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Current revision of the fundamental Eurocode for design of civil engineering structures

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ABSTRACT: the present, globally-applicable revision of the fundamental EN 1990 Eurocode for the design of buildings and civil engineering structures is briefly summarised. General requirements are further elaborated with respect to structural resistance, serviceability and durability. In addition, provisions for robustness, sustainability and fire safety are included. An appropriate level of structural reliability should consider the consequences and possible causes of failure, public aversion and costs associated with reducing the risk of failure. However, the choice concerning the reliability level is left to national interpretation. The target reliability indexes are indicated for one-year and 50-year reference period, with no explicit link to the design working life being provided in the final draft of prEN 1990. It is proposed that the consequences of structural failure be organised into five categories; however, without providing recommendations on the target reliability indices for the lowest and highest consequence class.
Supplementary guidance on structural robustness is proposed in prEN 1990, Annex E. A structure should have a sufficient level of robustness that it will not be damaged to an extent disproportional to the original cause. The working life design should be considered for time-dependent performance of the structures. Ultimate and serviceability limit states should be verified for all relevant design situations. Apart from the commonly-used partial factor method, which comprises a basic method for structural verification, additional guidance is also given for application of non-linear methods. The partial factors have been newly-calibrated with the aim of achieving a more balanced reliability level for structures from different materials and loading effects.

KEY WORDS: basis of design, civil engineering, consequences class, design working life, durability, Eurocode, partial factor method, robustness, serviceability, sustainability, target reliability, ultimate limit state

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Текущий пересмотр основного Еврокода при проектировании строительных конструкций

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АННОТАЦИЯ: представлен применяемый в настоящее время пересмотр основного Еврокода EN 1990 при проектировании зданий и сооружений гражданского строительства. Доработаны основные требования с учетом структурного сопротивления, эксплуатационной надежности и долговечности. Кроме того, включены положения, касающиеся прочности, устойчивости и пожарной безопасности. При соответствующем уровне надежности конструкции следует учитывать возможные причины сбоя и последствия, неприятие общественностью и затраты, связанные со снижением риска сбоя. Однако выбор относительно уровня надежности остается за национальным толкованием. Целевые показатели надежности указаны для годичного и 50-летнего исходного (базисного) периода, причем в окончательном проекте prEN 1990 года нет прямой ссылки на расчетный срок эксплуатации. Предлагается разделить последствия разрушения конструкции на пять категорий, однако без рекомендаций по целевым показателям надежности для самого низкого и самого высокого класса последствий.
Дополнительное руководство по структурной устойчивости предлагается в приложении prEN 1990, Annex E. Структура должна иметь достаточный уровень надежности, чтобы не быть поврежденной в степени, несоразмерной первоначальной причине. Расчетный срок эксплуатации должен рассматриваться для зависящих от времени эксплуатационных структур. Конечные и предельные состояния работоспособности должны быть верифицированы для всех соответствующих проектов. Помимо широко используемого метода парциальных коэффициентов, который включает в себя базовый метод структурной верификации, даются дополнительные указания по применению нелинейных методов. Парциальные коэффициенты были заново откалиброваны для достижения более сбалансированного уровня надежности для конструкций из различных материалов и эффектов нагружения.

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КЛЮЧЕВЫЕ СЛОВА: основы проектирования, гражданское строительство, последствия, расчетный срок эксплуатации, долговечность, Еврокод, метод парциальных факторов, надежность, исправность, устойчивость, целевые показатели надежности, предельное состояние

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INTRODUCTION

The fundamental Eurocode EN 1990:2002 [1] establishes principles and requirements for safety, serviceability and durability that are intended for use in the structural design of buildings and civil engineering works, including geotechnical aspects, fire safety, earthquakes, execution and temporary structures. The final draft prEN 1990 [2] is a material-independent standard that should be used in conjunction with Eurocode 1991 for action on structures and with other material-dependent European Standards for the design and assessment of structures made of various materials.

The current global revision of the fundamental Eurocode EN 1990 [1] is intended to elaborate further general principles concerning actions, structural resistance, serviceability and durability, taking other relevant documents into account [3–5]. In addition, provisions for robustness, sustainability and fire safety are to be reformulated. The newly-formulated text should follow basic principles of comprehensiveness as well as enhanced European Committee for Standardisation (CEN) principles of “ease of use”. In order to support the ease of their use by designers, it was agreed that such principles should be achieved in the further development of the Eurocodes through:

1. Improving clarity.
2. Simplifying routes through the Eurocodes.
3. Limiting, where possible, the inclusion of alternative rules of application and a reduction in Nationally Determined Parameters (NDPs).
4. Avoiding or removing rules of little practical use in design.

However, such simplifications should be limited to the extent that they are technically justified and seek to avoid additional and/or empirical rules for a particular structure or for structural-element types.

Since the latest draft of the revised prEN 1990 [2] is incomplete, it is expected that a number of clauses may be adjusted or supplemented. The new Eurocode on basis of design will be accompanied by the revised standards on actions (EN 1991) and by revised material-oriented standards (EN 1992 to EN 1999). The new Eurocodes should provide improved physically-based models for actions that will better reflect interactions between loads and changes in the environment.

REQUIREMENTS

In the basic requirements, the necessity to comply with all the assumptions relied on in the Eurocodes is emphasised. Additional clauses on robustness and sustainability are appended. National choices in interpreting reliability levels should take the relevant factors into account, including:

1. The possible consequences of failure in terms of loss of life, injury and potential economic losses.
2. The possible cause and/or mode of attaining a limit state.
3. Public aversion to failure.
4. Costs and procedures necessary for reducing the risk of failure.

Table 1. Definition of consequence classes

Consequence Class		Severity in terms of	
		loss of human life	economic, social or environmental consequences
CC4	Highest consequences	Extreme	Huge
CC3	Higher consequences	High	Very great
CC2	Normal consequences	Medium	Considerable
CC1	Lower consequences	Low	Small
CC0	Lowest consequences	Very low	Insignificant

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Consequences of structural failure are organised into five subsequent classes, denoted CC0 to CC4, which depend on societal and economic aspects as indicated in Table 1. Provisions for the classes CC0 and CC4 are outside of the scope of the Eurocodes.

Target reliability levels related to consequence classes shall be given in the National Annexes. To assist national authorities in defining the target reliability levels applicable in a country, tentative values of reliability indices β related to ultimate limit state, consequence classes CC1, CC2 and CC3, as well as to one-year and 50-year reference periods, are indicated in Table 2. These values are based on previous studies [4, 5] and Annex C of prEN 1990 [2]; seismic situations are explicitly excluded. It is not specified whether the values in Table 2 are applicable for design situations associated with accident and fire; moreover, recommendations for Serviceability Limit States are also missing.

Table 2. Recommended target values for reliability index β (ultimate limit state)

Reliability class	Target values for β	
	1 year reference period	50 years reference period
RC3	5.2	4.3
RC2	4.7	3.8
RC1	4.2	3.3

prEN 1990 [2] does not include the possible transformation of the reliability level in relation to other reference periods even though this may be required for specifying reliability elements for design and assessment of common structures. Such a tool is proposed in the final draft of the Technical Specification on Assessment of existing structures [6] and in literature [7–11].

Separate clauses are devoted to robustness, design of working life, sustainability, durability and quality management. In particular a structure is to be designed and executed in such a way as to possess robustness in such a way that it will, during its designed working life, not be damaged by events caused by hazards to an extent disproportionate to the original cause. Additional robustness levels to those achieved by conforming to the Eurocodes should be provided to structures when specified by the client and/or the relevant authority. For example, adequate robustness may be provided by measures adopted to limit:

• damages due to identifiable events caused by foreseeable hazards;

• consequences of unidentifiable events caused by foreseeable or unforeseeable hazards.

A suitable combination of the following design measures may be adopted to provide adequate robustness against unidentifiable events caused by hazards:

• enhance redundancy;

• design of key elements to sustain notional accidental actions;

• design the structure and its parts according to prescriptive rules to provide sufficient integrity and ductility.

Concerning sustainability, prEN 1990 [2] recommends that the impact of the structure on the environment during its entire life cycle should be made as low as reasonably practicable by the choice of building materials and solutions, with due consideration of recyclability, durability and use of environmentally-compatible materials.

BASIC VARIABLES

Actions are classified by their variation in time as follows:

• permanent actions G;

• variable actions Q;

• accidental actions A.

The characteristic value F_k of an action shall be specified:

• as a mean-, upper-, lower- or nominal value (which does not refer to a known statistical distribution);

• in the project documentation, provided that consistency is achieved with the methods of EN 1991.

The characteristic value of a permanent action shall be assessed as follows:

• if the variability of G can be considered as small, a single value G_k may be used;

• if the variability of G cannot be considered as small, or where a range of values needs to be considered, two values shall be used: an upper value G_k when the effect of the action is unfavourable and a lower value $G_{k,fav}$ when the effect of the action is favourable.

The variability of G may be disregarded if G does not vary significantly during the designed working life of the structure and its coefficient of variation is small. G_k may then be taken equal to the mean value.

Water actions are also newly described in detail, classified to permanent, variable or accidental actions and their representative values are given.

For variable actions, the characteristic value Q_k shall correspond to either:

• An upper value with an intended probability of not being exceeded or a lower value with an intended probability of being achieved, during some specific reference period;

• A nominal value, which may be specified in cases where a statistical distribution is not known.

The characteristic value of climate actions is based upon the probability of 0.02 of its time-varying part being exceeded for a reference period of one year; this is equivalent to a mean return period of 50 years for the time-varying part. Characteristic values of traffic load effects on road bridges are based on a 1000-year return period, i.e. the probability of exceeding them by 5 % in 50 years.

For accidental actions, the design value A_d should be specified for individual projects. For seismic actions, the design value A_{Ed} should be assessed from

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the characteristic value A_{Ek} or specified for individual projects.

The basis for fatigue actions is provided by models for fatigue actions given in EN 1991.

The characteristic value of material property is normally defined as:

- where a low material or product property value is unfavourable, the characteristic value should be defined as the 5 % fractile value;
- where a high value of material or product property is unfavourable, the characteristic value should be defined as the 95 % fractile value.

Unless the design of the structure is sensitive to deviations of geometrical parameters, their characteristic values should be represented by their nominal values. If the design of the structure is sensitive to deviations of geometrical parameters, corresponding imperfections defined in the other Eurocodes should be taken into account. When there is sufficient data, the characteristic value of a geometrical parameter may be determined from its statistical distribution and used instead of a nominal value.

LIMIT STATE DESIGN

The traditional distinction between ultimate limit state and serviceability limit state is recognised. These limit states are considered also for verification of other requirements imposed on durability and sustainability. Additionally, it is stated that the limit states shall be verified using appropriate structural and load models. The partial factor method as given in EN 1990 is defined as a basic method.

The relevant design situations shall be selected while considering the circumstances under which the structure is required to fulfil its function. Design situations shall be classified as follows:

- persistent design situations, which refer to the conditions of normal use;
- transient design situations, which refer to temporary conditions applicable to the structure, e.g. during execution or repair;
- accidental design situations, which refer to exceptional conditions, e.g. to fire, explosion, impact or the consequences of localised failure;
- seismic design situations, which refer to conditions applicable to the structure when subjected to seismic events;
- fatigue design situations, which refer to conditions applicable to the structure when subjected to repeated cycles of loads or deformations.

The design value of resistance R_d for a specific design situation may be calculated using the general relationship:

$$R_d = \frac{1}{\gamma_{Rd}} R\left\{\frac{\eta X_k}{\gamma_m};\ a_d;\ \Sigma F_{Ed}\right\},$$

- where γ_{Rd} is a partial factor accounting for uncertainty in the resistance model, and for geometric deviations, if these are not modelled explicitly; $R\{\ldots\}$ denotes the output of the resistance model; η is a conversion factor accounting for scale effects, effects of moisture and temperature, of ageing of materials, as well as any other relevant parameters; X_k represents the characteristic values of material or product properties; γ_m is a partial factor accounting for unfavourable deviation of the material or product properties from their characteristic values, the random part of the conversion factor $\eta$the design value of the leading variable action;
- the design combination values of accompanying variable actions.

The load effects F_d for persistent and transient design situations may be determined using the basic expression:

$$\Sigma F_d = \sum_i \gamma_{G,i} G_{k,i} + \gamma_{Q,1} Q_{k,1} + \sum_{j>1} \gamma_{Q,j} \psi_{0,j} Q_{k,j} + \left(\gamma_P P_k\right),$$

where $\gamma_{G,i}$ is the partial factor applied to that permanent action; $G_{k,i}$ is the characteristic value of a permanent action; $\gamma_{Q,j}$ is the partial factor applied to the variable action; $Q_{k,j}$ is the characteristic value of a variable action; $\psi_{0,j}$ is the combination factor applied to the variable action; γ_P is the partial factor applied to the pre-stress;

Table 3. Combinations of actions for ultimate and serviceability limit states

Limit state	Ultimate limit states				Serviceability limit states			
Design action	Persistent and transient	Accidental	Seismic	Fatigue	Characteristic	Frequent	Quasi-permanent	Seismic
Permanent $G_{d,j}$	$\gamma_{G,j} G_{k,j}$	$G_{k,j}$	$G_{k,j}$	$G_{k,j}$	$G_{k,j}$	$G_{k,j}$	$G_{k,j}$	$G_{k,j}$
Leading variable $Q_{d,1}$	$\gamma_{Q,1} Q_{k,1}$	$\psi_{1,1} Q_{k,1}$ or $\psi_{2,1} Q_{k,1}$	$\psi_{2,i} Q_{k,i}$	$\psi_{1,1} Q_{k,1}$	$G_{k,1}$	$\psi_{1,1} Q_{k,1}$	$\psi_{2,i} Q_{k,i}$	$\psi_{2,i} Q_{k,i}$
Accompanying variable $Q_{d,i}$	$\gamma_{Q,i} \psi_{0,i} Q_{k,i}$	$\psi_{2,i} Q_{k,i}$		$\psi_{2,i} Q_{k,i}$	$\psi_{0,i} Q_{k,i}$	$\psi_{2,i} Q_{k,i}$		
Prestress P_d	$\gamma_P P_k$	P_k	P_k	P_k	P_k	P_k	P_k	P_k
Accidental A_d	—	A_d	—	—	—	—	—	—
Seismic A_{Ed}	—	—	A_{Ed}	—	—	—	—	A_{Ed}
Fatigue Q_{fat}	—	—	—	Q_{fat}	—	—	—	—

P_k is the characteristic value of any pre-stress applied to the structure (if present).

Two other expressions for load combination rules can be applied; the choice is an NDP.

Table 3 further clarifies the load combinations for ultimate and serviceability limit states according to EN 1990. For the ultimate limit state, as well as for a persistent and transient design situation, the above-mentioned basic expression is considered only in Table 3.

Besides the basic partial factor (semi-probabilistic) method, reliability requirements can be checked by the following approaches according to prEN 1990 [2]:

- reliability-based, in which the structure fulfils a set of reliability requirements;
- risk-informed, in which the sum of all costs (building, maintenance, etc.) and economic risks (with respect to failure or malfunctioning) is minimised while fulfilling applicable human safety criteria.

The reliability-based approach may be applied to design situations where uncertainties in the representation of loads, load effects, material resistances, and system effects are of such a nature that the reliability-based approach gives a significantly better representation of reality than the partial factor design format. Design situations that are not covered by the partial factor design format can include:

- situations where relevant loads or hazard scenarios are not covered by EN 1991;
- the use of building materials or combination of different materials outside the usual application domain, e.g. new materials, behaviour at very high temperatures;
- ground conditions, such as rock, which are strongly affected by discontinuities and other geometrical phenomena.

The reliability-based approach should also be used for the calibration of partial factors in the semi-probabilistic approach.

The use of the risk-informed approach may apply to design situations where both the uncertainties and the consequences are outside common ranges. As an example, such design situations may be those associated with accidents and those which clearly deviate from situations generally covered by the Eurocodes. Relevant guidance can be found in ISO 2394 [3].

Risk-informed and reliability-based approaches shall only be employed if uncertainties are represented consistently on the basis of unbiased assumptions.

DESIGN ASSISTED BY TESTING

Testing may be used to determine parameters for use in design. Testing is carried out, for example, in the following circumstances:

- if adequate calculation models are not available;
- in order to confirm by control checks assumptions made in the design;
- in order to define *S-N* curves;
- in order to determine pressure or force coefficients for wind actions;
- if a large number of similar components are to be used;
- in order to verify dynamic behaviour of the structure.

The statistical uncertainty due to a limited number of test results shall be taken into account. A detailed statistical procedure is described in informative Annex D of prEN 1990 and other references [7, 8]. Partial factors (including those for model uncertainties) should be specified to provide the required level of reliability.

ANNEXES

PrEN 1990 [2] includes five annexes:

- Annex A (normative) Application rules for buildings and geotechnical works; bridges; towers, masts and chimneys; silos and tanks; structures supporting cranes and other machineries; and for marine coastal structures;
- Annex B (informative) Management measures to achieve intended reliability;
- Annex C (informative) Reliability analysis and code calibration;
- Annex D (informative) Design assisted by testing;
- Annex E (informative) Additional robustness provision for buildings.

CONCLUSIONS

The forthcoming revision of the basic Eurocode prEN 1990 for design of buildings and civil engineering structures elaborates a number of provisions concerning structural resistance, serviceability and durability. In addition, it presents new provisions for robustness, sustainability, and fire safety. An appropriate level of structural reliability should consider the consequences and possible causes of failure, public aversion and the costs involved in reducing the risk of failure. The choice of the reliability level is left open to decision and calibration at the national level. The final draft is supplemented by a number of annexes devoted to application rules for different types of structure, management, reliability analysis, design by testing and robustness. Ongoing revisions of the EN 1991 standards indicate that the new suite of Eurocodes should provide improved physical-based models for actions that will introduce new types of actions, present improved models and better reflect interactions between loads and changes in the environment.

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