Eurocode 7 for geotechnical design – a model code for non-EU countries?

L'Eurocode 7 pour le calcul géotechnique – un code modèle pour les pays non Européens?

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ABSTRACT

Eurocode 7 has been described as an 'umbrella' code, which can accommodate various geotechnical practices, and as such is well suited for adoption not only throughout Europe but also in other parts of the world. This paper reviews Eurocode 7's suitability in this regard and is divided into three parts: Part 1 provides an overview of Eurocode 7 Part 1; Part 2 discusses experience implementing the code in Europe; and Part 3 summarizes attitudes towards the code in some non-European countries.

RÉSUMÉ

L'Eurocode 7 a été décrit comme un code « chapeau », qui peut prendre en compte diverses pratiques géotechniques. A ce titre, il est bien adapté non seulement pour être utilisé au travers de l'Europe, mais également dans d'autres parties du monde. Cet article examine cette adaptabilité. Il est divisé en trois parties : la première présente globalement l'Eurocode 7-Partie 1, la deuxième concerne l'expérience de sa mise en œuvre en Europe et la troisième résume les attitudes de certains pays non Européens vis-à-vis de lui.

Keywords : Codes, standards, Eurocode 7, geotechnical design, non-EU countries

1 EUROCODE 7 "GEOTECHNICAL DESIGN"

Eurocode 7 for geotechnical design consists of two documents: *General rules* (Part 1) and *Ground investigation and testing* (Part 2). The first (EN 1997-1) is now completed and implemented as a full European Standard in the thirty member countries of CEN, the European Committee for Standardization. The second (EN 1997-2) has also been published and is in the process of being implemented throughout CEN's member countries.

1.1 *Overview of Eurocode 7 Part 1: General rules*

EN 1997-1 is a general document that gives mainly principles for geotechnical design inside the general framework of Limit State Design (LSD). These principles are relevant to the calculation of geotechnical actions on buildings and civil engineering works and to the design of structural elements in contact with the ground (footings, piles, basement walls, etc.). Detailed design rules or calculation models, i.e. precise formulae and charts, are only given in informative Annexes. The main reason for this is that design models in geotechnical engineering practice differ from one country to another, and it was not possible during drafting of Eurocode 7 to reach consensus, especially when many of these models still need to be calibrated and adapted to the LSD approach.

EN 1997-1 includes general sections on the basis of geotechnical design and geotechnical data as well as sections on fill, dewatering, ground improvement and reinforcement and on supervision of geotechnical construction. They are followed by specific sections dealing with spread and pile foundations, anchorages, retaining structures, hydraulic failure, overall stability, and embankments. Several Annexes are included. Annex A gives values for the partial factors for verification of Ultimate Limit States (ULSs) in persistent and transient design situations ('fundamental combinations'), as well as correlation factors for determining the characteristic values of pile resistance. The numerical values for the partial and correlation factors given in Annex A are 'recommended' values, offered by CEN for national adoption. The actual values of the factors to be used in practice can be changed by each National Standards Body in its National Annex to EN 1997-1. Annexes B to J (which are informative, i.e. not mandatory) contain geotechnical calculation models and can be given a 'normative' status by the National Standards Bodies.

Each country is free to supplement the general rules of Eurocode 7 by 'Non-Contradictory Complementary Information' (NCCI), in order to specify the calculation models and design rules to be applied in its country. The nature of this NCCI will depend on the choices made in regard to the application of the informative Annexes of Eurocode 7 and may be presented in the form of national standards. Whatever their content, these standards have to respect in all aspects the principles of Eurocode 7.

The ULSs to be checked are defined by EN 1997-1 (see Clause 2.4.7.1 in EN 1997-1), so as to be consistent with the head Eurocode, EN 1990 *Basis of design*, as follows:

- 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

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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).

The discussions about verifications of geotechnical design usually focus on approaches performed through calculations. Nevertheless, it should be stressed that calculations are not the only means for checking that the basic requirements are fulfilled. Limit states may also be verified by one or a combination of the use of calculations, adoption of prescriptive measures, experimental models and load tests, and the Observational Method (see Clause 2.1 in EN 1997-1).

Since an objective of the Eurocodes is harmonization of design rules or procedures in construction across different materials and between different countries, a single format will be used in future for the mathematical analysis of ultimate limit states throughout the construction sector in Europe. Accordingly, in the case of ultimate limit states where the strength of the structural material or the ground is significant, for every cross-section of a structure, soil-structure interface, and the soil, it will have to be verified that the design value of the effect of actions, E_d, never exceeds the design resistance, R_d, i.e.:

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

There has to be a clear-cut distinction between effects of actions and resistances in order for Equation (1) to be applied. Such a distinction can be made without much difficulty in other fields of structural engineering. However, because geotechnical engineering is primarily concerned with frictional materials, there are many cases in which this distinction is unclear.

Additional problems concerning application of Equation (1) arise because there are two entirely different ways of introducing partial factors in geotechnical engineering, as follows.

1.2 *Material factor design*

The effect of actions and resistance, E_d and R_d, can be determined by what is known as the 'material factor design method'. This method avoids confusion between effects of actions and resistances by applying partial factors directly to actions and material strengths, represented by characteristic shear parameters, $\tan\varphi'_k$, c'_k and $c_{u,k}$. Thus the design value of the effective coefficient of shearing resistance, $\tan \varphi'_d$, is determined by dividing the characteristic coefficient of shearing resistance, $\tan \varphi'_k$, by the partial factor for shearing resistance, γ_φ. Similarly, the design effective cohesion, c'_d, and design undrained strength $c_{u,d}$ are obtained by dividing the characteristic cohesion, c'_k, or undrained strength $c_{u,k}$ by the partial factors $\gamma_{c'}$ or γ_{cu},.

The design action effect and resistance, E_d and R_d, to be used in Equation (1) are then determined with design values of the parameters, φ'_d, c'_d. and $c_{u,d}$. Partial factors are applied to actions from structures and actions due to the weight of ground and groundwater or, where this would be physically unreasonable, to the effects of these — for example to bending moments in structures.

1.3 *Load and resistance factor design*

In the 'load and resistance factor design (LFRD), partial factors are applied to actions and resistances. There are two procedures for performing verifications (see Frank et. al., 2004). Partial factors γ_F are either applied to the characteristic actions F_k at the start of the calculation and the entire calculation is subsequently performed with design actions and characteristic resistances; or the entire calculation is performed with characteristic values and the partial factors γ_E are not introduced until the end on the characteristic effect of actions E_k when the ultimate limit state condition is checked:

$$E_d = E\,(F_k \cdot \gamma_F) \text{ or } E_d = E_k \cdot \gamma_E \text{ where } \gamma_E = \gamma_F \tag{2}$$

However, in both procedures the design value R_d of the resistance is obtained by applying the partial factor γ_R for geotechnical resistance to the characteristic value R_k, i.e.:

$$R_d = R_k / \gamma_R \tag{3}$$

Equation (3) with the first option of Equation (2) is essentially the 'LRFD' method used in American codes.

The different ways of introducing partial factors into the calculations explained above are the principal reason why Eurocode 7 Part 1 offers three Design Approaches for verifying the GEO and STR ultimate limit states for persistent and transient situations. Each member state can specify in its National Annex which of these three Design Approaches (DAs) to allow (for example, some countries allow DA1 only, while others permit DAs 2 and 3 only). The numerical values of the partial factors to be applied in a given Design Approach are also determined nationally and must be specified in the National Annex to EN 1997–1.

The three Design Approaches of Eurocode 7 Part 1 differ in the way in which they distribute partial factors between geotechnical actions and resistances. They are not presented here, instead reference is made to the extensive literature on this subject, e.g. Frank et al (2004), Vogt and Schuppener (2006), Simpson (2007), or Bond and Harris (2008).

1.4 *Summary*

Eurocode 7 can rightly be called an 'umbrella code' which gives countries the option of accommodating their national geotechnical experience. For example, EN 1997-1 only gives recommended values for the partial factors and proposes three Design Approaches for the verification of ultimate limit states, which have to be decided upon by the national standards bodies. While on the one hand, this does not provide a complete prescription of the design process, it constitutes an openness which makes the adoption and implementation of Eurocode 7 attractive, not only in Europe but also world-wide, as it facilitates the possible gradual evolution and convergence of national and traditional geotechnical design procedures.

2 APPLICABILITY OF EUROCODE 7 PART 1: DESIGN EXAMPLES FROM THE 2005 DUBLIN WORKSHOP

Eurocode 7 is meant to apply to all common geotechnical design situations. This was illustrated by an International Workshop on the Evaluation of Eurocode 7, held in Trinity College Dublin on 31st March and 1st April 2005 (Orr, 2005).

2.1 *Workshop and design examples*

The Workshop was organised by three committees: European Technical Committee 10 (ETC 10) of the ISSMGE, Work Package 2 (WP2) of *Geotechnet*, the European Geotechnical Network for Research and Development; and Technical Committee 23 (TC 23) of the ISSMGE. In order to evaluate the application of Eurocode 7, the ten design examples listed below were distributed, prior to the Workshop, to the members of these committees who were asked to prepare solutions in accordance with Eurocode 7:

1. Spread foundations with a vertical central load
2. Spread foundations with an inclined eccentric load
3. Pile foundation designed from soil parameters
4. Pile foundation designed from load test results
5. Gravity retaining wall
6. Embedded retaining wall
7. Anchored retaining wall
8. Uplift of a deep basement (hydraulic failure)
9. Heave failure of an excavation
10. Embankment on soft ground

2.2 *Findings from the design examples and application of Eurocode 7*

Solutions for these design examples were received from geotechnical engineers from many countries. The range of solutions received, their average values, together with 'model solutions' for each example, are presented in Table 1. The model solutions were prepared by a single person using each of the Design Approaches, 1 to 3.

Based on the extreme values received, the example with the least variation (5%) in results was no. 4, pile foundation designed from load test results. For the spread foundations (nos. 1 and 2), the results varied by 24%; while the greatest variation in results (62%) occurred for the pile foundation designed from soil parameter values (no. 3). Comparing the averages of the solutions received with the averages of the model solutions, it can be seen from Table 1 that the 'average solution received' is very similar to the 'average model solution', with some slightly more conservative and some slightly less conservative.

The solutions to these examples were sent to reporters who were asked to identify the reasons for their differences. The reporters found that the variations were similar to those obtained using national standards and the differences that occurred arose from the use of different calculation models and design assumptions (which are not specified in Eurocode 7), rather than from alternative interpretations of Eurocode 7 or the use of different Design Approaches. Some of the variation occurred because engineers made different assumptions regarding aspects of the examples that were not defined precisely. Others arose because of calculation errors.

As with the introduction of any new code, it will take a little time for geotechnical engineers to develop experience using Eurocode 7, to fully understand it, and become comfortable with using it. This is particularly so since Eurocode 7 is based on limit state concepts and differs significantly from most existing (non limit state) geotechnical codes.

Table 1: Workshop design examples and comparison of solutions received with model solutions

Example	Type	Required Parameter	Range of Solutions Received	% Range	Average of Solutions Received	Average of Model Solutions
1	Spread Foundation, vertical central load	Foundation width, B	1.4 – 2.3m	± 24%	1.8	2.1
2	Spread foundation, inclined eccentric load	Foundation width, B	3.4 – 5.6m 5.2 – 9.5m	± 24% ± 29%	4.3 (ULS) 8.9 (SLS)	4.0 (ULS) 7.0 (SLS)
3	Pile foundation from soil parameter values	Pile length, L	10.0 – 42.8 m	± 62%	19.2	15.4
4	Pile foundation from load test results	Number of piles, N	9 - 10	± 5%	9	9.5
5	Gravity retaining wall	Wall width, B	3.1 – 5.2 m	± 37%	4.5	4.6
6	Embedded retaining wall	Wall embedment D	3.9 – 6.9 m	± 28%	5.8	4.4
7	Anchored retaining wall	Wall embedment D	2.3 – 7.0 m	± 51%	4.5	4.0
8	Uplift of basement below groundwater	Base slab thickness, T	0.42 – 0.85 m	± 33%	0.7	0.6
9	Heave of excavation due to seepage	Hydraulic head, H	3.3 – 8.8m	± 45%	5.6	6.8
10	Embankment on soft ground	Embankment height, H	1.6 – 3.4 m	± 36%	2.5	2.3

3 COMMENTS OF NON-EUROPEAN COUNTRIES

Many countries across the world have been watching the development of the Eurocodes with great interest. This applies particularly to countries that have strong cultural or trade links with Europe. The response of some such countries to the Eurocodes is outlined below.

3.1 *South Africa*

South Africa does not have a geotechnical design code. Most geotechnical design is done using working stress design methods in accordance with foreign standards, text books or authoritative technical papers.

Since the mid-1990s, South Africa has expressed an interest in the Eurocodes. However, the action combination schemes contained in the South African 'loading' code were incompatible with those in the earlier drafts of the Eurocodes. In 1998, a decision was taken to revise the loading code, making allowance for geotechnical actions and improving compatibility with international codes such as EN 1990 and ISO 2394. Two developments in the Eurocodes in the early 2000s facilitated this revision. The first was the introduction of Equations 6.10a and 6.10b as alternatives to Equation 6.10 in EN 1990, a formulation very similar to that in the earlier South African code. The second was the acceptance of the principle that safety (or reliability) is the responsibility of the individual member states and the resulting acceptance of nationally determined parameters for use with the Eurocodes. The revision of the code has now been completed. It is fully compatible with the Eurocodes and makes specific provision for geotechnical design (Day & Retief, 2008).

For South Africans, the purpose of the Eurocodes in Europe, namely regulation of international trade and harmonisation of practice between member states, differs from the purpose of local design standards which are intended to be practical design guides written by engineers for engineers. The need for the Eurocodes to accommodate diverse practices and environments (both physical and regulatory) across Europe is seen to have resulted in a complex set of documents. Despite this, many of the materials disciplines (concrete, steel, etc) are considering either adopting or adapting the Eurocodes for local use.

The geotechnical fraternity favours drafting a local standard for geotechnical design based on EN 1997-1. However, as they lack the experience with limit state design, it has been decided to implement EN 1997-1 together with the provisions of the revised loading code in parallel with existing design methods for a period of five years where after a final decision will be made on drafting a South African geotechnical design standard.

3.2 *Singapore*

Singapore generally uses British Standards. Although some of these advocate partial factor LSD, most engineers are more comfortable with WSD. There are reservations about the proliferation of methods and partial factors permitted in the Eurocodes and a concern that this could lead to errors being made by those not acquainted with the intricacies of the various design approaches.

Indications are that the Building and Construction Authority will follow the UK's lead and adopt the BS-EN standards but with some time delay. Any Singaporean National Annexes will be based on UK National Annexes, adapted for local conditions.

Seminars and workshops have been held for members of professional bodies and universities. Training courses on Eurocode 7 have been well-attended over the past three years.

3.3 *Hong Kong*

Civil and structural design practice in Hong Kong is strictly regulated by the Hong Kong Government's Buildings Department (BD) for foundations, slopes, and retaining walls and the Geotechnical Engineering Office (GEO) for private projects. Most design is currently based on British Standards, although GEO has its own design guides, some of which use global safety factors and others partial factors/LSD.

Many HK engineers regard the Eurocodes as too complicated and unnecessary, although some globally-based companies welcome Eurocode 7.

The Government has recently appointed consultants to advise it on the possibility of adopting the Eurocodes as a replacement for existing British Standards. Trial designs of four existing structures were conducted. As part of this work, a series of training and review workshops, looking at the consequences of adopting the Eurocodes, were held in 2008. Amongst several options considered, two were prominent: 1) to prepare Hong Kong National Annexes for each of the 58 parts of the 10 Eurocodes; or 2) to adopt UK National Annexes but supplemented with Hong Kong guidance documents, such as updated Departmental Standards.

Adoption of the Eurocodes has been recommended and further studies, covering wind, traffic, and seismic actions, properties of concrete, and limit state foundation design, are proposed. No official decision has yet been made to adopt the Eurocodes.

3.4 *Japan*

Limit state design (LSD) methods started making an appearance in Japan in the late 1980's. However, the development of performance based design (PBD) standards has enjoyed more prominence partly as a result of the WTO/TBT Agreement. The development of PBD standards has also been spurred on by public accountability particularly in infrastructure design.

In the framework under which Japanese design codes are being developed, only the performance requirements are mandatory and the designer can choose from a number of design verification methods including reliability based design, LSD, or load and resistance factor design.

The Japanese Geotechnical Society's (JGS's) Geo-code 21, which was completed in 2004, borrows and adapts some of the concepts contained in EN 1997-1 including the Geotechnical Categories, determination of characteristic values, and use of check lists. The characteristic value is based more on the mean value than that advocated in EN 1997-1 and the recommended method of design verification is LRFD. This allows designers to keep track of the most likely performance of the structure until the end of the analysis phase of the design, when the resistance factors are applied.

As there was no code setting out the bases of PBD, Chapter 0 of Geo-code 21 was written to perform the same function as EN 1990 *Basis of design* fulfils in the Eurocodes. This has triggered a move by the Japanese Society of Civil Engineers to draft an equivalent code covering all types of structures.

The JGS has a vision of establishing a PBD umbrella code that can coexist with the Structural Eurocodes, future Asian regional codes and some North American codes.

3.5 *Brazil*

Although Brazilian structural engineers have been using LRFD for some time, most geotechnical engineering codes still use global factor of safety methods. The foundation code is has been under revision for some years but has been delayed by debates on how to provide for "safety" in the revised code.

The feeling is that the Eurocodes are state-of-the-art but are too complicated for everyday use, particularly in their interrelationship and structure. There is strong motivation for evolving Brazilian codes that are similar in concept to the Eurocodes.

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