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The Structural Eurocodes – Conceptual Approach

Eurocodes structuraux – Concept général

Eurocodes für den konstruktiven Ingenieurbau – Generalkonzept

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SUMMARY

The paper «Conceptual Approach» is divided into three parts. Part 1 deals with the technical and legal background for the development of the Structural Eurocodes in the European Committee for Standardization (CEN). Part 2 describes the safety concept applicable to the Eurocodes including the intended verification procedures, and finally Part 3 considers specific questions arising in the structural fire design and in the design of structure and foundation.

RESUME

La présente introduction aux Eurocodes structuraux est composée de trois parties. La première partie traite des bases techniques et juridiques qui ont permis la préparation des Eurocodes par le Comité Européen de Normalisation. La deuxième partie décrit le concept de sécurité appliqué dans les Eurocodes, ainsi que les méthodes de vérification prévues. La troisième partie traite de questions particulières relatives au dimensionnement au feu et au projet des structures et des fondations.

ZUSAMMENFASSUNG

Der Beitrag «Conceptual Apporach» gliedert sich in drei Teile. Der erste Teil behandelt den technischen und den rechtlichen Hintergrund für die Ausarbeitung der Eurocodes für den konstruktiven Ingenieurbau beim Europäischen Komitee für Normung (CEN). Im zweiten Teil wird das für die Eurocodes gültige Sicherheitskonzept einschliesslich der vorgesehenen Nachweisverfahren vorgestellt. Der dritte Teil geht auf spezielle Fragen bei der Bemessung mit Brandeinwirkung und beim Entwurf von Bauwerk und Gründung ein.

THE STRUCTURAL EUROCODES

- CONCEPTUAL APPROACH -

1. TECHNICAL AND LEGAL BACKGROUND

Günter Breitschaft

1.1 The History

The idea to develop models for an international set of Codes for structural design for the different materials used in construction and applicable to all kinds of structures was born in 1974 based on an agreement between several technical-scientific organisations.

The activities of these organisations in the field of coordination of principles, agreement on technical matters and prestandardization are of outstanding importance for international standardization. They comprise experts from many countries serving the exchange of scientific findings and practical experiences. Without the obligation for formulating mandatory rules, state-of-the-art reports are elaborated, and also - as far as possible and necessary - recommendations for corresponding future rules (e.g. Model Codes). There would be no international standardization without the preparatory work and without the mutual agreement in these organisations. In the construction sector, the following associations are involved in this preparatory work in particular:

IABSE	-	International Association for Bridge and Structural Engineering
CIB	-	International Council for Building Research, Studies and Documentation
RILEM	-	International Association of the Testing and Research Laboratories for Materials and Constructions
CEB	-	Euro-International Committee for Concrete
FIP	-	International Federation for Prestressed Concrete
ECCS	-	European Convention for Constructional Steelworks
JCSS	-	Joint Committee on Structural Safety (as a common committee of the aforementioned organisations for aspects related to structural safety)
ISSMFE	-	International Society for Soil Mechanics and Foundation Engineering.

In close cooperation the common basic rules for structural design were developed in the JCSS. Requirements for safety and serviceability of structures based on the principle of risk in terms of reliability conditions were formulated. It was the aim to use these rules as a common basis for the material-related design codes. Some of the organisations, such as CEB, CIB, ECSS and parts of ISSMFE, developed then models or recommendations for the material-related design codes based on the agreed common rules as mentioned above.

Thus the technical basis was prepared for a formal establishment of the "Structural Eurocodes" with the aim of a two-dimensional harmonisation
- across the borders of states,
- between different construction materials, construction methods and types of building and civil engineering works

to achieve full consistency and compatibility of the various codes with each other and to obtain comparable safety levels.

Already at the end of the seventies the Commission of the European Communities took the initiative for elaborating the Eurocodes by using the above preparatory work. Directed by a Steering Committee chaired by the EC Commission the first drafts of the individual Eurocodes were prepared by technical working groups in accordance with the basic principles of standardization, i.e. with a comprehensive participation of expert organisations and professions. Already at this stage of the works the working programme described below was developed in detail. However, due to still missing legal bases concerning the envisaged legal status of the Eurocodes in the EC Member States and due to difficulties in financing the works could not been carried out as speedy as it would have been technically possible. These legal bases at Community level were only effected at the end of the eighties, as is described in the following section.

1.2 The Political and Legal Background

The Roman Treaties of 1957 establishing the European Economic Community have been modified and amended since 1985 by essential decisions taken in order to create the conditions for completing the Internal Market until 1992. On the basis of the European Single Act of 1987 it was intended to initiate a comprehensive harmonization of technical rules and regulations in order to remove - among other things - technical barriers to the free movement of goods and to the exchange of services.

For realizing measures of this kind, the European Community disposes of the legal instrument of the Council Directive. A Council Directive defines the essential requirements for the range of products or plants to be regulated and refers, for the rest, to European technical specifications consisting, in general, of European standards established by the European Standard Organisation CEN/CENELEC. After adoption within the Council of Ministers by weighted voting, a Council Directive has to be transposed into national law of the Member States.

In the construction sector,
- the Public Works Directive 89/440/EEC

  and
- the Service Directive (Draft)

are thus important for the harmonization of technical rules, as in the request for tenders and placing of orders on public construction works and engineering services the harmonized European technical specifications have to be used as a technical basis.

The Council Directive on the approximation of laws, regulations and administrative provisions of the Member States relating to construction products (CPD 89/106/EEC) is of central importance. It applies to the whole "construction sector" and defines right at the beginning the essential requirements in the following fields:
- mechanical resistance and stability
- safety in case of fire
- hygiene, health and the environment
- safety in use
- protection against noise
- energy economy and heat retention.

These essential requirements apply to works, from which the special requirements for a product will be derived. They also require that as far as economic aspects are concerned construction works are fit for their intended use and represent - under normal maintenance conditions - an economically reasonable working life.

Concerning the required levels of reliability for the satisfaction of the essential requirements Art. 3(2) of the CPD is of importance:

"2. In order to take account of possible differences in geographical or climatic conditions or in ways of life as well as different levels of protection that may prevail at national, regional or local level, each essential requirement may give rise to the establishment of classes in the documents referred to in paragraph 3 and the technical specifications referred to in Article 4 for the requirement to be respected."

A detailed description of the essential requirements is given in the so-called interpretative documents (ID).

The Council Directive on Building Products defines in these interpretative documents the European technical specifications
- as harmonized standards established by CEN or CENELEC, respectively, on behalf of a mandate given by the Commission of the European Communities (CEC)
  or
- as European technical approvals issued by the relevant approval bodies nominated by the Member States in cases where harmonized standards do not or not yet exist.

The Council Directive on Building Products obliges the Member States to take care that these European technical specifications become valid in their relevant countries and to withdraw their corresponding national standards or rules after a certain period of transition.

The mandates given by the CEC to CEN for the establishment of a harmonized standard are based on the relevant *"Interpretative Documents"*.

1.3 The Essential Requirement "Mechanical Resistance and Stability"

The relevant Interpretative Document "Mechanical Resistance and Stability (ID 1) defines, in technical terms, the decisive and obligatory conditions for the elaboration of "Structural Eurocodes" within CEN/TC 250. For the definition of the fundamental code concept the following documents have, as far as possible, been taken into consideration:

- General Principles on Quality Assurance for Structures,
- General Principles for Structural Design
  both elaborated by the Joint Committee on Structural Safety (JCSS)
  and published by IABSE (IBSN3-85748-026-2)
- ISO 2394 - General Principles on Reliability for Structures

The general requirement relating to safety of construction works is as follows:

"The construction works must be designed and built in such a way that the loadings that are liable to act on it during its construction and use will not lead to any of the following:
(a) collapse of the whole or part of the work;
(b) major deformations to an inadmissible degree;
(c) damage to other parts of the works or to fittings or installed equipment as a result of major deformation of the load-bearing construction;
(d) damage by an event to an extent disproportionate to the original cause."

This essential requirement, as far as applicable, shall be satisfied with acceptable probability for an economically reasonable working life of the works. The satisfaction of the essential requirement is assured by a number of measures which are interrelated and concern in particular the following:
- the planning and design of the works, the execution of the works and necessary maintenance.
- the properties, performances and use of the construction products.
- the relevant quality assurance procedures concerning design, production and execution."

A definition is also given for the term of the *"economically reasonable working life"* in connection with the required durability of the construction work. This period of time shall be fixed by taking account of all relevant aspects, such as
- costs of design, construction and use,
- cost arising from hindrance of use,
- risks and consequences of failure of the work during its working life and costs of insurance covering these risks,
- costs of maintenance, care and repair of the construction.

The verification of the satisfaction of the essential requirement shall be based on the **Limit State** concept using appropriate design models (supplemented, if necessary, by tests). In general, distinction is made between

- **Ultimate Limit States** and
- **Serviceability Limit States.**

The verification procedure shall use the **Partial Safety Factor Format** with representative values for actions and the properties of products. Simplified design rules based on the limit state concept are foreseen using simplified calculation methods or by specifying particular detailing rules.

ID 1 finally specifies:

"For establishing harmonized European classes of safety in the EUROCODES, the following means for achieving levels of protection are relevant:
a) representative values of actions;
b) numerical values of the safety factors and other safety elements;
c) requirements of serviceability limit states;
d) durability requirements;
e) provisions for avoiding or limiting damage by an event to an extent disproportionate to the original cause;
f) accuracy of mechanical models used;
g) stringency of the detailing rules;
h) various quality assurance procedures."

Where Member States wish to adopt special levels of protection in their territory, a differentiation using only the means b), e) and h) for achieving the desired level of protection is permitted.

1.4 The Transfer of the Eurocodes to CEN

With reference to the so-called "**New Approach** to technical harmonization and standards" adopted by a Council Resolution of May 1985 the further development of the Eurocodes was transferred, at the end of 1989, to the European Committee for Standardization (CEN).
In May 1990 CEN created a new Technical Committee, CEN/TC 250 *"Structural Eurocodes"*. This Committee was given the mandate to elaborate Codes of Practice within the following scope:

"Standardization of structural design rules for building and civil engineering works taking into account the relationship between design rules and the assumptions to be made for materials, execution and control."

The creation of TC 250 was mainly initiated by and based on, respectively
- the preparatory work done by international technical-scientific organisations in the construction sector,
- the relevant standards of the International Organisation for Standardization (ISO),
- decisions taken in the European Community with respect to the creation of the European Internal Market, which was joined by the Member States of the European Free Trade Association (EFTA).

1.5 The EUROCODE programme in CEN/TC 250

The working programme complies with the given conditions of the above-mentioned Interpretative document ID 1 and is based on a special agreement between CEC and CEN. Among other things, the following is specified:

"The EUROCODES are intended to serve as reference documents to be recognized by the authorities of the Member States for the following purposes:
a) as a means to prove compliance of building and civil engineering works with the essential requirements;
b) as a basis for specifying contracts for the execution of construction works and related engineering services;
c) as a framework for drawing up harmonized technical specifications for construction products. ..."
"The EUROCODE programme provides for a consistent and comprehensive system of structural design standards covering all types of building and civil engineering works in the different construction materials, the various construction methods and other aspects of design which are of general practical importance. ..."
"With a view to the realization of the existing work programme and its further development, CEN will ... set up a Technical Committee "Structural EUROCODES" with overall responsibility for all CEN work on structural design codes. ... It is understood that no structural design codes within the scope of EUROCODE mandates will be prepared within other CEN Technical Committees."

The programme is further influenced by the basic idea of a two-dimensional harmonization

The *EUROCODE* programme provides for a total set of nine volumes according to the following classification:
EUROCODE 1
for actions on structures (design loads)
EUROCODE 2
for concrete, reinforced concrete and prestressed concrete structures
EUROCODE 3
for steel structures
EUROCODE 4
for composite steel and concrete structures

EUROCODE 5
for timber structures
EUROCODE 6
for masonry structures
EUROCEDE 7
for foundations and geotechnical engineering
EUROCODE 8
for structures in seismic zones
EUROCODE 9
for aluminium structures.

Up to now a preliminary mandate - agreed between CEC/EFTA and CEN - provides for the following detailed programme:

EUROCODE 1 - Actions on structures
Part 1 : Basis of Design (described in detail in Chapters 2 and 3 of this contribution)
Part 2 : Gravity and imposed loads, snow, wind and fire loads
Part 2A: Thermal actions
Part 2B: Construction loads and deformations imposed during execution
Part 2C: Accidental actions
Part 2D: Water and wave loads
Part 2E: Soil and water pressure
Part 3 : Traffic loads on bridges
Part 4 : Loads in silos and tanks
Part 5 : Actions induced by cranes and machinery
Part 10: Actions on structures exposed to fire.

EUROCODES 2 to 9 - intended for direct application - are elaborated in several parts. Part 1 contains the physical bases for the considered type of construction and also the rules necessary for design and execution of common structures. Further separate parts include the supplementary rules for special structures, such as bridges, masts and tower-like structures or certain agricultural buildings. Another part of each code will contain the details for the determination of the carrying capacity and stability of the structures and parts thereof in the event of fire.

In the texts of the *EUROCODES* distinction is made between **basic principles** and **rules for application**. Compliance with a EUROCODE always necessitates the observance of the principles, whereas the rules for application can be replaced in the individual case by equivalent alternatives if it is shown that they satisfy the principles. It is thus intended to provide a more flexible use by allowing deviations within the scope of the EUROCODE.

EUROCODES 2 to 9 refer
- on the one side to EUROCODE 1 for the actions on structures, i.e. the loadings,
- on the other side to European material standards to be established by CEN or to European technical approvals.

Up to now, a preliminary mandate - agreed between CEC and CEN - foresees the following detailed programme:

EUROCODE 2
Design of concrete structures

Part	1	General rules and rules for building
	2	Reinforced and prestressed concrete bridges
	3	Concrete foundations
	4	Liquid-retaining and containment structures
	5	Marine and maritime structures
	6	Massive structures
	10	Structural fire design of concrete structures

EUROCODE 3
Design of steel structures

Part	1	General rules and rules for buildings
	2	Bridges and plated structures
	3	Towers, masts and chimneys
	4	Tanks, silos and pipelines
	5	Piling
	6	Crane structures
	7	Marine and maritime structures
	8	Agricultural structures
	10	Structural fire design of steel structures

EUROCODE 4
Design of composite steel and concrete structures

Part	1	General rules and rules for buildings
	2	Bridges
	10	Structural fire design of composite steel and concrete structures

EUROCODE 5
Design of timber structures

Part	1	Common unified rules for timber structures
	2	Timber bridges
	10	Structural fire design of timber structures

EUROCODE 6
Design of masonry structures
Part 1 General rules for buildings
2 Simplified rules for masonry structures
10 Structural fire design for masonry structures

EUROCODE 7
Geotechnics
Part 1 Geotechnics, common design rules
2 Standards for geotechnical laboratory tests
3 Standards for geotechnical field tests
4 Specific geotechnical structures

EUROCODE 8
Design of structures in seismic regions
Part 1 General rules and rules for buildings
1A Buildings in seismic regions; strengthening and repair
2 Bridges
3 Towers, masts, chimneys
4 Silos, tanks, pipelines
5 Foundations, retaining structures and geotechnical aspects

In a first step, the individual Codes and their relevant parts are published as European prestandards (ENV). In 1992 EUROCODE 2, EUROCODE 3, EUROCODE 4 and probably EUROCODE 5 - Part 1 one of each - will be available. The first parts of EUROCODE 1 are foreseen for 1993. After a test period, their transposition into EN standards is planned. Final publication will depend to a great extent on CEN internal methods of proceeding, where experience has shown there is room for improvement.

1.6 Organisation of CEN/TC 250

The mandate to elaborate Structural EUROCODES was given to a Technical Committee (TC) consisting of altogether 9 Subcommittees (SC). Delegates of the member organisations of CEN of 18 countries (EC + EFTA countries) are represented within this TC and its SCs. The relevant SC charges small project teams consisting of up to 6 experts with the elaboration of drafts of the different Codes and their individual parts. Presidency and Secretariat of TC and SCs are distributed among the different member organisations. Furthermore, TC as well as each SC dispose of a technical Secretary. For the agreement on overlapping questions as well as for the preparation of decisions to be taken by the Technical Committee, the chairman of the TC is assisted by a coordination group consisting of the chairmen of the different SCs.
This form of organisation was chosen in order to ensure that the Codes will be elaborated on a unified basis.

1.7 Liaisons with other Organisations

Liaisons of the Technical Committee have been established with the following organisations:

CEC	Commission of European Communities
EFTA	Secretariat: European Free Trade Association
CEDIC	European Committee of the Consulting Engineers of the Common Market
FIEC	European Construction Industry Federation
CEPMC	Council of European Producers of Materials for Construction
UIC	International Union of Railways

Further liaisons are, or will be, established with the technical-scientific organisations mentioned at the beginning of the present paper as well as with the relevant ISO-Committees depending in each individual case on the fields of activity on TC or SC levels.

1.8 Final Remarks

With the elaboration of Structural EUROCODES a comprehensive set of standards reflecting the actual state of the art will be created in accordance with the Council Directive on Construction Products for the European space in the field of structural engineering.
It is intended to give it a format which
on the one hand takes account of
- the aspects of public safety
- the interests of public and private clients with regard to economy and serviceability

on the other hand takes account of
- the necessary liberty of the designers
- the efforts for innovation made by the construction industry.

In order to achieve this objective, all interested engineers are thus invited to participate in the final elaboration of these documents by giving their comments and observations to the different draft versions.

There is still a number of open questions. The IABSE Conference in Davos may be used to give the answers to some of them.

2. BASIS OF DESIGN

- GENERAL CONCEPT -

Lars Ostlund

The chapter "BASIS OF DESIGN" will become Part. 1 of EUROCODE 1 "Actions on structures". It will be developed in a specific Project team inclose cooperation with all Subcomittees of CEN/TC 250 and will be finally agreed upon in the TC 250 itself.

The following description of the content is taken from a working document. Thus it should be regardet as being under discussion.

The objectives of this Part 1 of Eurocode 1 are to establish the principles and requirements for safety and serviceability of structures and to describe the methods of design and verification.

2.1 Requirements and assumptions

Structures and structural elements shall be designed, constructed and maintained so that, with appropriate degrees of reliability, they will

- perform adequately under all expected actions
- withstand all actions and other influences likely to occur during execution and use and have adequate durability in relation to maintenance costs
- not be subsequently damaged disproportionatoly to the original cause in the case of exceptional hazards.

The meaning of the form "appropriate degrees of reliability" means that the reliability may be different for different structures. Thus, considering the consequences of failure, a differentiation into reliability classes may be done.

Class	**Consequences of failure**
1	Risk to life low, economic and sociel consequences small or negligible.
2	Risk to life medium, economic or social consequences considerable.
3	Risk to life high, economic or social consequences very great.

The requirements for structural integrity implies that appropriate measures shall be taken to counter different kinds of hazards. The measures would basically consist of one or more of the following possibilities:

a) Designing the structure according to the rules given in the Eurocodes.

b) Protection and eliminating measures which can be used for forseeable actions and errors.

c) Designing the structure in such a way that local damage does not lead to immediate collapse of the structure.

Hazards include normal actions, exceptional actions, environmental influences and gross errors.

Some assumptions are associated with the validity of the design principles given in "Basis of Design".
- Structures are designed by appropriately qualified personnel and are carried out by personnel having the necessary still and experience.
- The construction materials and products are used as specified in the Eurocodes or in the relevant material or product specifications. Adequate quality assurance measures are applied.
- The structure will be adequately maintained.

2.2 Principles of limit state design

Limit states are the boundaries of a domain within which the structure is assumed to satisfy the design criteria.

Limit states are classified into
- ultimate limit states
- serviceability limit states

Ultimate limit states are those associated with collapse, or with other forms of structural failure which may endanger the structural safety.

The passage of an ultimate limit state is considered to cause failure.

Serviceability limit states are those associated with specified service criteria for normal use.

In the case of permanent damage or permanent unacceptable deformations the first passage of a serviceability limit state is irreversible and is considered to cause failure.

In other cases, such as temporary damage, temporary deformations or vibrations, the passage of a serviceability limit state may be reversible and then a passage of a limit state does not always cause failure.

For the ultimate limit states and those serviceability limit states where the passage of a limit state causes a permanent damage the design requirements (for the simpliest case) may be written

$$S_d \leq R_d$$

with the design value of the action effect

$$S_d = S\ (F_d, a_d, f_d)$$

where F_d is the design value of an action

a_d is the design value of a geometrical quantity

f_d is the design value of a material property

In other cases of serviceability limit states the design requirements can often be written

$$S_d = S(F_d, a_d, f_d) \leq C$$

S_d is the design value of an action effect relevant for the serviceability limit state, for example, a deflection, the intensity of vibrations, a crack with in a concrete structure, etc.

C is a limiting condition corresponding to the action effect S_d.

2.3 Basic variables
2.3.1 Actions

Actions are classified by the variation of their magnitude with time:
- permanent actions (G)
- variable actions (Q)
- accidental actions (A).

Actions are classified by their spatial variation:
- fixed actions
- free actions

Actions are classified by the structural response:
- static actions
- dynamic actions.

Other classifications are to be considered in special cases.

A permanent action has normally a unique representative value, G_x, the mean value.

A variable action has the following representative values:
- the characteristic value Q_k
- the combination value $\psi_0 Q_k$
- the frequent value $\psi_1 Q_k$
- the quasi-permanent value $\psi_2 Q_k$

A accidental action normally has a unique value, A_k.

2.3.2 Material properties

A material property is represented by its characteristic value, f_k, which in general corresponds to an a priori specified fractile of the assumed statistical distribution of the particular property in the supply produced within the scope of the relevant material standard. Testing procedures (one or more) for the determination of characteristic values shall be specified.

A characteristic value is associated with the results of the tests made on the specified test specimens. By means of an appropriately specified conversion factor, η, this value is converted to a value which is assumed to be valid for the material in the structure and which is used for the determination of design values.

2.3.3 Geometrical data

For a completed structure the measures which describe the geometry of the structure generally deviate more or less from the measures specified by the designer. This deviations may concern the following three cases:
- the overall shape and size of the structural system
- the shape of the components
- the shape and size of cross sections, support areas, connections etc.

For those measures for which deviations are important with regard to the safety, servicebility or durability of a structure tolerances are given.

Tolerances for the two last cases mentioned above are given in the relevant Eurocodes.

The geometrical data are represented by their characteristic values, a_k, which usually correspond to the measures specified by the designer on drawings, in descriptions etc.

2.4 Structural analysis

Some principles will be given which are common for structures of different types and materials. They concern
- Mechanical models
- Dynamic analysis
- Interaction between soil and structure
- The use of finite element methods.

Some principles are also given for "Design by testing".

2.5 Verification

The basic variables are introduced into the calculation model with their design values F_d for actions, f_d for material properties and a_d for geometrical data. The design values are

$$F_d = \gamma_f F_k$$

$$f_d = \frac{\eta \cdot f_k}{\gamma_m}$$

$$a_d = a_k \pm \Delta a$$

F_k are representative values of actions (see 4.2)

f_k are characteristic values of material properties (see 5)

a_k are characteristic values of geometrical data (see 6)

γ_f are partical factors for material properties

γ_m are partial factores for material properties

η are conversion factors (see 5)

Δa are additive geometrical data

The values of γ_f and γ_m are generally different for the ultimate limit states and the serviceability limit states.

The design value, R_d, of the resistance may be obtained from the design values f_d and a_d so that

$$R_d = R\ (a_d,\ f_d)$$

In some cases the design value, R_d, is obtained from the characteristic values (or norminal values) f_k and a_k so that

$$R_d = R\ (f_k,\ a_k)/\gamma_R$$

where γ_R is a partial factor for the resistance.

In some cases the partial factors for actions may include the effect of uncertainties of an action effect model. In a similar way the partial factors for material properties may include the effect of uncertainties in the geometrical data and in the resistance model. Sometimes it also include the conversion factor, η, (its systematic part). Such cases should be regardet as deviations from the principles described above and the notations γ_f and γ_m, should then be substituted by γ_F and γ_M

Actions shall be combined so that they produce the most unfavourable effect on the structure for the limit state considerer.

Actions which cannot occur simultaneously (for example, due to physical reasons) should not enter together into a combination.

For the ultimate limit states there are two types of combination of actions
- Fundamental combinations
- Accidental combinations.

For the serviceability limit states there are three types of combination.
- The rare combinations are used mainly in those cases when exceedance of a limit state causes a permanent local damage or a permanent unacceptable deformation.
- The frequent combinations are used mainly in those cases when exceedance of a limit state causes local damage, large deformations or vibrations which are temporary.
- The quasi-permanent combinations are used when long term effects are of importance.

Numerical values of γ-factors are given.

The conditions for simplified verification methods as mentioned in JD 1 are included.

Annexes

A number of annexes are foreseen. They are of two types
- annexes which give more detailed information which may be wanted by designers and other users of the standard, for example, criteria concerning vibrations.
- annexes directed to other subcommittees and project teams and which give recommendation for the estimation of characteristic values, ψ-factors etc.

The division of the content of "Basis of Design" in those parts which are in the main text and those parts which are in annexes ist not done so far.

3. BASIS OF DESIGN - SPECIFIC ASPECTS -

Marita Kersken-Bradley

3.1 STRUCTURAL FIRE DESIGN

3.1.1 Prescriptive rules or hot design

In cold design we are concerned with the performance of the entire structure, often using highly sophisticated computer codes for structural analysis and optimizing the structure. For fire protection this high-tech complex structure is considered in terms of archaic elements as beams and columns, for which some "repair" has to be done to comply with fire protection requirements - which in turn remain unquestioned by the designer.

On the one hand, this discrepancy is explained by the fact, that for a long time the assessment of fire resistance was limited to the testing of members in furnaces. The test results were only valid for the specific member tested, defined by its dimensions and detailing. And only this specific information could be given to the designer: A member which looks like fig. ... has 30 minutes of fire resistance (or is rated as R 30).

With increasing experience in testing, inter- and extrapolation of test results became possible and more information could be given to the designer: A member which looks like fig. ... has 30 to 60 minutes of fire resistance, depending on the following parameters ... . This manner of presenting information - in terms of "tabulated data" or "prescriptive approach" - has been the most common approach within the European countries for decades.

The *advantage* of tabulated data: They are simple to use, you need no special knowledge to perform (and to check) fire design.

The *disadvantage*: The approach is not so simple, if your design is not included in the tabulated data. But even so, it is barely possible to optimize a design for "cold" and fire conditions.

On the other hand, as long as general safety requirements could not be verified by technical methods, building regulations had to more or less stringently prescribe fire protection solutions e.g. fire resistance classes.

The *advantage* of prescribed fire resistance classes: No thinking is required.

The *disadvantage*: Is obvious for steel and timber designers, confronted with high fire resistance requirements

3.1.2 Options for structural fire design in the framework of Eurocodes

For dealing with fire design within a set of structural codes there are basically several options.

The first is to have a separate fire code, covering all aspects of fire design for all types of material, e.g. as EC 8 for seismic design.

Advantage: Easy coordination of rules relating to different types of structures and materials, no need for duplicating rules (beneficiary: the code writer)

Disadvantage: Difficult to overcome the gap between "cold" and fire design and to coordinate cold and fire design rules (concerned: the designer)

The next option is to include all information relating to fire design as directly as possible in the basic codes (i.e. in Part 1). This would imply e.g. that in EC 2 the section on concrete covers would include rules on axis distance, and detailing of reinforcement would meet fire resistance requirements, etc.

Advantage: Maximum consistency between cold and fire design

Disadvantage: The basic code may become rather volumnuos or possibly less economic for cases with no fire resistance requirements.

Finally, each basic code can be associated with supplementary parts (or annexes) for fire design, together with a supplementary part in the EC Actions, cf. table 1 - the option selected for the Eurocodes. This is more or less a compromise between the two previous options, which allows a fairly consistent treatment of fire design across EC 2-6 on the one hand and will - if only gradually - narrow the gap between cold and fire design.

EC			Fire Part
EC 1 - Actions	Part 1	...	Part 10
EC 2 - Concrete	Part 1	...	Part 10
EC 3 - Steel	Part 1	...	Part 10
EC 4 - Composite	Part 1	...	Part 10
EC 5 - Timber	Part 1	...	Part 10
EC 6 - Masonry	Part 1	...	Part 10

Table 3.1 Structural Fire Design in the Framework of Eurocodes
(numbers of Parts may still change)

3.1.3 What should be codified?

With increasing knowledge in structural fire behaviour and gradually developing calculation methods, the amount of information which can be presented by tabulated data is enormously increasing. With regard to codification of structural fire design we could:

1. Include all this information in codes or standards, giving increasing volumes of tabels with increasing supplements to tables, accounting for various conditions
2. Give only safe-side prescriptions which cover all unfavourable conditions which, however, will be uneconomic in most cases - by definition

3. Include tabulated data only for the most frequent cases (if at all) and give (calculation) rules for
- *setting up/using design aids outside the code*
- *direct fire design in special cases*
- *including fire design in structural computer codes*

It is the third route which was selected within the 1990 Eurocode 2-6 drafts for fire design.

As for fire actions we could

1. Promote a fire engineering approach and only allow for fire models respresenting natural fires (which would be very progressive but not very usefull for the designer, having to prove compliance with building regulations)

2. Only allow for the standard fire exposure (which would be very simple but would not reflect the state of the art)

3. Focus on the standard fire exposure but "open the door" for other exposures, including fire models representing natural fires

Again the third approach was adopted in the Eurocode Action draft on "Actions on Structures in Fire Exposure" of June 1990.

3.1.4 State of progress

In June 1990 the first set of drafts was presented at a symposium in Luxembourg. After an interim period during which national comments were collected, redrafting started autumn 1991. Versions for SC voting should be available be the end of 1992 or beginning of 1993.

3.1.5 Actions on structures exposed to fire

This part of the Eurocode on Actions deals with mechanical and thermal actions on structures for the accidental situation of fire exposure. It is intended for use in conjunction with Part 10 of Eurocodes 2 to 6. Supplementary to principles and rules for application strictly relating to actions, some principles and definitions, which are independent of the type of material and construction, are also given.

As mentioned in section 3.1.2 herein, the present version will deal with fire models for determining thermal actions only to the extent that the "door is opened". It is intended to draft a second or supplementary part, giving basic information on fire models, at a later stage. The main reason being, that for giving basic information on fire models some pre-codification work is still neccessary which would delay progress. Hence, the version to be expected by the end of the year will cover:

Thermal actions

Thermal actions are given by the net heat flux to the members of a structure, considering thermal radiation and convection from and to the fire environment. Gas-temperatures are given either

- as nominal time-temperature-curves or
- depending on physical parameter.

NOMINAL TIME-TEMPERATURES-CURVES are given as follows

- *the (ISO) standard time-temperature curve*
- *an external fire curve*
- *the Hydrocarbon curve*

PROCEDURES DEPENDING ON PHYSICAL PARAMETERS cover

- *a nominal fire load density* for relating standard fire resistance requirements to physically based thermal actions
- *design fire load densities*to be used for fire models
- *simple fire models* for compartment fire exposure and external members

Mechanical Actions

Mechanical actions cover

- Actions from normal conditions of use
- Indirect fire actions (resulting from thermal expansions)

The following accidental combination (given in symbolic form) is given in accordance with the general basis of design:

$$[\gamma_{GA}]G_k + \psi_{1,1}Q_{k,1} + \psi_{2,i}\,Q_{k,i} + A_{d,ind}$$

where	G_k	characteristic values of permanent actions
	$Q_{k,1}$	characteristic value of one (the main) variable action
	$Q_{k,i}$	characteristic values of the other variable actions
	$A_{d,ind}$	time dependent design value of indirect actions, where relevant
	γ_{GA}	= [1.0] safety factor for permenent actions in the accidental situation, probably given as a "boxed value", i.e. may be specified nationally
	$\psi_{1,1}$, $\psi_{2,i}$	combination factors according to the relevant Parts of EC 1.

Where effects of actions can be assumed not to change during fire exposure, a simplified assessment is suggested:

$$E_{d,f} = \eta_f \cdot E_d$$

where E_d — the design value of the relevant effects of actions from the fundamental combination according to Part 1 of Eurocodes 2 to 6 (including γ_F values)

$E_{d,f}$ — the corresponding design value for the fire situation.

η_f — $= ([\gamma_{GA}] + \psi_{1,1} \cdot \xi) / (\gamma_G + \gamma_Q \cdot \xi)$ where $\xi = Q_k/G_k$ is the ratio between permanent and variable actions

This simplification, in particular the load level η_f, is still under discussion. Also the aforementioned accidental combination in relation to fire rating tests is still pending on the procedures for planning and evaluating these tests.

3.1.6 Structural fire design parts EC 2-6

The fire parts (10) of EC 2-6 give rules on how to design a structure for the mech-anical and thermal actions in fire exposure, as given in EC 1.

The main emphasis is on design rules for GIVEN FIRE RESISTANCE REQUIREMENTS in terms of exposure time to the standard time-temperature-curve. EC 3 also gives rules for designing external members for thermal actions on external members given in EC 1.

The performance requirements are
- the load bearing function (Criterion "R") of the structure.
- the separating function, which is associated with two criteria

    - integrity ("I")
    - thermal insulation ("E")

In principle, the load bearing function can be verified by calculations, accounting for the relevant actions and material properties at elevated temperatures, cf. fig. 1

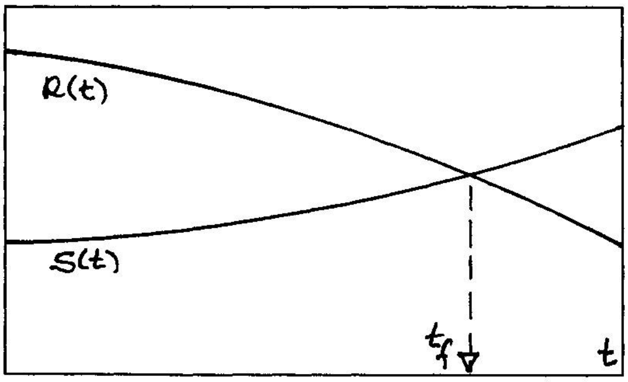

Fig. 3.1 Principle of verifying fire resistance requirements relating to the load bearing function

The separating function is mainly depending on the detailing, as e.g. detailing of a vessel to be water-proof.

Basically relating to the load-bearing function three design procedures are envisaged

1. The prescriptive approach, i.e. tabulated data for individual members
2. Calculation rules, where possible, similar to those used in normal design (which obviously is the most desireable procedure)
3. General calculation models, which simulate the structural performance during fire exposure

Depending on the extent to which calculations rules (2) are available and give economic designs, EC 2-6 differ with regard to the emphasis they place on the various procedures:

- The main approach in EC 2 will be the prescriptive approach (1)
- EC 3 focusses on calculation models (2), no tabulated data
- EC 4 utilizes all three procedures
- EC 5 gives only calculation models (2)
- and EC 6, at present, is confined to tabulated data (1)

It may be noted, that these differences in main procedures are also motivated by differences in sensitivity of structures to fire exposure; hence, enforcing a more unified approach may not be reasonable.

3.2 SOIL-STRUCTURE-INTERACTION

Please note the following use of notions by non-british, non-geotechnical-engineers: The term *soil* used herein describes the supporting system of the ground, responding to pressure from the foundation members. The term *foundation* covers soil plus foundation member. The term *structure* covers the foundation members plus whatever they support (building or bridge), which in turn is then denoted as the *superstructure.*

Furthermore, this contribution mainly refers to *spread foundations* and does not reflect the state of drafting in the Eurocodes but rather some preliminary ideas by a small group of engineers. It may help solving some of many problems in soil-structure-interaction.

3.2.1 Where are the problems?

Since we have building on soil for quite some time without major problems - and if problems occur they may become tourist attractions - why is soil-structure-interaction a problem in modern code writing?

There are two problems:

First is the problem mutual understanding and interface between structural and geotechnical engineering.

Second is the problem of load levels, safety factors, etc., which is related to the first problem and evolved from introducing the partial safety factor format in codes.

No problem and only stated for clarification is the following: Only differences in settlement may affect the structure in terms of forces and moments. The absolute settlement may be of concern for various reasons, but does not affect the structural performance.

3.2.2 Joint soil-structure system analysis

Imagine, you are designing a bridge, you being a team of structural and geotechnical experts. You already have commonly agreed on the general bridge and foundation design.

You know the structural properties of your bridge in terms of its load-deformation-behaviour or simply, stiffnesses and load bearing capacity. You also know the properties of the foundation in terms of its load-settlement-behaviour or simply, its stiffness and bearing capacity (load level at which the soil seizes to fullfill its supporting function), cf. fig. 3.2.1

Then you may model your structure e.g. according to fig. 3.2.2 as a bridge supported by springs, the springs performing in accordance with fig 3.2.1. For values of material properties, cf. section 3.2.4 herein.

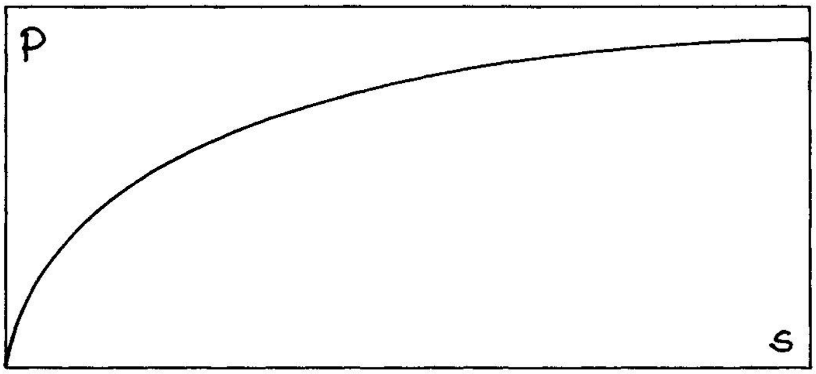

Fig. 3.2.1 Load-settlement behaviour

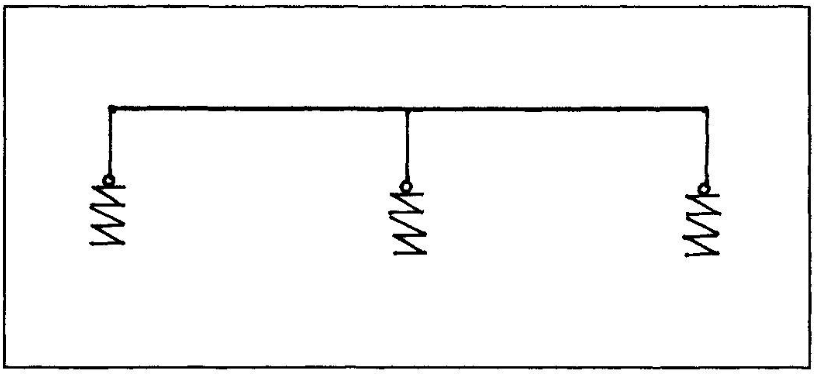

Fig. 3.2.2 Joint soil-structure system (example)

For verifying SLS you perform an elastic analysis of the system, applying loads according to the relevant combination and check the SLS criteria.

For verifying ULS you will generally perform a non-linear analysis: In the most general form of analysis you apply loads to the structure and gradually increase these loads, watching the development of forces and moments. At some load level (P_{ult}) a further increase causes one or several of the following states:

- the bearing capacity of the bridge is exhausted
- the bearing capacity of foundation members is exhausted
- the global stabilty of the structure is lost
- the bearing capacity of the soil is exhausted.

Theoretically, the last state mentioned is not a limit state in its own right: If attaining the bearing capacity of the soil results in failure of the structure - this is identified by the structural performance; on the other hand the bearing capacity of the soil may (locally) be exhausted, without causing failure in the structure. But this is not really important.

Depending on how material properties were introduced in the analysis, some adaption of the ultimate load level may be required (cf. section 3.2.4). If this load level is higher than the load level resulting from the fundamental combination, then (ULS) safety requirements are satisfied.

This type of analysis, in which the joint soil-structure-system is considered, is referred to as *modeling procedure 3.*

3.2.3 Separate analysis of systems

We generally do not consider the joint soil-structure-system but analyse separate systems, cf. fig. 3:2.3

- the structure or superstucture - say system A
- the soil or foundation - say system B

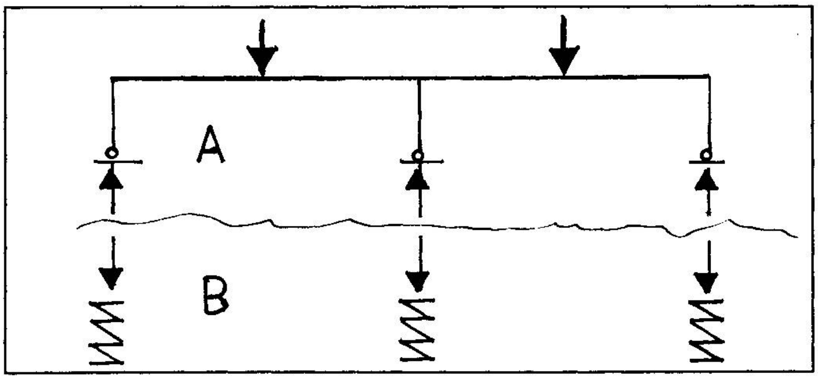

Fig. 3.2.3 Separate soil/structure systems

First simplification

We may proceed as follows:

1. We analyse system A and calculate the loading on system B assuming vertically rigid support of system A

2. We forget about system A and from the loading on system B we analyse system B

3. We calculate the deformations (settlements) of system B

4. Now we forget about system B and apply the calculated settlements to the support of system A and analyse system A.

5. For thus determined forces and moments we finally verify system A

6. And of course, we also verify system B

This procedure is denoted as *modeling procedure 2* herein. It seems, that it may always be applied but may sometimes lead to uneconomic designs.

The error involved c ı be checked by comparing the loading on system B in the 1. and 4. step. If the error is deemed too large we could repeat step 2 to 4 with the new loading on system B. With much time available we can continue to repeat the procedure untill the error tends to zero: Hence, we performed an iterative analysis of the joint soil-structure-system (transition to modeling approach 3).

Next simplification

But generally we are not paid for minimizing aformemtioned types of error and experience shows that - within certain limits - the effects of differential settlements on system A may be negligible.

Hence, on the basis of systematic calculations (supporting field investigations [1]) we may identify *limitations on settlements related to structural conditions* up to which an analysis of the structure accounting for differential settlements (step 4) is dispensible.

I.e. for a certain field of application only steps 1 to 3 and 6 need to be perfomed in the first place. If the calculated differential settlements - remain below aforementioned limitations, then system A is analyzed without possible settlements. This further simplification is denoted as *modeling procedure 1*

Even simpler

Finally, if we start saving calculation effort, we may ask, whether calculation of settlements is always required.

Again on the basis of systematic investigations we may identify *conditions for structures and foundations* which ensure that differential settlements are small and/or effects of differential settlements are small.

So within the field of application for modeling procedure 1, a smaller field of application may be identified for which settlements need not be calculated at all, i.e. only steps 1 and 2 and 6 are performed - giving *modeling procedure 0.*

3.2.4 Safety handling

Structural properties

After clarifying the mechanics, lets have a look at safety factors or design values to be adopted for the various calculations.

Starting with modeling procedure 3 again (but the conclusions are valid for all procedures) the following ist noted for structural properties:

It is rather straightforward, that consideration of an extended structure is no reason to use other values for structural properties than when analysing the structure alone:

For SLS calculations material properties are represented by values which are in the magnitude of mean values.

When calculating deformation of structures in the context of an hyperstatic anaysis (SLS and ULS), this is usually performed with stiffness-values in the magnitude of mean values.

When performing a non-linear analysis (for ULS), also strength properties are adopted in the magnitude of mean values.

I.e. for SLS calculations and for ULS analysis structural material properties are represented by X_m. On the other hand, geometrical imperfections - where relevant - are introduced with upper or lower characteristic values.

Soil properties

Obviously, soil properties should be treated in the same way as structural properties, i.e. they are generally represented by values in the magnitude of mean values. But the question is: When is the effect of variations of soil properties comparable to geometrical imperfections?

Tentatively the following criteria may be identified: Where the the resulting forces and moments in the structure
- are very sensitive to variations of the soil-structure stiffness ratio
- are very sensitive to local variations of soil stiffnesses or bearing capacity
- or where local variations can be expected to be large

upper and/or lower values should be used.

Having in mind some possible redistribution of forces and moments throughout the structure, the issue of sensitivity mainly refers to basic changes in the distribution of forces and moments (e.g. positive instead of negative moments). Hence, the cases where upper and/or lower values will be required in practice will be small. In our bridge example, however, we would check the effect of upper and lower stiffness values at different supports.

Load-levels for joint soil-structure analysis

For joint soil-structure analysis the relevant load combination for SLS and ULS will be applied as when analysing the structure alone.

With regard to the ultimate load level determined from non-linear analysis there is a need to make up for the difference between actually required design values for material properties and the values adopted in the analysis. Hence, the load level at which structural failure occured (cf. P_{ult} in section 2) needs to be adjusted. When using mean values X_m in the analysis, the load level P_{ult} is multiplied by

$$(1/\gamma_M) \cdot (X_k/X_m)$$

If this load level is higher than the load level resulting from the fundamental combination of actions, then ULS is verified.

Load levels for separate system analysis

If we now turn to the separate analysis of systems, we first have to decide on the load level to be used for determining the loading on system B (step 1).

For *SLS* verification in conjunction with soil-structure interaction we may agree on the permanent combination and proceed as follows:

1. We apply the *permanent* combination, analyse system A and calculate the loading on system B assuming vertically rigid support of system A
2. From the loading on system B we analyse system B
3. We calculate the deformations (settlements) of system B
4. Now we apply these settlements to the support of system A and analyse system A
5. For thus determined forces and moments we finally verify system A for SLS requirements
6. Foundation members are checked with regard to crack width criteria

For *ULS* verification we would be inclined to use the fundamental load combinations. However, it can be shown, that this gives settlements which are in excess of what we were used to in the pre-partial-safety-factor era. Hence, we may proceed as follows:

1. We apply the *rare* combination, analyse system A and calculate the loading on system B assuming vertically rigid support of system A

2. From the loading on system B we analyse system B

3. We calculate the deformations (settlements) of system B

4. Now we multiply the settlements - as indirect actions - with $\gamma_{F,ind}$ and apply these settlements to the support of system A and analyse system A for the γ_F -fold actions of step 1

5. For thus determined forces and moments we finally verify system A

6. Likewise, system B is verified for the γ_F - fold loading on system B according to step 2.

For the simpler modeling procedures, e.g. steps 4 and 5 are omitted and the settlements of step 3 are compared with specified limitations relevant for SLS and ULS

3.2.5 Conclusions

It may work this way, but more trial calculations are neccessary and many more problems are available for extensive intellectual exercises.

Reference given only as an example

[1] Skempton/MacDonald; The allowable settlement of buildings, Proc. Inst. Civ. Engineers, Part III, Vol. 5, pp 727, London, 1956

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