.2: γ_G=1.0; γ_Q=1.30; γ_b= 1.6; γ_s= 1.3; γ_t= 1.5	γ_G=1.35; $\gamma_{G;fav}$=1.0; γ_Q=1.5 ; γ_b= 1.1; γ_s= 1.1; γ_t= 1.1;	γ_G=1.35; $\gamma_{G;fav}$=1.0; γ_Q=1.5; γ_b= 1.1; γ_s= 1.1; γ_t= 1.1;
	UK: C.2: γ_t= 1.6 P, IRL: C.1 and C.2: γ_R =1.5 LT: C.1 and C.2: γ_R =1.4 I: C.1: γ_G = 1.5, $\gamma_{G,fav}$ = 1.3, γ_b= γ_s= 1.0; γ_t= 1.2; C.2: γ_G = 1.3, γ_b= γ_s=1.35, γ_t= 1.6 RO: C.1: γ_b=γ_s= γ_t= 1.0; C.2: γ_b= γ_s= γ_t= 1.3; B: undecided	CH: γ_t= 1.4 E: global γ_R = 3.0 D: γ_b= 1.4; γ_s= 1.4; γ_t= 1.4; SLO, SF, GR, A: γ_R = 1.3 + ξ (Table A.10) DK: γ_G= 1.2 / 1.0; γ_b= 1.3; γ_s= 1.3; γ_t= 1.3; γ_R= 1.0; ξ = 1.5 PL, F, L, SK: undecided	NL: CPT-method: $\gamma_{G,fav}$=0.90; material factor on q_c: γ_b =γ_s=γ_t=1.2 and ξ (Table A.10)
Example 4: pile foundation – determination of the number of piles from pile load tests on driven piles	C.1: γ_G= 1.35; γ_Q= 1.50; γ_b= γ_s= γ_t= 1.0; C.2: γ_G= 1,0; γ_Q= 1.30; γ_b= 1.3; γ_s= 1.3; γ_t= 1.3	γ_G =1.35; γ_Q=1.50; $\gamma_{G;fav}$= 1.0 γ_b= 1.1; γ_s= 1.1; γ_t= 1.1;	γ_G =1.35; $\gamma_{G;fav}$= 1.0; γ_Q=1.5; γ_b= 1.1; γ_s= 1.1; γ_t= 1.1;
	IRL: C.2: γ_t=1.3; C.2: γ_t=1.50; LT: C.1: γ_t= 1.1, γ_R =1.3; C.2: γ_t = 1.5, γ_R =1.3 P: C.2: γ_R =1.0 I: C.1: γ_G= 1.5; $\gamma_{G,fav}$ = 1.3, γ_b= γ_s= 1.0, γ_t= 1.2 ; C.2: γ_G= 1,3; γ_b= 1.35; γ_s= 1.3, γ_t= 1.6 RO: C.1: γ_t= 1.6, C.2: γ_t= 1.3; B; undecided	CH: γ_t= 1.3; D: γ_t= 1.20 ; γ_R = 1.05 DK: γ_G = 1.2 / 1.0; γ_t= 1.3 ; γ_R = 1.0; ξ = 1.1 / 1.25 E, F, L, SK, PL: undecided	NL: γ_G = 1.20; γ_R = 1.2 and ξ (Table A.9)

List of symbols see also Table 3
γ_b: partial factor on the base resistance
γ_s: partial factor on the shaft resistance
γ_t: partial factor for the total resistance of the pile
γ_R: model factor

Most Member States will use the partial factors recommended in EC 7-1 for the verification of the embedment depth of anchored sheet pile quay walls (see Table 5), but there are some changes to the conservative and some to the less conservative side. However, it is interesting to note that the Netherlands has chosen noticeably lower partial factors for the soil parameters and for the actions coming from a structure. It should also be noted that Switzerland has a highly differentiated way of factoring earth and water pressures, Germany and Austria apply reduced partial factors in transient design situations while Spain again uses the global concept.

Most Member States have introduced Design Approach DA 3 for the verification of slope stability (see Table 5). However, none of the countries has adopted all of the partial factors recommended in Annex A of EC 7-1 although the differences are not very great. The Member States that selected Design Approach DA 1 adopted the recommended partial factors of Annex A, except for Belgium which reduced the partial factor for the variable action in Combination 2 to γ_Q = 1.10 and Lithuania which reduced the partial factor on favourable actions to $\gamma_{G;fav}$ = 0.90. Design Approach DA 2 was only selected by Spain which retained the global safety concept.

The evaluation of the results of the comparative design for the workshop in Dublin (see ORR, 2005) indicates that, for slope stability, Design Approach DA 1 Combination 2, which is very similar to Design Approach DA 3, will be relevant for design. So, in a next step towards harmonization, a reduction in the number of design approaches and partial factors could be possible for the verification of slope stability, taken in isolation. However, it will be necessary to ensure that situations including slopes, retaining structures and foundations acting in combination are accommodated, which is the benefit claimed for DA 1. A result which is also quite promising for future harmonization is the fact that all Member States use the partial factor on weight density, γ_γ, of 1.0 as recommended in Table A.4 of EN 1997-1.

Table 5 Selection of partial factors for GEO limit states of retaining walls and slopes

Design example	DA 1: recommended factors	DA 2: recommended factors	DA 3: recommended factors
	Member State: Differing value	Member State: Differing value	Member State: Differing value
Example 7: anchored sheet pile quay wall	C.1: γ_G=1.35; $\gamma_{G;fav}$= 1.0; γ_Q= 1.50 C.2: γ_φ= 1.25; γ_G= 1.0; γ_Q= 1.30	$\gamma_{G;unfav}$=1.35; $\gamma_{G;fav}$ =1.0; γ_Q= 1.5; $\gamma_{R;e}$ = 1.40	γ_φ= γ_c= 1.25; γ_{cu}=1.40; γ_Q= 1.30; structure: γ_G=1.35; $\gamma_{G,fav}$=1.0; γ_Q=1.5
	B: C.2. γ_Q = 1.10 I: C.2: γ_c=1.40 IRL: C.1: γ_G=$\gamma_{G;fav}$= 1.35 LT: undecided	D: $\gamma_{G;fav}$=1.35 CH: γ_G(Water)= 1.20; $\gamma_{G;fav}$= 0.80; E: global $\gamma_{R;e}$ = 1.8 F, SK, L, PL: undecided	NL: γ_φ = 1.15, γ_c =1.05, γ_{cu} =1.6; structure: $\gamma_{G,fav}$= 0.9; γ_Q=1.0 DK: γ_φ = 1.2; structure: γ_G=1.2/1.0; $\gamma_{G,fav}$= 1.0/0.9;
Example 10: road embankment – determination of the maximum height using the slope stability as criterion	C.1: γ_G = 1.35; $\gamma_{G,fav}$= 1.0; γ_Q= 1.5; C.2: γ_G= 1.0; γ_Q= 1.3,γ_φ= γ_c= 1.25, γ_{cu}=1.40;	γ_G = 1.35; $\gamma_{G;fav}$= 1.0, γ_Q= 1.5; $\gamma_{R;e}$= 1.1 $\gamma_{\varphi'}$= $\gamma_{c'}$= γ_{cu}=1.0;	γ_φ= γ_c=1.25; γ_{cu}=1.40; γ_Q= 1.30; $\gamma_{R;e}$=1.4; structure: γ_G= 1.35; $\gamma_{G,fav}$=1.0; γ_Q=1.5, $\gamma_{R;e}$= 1.0
	B: C.2: γ_Q = 1.10; IRL: C.1: γ_G=$\gamma_{G;fav}$ =1.35 LT: C.1: $\gamma_{G,fav}$ = 0.90;	F: $\gamma_{R;e}$ = 1.5 for soft soils E: global $\gamma_{R;e}$ = 1.5	D, A: γ_{cu}= 1.25; CH: γ_φ=1.2; γ_c= 1.5, γ_{cu}= 1.5; NL: γ_c= 1.45, γ_{cu}= 1.75; GR, IRL: $\gamma_{R;e}$= 1.1; DK: γ_φ = 1.2; γ_c= 1.2, γ_{cu}= 1.8; Structure: SF, D, GR, CH: γ_G=$\gamma_{G,fav}$ =1.0 NL: $\gamma_{G,fav}$= 0.9 DK: γ_G =1.2 /1.0; $\gamma_{G,fav}$= 1.0/0.9 PL, F, L, SK: undecided

List of symbols see Table 3 and 4
$\gamma_{R;e}$: partial factor for earth resistance

6 FURTHER STEPS TOWARDS IMPLEMENTATION AND HARMONIZATION

6.1 Education and training

The general policy of the European Commission is to improve the competitiveness of the construction industry. Further harmonization is therefore necessary. Establishing the design approaches and the values of the partial factors for the verifications in each Member State and specifying them in a National Annex is only the first step in the implementation of a Eurocode. It is obvious that extensive training is required in the Member States if the EN Eurocodes are to be applied adequately. The training of staff is the responsibility of industry in cooperation with national authorities and National Standards Bodies and will be supported by the European Commission. Training programmes have been established in all the Member States and numerous courses and seminars have been held. Even in Croatia, a future EU Member State, a course on EC 7-1 was held in May 2007.

6.2 Maintenance

Maintenance of the Eurocodes is essential to preserve their credibility, integrity and relevance, as well as to ensure that they do not contain any errors. Especially after their implementation and initial application, the Eurocodes are likely to give rise to technical, editorial and possibly legal questions. Therefore, maintenance will involve:

- correction of errors
- technical amendments with regard to urgent matters of health and safety
- technical and editorial improvements
- resolution of matters of interpretation
- elimination of inconsistencies and misleading statements
- development of new items.

CEN/TC250 is responsible for the maintenance of the Eurocodes which will proceed according to CEN rules. A special Maintenance Group of Subcommittee 7 (SC 7) which is in charge of Eurocode 7 was established in October 2006 to deal with these items with respect to EC 7-1.

All feedback from the application of the Eurocodes in the Member States should be submitted to the National Standards Bodies (NSB) using templates and processed by the responsible and competent national standardization committee according to national rules (see Figure 2). The comments should be dealt with as far as possible by the NSBs in the Member States; only comments that have an effect on corrections or amendments and matters of interpretation should be forwarded to SC 7 or its Maintenance Group.

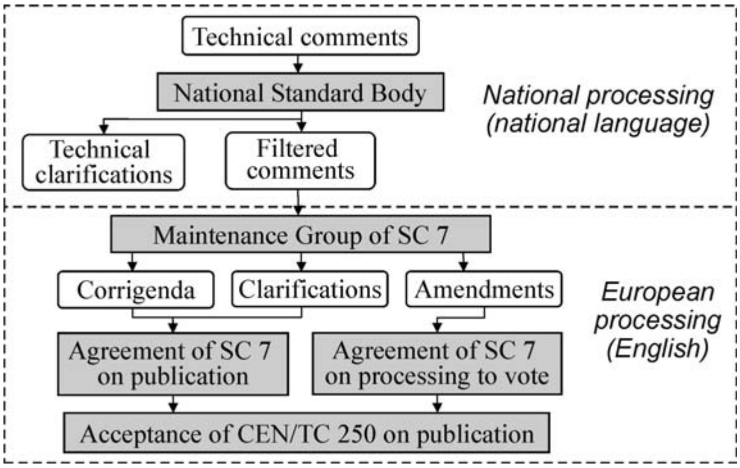

Fig.2 Flowchart for the maintenance of the Eurocodes

The maintenance activities should be divided into three parts:

- the short term (immediate or within a year)
- the medium term (the regular five-year review)
- the long term (greater than five years)

The short-term activities involve the technical amendments with regard to urgent matters of safety and the correction of technical and editorial errors (e.g. mistakes in symbols, typographical errors). Corrigenda will eventually be issued at the end of the short-term period.

Reviews of European Standards will be initiated by the relevant Technical Committee (TC) four years after ratification of the EN at the latest. The appropriate SC is responsible for the scientific and technical aspects of those parts of the EN Eurocode that fall within its responsibility and field of competence. The review of the technical and editorial improvements and the resolution of matters of interpretation will be prepared by the Maintenance Group which will collect, identify and analyse the comments. The Maintenance Group will also consider whether liaisons need to be established with other SCs and CEN/TCs for structural components, execution or testing. Eventually, drafts for corrigenda, clarifications of matters of interpretation and amendments will be prepared for the SC. These drafts must all be agreed upon by the SC by resolution. To ensure efficiency and consistency, CEN/TC 250 will coordinate the publication of corrigenda and amendments to the EN Eurocode Parts produced by the SCs.

The general issues for further harmonization are laid down in a recommendation of the Commission as follows:

Member States should use the recommended values provided by the Eurocodes. When nationally determined parameters have been identified in the Eurocodes, they should diverge from those recommended values only where geographical, geological or climatic conditions or specific levels of protection make that necessary.

Member States should, ..., compare the nationally determined parameters implemented by each Member State and assess their impact as regards the technical differences for works or parts of works. Member States should, at the request of the Commission, change their nationally determined parameters in order to reduce divergence from the recommended values provided by the Eurocodes. (EC (2003b))

Although the Member States retain sole responsibility for the levels of safety of works they are strongly encouraged to minimize the number of cases in which recommendations for a value or method are not adopted for their Nationally Determined Parameters (NDP). Therefore, the principal objectives of further harmonization are as follows:

- the reduction of NDPs in the EN Eurocodes resulting from different design cultures and procedures in structural analysis
- the reduction of NDPs and their variety through the strict use of recommended values
- the gradual alignment of safety levels across Member States.

Moreover, it is important to harmonize not only the values of the NDPs (harmonization across national borders), but also the design procedures.

This work of the Maintenance Group will be supported by the development and maintenance of an EN Eurocodes informatics platform by the Joint Research Centre of the EC in Ispra, Italy. The platform includes the NDPs and National Annexes database as well as a database of background documents on the recommended values and on the reasons for deviations in the National Annexes. This will permit the statistical analysis of the NDPs and support both the expert analysis and the elaboration of technical justification documents.

6.3 Research for further harmonization

6.3.1 General

In the long term, matters relating to the development of new items will be examined, e.g. the harmonization of calculation methods or the evaluation of test results with respect to the selection of characteristic values of ground parameters in geotechnical design. New EN Eurocodes or Parts can only be developed following appropriate studies and research along with substantial practical experience. Research is encouraged by the following recommendation of the Commission:

Member States should undertake research to facilitate the integration into the Eurocodes of the latest developments in scientific and technological knowledge. Member States should pool the national funding available for such research so that it can be used at Community level to contribute to the existing technical and scientific resources for research within the Commission, in cooperation with the Joint Research Centre, thus ensuring an ongoing increased level of protection of buildings and other civil works, specifically as regards the resistance of structures to earthquakes and fire. (EC (2003b))

For geotechnical design this may include, e.g.

- comparative studies of the different design approaches and values of partial factors used in geotechnical verifications in the Member States to evaluate the potential for further harmonization and
- investigations of the interpretation und evaluation of field and laboratory tests in the Member States with respect to the establishment of characteristic values of ground parameters.

The general issues for further harmonization are laid down in the following European Commission recommendation (EC (2003b)):

Member States should use the recommended values provided by the Eurocodes. When nationally determined parameters have been identified in the Eurocodes, they should diverge

from those recommended values only where geographical, geological or climatic conditions or specific levels of protection make that necessary.
Member States should, ..., compare the nationally determined parameters implemented by each Member State and assess their impact as regards the technical differences for works or parts of works. Member States should, at the request of the Commission, change their nationally determined parameters in order to reduce divergence from the recommended values provided by the Eurocodes.

Although the Member States retain sole responsibility for the levels of safety of works they are strongly encouraged to minimize the number of cases where recommendations for a value for their Nationally Determined Parameters (NDP) are not adopted. Moreover, it is important to harmonize not only the values of the NDPs (harmonization across national borders), but also the Design Approaches given as options in EC 7-1.

Therefore, the principal objectives of further harmonization of EC 7-1 and EC 7-2 are as follows:

- the harmonization of parameter evaluation based on field and laboratory tests
- the harmonization of the models used for the calculation of geotechnical actions and resistances
- the reduction of NDPs and their variety,
- the gradual alignment of safety levels across Member States and
- the reduction of Design Approaches from different design cultures.

6.3.2 Eurocode 7-1 General rules

Questionnaires linked to practical examples (also see section 5) were sent to the CEN Members to gather information about the selection of the partial factors and design approaches). The examples were taken from geotechnical design examples prepared for the International Workshop on the Evaluation of EC 7-1 held in Trinity College, Dublin 2005 (ORR, 2005). The evaluation of the questionnaires showed the following distinct results (SCHUPPENER, 2007):

- All three design approaches given as options in EC 7-1 for the verification of ground limit states are used by the Member States.
- Most Member States selected their own values of the partial factors of safety and will only partly use the values recommended in Annex A of EC 7-1.
- However, there are limit states where the results of the design are at first sight not so different in spite of the variability of design approaches and factors of safety used.
- For Member States where seismic conditions apply, most of the model factors need to be defined and quantified for a sound and economical geotechnical design.

Research is needed to investigate the potential for harmonization in geotechnical design. It should be conducted in the following steps for each typical geotechnical structure and/or limit state:

- collection of detailed information on the application of EC 7-1 (i.e. design approach, partial factors and calculation model) in the Member States for the verification of the geotechnical structure and/or limit state;
- comparative calculations and studies on the different applications of the EC 7-1 with respect to the resulting design;
- evaluation of the results with respect to the potential for harmonization;
- recommendations for the adaptation of EC 7-1 and/or Nationally Determined Parameters.

6.3.3 Eurocode 7-2 Ground investigation and testing

There are no Nationally Determined Parameters in EC 7-2. However, this part of Eurocode 7 contains a number of informative annexes in which procedures are described on how the test results

- can be evaluated with respect to the determination of values of geotechnical parameters and coefficients commonly used in design or
- can be used directly for geotechnical design.

Some of these Annexes - especially the ones related to field tests - give guidance on the use of the values in the sample calculation models in the Annexes of EC 7-1. Further research should be directed towards the harmonization of accepted and well-proven procedures given in the annexes as well as towards extending the existing data base. In spite of the large number of known procedures for the evaluation of the results of laboratory and field tests little is known about their acceptance and application in specific design examples in the Member States. Thus, the research above also needs to include the evaluation of the potential for harmonization of the procedures for the evaluation of field and laboratory tests in the Member States with a view to establishing derived values.

For each of the recommended procedures the research should be carried out in the following stages:

- gathering information on the application of the procedure in the Member State;
- comparative studies on the differences in the applications;
- evaluation of the results with respect to the potential for harmonization and
- recommendations for the adaptation and/or adoption as a standard procedure in EC 7-2.

7 CONCLUDING REMARKS

The work on the elaboration of a common framework for geotechnical design throughout Europe, i.e. Eurocode 7, started nearly 25 years ago. Part 1 of EC 7 - General rules - has been completed and the European Member States are now starting to implement it in their national systems of standards. EC 7-1 is an umbrella code as analytical geotechnical models are given in informative annexes instead of the normative core text. Moreover, EC 7-1 contains a number of options which have to be decided upon by the national standards bodies, such as three design approaches for the verification of geotechnical ultimate limit states and the values of the partial factors. On the one hand, this is of course a shortcoming for a code but, on the other hand, it constitutes an openness which makes the adoption and the implementation of the code attractive, not only in Europe but also world-wide, as a gradual evolution of national traditions of design procedures is possible. However, further harmonization will be necessary in future to improve the competitiveness of industry and promote sustainable development. The evaluation of questionnaires on the selection of the design approaches for the verification of geotechnical ultimate limit states and the values of the partial factors in the Member States shows that there is great potential for the harmonization of geotechnical design in Europe which must be investigated by research to support and prepare the next steps in standardization.

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