EUROCODES
Background and Applications

“Dissemination of information for training” workshop

18-20 February 2008

Brussels

EN 1990
Eurocode: Basis of structural design

Organised by
European Commission: DG Enterprise and Industry, Joint Research Centre

with the support of
CEN/TC250, CEN Management Centre and Member States
EN 1990 - Eurocode: Basis of structural design
*Alcide de Gasperi room*

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
<th>Speaker and Affiliation</th>
</tr>
</thead>
<tbody>
<tr>
<td>13:40-13:50</td>
<td>Introduction by chairman</td>
<td>H. Bossenmayer <em>CEN/TC250</em></td>
</tr>
<tr>
<td>13:50-14:00</td>
<td>Introduction to EN 1990</td>
<td>H. Gulvanessian <em>CEN/TC250</em></td>
</tr>
<tr>
<td>14:00-14:30</td>
<td>EN 1990: Sections 1 and 2</td>
<td>H. Gulvanessian <em>CEN/TC250</em></td>
</tr>
<tr>
<td>14:30-15:10</td>
<td>EN 1990: Sections 3 and 4</td>
<td>P. Spehl <em>SECO</em></td>
</tr>
<tr>
<td>15:10-15:40</td>
<td>Coffee</td>
<td></td>
</tr>
<tr>
<td>15:40-16:40</td>
<td>Section 6 and Annex A(1) and Annex A(2)</td>
<td>J.-A. Calgaro <em>CEN/TC250 Chairman</em></td>
</tr>
<tr>
<td>16:40-17:15</td>
<td>Annexes B and C</td>
<td>A. Vrouwenvelder <em>TNO</em></td>
</tr>
<tr>
<td>17:15-17:50</td>
<td>Section 5 and Annex D</td>
<td>G. Sedlacek <em>RWTH Aachen</em></td>
</tr>
<tr>
<td>17:50-18:00</td>
<td>Discussion and close</td>
<td></td>
</tr>
</tbody>
</table>

All workshop material will be available at [http://eurocodes.jrc.ec.europa.eu](http://eurocodes.jrc.ec.europa.eu)
INTRODUCTION TO EN 1990

H. Gulvanessian
CEN/TC250
EN 1990: Eurocode: Basis of Structural Design
The Head Eurocode
An Innovative Structural Safety Code Of Practice

Professor Haig Gulvanessian CBE
Civil Engineering and Eurocodes Consultant
Visiting Professor, Imperial College, London

Objectives of EN 1990: Basis of Structural Design
EN 1990 establishes principles and requirements for the
* Safety
* Serviceability
* Durability
of structures; and describes
* The basis for their design and verification, and
* Gives guidelines for related aspects of structural reliability

EN 1990 is the Head Eurocode
For the design of buildings and civil engineering
works every Eurocode part from,
EN 1991: Eurocode 1: Actions on Structures, and
The design Eurocodes EN 1992 to EN 1999
has to be used together with EN 1990

EN 1990 provides the material independent and safety related information required for the design of buildings, and civil engineering works for the Eurocodes suite.

Intended Users of EN 1990
EN 1990 is intended for use by
* Committees drafting Standards for Structural Design and related products, testing and execution Standards
* Clients (e.g. for the formulation of the specific requirements on reliability levels and durability)
* Designers and Constructors
* Relevant Competent Authorities
EN 1990: Contents

- Foreword
- Section 1: General
- Section 2: Requirements
- Section 3: Principles of limit states
- Section 4: Basic variables
- Section 5: Structural analysis and design assisted by testing
- Section 6: Verification by the partial factor method
- Annex A(n): Application for buildings (1): bridges (2)
- Annex B: Management of structural reliability for construction works
- Annex C: Basis for partial factor design and reliability analysis
- Annex D: Design assisted by testing

Thank you for your attention.
EN 1990: SECTIONS 1 AND 2

H. Gulvanessian
CEN/TC250
EN 1990: Eurocode: Basis of Structural Design
The Key Head Eurocode
An Innovative Structural Safety Code Of Practice
EN 1990 – Sections 1 and 2

Professor Haig Gulvanessian CBE
Civil Engineering and Eurocodes Consultant
Visiting Professor, Imperial College, London

SECTION 1 - GENERAL
1.1 Scope
1.2 Normative References
1.3 Assumptions
1.4 Distinction between Principles and Application rules
1.5 Definitions
1.6 Symbols

1.1 Scope
(1) EN 1990 establishes Principles and requirements for the safety, serviceability and durability of structures, describes the basis for their design and verification and gives guidelines for related aspects of structural reliability.
(2) EN 1990 is intended to be used in conjunction with EN 1991 to EN 1999 for the structural design of buildings and civil engineering works, including geotechnical aspects, structural fire design, situations involving earthquakes, execution and temporary structures.
NOTE For the design of special construction works (e.g. nuclear installations, dams, etc.), other provisions than those in EN 1990 to EN 1999 might be necessary.
(3) EN 1990 is applicable for the design of structures where other materials or other actions outside the scope of EN 1991 to EN 1999 are involved.
(4) EN 1990 is applicable for the structural appraisal of existing construction, in developing the design of repairs and alterations or in assessing changes of use.
NOTE Additional or amended provisions might be necessary where appropriate.
1.4 Distinction between Principles and Application Rules

- The Principles (letter P) comprise:
  - general statements and definitions for which there is no alternative, as well as
  - requirements and analytical models for which no alternative is permitted unless specifically stated.
- It is permissible to use alternative design rules different from the application rules given in EN 1990, provided that it is shown that the alternative rules accord with the relevant principles and are at least equivalent with regard to resistance, serviceability and durability which would be achieved for the structure using Eurocodes.

Note: If an alternative design rule is substituted for an application rule, the resulting design cannot be claimed to be wholly in accordance with EN 1990 although the design will remain in accordance with the Principles of EN 1990.

1.5 Definitions

For the structural Eurocode suite, attention is drawn to the following key definitions, which may be different from current national practices:

- “Action” means a load, or an imposed deformation (e.g. temperature effects or settlement).
- “Effects of Actions” or “Action effects” are internal moments and forces, bending moments, shear forces and deformations caused by actions.
- “Strength” is a mechanical property of a material, in units of stress.
- “Resistance” is a mechanical property of a cross-section of a member, or a member or structure.
- “Execution” covers all activities carried out for the physical completion of the work including procurement, the inspection and documentation thereof. The term covers work on site; it may also signify the fabrication of components off site and their subsequent erection on site.

1.6 Symbols

Some Important Terms

Actions (F)

- Permanent Actions (G)
- Variable Actions (Q)
- Accidental Actions (A)
- Seismic Action (A_s)

Values of Actions

Representative Values of Actions

- Characteristic Value (Q_k)
- Combinations Value of a Variable Action (ψ_k Q_k)
- Frequent Value of a Variable Action (ψ_1 Q_k)
- Quasi-permanent Value of a Variable Action (ψ_2 Q_k)

The fundamental requirements in EN 1990 for the reliability of construction works include:

Structural safety: 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 economic way sustain all actions likely to occur during execution and use. Safety of people, the structure and contents.

Serviceability: 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 economic way remain fit for the use for which it is required. Functioning, comfort and appearance of the structure.

The fundamental requirements:

Robustness

A structure shall be designed and executed in such a way that it will not be damaged by events such as:

- Explosions
- Impact and
- Consequences of human errors

Note: The events to be taken into account are those agreed for an individual project with the client and the relevant authority.
EN 1990 : EUROCODE: BASIS OF STRUCTURAL DESIGN

Robustness - Limits of admissible damage

(A) is:
- 15% of the floor area or
- 100 m² whichever is the smaller, in each of two adjacent storeys

a) is the plan
b) is the elevation

(B) : Notional columns to be removed

Robustness of Buildings and Civil Engineering Works

Limiting potential damage from identified hazards

EN 1990 gives principles for limiting potential damage by a number of means including:

- avoiding, eliminating or reducing the hazards to which the structure can be subjected;
- selecting a structural form which has low sensitivity to the hazards considered;
- selecting a structural form and design that can survive adequately the accidental removal of an individual member or a limited part of the structure, or the occurrence of acceptable localised damage;
- avoiding as far as possible structural systems that can collapse without warning;
- tying the structural members together.

Robustness: Acceptable extent of collapse in the event of a local failure in a large span building

THE REQUIREMENTS

Fundamental requirements (safety; serviceability; robustness and fire)

Reliability differentiation
Design working life
Durability
Quality Assurance
Reliability differentiation

An appropriate degree of reliability for the majority of structures is obtained by design and execution according to Eurocodes 1 to 9, with appropriate quality assurance measures.

EN 1990 provides guidance for obtaining different levels of reliability.

Background and Applications

Public perception does not accept fatalities and injuries due to structural failure (at home, at the work place, during recreational and other activities etc), for the design working life of a structure compared to fatalities arising from other hazards and events.

The choice of the levels of reliability for a particular structure should take account of the relevant factors, including:

- the possible cause and/or mode of attaining a limit state;
- the possible consequences of failure in terms of risk to life, injury, potential economical losses;
- public perception to failure;
- the expense and procedures necessary to reduce the risk of failure.

<table>
<thead>
<tr>
<th>Consequences Class</th>
<th>Description</th>
<th>Example of buildings and civil engineering works</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC3</td>
<td>High consequence for loss of human life, or economic, social or environmental consequences very great</td>
<td>Aircrafts, bridges, public buildings where consequences of failure are high (e.g. a concert hall)</td>
</tr>
<tr>
<td>CC2</td>
<td>Medium consequence for loss of human life, economic, social or environmental consequences considerable</td>
<td>Residential and office buildings, public buildings where consequences of failure are medium (e.g. an office building)</td>
</tr>
<tr>
<td>CC1</td>
<td>Low consequence for loss of human life and economic, social or environmental consequences small or negligible</td>
<td>Agricultural buildings where people do not normally enter (e.g. for storage), greenhouses</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Risk</th>
<th>Hazard</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building hazards</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accidental</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Theft</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fire</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Earthquake (UK)</td>
<td>0.05</td>
<td>Earthquake (US)</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Earthquake (Japan)</td>
<td>0.05</td>
<td>Earthquake (Japan)</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exploitation</td>
<td>0.05</td>
<td>Earthquake (Japan)</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other incidents</td>
<td>0.05</td>
<td>Earthquake (Japan)</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Public vs. Private</td>
<td>0.05</td>
<td>Earthquake (Japan)</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Casual accidents (UK)</td>
<td>0.05</td>
<td>Casual accidents (UK)</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poisons</td>
<td>0.05</td>
<td>Casual accidents (UK)</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fire &amp; Health Hazards</td>
<td>0.05</td>
<td>Casual accidents (UK)</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disease</td>
<td>0.05</td>
<td>Casual accidents (UK)</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Personal accidents (UK)</td>
<td>0.05</td>
<td>Casual accidents (UK)</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All causes (UK, 1973)</td>
<td>0.05</td>
<td>Casual accidents (UK)</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All causes (US, 1971)</td>
<td>0.05</td>
<td>Casual accidents (UK)</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Man aged 60</td>
<td>0.05</td>
<td>Casual accidents (UK)</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Man aged 30</td>
<td>0.05</td>
<td>Casual accidents (UK)</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole population</td>
<td>0.05</td>
<td>Casual accidents (UK)</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Risk expressed as a probability of death for typical exposed person per calendar year.
EN 1990: Annex B: Tools for the management of structural reliability

Depending upon the consequences of failure, the main tools selected in EN1990 Annex B for the management of structural reliability of construction works are:

• differentiation by \( \beta \) (reliability index) values; at this stage, this is a specialist activity;
• modification of partial factors;
• design supervision differentiation;
• inspection during execution.

THE REQUIREMENTS

Fundamental requirements (safety; serviceability; robustness and fire)
Reliability differentiation
Design working life
Durability
Quality Assurance

The requirements for design working life states:

The design working life is the assumed period for which a structure is to be used for its intended purpose with anticipated maintenance but without major repair being necessary:

• a design working life of
  • 50 years for buildings
  • 100 years for bridges

is recommended in EN 1990.

Notion of design working life useful for

• The selection of design actions
• (e.g. wind, earthquake)
• Consideration of material property deterioration
• (e.g. fatigue, creep)
• Life cycle costing
• Evolve maintenance strategies
Durability

It is an assumption in design that the durability of a structure or part of it in its environment is such that it remains fit for use during the design working life given appropriate maintenance.

The structure should be designed in such a way that deterioration should not impair the durability and performance of the structure having due regard to the anticipated level of maintenance.

Interrelated factors to be considered:
• The intended and future use of the structure
• The required performance criteria
• The expected environmental influences
• The composition, properties and performance of materials
• The choice of structural system

In order to provide a structure that corresponds to the requirements and to the assumptions made in the design, appropriate quality management measures should be in place. These measures comprise:
• definition of the reliability requirements,
• organisational measures, and
• controls at the stages of design, execution, use and maintenance.

EN ISO 9001:2000 is an acceptable basis for quality management measures, where relevant.

THE REQUIREMENTS

Fundamental requirements (safety; serviceability; robustness and fire)
Reliability differentiation
Design working life
Durability
Quality Assurance

References:
1) ISO 2394: General principles on reliability for structures
Thank you for your attention
EN 1990: SECTIONS 3 AND 4

P. Spehl
SECO
**Eurocode - Basis of structural design**

**EN 1990 : Sections 3 & 4**

---

**EN 1990 : Section 3**

Principles of limit states design

---

**Requirements**

- **SAFETY**
  - of people /of structure
  - resistance
  - stability

- **SERVICEABILITY**
  - functions
  - comfort
  - appearance

- **DURABILITY**
  - fatigue

---

**Verification**

**DESIGN SITUATIONS**
- persistent, transient, accidental, seismic

**AGENTS**
- gravity, wind, solar radiation, earthquake…

**ACTIONS**
- load, pressure, temperature, ground acceleration…

**COMBINATIONS OF ACTIONS**
- actions likely to occur simultaneously

**EFFECTS**
- force, moment, rotation, displacement

---

**ULTIMATE LIMIT STATES**

- rupture
- collapse
- loss of equilibrium
- transformation into a mechanism
- failure caused by fatigue

---

**SERVICEABILITY LIMIT STATES**

- deformations
- vibrations
- cracks
- damages adversely affecting use
Design procedure

**REQUIREMENTS**

- SAFETY
- SERVICEABILITY
- DURABILITY

**DESIGN SITUATIONS**

- AGENTS
- ACTIONS
- COMBINATIONS OF ACTIONS
- EFFECTS

**ULTIMATE LIMIT STATES** | **SERVICEABILITY LIMIT STATES**

---

Limit state design

Structural and load models (physical or mathematical) using design values for:

- **actions**
- **material or product properties**
- **geometrical data**

Load cases should be selected, identifying:

- **load arrangements,**
- **possible deviations**
  - from assumed directions and positions of actions,
  - sets of deformations and imperfections,
  that should be considered simultaneously

---

Verifications at limit states

**ULTIMATE**

- **Resistance:** effects of actions $E_a \leq R_a$ resistance
- **Static equilibrium:**
  - destabilising actions $E_{d,\text{dst}} \leq E_{d,\text{st}}$ stabilising actions

**SERVICEABILITY**

- **Criterion C:**
  - design effect $E_d \leq C_d$ design criterion

---

EN 1990 - Probabilistic methods

<table>
<thead>
<tr>
<th>CONSEQUENCES OF FAILURE</th>
<th>STRUCTURAL RELIABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Description</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>class</td>
<td>for loss of human life</td>
</tr>
<tr>
<td>class</td>
<td>economic, social</td>
</tr>
<tr>
<td>class</td>
<td>or environmental</td>
</tr>
<tr>
<td>class</td>
<td>consequences</td>
</tr>
<tr>
<td>class</td>
<td>failure probability</td>
</tr>
<tr>
<td>C03</td>
<td>high</td>
</tr>
<tr>
<td>C02</td>
<td>medium</td>
</tr>
<tr>
<td>CC1</td>
<td>low</td>
</tr>
</tbody>
</table>

(1 year reference period)

---

EN 1990 : Section 4

Basic variables
Actions and environment influences

CLASSIFICATIONS:
- **permanent** \( G \): self-weight, shrinkage, settlements, prestressing \( P \) (imposed force/deformation),…
- **variable** \( Q \): imposed loads, wind, snow, temperature,…
- **accidental** \( A \): impacts, explosions, seismic actions…

NOTE: water may be permanent or variable
snow, wind, seismic actions may be variable or accidental

- by **origin**: direct or indirect
- by **spatial variation**: fixed or free
- by **nature or structural response**: static or dynamic

Representative values of actions

**Characteristic value** (main representative value):
- mean value if variability small: \( G_k, P_m \)
- upper or lower value if variability not small:
  - \( G_{k,\text{inf}} \) (5 % fractile), \( P_{k,\text{inf}} \)
  - \( G_{k,\text{sup}} \) (95 % fractile, i.e. probability of exceedence 5 %), \( P_{k,\text{sup}} \)
  - \( Q_k \) (climatic actions: probability of exceedence 2 %/year)
  - \( A_k \) (seismic actions)
- **nominal value**
- value specified for an individual project: \( A_d \)

Other representative values of actions

**Combination values**, \( \Psi_0 Q_k \):
- for ultimate limit states of permanent and transient design situation
- for irreversible serviceability limit states

**Frequent values**, \( \Psi_1 Q_k \) (e.g. during 1 % of the reference period):
- for ultimate limit states of involving accidental actions
- for reversible serviceability limit states

**Quasi-permanent values**, \( \Psi_2 Q_k \) (e.g. during 50 % of the period):
- for ultimate limit states involving accidental actions
- for reversible serviceability limit states

Material and product properties

Representative values from standardised tests:
- when a limit state verification is sensitive to variability:
  - **lower characteristic value** (5 % fractile) where a low value is unfavourable
  - **upper characteristic value** (95 % fractile, i.e. probability of exceedence 5 %) where a high value is unfavourable
- where statistical data are insufficient: **nominal values**
- **mean values** for structural stiffness and thermal expansion

Effects of repeated actions (fatigue) = reduction of resistance

Geometrical data

Representative values:
- **characteristic values** (a prescribed fractile) where statistical distribution is sufficiently known
- directly **design values** (e.g. imperfections)

Tolerances for connected parts shall be mutually compatible

Code of Hammurabi (1760 BC)

- “If a builder build a house for some one, and does not construct it properly, and the house which he built fall in and kill its owner, then that builder shall be put to death.” (Art. 229)
- “If it ruin goods, he shall make compensation for all that has been ruined, and inasmuch as he did not construct properly this house which he built and it fell, he shall re-erect the house from his own means.” (Art. 232)
Civil Code of Napoleon (1804)

“If the edifice, built at a set price, perish in whole or in part by defect in its construction, even by defect in the foundation, the architect and the contractor are responsible therefor for ten years.” (Art. 1792)

Applicability of standards (calculation methods, e.g. Eurocodes)

<table>
<thead>
<tr>
<th>Source</th>
<th>CIVIL CODE</th>
<th>LAW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical requirements</td>
<td>JURISPRUDENCE of the COURTS</td>
<td>REGULATIONS</td>
</tr>
<tr>
<td>Application</td>
<td>a posteriori</td>
<td>a priori</td>
</tr>
<tr>
<td>Standards (e.g. Eurocodes)</td>
<td>Referenced good practice but not compulsory</td>
<td>Compulsory only if imposed by regulation</td>
</tr>
</tbody>
</table>

Construction products directive

Eurocodes: “a harmonised tool”

“Beyond the defense of national positions,” like Jean MONNET wrote in his Memoirs, “something new and strong comes into living within the team: it’s the European spirit which is the fruit of the work together and, above all, of the need to come to a common conclusion after the discussion.”

“the European spirit”

Merci de votre attention
SECTION 6, ANNEX A(1) AND ANNEX A(2)

J.-A. Calgaro
CEN/TC250 Chairman
The selected design situation shall be sufficiently severe and so varied as to encompass all conditions which can reasonably be foreseen to occur during the execution and use of the structure (3.2(3)P).

### Representative values of actions

<table>
<thead>
<tr>
<th>Action Type</th>
<th>Permanent actions</th>
<th>Variable actions</th>
<th>Accidental actions</th>
<th>Seismic actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristic</td>
<td>$Q_k$</td>
<td>$Q_L$</td>
<td>$Q_{pk}$</td>
<td>$Q_{ps}$</td>
</tr>
<tr>
<td>Nominal value</td>
<td>$A_1$</td>
<td>$A_2$</td>
<td>$A_{ps}$</td>
<td></td>
</tr>
<tr>
<td>Combination value</td>
<td>$\psi Q_k$</td>
<td></td>
<td>$A_{pk}$</td>
<td></td>
</tr>
<tr>
<td>Frequent value</td>
<td>$\psi Q_L$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quasi-permanent</td>
<td>$\psi Q_{ps}$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Permanent actions

- **Small variability**
  - $Q_{k,0.05}$
  - $Q_{k,0.95}$

- **High variability**
  - $Q_{k,0.05}$
  - $Q_{k,0.95}$

### Variable actions

- **Instantaneous value of $Q$**
  - Characteristic value $Q_k$
  - Combination value $\psi Q_k$
  - Quasi-permanent value $\psi Q_{ps}$

- **Return period**
  - $T = \frac{R}{p}$
  - $p$ : probability of exceedance during the reference period
  - $R$ : reference period (e.g., 1 year or 50 years)
**EUROCODES**

### Background and Applications

#### Verification by the partial factor method

**6.1 General**

**6.2 Limitations**

**6.3 Design values**

**6.4 Ultimate limit states**

**6.5 Serviceability limit states**

---

**Material and product properties**

![Material and product properties diagram]

**Turkstra’s rule (1972):** Within the set of variable actions applicable to a structure, one of them is selected and called «leading variable action»; the other variable actions are accompanying actions and are taken into account in the combinations of actions with their combination values. The set including all permanent actions, the leading variable action and the relevant accompanying variable actions forms a combination of actions. The various values of actions used in the verifications are called «representative values».

---

**How to establish a combination of actions**

![How to establish a combination of actions diagram]

**Ultimate limit states**

- **EQU**: Loss of static equilibrium of the structure or any part of it considered as a rigid body, in which:
  - minor variations in the value or the spatial distribution of actions from a single source are significant;
  - the strengths of construction materials or ground are generally not governing.

- **STR**: Internal failure of the structure or structural elements, including footings, piles, basement walls, etc., in which the strength of construction materials or excessive deformation of the structure governs.

- **GEO**: Failure or excessive deformation of the ground in which the strengths of soil or rock are significant in providing resistance.

- **FAT**: Fatigue failure of the structure or structural elements.

---

**Design values**

![Design values diagram]

**Ultimate limit states**

![Ultimate limit states diagram]
6.4.2 Verifications of static equilibrium and resistance

Ultimate limit states of static equilibrium (EQU):

\[ E_{d,EQU} \leq E_{d,th} \]

Ultimate limit states of resistance (STR/GEO):

\[ E_{d,STR} \leq R_d \]

6.5 Serviceability limit states

\[ E_E \leq C_E \]

\( C_E \) is the limiting design value of the relevant serviceability criterion.

\[ E_E \] is the design value of the effects of actions specified in the serviceability criterion, determined on the basis of the relevant combination.

### Combinations of actions

<table>
<thead>
<tr>
<th>Combination</th>
<th>Reference EN 1990</th>
<th>General expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fundamental (for persistent and transient design situations)</td>
<td>6.10</td>
<td>[ \sum_{i,j,k} \left[ \psi \gamma \gamma \gamma \xi \right] \sum_{i} \left[ Q_i + Q_{ki} \right] ]</td>
</tr>
<tr>
<td>6.10 a/b</td>
<td>[ \sum_{i,j,k} \left[ \psi \gamma \gamma \gamma \xi \right] \sum_{i} \left[ Q_i + Q_{ki} \right] ]</td>
<td></td>
</tr>
<tr>
<td>Accidental (for accidental design situations)</td>
<td>6.11</td>
<td>[ \sum_{i,j,k} \left[ \psi \gamma \gamma \gamma \xi \right] \sum_{i} \left[ Q_i + Q_{ki} \right] ]</td>
</tr>
<tr>
<td>Seismic (for seismic design situations)</td>
<td>6.12</td>
<td>[ \sum_{i,j,k} \left[ \psi \gamma \gamma \gamma \xi \right] \sum_{i} \left[ Q_i + Q_{ki} \right] ]</td>
</tr>
</tbody>
</table>

### Origin of expressions 6.10 and 6.10 a/b

\[ \rho = \frac{Q_k}{Q_h + Q_k} \]

\[ 1,35G_k + 1,5Q_k \]

\[ 1,1G_k + 1,5Q_k \]

\[ 1,5G_k + 1,5Q_k \]

\[ 1,25G_k + 1,65Q_k \]

\[ 1,35G_k + 1,65Q_k \]

\[ 1,5G_k + 1,75Q_k \]

\[ 1,65G_k + 1,8Q_k \]

### 6.5.3 Serviceability limit states: combinations of actions

- **Characteristic Combination (irreversible SLS)**

\[ \sum_{i,j,k} \left[ \psi \gamma \gamma \gamma \xi \right] \sum_{i} \left[ Q_i + Q_{ki} \right] \]

- **Frequent Combination (reversible SLS)**

\[ \sum_{i,j,k} \left[ \psi \gamma \gamma \gamma \xi \right] \sum_{i} \left[ Q_i + Q_{ki} \right] \]

- **Quasi-permanent Combination (reversible SLS)**

\[ \sum_{i,j,k} \left[ \psi \gamma \gamma \gamma \xi \right] \sum_{i} \left[ Q_i + Q_{ki} \right] \]
Annex A1 (normative) Application for Buildings

A1.1 Field of application
A1.2 Combinations of actions
   A1.2.1 General
   A1.2.2 Values of ψ factors
A1.3 Ultimate limit states
   A1.3.1 Design values of actions in persistent and transient design situations
   A1.3.2 Design values of actions in the accidental and seismic design situations
A1.4 Serviceability limit states
   A1.4.1 Partial factors for actions
   A1.4.2 Serviceability criteria
   A1.4.3 Deformations and horizontal displacements
   A1.4.4 Vibrations

Table A1.2(A) – Design values of actions (EQU) (Set A)

<table>
<thead>
<tr>
<th>Action</th>
<th>Unfavourable</th>
<th>Favourable</th>
<th>Mean (if any)</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent actions</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unfavourable</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Favourable</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NOTE 1 The ψ values may be set by the National annex. The recommended set of values for ψ are:

ψ(EQU) = 1,10
ψ(STR) = 0,90
ψ(STR) = 1,50 where unfavourable (0 where favourable)
ψ(GEO) = 1,50 where unfavourable (0 where favourable)

NOTE 2 In cases where the verification of static equilibrium also involves the resistance of structural members, as an alternative to two separate verifications based on Tables A1.2(A) and A1.2(B), a combined verification, based on Table A1.2(A), may be adopted, if allowed by the National annex, with the following set of recommended values. The recommended values may be altered by the National annex.

ψ(EQU) = 1,35 ; ψ(STR) = 1,5 ; ψ(GEO) = 1,50 where unfavourable (0 where favourable)

provided that applying ψ(EQU) = 1,00 both to the favourable part and to the unfavourable part of permanent actions does not give a more unfavourable effect.
NOTE 3 The characteristic values of all permanent actions from one source are multiplied by \( p_{\text{rec}} \) and \( \xi \) if the total resulting action effect is unfavourable and \( \xi_{\text{rec}} \); if the total resulting action effect is favourable. For example, all actions originating from the self weight of the structure may be considered as coming from one source; this also applies if different materials are involved.

NOTE 4 For particular verifications, the values for \( p_{\text{rec}} \) and \( \xi \) may be subdivided into \( \gamma \) and \( \gamma_{\text{rec}} \) and the model uncertainty factor \( \gamma_{\text{rec}} \). A value of \( \gamma_{\text{rec}} \) in the range 1.05 to 1.15 can be used in most common cases and can be modified in the National annex.

NOTE 1 The choice between 6.10, or 6.10a and 6.10b will be in the National annex. In case of 6.10a and 6.10b, the National annex may in addition modify 6.10a to include permanent actions only.

NOTE 2 The \( \gamma \) and \( \xi \) values may be set by the National annex. The following values for \( \gamma \) and \( \xi \) are recommended when using expressions 6.10, or 6.10a and 6.10b.

- \( \gamma_{\text{rec}} = 1.35 \)
- \( \xi = 1.00 \)
- \( \xi = 1.50 \) where unfavourable (0 where favourable)
- \( \xi = 1.50 \) where unfavourable (0 where favourable)
- \( \xi = 0.85 \) (so that \( \xi_{\text{rec}} = 0.85 \times 1.35 \pm 1.15 \))

See also EN 1991 to EN 1999 for \( \gamma \) values to be used for imposed deformations.
Background and Applications

Note 1: The combinations of actions are based on the recommended values given in Annex A2.

Note 2: Except for roofed bridges, it is assumed that snow loads on road bridges may be assessed as snow loads on the ground.

---

Examples of combinations of actions for road bridges

Group of loads $g_4$: crowd loading

Group of loads $g_5$: special vehicles

(+ special conditions for normal traffic)

---

Table A.2.1 Recommended values of $\psi$ factors for road bridges

<table>
<thead>
<tr>
<th>Permanent design situations</th>
<th>Transient design situations</th>
<th>Permanent actions</th>
<th>Transient actions</th>
<th>Leading variable action</th>
<th>Corresponding variable action (*1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$g_1$</td>
<td>$g_1$</td>
<td>$\alpha$</td>
<td>$\beta$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$g_2$</td>
<td>$g_2$</td>
<td>$\alpha$</td>
<td>$\beta$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$g_3$</td>
<td>$g_3$</td>
<td>$\alpha$</td>
<td>$\beta$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(*1) Variable actions are those considered in Tables A2.1 to A2.3.
Table A2.4(B) - Design values of actions (STR/GEO) (Set B)

<table>
<thead>
<tr>
<th>Permanent and Transient Design Situation</th>
<th>Permanent actions</th>
<th>Leading variable action(*)</th>
<th>Accompanying variable actions(*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unfavourable</td>
<td>p_{unc,0}γ_{unc}</td>
<td>p_{unc,0}</td>
<td>p_{unc,0}γ_{unc,0}</td>
</tr>
<tr>
<td>Favourable</td>
<td>p_{f,0}γ_{f,0}</td>
<td>p_{f,0}</td>
<td>p_{f,0}γ_{f,0,0}</td>
</tr>
<tr>
<td>Others</td>
<td>p_{o,0}γ_{o,0}</td>
<td>p_{o,0}γ_{o,0}</td>
<td>p_{o,0}γ_{o,0}</td>
</tr>
</tbody>
</table>

(*) Variable actions are those considered in Tables A2.1 to A2.3.

Table A2.4(C) - Design values of actions (STR/GEO) (Set C)

<table>
<thead>
<tr>
<th>Permanent and Transient Design Situation</th>
<th>Permanent actions</th>
<th>Leading variable action(*)</th>
<th>Accompanying variable actions(*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unfavourable</td>
<td>p_{unc,0}γ_{unc}</td>
<td>p_{unc,0}</td>
<td>p_{unc,0}γ_{unc,0}</td>
</tr>
<tr>
<td>Favourable</td>
<td>p_{f,0}γ_{f,0}</td>
<td>p_{f,0}</td>
<td>p_{f,0}γ_{f,0,0}</td>
</tr>
<tr>
<td>Others</td>
<td>p_{o,0}γ_{o,0}</td>
<td>p_{o,0}γ_{o,0}</td>
<td>p_{o,0}γ_{o,0}</td>
</tr>
</tbody>
</table>

NOTE: The γ values may be set by the National Annex. The recommended set of values for the characteristic combinations are given in Table A2.4(C) of EN 1991-1. For the other combinations, the recommended set of values are given in Table A2.4(B) of EN 1991-1.

EN 1990 – Section 6, Annexes A1 & A2

1) The recommended values of γ_{f,0}, γ_{unc,0}, and γ_{o,0} for gr1a and gr1b are given for road traffic corresponding to adjusting factors a_{f,0}, a_{unc,0}, and a_{o,0} and equal to 1. Those relating to UDL correspond to common traffic scenarios, in which a rare accumulation of lorries can occur. Other values may be envisaged for other classes of routes, or of expected traffic, related to the choice of the corresponding γ factors. For example, a value of γ_{f,0} other than zero may be envisaged for the UDL system of LM1 only, for bridges supporting a severe continuous traffic. See also EN 1998.

2) The combination value of the pedestrian and cycle-track load, mentioned in Table 4.4a of EN 1991-2, is a "reduced" value. γ_{f,0}, and γ_{o,0} factors are applicable to this value.

3) The recommended γ_{o,0} value for thermal actions may in most cases be reduced to 0 for ultimate limit states EQU, STR and GEO. See also the design Eurocodes.

EN 1990 – Section 6, Annexes A1 & A2

Fundamental combinations of actions based on expression 6.10

1) The recommended values of γ_{f,0}, γ_{unc,0}, and γ_{o,0} for gr1a and gr1b are given for road traffic corresponding to adjusting factors a_{f,0}, a_{unc,0}, and a_{o,0} and equal to 1. Those relating to UDL correspond to common traffic scenarios, in which a rare accumulation of lorries can occur. Other values may be envisaged for other classes of routes, or of expected traffic, related to the choice of the corresponding γ factors. For example, a value of γ_{f,0} other than zero may be envisaged for the UDL system of LM1 only, for bridges supporting a severe continuous traffic. See also EN 1998.

2) The combination value of the pedestrian and cycle-track load, mentioned in Table 4.4a of EN 1991-2, is a "reduced" value. γ_{f,0}, and γ_{o,0} factors are applicable to this value.

3) The recommended γ_{o,0} value for thermal actions may in most cases be reduced to 0 for ultimate limit states EQU, STR and GEO. See also the design Eurocodes.

EN 1990 – Section 6, Annexes A1 & A2

Characteristic combinations of actions

\[ \gamma_{f,0} \]

\[ \sum_{i} (G_{o,0} \cdot \psi_{o,0} \cdot Q_{i}) \cdot F_{q,0} = P_{f} \]

\[ \gamma_{o,0} \]

\[ \sum_{i} (G_{o,0} \cdot \psi_{o,0} \cdot Q_{i}) \cdot F_{q,0} = P_{o} \]

\[ P_{f} \]

Characteristic value of the prestressing force

\[ G_{o,0} \]

Uneven settlements to be taken into account where relevant.

EN 1990 – Section 6, Annexes A1 & A2

Representation of the action of uneven settlements Gset.
**EUROCODES Background and Applications**

**EN 1990 – Section 6, Annexes A1 & A2**

**Frequent combinations of actions**

\[
\left\{ \sum_{i=1}^{n} g_i G_{A,i} \right\} \cdot a_i \cdot P_i \cdot e_i \cdot \gamma_i
\]

**Quasi-permanent combinations of actions**

\[
\left\{ \sum_{i=1}^{n} g_i G_{A,i} \right\} \cdot a_i \cdot P_i \cdot e_i \cdot \gamma_i
\]

**EN 1991-2 – Groups of loads for footbridges**

**Group of loads gr1**

**Group of loads gr2**

**Table A2.2**

<table>
<thead>
<tr>
<th>Action</th>
<th>Symbol</th>
<th>Symbol (during execution)</th>
<th>(\dot{\gamma}_G)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic loads</td>
<td>(g_1)</td>
<td>0.40, 0.40</td>
<td>0</td>
</tr>
<tr>
<td>Wind forces</td>
<td>(g_2)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Thermal actions</td>
<td>(g_3)</td>
<td>0.3, 0.2</td>
<td>0</td>
</tr>
<tr>
<td>Snow loads</td>
<td>(Q_{g4})</td>
<td>0.6, 0.6, 0.9</td>
<td>0.8</td>
</tr>
<tr>
<td>Construction loads</td>
<td>(Q_{g5})</td>
<td>1.2, 0, 0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

1) The recommended \(\dot{\gamma}_G\) value for thermal actions may in most cases be reduced to 0 for ultimate limit states EQU, STR and GEO. See also the design Eurocodes.

**Fundamental combinations of actions based on expression 6.10**

\[
\left\{ \sum_{i=1}^{n} (1.35g_i G_{A,i} + 1.00G_{D,j}) \right\} \cdot a_i \cdot P_i \cdot e_i \cdot \gamma_i
\]

**P**

Prestressing: Definition in design Eurocodes. Usually \(P_P = P_{max} \times \dot{\gamma}_P = 1\)

\(G_{D,j}\)

Uneven settlements to be taken into account where relevant, with \(\dot{\gamma}_G = 1.20\) or 1.00 in case of linear analysis.

**Some dates and backgrounds**
Thank you for your attention
ANNEXES B AND C

A. Vrouwenvelder
TNO
**EN1990**  
Basis of Structural Design  

Annex B Reliability Differentiation  
Annex C Reliability Theory  

Ton Vrouwenvelder  
TNO / TU Delft  

---  

- randomness - natural variability  
- statistical uncertainties - lack of data  
- model uncertainties - simplified models  
- vagueness - imprecision in definitions  
- gross errors - human factors  
- ignorance - lack of knowledge  

---  

To get a grip:  
- Mechanical models  
- Statistical models  
- Engineering judgement  
- Robustness  
- Quality Control  

---  

**EN 1990: Annexes B / C (Informatieve)**  
- Consequences classes  
- Differentiation of beta values and partial factors  
- Background for Partial Factor design  
- Background for Probabilistic design  

---  

**Reliability calculation**  

\[ P_f = P(R < E) = \int_{R < E} \phi_R(r) \phi_E(e) \, dr \, de \]  

---  

**JCSS Probabilistic Model Code**  

Part 1  
Basis of Design  
Part 2  
Modeling of loads  
Part 3  
Modeling of structural properties  

http://www.jcss.ethz.ch/  
select "publications"  
select "jcss model code"
Simple example

\[ g = R - E \]
\[ \mu_R = 100 \]
\[ \mu_E = 50 \]
\[ \sigma_R = 10 \]
\[ \sigma_E = 10 \]

First Order Second Moment method

\[ g = R - E \]
\[ \mu_g = \mu_R - \mu_E = 100 - 50 = 50 \]
\[ \sigma_g^2 = \sigma_R^2 + \sigma_E^2 = 14^2 \]
\[ \beta = \frac{\mu_g}{\sigma_g} = 3.54 \]
\[ P_f = P(Z < 0) = \Phi(-\beta) = 0.0002 \]

Reliability index \( \beta \)

<table>
<thead>
<tr>
<th>( \beta )</th>
<th>1.3</th>
<th>2.3</th>
<th>3.1</th>
<th>3.7</th>
<th>4.2</th>
<th>4.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P(F) = \Phi(-\beta) )</td>
<td>( 10^{-1} )</td>
<td>( 10^{-3} )</td>
<td>( 10^{-5} )</td>
<td>( 10^{-6} )</td>
<td>( 10^{-8} )</td>
<td></td>
</tr>
</tbody>
</table>

Probability of Failure = \( \Phi(-\beta) \approx 10^{-\beta} \)

Format Partial Factor Design

\[ E_d < R_d \]
\[ E_d = E(\gamma' G_k \gamma Q_k) \]
\[ R_d = R_k / \gamma_M \]

\( R_k \) characteristic value of resistance
\( G_k Q_k \) characteristic value of load
\( \gamma_M, \gamma_G, \gamma_Q \) partial factors

Reliability Methods

<table>
<thead>
<tr>
<th>Deterministic methods</th>
<th>Probabilistic methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Historical methods</td>
<td>FORM level II</td>
</tr>
<tr>
<td>Empirical methods</td>
<td>Probabilistic level III</td>
</tr>
</tbody>
</table>

Calibration

Partial factor methods (level I)

Partiale factor for R

\[ \gamma_k = \frac{R_{kur}}{R_k} = \frac{R_{kur}}{\mu_R - \alpha_R \beta_k \sigma_R} \]
\[ P(R|R_k) = \Phi(-\alpha_R \beta_k) \]
ISO 2394 STANDARD ALFA-values

<table>
<thead>
<tr>
<th>Dominant Variable</th>
<th>Load</th>
<th>Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>α = 0.70</td>
<td>α = 0.80</td>
<td></td>
</tr>
<tr>
<td>Other variables</td>
<td>α = -0.28</td>
<td>α = 0.32</td>
</tr>
</tbody>
</table>

Table 2: Target reliability index $\beta$ for Class RC 2 structural members

<table>
<thead>
<tr>
<th>Limit state</th>
<th>Target reliability index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate</td>
<td>4.7, 3.8</td>
</tr>
<tr>
<td>Fatigue</td>
<td>1.5 to 3.8</td>
</tr>
<tr>
<td>Serviceability (irreversible)</td>
<td>2.9, 1.5</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>1) See Annex B</td>
<td></td>
</tr>
<tr>
<td>2) Depends on degree of inspectability, reparability and damage tolerance.</td>
<td></td>
</tr>
</tbody>
</table>

Four design values for ULS

![Diagram showing four design values for ULS](image)

Uncertainty in representative values of actions
- $\gamma_L$
- $\gamma_A$
- $\gamma_M$
- $\gamma_B$

Model uncertainty in actions and action effects
- $\gamma_A$
- $\gamma_B$

Model uncertainty in structural resistance
- $\gamma_M$
- $\gamma_B$

Uncertainty in material properties
- $\gamma_M$
- $\gamma_B$

Figure 3: Relation between individual partial factors
Brussels, 18-20 February 2008 – Dissemination of information workshop 19
EUROCODES
Background and Applications

μ = mean value
V = \( \alpha \beta \)
\( \alpha \) = FORM factor
\( \beta \) = reliability index

**Permam loads**

\[ G_d = \mu_d (1 - \alpha E \beta V_d) \]

<table>
<thead>
<tr>
<th>Unfavorable</th>
<th>Dominant</th>
<th>( \alpha )</th>
<th>( \beta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>yes</td>
<td>yes</td>
<td>1.05</td>
<td>0.70</td>
</tr>
<tr>
<td>yes</td>
<td>no</td>
<td>1.05</td>
<td>0.28</td>
</tr>
<tr>
<td>no</td>
<td>yes</td>
<td>1.00</td>
<td>0.80</td>
</tr>
<tr>
<td>no</td>
<td>yes</td>
<td>1.00</td>
<td>0.80</td>
</tr>
</tbody>
</table>

In EN 1990 one finds: 1.35, 1.35

\[ \xi = 1.15, 1.00, 1.00 \]

\[ \mu = \beta \alpha \mu \]

\[ G_{E,\text{max}}(s) = \left( 1 + 3.8 \gamma Q \right) V \]

Variable loads

\[ Q_d = \mu_d (1 - \alpha E \beta V_d) \]

<table>
<thead>
<tr>
<th>Unfavorable</th>
<th>Dominant</th>
<th>( \alpha )</th>
<th>( \beta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>yes</td>
<td>yes</td>
<td>1.05</td>
<td>0.70</td>
</tr>
<tr>
<td>yes</td>
<td>no</td>
<td>1.05</td>
<td>0.28</td>
</tr>
<tr>
<td>no</td>
<td>yes</td>
<td>1.00</td>
<td>0.80</td>
</tr>
<tr>
<td>yes</td>
<td>no</td>
<td>1.00</td>
<td>0.80</td>
</tr>
</tbody>
</table>

In EN 1990 one finds 1.5

\[ \Psi_o = 1.27/1.61 = 0.8. \]

So maybe \( \beta = 3.8 \) is not really true.

**Variable load / Gumbel distribution**

<table>
<thead>
<tr>
<th>Load</th>
<th>( V_d (T = 50 \text{ jaar}) )</th>
<th>( \gamma )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>0.20</td>
<td>2.04</td>
</tr>
<tr>
<td>Snow (land climate)</td>
<td>0.15</td>
<td>1.77</td>
</tr>
<tr>
<td>Snow (sea climate)</td>
<td>0.30</td>
<td>2.67</td>
</tr>
<tr>
<td>Floor load (20 m²)</td>
<td>0.30</td>
<td>1.50</td>
</tr>
</tbody>
</table>

**Stochastic variable load Model**

\[ F_{\text{Smax}}(s) = (F_S(s))^N \]

N independent loads of duration \( \Delta t \):

**Variable loads / PSI values**

<table>
<thead>
<tr>
<th>Theory</th>
<th>Permanent</th>
<th>Economic</th>
<th>Floor</th>
<th>Snow</th>
<th>Wind</th>
<th>Accidental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent</td>
<td>1.00</td>
<td>0.68</td>
<td>0.76</td>
<td>0.78</td>
<td>0.78</td>
<td></td>
</tr>
<tr>
<td>Economic</td>
<td>1.00</td>
<td>0.76</td>
<td>0.68</td>
<td>0.78</td>
<td>0.78</td>
<td></td>
</tr>
<tr>
<td>Floor</td>
<td>1.00</td>
<td>0.68</td>
<td>0.76</td>
<td>0.78</td>
<td>0.78</td>
<td></td>
</tr>
<tr>
<td>Snow</td>
<td>1.00</td>
<td>0.76</td>
<td>0.68</td>
<td>0.78</td>
<td>0.78</td>
<td></td>
</tr>
<tr>
<td>Wind</td>
<td>1.00</td>
<td>0.68</td>
<td>0.76</td>
<td>0.78</td>
<td>0.78</td>
<td></td>
</tr>
<tr>
<td>Accidental</td>
<td>1.00</td>
<td>0.76</td>
<td>0.68</td>
<td>0.78</td>
<td>0.78</td>
<td></td>
</tr>
</tbody>
</table>

**Reliability differentiation**

**Design supervision differentiation**

**Inspection during execution**
Table 1: Definition of consequences classes

<table>
<thead>
<tr>
<th>Consequences Class</th>
<th>Description</th>
<th>Examples of buildings and civil engineering works</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC3</td>
<td>High consequence for loss of human life, or economic, social or environmental consequences very great</td>
<td>Grandstands, public buildings where consequences of failure are high</td>
</tr>
<tr>
<td>CC2</td>
<td>Medium consequence for loss of human life, economic, social or environmental consequences considerable</td>
<td>Residential and office buildings, public buildings where consequences of failure are medium</td>
</tr>
<tr>
<td>CC1</td>
<td>Low consequence for loss of human life, and economic, social or environmental consequences small or negligible</td>
<td>Agricultural buildings where people do not normally enter (e.g. storage buildings), greenhouses</td>
</tr>
</tbody>
</table>

Particular members of the structure may be designated at the same, higher or lower consequences class than for the entire structure.

Table 2: Recommended minimum values for reliability index $\beta$ (ultimate limit states)

<table>
<thead>
<tr>
<th>Reliability Class</th>
<th>Minimum values for $\beta$</th>
<th>1 year reference period</th>
<th>100 years reference period</th>
</tr>
</thead>
<tbody>
<tr>
<td>RC3</td>
<td>5.2</td>
<td>4.3</td>
<td></td>
</tr>
<tr>
<td>RC2</td>
<td>4.7</td>
<td>3.8</td>
<td></td>
</tr>
<tr>
<td>RC1</td>
<td>4.2</td>
<td>3.3</td>
<td></td>
</tr>
</tbody>
</table>

Table 3: $K_{FI}$ factor for actions

$K_{FI}$ should be applied only to unfavourable actions.

Table 4: Design supervision levels (DSL)

<table>
<thead>
<tr>
<th>Design Supervision Levels</th>
<th>Characteristics</th>
<th>Minimum recommended requirements for checking of calculations, drawings and specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSL3</td>
<td>Extended supervision</td>
<td>3rd party checking</td>
</tr>
<tr>
<td>DSL2</td>
<td>Normal supervision</td>
<td>2nd party checking</td>
</tr>
<tr>
<td>DSL1</td>
<td>Normal supervision</td>
<td>1st party checking</td>
</tr>
</tbody>
</table>

Table 5: Inspection levels (IL)

<table>
<thead>
<tr>
<th>Inspection Levels</th>
<th>Characteristics</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>IL3, relating to RC3</td>
<td>Third-party inspection</td>
<td>Third-party inspection</td>
</tr>
<tr>
<td>IL2, relating to RC2</td>
<td>Normal inspection</td>
<td>Inspection in accordance with the procedures of the organisation</td>
</tr>
<tr>
<td>IL1, relating to RC1</td>
<td>Normal inspection</td>
<td>Self-inspection</td>
</tr>
</tbody>
</table>

The rules are to be given in the relevant execution standards.

B6(1) A partial factor for a material or product property or a member resistance can be reduced if an inspection class higher than that required according to Table B5 and/or more severe requirements are used.
Relevant Background Documents

ISO 2394

JCSS documents (http://www.jcss.ethz.ch/)

Background document for the ENV-version of Basis of Design, ECCS/JCSS, 1996

IABSE Conferences Delft (1996) and Malta (2001)

Leonardo da Vinci Project CZ/02/B/F/PP-134807
Handbooks Implementation of Eurocodes (2005)
SECTION 5 AND ANNEX D

G. Sedlacek
RWTH Aachen
Eurocode – EN 1990
Basis of Structural Design

Structural Analysis and Design by Testing

Gerhard Sedlacek  
Christian Müller  
RWTH Aachen

SECTION 5 STRUCTURAL ANALYSIS AND DESIGN ASSISTED BY TESTING

5.1 STRUCTURAL ANALYSIS
5.1.1 Structural modelling
5.1.2 Static actions
5.1.3 Dynamic actions
5.1.4 Fire design

5.2 DESIGN ASSISTED BY TESTING

Actions

Verification: ULS (static)

Material | Geometry
---|---
linear   | non-linear
imperfection included

Linear actions in the design analysis based on the following assumptions:

- Simple actions affecting members and joints
- Non-linear behaviour
- Non-linear deformation

For dynamic actions:

- Non-linear behaviour
- Non-linear deformation

For linear actions:

- Linear behaviour
- Linear deformation

For static actions:

- Linear behaviour
- Linear deformation

For equivalent actions:

- Linear behaviour
- Linear deformation

Product Resistance

Code for type of static analysis

| Material | Geometry
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>linear</td>
<td>non-linear</td>
</tr>
<tr>
<td>LA</td>
<td>GNA</td>
</tr>
<tr>
<td>MNA</td>
<td>GMNA</td>
</tr>
</tbody>
</table>
ANNEX D (INFORMATIVE) DESIGN ASSISTED BY TESTING

D4 PLANNING OF TESTS
D5 DERIVATION OF DESIGN VALUES
D6 GENERAL PRINCIPLES FOR STATISTICAL EVALUATIONS
D7 STATISTICAL DETERMINATION OF A SINGLE PROPERTY

Contents of Annex D

80,3;5,08,0 expmR 2 8
"Contents of Annex D for presentation of resistance [6.3.5(4)]"

Procedure to obtain reliable values \( R_k \)

\[
X_k = \left( 1 - 1.16 \right) \chi_k\text{ from table D1} \\
X_k \text{ and } V_k \text{ from} \\
X_k = \frac{1}{n} \sum_{i=1}^{n} (x_i - \mu) \frac{x_i}{\sigma} \\
\sigma_x = \frac{1}{n-1} \sum_{i=1}^{n} (x_i - \mu)^2 \\
V_x = \frac{\sigma_x}{\mu} \\
X_k = \frac{X(k \sigma)}{\mu} \\
V_x = \frac{\sigma_x}{\mu} \\
X_k = \left( 1 - 1.16 \right) \chi_k \text{ from table D2} \\
X_k \text{ and } V_k \text{ from} \\
X_k = \frac{1}{n} \sum_{i=1}^{n} (x_i - \mu) \frac{x_i}{\sigma} \\
\sigma_x = \frac{1}{n-1} \sum_{i=1}^{n} (x_i - \mu)^2 \\
V_x = \frac{\sigma_x}{\mu} \\
X_k = \frac{X(k \sigma)}{\mu} \\
V_x = \frac{\sigma_x}{\mu} \\
X_k = \left( 1 - 1.16 \right) \chi_k \text{ from table D3} \\
X_k \text{ and } V_k \text{ from} \\
X_k = \frac{1}{n} \sum_{i=1}^{n} (x_i - \mu) \frac{x_i}{\sigma} \\
\sigma_x = \frac{1}{n-1} \sum_{i=1}^{n} (x_i - \mu)^2 \\
V_x = \frac{\sigma_x}{\mu} \\
X_k = \frac{X(k \sigma)}{\mu} \\
V_x = \frac{\sigma_x}{\mu} \\
X_k = \left( 1 - 1.16 \right) \chi_k \text{ from table D4} \\
X_k \text{ and } V_k \text{ from} \\
X_k = \frac{1}{n} \sum_{i=1}^{n} (x_i - \mu) \frac{x_i}{\sigma} \\
\sigma_x = \frac{1}{n-1} \sum_{i=1}^{n} (x_i - \mu)^2 \\
V_x = \frac{\sigma_x}{\mu} \\
X_k = \frac{X(k \sigma)}{\mu} \\
V_x = \frac{\sigma_x}{\mu} 
\]

Failure modes

- Ductile failure
-Brittle failure
-Excessive deformation by yielding
-Excessive deformation by member failure by instability
-Excessive deformation by fracture after yielding

1. Mode 0
2. Test evaluation
3. Recommended values
4. Characteristic value

Reliability links between Product Standard, Execution Standard and Eurocode 3

Requirements for quality

Tests with members complying with Product Standard and Execution Standards

Evaluation of \( R_k \) acc. to EN 1990
Determination of characteristic values $R_k$ and $J_M$ values from tests

- Conditions for numerical value of $J_M$
- Product standards for materials and semi-fabricated products: EN 10025
- Execution standard: EN 1090 – Part 2
- Design standard: Eurocode 3
- Prefabricated steel component for component testing
- Component tests to determine $R_{exp}$
- Engineering model to determine $R_{calc}$
- $R_k = \frac{J_M}{R_d}$
- Classification accord. to $J_M$ (1.0; 1.10; 1.25)
- $J_M = \frac{R_k}{R_d}$
- Test evaluation accord. to EN1990- Annex D

*Parameter X1: $R_{exp}/R_{calc}$*

<table>
<thead>
<tr>
<th>$R_{exp}/R_{calc}$</th>
<th>1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{exp}/R_{calc}$</td>
<td>0.5</td>
</tr>
<tr>
<td>$R_{exp}/R_{calc}$</td>
<td>0.0</td>
</tr>
</tbody>
</table>

*Parameter X2:

- $\frac{R_{exp}}{R_{calc}}$ = 1.0

Use of test evaluation method for various regulatory routes

- Practical Application proving satisfactory
- Acknowledged state of the art
- Time

<table>
<thead>
<tr>
<th>R &amp; D</th>
<th>Unique Verification</th>
<th>Technical Approval</th>
<th>Standardisation</th>
</tr>
</thead>
</table>

Common design rules for column, lateral torsional, plate and shell buckling

- $\chi = \frac{R_k}{\gamma_M}$
- $\alpha_{u,k}E_d = \frac{R_k}{\gamma_M}$
- $\frac{\alpha_{u,k}E_d}{\gamma_M} = \frac{\alpha_{u,k}}{\gamma_M}$

Probability distribution of experimental data

- Characteristic values: $R_k = R_{exp} / \gamma_M$
- Design values: $R_k = R_{exp} / \gamma_M$
- Recommended partial factor $\gamma_M$

Test evaluation for buckling curves and $J_M$-values

- Column buckling
- Lateral torsional buckling
- Plate buckling
- Shell buckling