Further Developments of Eurocodes

And Geotechnical Issues

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10 Eurocodes – 58 Parts – 5320 pages

EN 1990
109 pages

EN 1991
783 pages

EN 1992
469 pages

EN 1993
1470 pages

EN 1994
334 pages

EN 1995
269 pages

EN 1996
276 pages

EN 1997
371 pages

EN 1998
686 pages

EN 1999
553 pages

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Development of the present generation of Eurocodes
EN 1990 Basis of Structural design

EC1 - Actions
EC2 - Concrete
EC3 - Steel
EC4 - Composite
EC5 - Timber
EC6 - Masonry
EC7 - Geotechnical design
EC8 - Earthquakes
EC9 - Aluminium
EN 1990

EN 1991

EN 1992 EN 1993 EN 1994
EN 1995 EN 1996 EN 1999

EN 1997

EN 1998

Structural safety, serviceability and durability, combinations of actions

Actions on structures

Design and detailing

Geotechnical and Seismic design
IMPLEMENTATION OF THE EN EUROCODES

EN 199n-p

Main text

Normative Annexes

Informative Annexes

Choices Nationally Determined Parameters (NDPs)

Decisions

Transformation into a National Standard (« NS » EN 199n-p)

National Annex (National Standard)

Project specification

EUROPE

MEMBER STATE

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**Next Steps**

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<th>PROMOTION / EDUCATION</th>
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**FURTHER DEVELOPMENT**

- **Evolution of the Eurocodes:**
  Preparation of the new generation of Eurocodes

- **Development of scientific and technical reports for:**
  - for new Eurocode Parts,
  - for new Eurocodes ENs
New Materials and/or Techniques

- **Existing Structures**
- **Structural Glass**
- **FRP**
- **Membrane Structures**
- **Robustness**
2008
Technical guidance
Starting publication

CEN Technical Reports
CEN/TC250
Acceptance

New Eurocode Parts
New Eurocode ENs

CEN Technical Specifications

Further development

Input from scientific and technical associations

2015
FROM THE CPD TO THE FUTURE CONSTRUCTION
PRODUCTS REGULATION

ANNEX I

Basic works requirements

Construction works as a whole and in their separate parts must be fit for their intended use.

Subject to normal maintenance, basic works requirements must be satisfied for an economically reasonable working life.
Basic works requirements

1. Mechanical resistance and stability
2. Safety in case of fire
3. Hygiene, health and the environment
4. Safety in use
5. Protection against noise
6. Energy economy and heat retention
7. Sustainable use of natural resources
7. Sustainable use of natural resources

The construction works must be designed, built and demolished in such a way that the use of natural resources is sustainable and ensure the following:

(a) recyclability of the construction works, their materials and parts after demolition;

(b) durability of the construction works;

(c) use of environmentally compatible raw and secondary materials in the construction works.
No fundamental changes in the existing Eurocodes

- Revision/evolution of the Eurocodes
- Preparation of Technical reports/specifications
  - Assessment of existing structures
  - Glass
  - FRP
  - Tensile surface structures
The limit state concept

Structural value

Irreversible limit states

Maintenance

Serviceability limit-state

Required level at the end of the intended working life

Safety margin

Ultimate limit-state

Time
General Principles of Structural Reliability in the Eurocodes
Overview of reliability methods
The semi-probabilitic format for the verification of construction works

The semi-probabilistic approach is based on rules, partially deterministic, that introduce safety at the following levels:

- Selection of appropriate representative values of the various random parameters (actions and resistances)
- Application of partial factors to these parameters
- Introduction of safety margins, more or less apparent, in the various models (models of actions, action effects and resistances).
THE BASIC MODEL WITH TWO VARIABLES

E  Effect of actions (for example, bending moment)
R  Resistance
Z = R-E  Safety margin
Z ≤ 0  Condition of failure
r – e = 0  Limit-state function

\[ p_f = P(Z \leq 0) \]  Probability of failure

\[ f_{E,R}(e,r) \]  Joint probability density of E and R

Probability of failure  
\[ p_f = \iint_{D_f} f_{E,R}(e,r)d\epsilon dr \]
Calculation of the probability of failure
Reliability approach

Assumptions:

*R*, *E* follow Normal laws characterised by *(µ_R, σ_R)* and *(µ_E, σ_E)*

⇒ *Z* = *R* − *E* follows a Normal law of characteristics:

\[ \mu_Z = \mu_R - \mu_E \quad ; \quad \sigma_Z = \sqrt{\sigma_E^2 + \sigma_R^2} \]

\[ F(z) = \Phi \left( \frac{z - \mu_z}{\sigma_z} \right) \]

\[ \Phi(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x} e^{-\frac{t^2}{2}} dt \]

Standard Normal law
A first approach of safety

Central safety factor

\[ \gamma = \frac{\mu_R}{\mu_E} \]
Coefficients of variation

\[ V_R = \frac{\sigma_R}{\mu_R} \quad V_E = \frac{\sigma_E}{\mu_E} \]

\[ E_k = \mu_E + k_E \sigma_E \]

\[ R_k = \mu_R - k_R \sigma_R \]

« Characteristic safety factor »

\[ \gamma_k = \frac{R_k}{E_k} = \frac{\mu_R - k_R \sigma_R}{\mu_E + k_E \sigma_E} = \gamma \times \frac{1 - k_R V_R}{1 + k_E V_E} \]
\[ p_f = \Phi(-\beta) \]

\[ \beta = \frac{\mu_R - \mu_E}{\sqrt{\sigma_R^2 + \sigma_E^2}} \]
Central safety factor

$$\gamma = \frac{\mu_R}{\mu_E}$$

Coefficients of variation

$$V_R = \frac{\sigma_R}{\mu_R} \quad V_E = \frac{\sigma_E}{\mu_E}$$

Reliability index

$$\beta = \frac{\mu_R - \mu_E}{\sqrt{\sigma_R^2 + \sigma_E^2}} = \frac{\gamma - 1}{\sqrt{V_E^2 + \gamma^2 V_R^2}} \Rightarrow \gamma = f(\beta)$$

Characteristic safety factor

$$\gamma_k = \frac{R_k}{E_k} = \frac{\mu_R - k_R \sigma_R}{\mu_E + k_E \sigma_E} = \gamma \times \frac{1 - k_R V_R}{1 + k_E V_E}$$

Partial factor design

$$\gamma_F E_k \leq \frac{R_k}{\gamma_M} \Rightarrow \gamma_F \times \gamma_M \leq \gamma_k$$

$$\beta \rightarrow \gamma \rightarrow \gamma_k \rightarrow (\gamma_F, \gamma_M) / \gamma_F \times \gamma_M \leq \gamma_k$$

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Boundary between safety and failure domains

\[
E_{k} \frac{E}{\sigma_{E}} = \frac{E_{m} + k_{E} \sigma_{E}}{\sigma_{E}}
\]

\[
E_{d} \frac{E}{\sigma_{E}}
\]

\[
D_f
\]

\[
D_s
\]

\[
E_{m} \frac{E}{\sigma_{E}}
\]

\[
C_d
\]

\[
\beta
\]

\[
\gamma_{F}
\]

\[
\beta
\]

\[
C_k
\]

\[
R_{d} = \frac{R_{k}}{\gamma_{M}}
\]

\[
E_{d} = \gamma_{F} E_{k}
\]

\[
\gamma_{F} E_{k} \leq \frac{R_{k}}{\gamma_{M}}
\]

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A tentative application

Sliding limit state:

\[ H \leq \frac{V \tan \phi}{\gamma} \]

Where:

\( H \) = horizontal component of resultant forces
\( V \) = vertical component of resultant forces
\( \phi \) = internal friction angle
\( \gamma \) = safety factor

Safety margin:

\[ Z = V \tan \phi - H \]

\( V, H \) and \( \tan \phi \) are assumed independant and following a Normal law.
\[ \mu_Z = \mu_V \times \mu_{\tan\phi} - \mu_H \]
\[ \sigma_Z^2 = \sigma_{V_{\tan\phi}}^2 + \sigma_H^2 = \sigma_V^2 \sigma_{\tan\phi}^2 + \mu_{\tan\phi}^2 \sigma_V^2 + \mu_V^2 \sigma_{\tan\phi}^2 + \sigma_H^2 \]

Where \( V_V \) and \( V_{\tan\phi} \) are the coefficients of variation of \( V \) and \( \tan\phi \). Adopting the notation:

\[ \mu_H = \lambda \mu_V \times \mu_{\tan\phi} \]

The reliability index is:

\[ \beta = \frac{\mu_Z}{\sigma_Z} = \frac{\mu_V \times \mu_{\tan\phi} - \mu_H}{\sqrt{\sigma_V^2 \sigma_{\tan\phi}^2 + \mu_{\tan\phi}^2 \sigma_V^2 + \mu_V^2 \sigma_{\tan\phi}^2 + \sigma_H^2}} = \frac{1 - \lambda}{\sqrt{V_V^2 + V_{\tan\phi}^2 + V_V^2 V_{\tan\phi}^2 + \lambda^2 V_H^2}} \]
With:

\[ V_V = 0,1 \quad V_{\tan \varphi} = 0,15 \quad V_H = 0,20 \]

\[ \beta \equiv \frac{1 - \lambda}{0,1 \sqrt{3,25 + 4 \lambda^2}} = \frac{\gamma - 1}{0,1 \sqrt{3,25 \gamma^2 + 4}} \]

With \( \gamma = \frac{1}{\lambda} \)

Assuming:

\( H_d = 1,35 \mu_H \quad \gamma = 1,2 (ULS) \quad \gamma H_d = 1,62 \mu_H \)

\( \Rightarrow \beta \approx 1,8 \quad \Rightarrow p_f \approx 0,06 \)
A few basic conclusions:

1) Probability of failure in geotechnical design, with safety factors usually adopted, turns out to be higher than for structures, which contradicts experience.

2) The basic random variables in geotechnical design are of a very different nature than the basic random variables in structural design.

3) In a structural member, the effect of actions is far more scattered than the resistance. In a bridge foundation, for example, the effect of actions, mainly due to permanent loads, is far less scattered than the bearing capacity of ground. The two types of problems are very different.

4) A probabilistic approach of geotechnical problems is not useless. It is necessary to compare the reliability levels in geotechnical design and in structural design, and to give the right interpretation of observed differences.
Personal conclusions: three dreams

1) The future Eurocode 7 should be enough developed to avoid the need to draft national accompanying standards.

2) A background document would be very useful to explain why the reliability levels obtained by using the usual safety factors are in general acceptable.

3) Try to harmonize the reliability levels corresponding to the 3 geotechnical approaches defined in EN 1990.
The Eurocodes: finally a nice meal, even the restaurant is not always comfortable

Thank you for your attention