ОБЩИЕ ПРОБЛЕМЫ СТРОИТЕЛЬНОЙ НАУКИ И ПРОИЗВОДСТВА

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IMPLEMENTATION AND APPLICATION OF EUROCODES

Technical and editorial problems may be encountered during the implementation of Eurocodes into the systems of national standards. The main technical problems to be solved include specification of the target reliability levels of different types of construction works, definition of characteristic values, partial and combination factors and load combination rules for structures and geotechnical design. It is expected that in the next generation of Eurocodes further harmonisation and reduction of NDPs on the basis of technical assessment will be provided.

Present generation of Eurocodes encompass a suite of 58 Parts which represents a great achievement in European harmonization of structural codes. The key role in the design of new and existing structures represents the concept of reliability differentiation of construction works and the selection of target reliability level. Recommended target reliability level, expressed commonly by reliability index b = $-\Phi^{-1}(p)$, where Φ denotes the standardized normal distribution function and p the failure probability, are provided in several documents.

Load combination rules for verification of geotechnical design (ULS of type GEO) give three alternative approaches leading in some cases to considerably different results. For example, resulting dimensions of common footing may have differences about 20 to 40 %.

Other technical problems of implementation include lack of guidance for application of different design situations. For example a structure under fire should be verified according to the accidental design situation for which alternative combination factors are indicated in EN 1990. During subsequent repair the structure should comply with the requirements for the transient design situation, for which, up to now, there are no explicit rules for existing structures provided by Eurocodes.

Another problem is a unified definition of the characteristic values for variable actions, particularly for imposed and climatic actions, when 0.98 fractile for time dependent components should be supplemented by probabilistic specification of resulting action effect (for example, for imposed load and wind).

System of Eurocodes constitutes a great achievement in harmonization of European standards for structural design. In national implementation, it is strongly recommended to specify a unique (unambiguous) variant chosen from recommended options. Terminology and translation should be adapted to the sense of the original English version. Other manner of translations may be confusing or misleading.

Key words: bases of design, target reliability, partial factors, national choice.

1. Introduction. Present generation of Eurocodes encompass a suite of 58 Parts which represents a great achievement in European harmonization of structural codes. The Eurocodes were developed with technical support of European and international scientific organizations including fib, JCSS, IABSE, RILEM, and standardization committees CEN and ISO. The scientific bases of structural design were developed by the JCSS in the document Probabilistic Model Code [1], and have been updated continuously. The International standard ISO 2394 [2] constitute general design rules relevant to the verification of wide majority of buildings and civil engineering works. The context of structural reliability is developed furthermore through standards for risk assessment, such as the standard ISO 13824 [3] and the JCSS Guideline on Risk Assessment [4].

Most European countries have already implemented Eurocodes into their system of national standards. They have developed National Annexes with selected Nationally

Determined Parameters (NDPs) supplemented in some cases also by non-contradictory information (NCCI). However, current existence of more than 1600 NDPs in Eurocodes and possibility for their national choice adversely influences intended harmonization of European standards for structural design.

Joint Research Centre (JRC) has prepared a database for collection of NDPs of CEN Member States. It is foreseen to analyse NDPs with intention for their further harmonization and considerable reduction. However, presently about half of CEN countries are filling up the JRC database only what makes considerable obstacle for analyses of NDPs. It is partly caused by slow implementation process in some countries, by technical problems including lack of experience mostly caused by non-regular attendance of meetings of the technical committee CEN/TC 250 and its subcommittees SC1 to SC9 and also by economic problems. Implementation of Eurocodes is running against several imperfections of Eurocodes as inaccuracies or faults, ambiguousness of interpretation of provisions and presence of alternative procedures. Despite that most problems were removed during translations and preparation of National Annexes, several questions of technical and editorial character remains still open.

The need for "simplification" and "shortening" of Eurocodes is a real problem for which satisfactory answers have not yet been found. The main difficulty of the problem is the feeling that what is too simple may be wrong, and what is exact is often too complex and may be unusable in practice.

The following critical review is based on the previous studies provided in [5—7] and includes only limited number of general problems noted during application of Eurocodes in the Czech Republic. Similar difficulties to those presented here may be encountered in other countries including Russia, where the concept of limit states in conjunction with the partial factor method has been used for a long time. Presented experience and technical findings included in the following text are expected to provide valuable recommendations for majority of countries implementing Eurocodes, and for their future revisions and improvements.

2. Selected technical problems

2.1. Target reliability level. The key role in the design of new and existing structures represents the concept of reliability differentiation of construction works and the selection of target reliability level. Recommended target reliability level, expressed commonly by reliability index $\beta = -\Phi^{-1}(p)$, where $\Phi(p)$ denotes the standardized normal distribution function and p the failure probability, are provided in several documents [2, 5, 6]. In EN 1990 [8] the target reliability index β is given for two reference periods (1 year and 50 years) as shown in Tab. 1. However, no explicit link between the target reliability level and the design working life is provided in [8].

Tab. 1. Reliability classification in accordance with EN 1990 [8]

Reliability class	Consequences of structural failure	Reliability index β for reference period		Examples of buildings and civil engineering works
		1 year	50 years	
RC3 – high	High	5,2	4,3	Granstands, public buildings
RC2 – normal	Medium	4,7	3,8	Residences and offices
RC1 – low	Low	4,2	3,3	Agricultural buildings

Table 1 is not easy to understand for common user and, in fact, may be misinterpreted. It should be underlined that a couple of β values (for 1 year and 50 years) given in Tab. 1 for each reliability class corresponds to the same reliability level. Practical application of these values depends on the time period considered in the verification, which may be linked to available probabilistic information concerning time variant basic variables (imposed load, climatic actions, seismic actions, etc.).

For example, for a building in reliability class 2 and the design working life of 50 years the reliability index β = 3,8 should be used provided that probabilistic models of basic variables are available for this period. The same reliability level is achieved when the reference period of 1 year and β = 4,7 are applied using the theoretical models for one year. Note that it could be sufficient to provide a set of values of reliability index β in Table 1 (taken from EN 1990 [8]) for a reference period of one year and apply a relationship given in Annex C [8] for other reference periods.

A more detail recommendation concerning reliability levels is provided by ISO 2394 [2] where the target reliability indices are indicated for the whole design working life (without any limitation) and related not only to the consequences, but also to the relative costs of safety measures (see Tab. 2).

Tab. 2. Target reliability index β (life-time, examples) in accordance with ISO 2394 [2].

Relative costs of safety measures	Consequences of failure			
	small	some	moderate	great
High	0	1,5	2,3	3,1
Moderate	1,3	2,3	3,1	3,8
Low	2,3	3,1	3,8	4,3

ISO 2394 [2] seems to recommend the reliability indices lower than those given in EN 1990 [8] even for the "small relative costs" of safety measures. ISO 2394 [2] recommends indices for "life-time", thus related to the design working life.

However, a clear link between the design working life and the target reliability level is not apparent from the both documents [2, 8]. Thus, it is not clear which target reliability index should be used for a given design working life different from 50 years (say 100 years applied commonly for bridges). Obviously, it is desired to clarify the link between the design working life and the reliability index and to provide guidance for specification of the target reliability level for a given design working life. It appears that the results of probabilistic optimization should be supplemented by practical recommendations.

2.2. Partial factor method. In accordance with the partial factor method accepted in EN 1990 [8] the design values of the basic variables, X_d and F_d, are usually not introduced directly into the design expressions. They are commonly expressed in terms of their representative values X_{rep} and F_{rep}, which may be:

the characteristic values X_k and F_k, i.e. values with a prescribed or intended probability of being exceeded, for example for actions, material properties and geometrical properties;

the nominal values X_{nom} and F_{nom}, which may be treated as characteristic values for material properties and design values for geometrical properties.

The representative values X_{rep} and F_{rep} should be divided and/or multiplied, respectively, by the appropriate partial factors to obtain the design values X_d and F_d. Considering the representative values X_{rep} and F_{rep} by their characteristic values X_k and F_k, the design values X_d and F_d can be expressed as

$$X_d = X_k/\gamma_M \qquad (6)$$

$$F_d = \gamma_F F_k \qquad (7)$$

where γ_M denotes the partial factor of materials properties, and γ_F the partial factor of action. Both partial factors γ_M and γ_F are in most cases greater than 1.

As described in the following sections, both partial factors γ_M and γ_F should include model uncertainties, which may significantly affect the reliability of a structure. As stated in EN 1990 [8], design values for model uncertainties may be incorporated into the design expressions through the partial factors γ_{Ed} and γ_{Rd} applied as follows:

$$E_d = \gamma_{Ed} E\left\{\gamma_{gj} G_{kj}; \gamma_P P; \gamma_{q1} Q_{k1}; \gamma_{qi} \psi_{0i} Q_{ki}; a_d \ldots\right\}; \qquad (8)$$

$$R_{\mathrm{d}} = R\{\eta X_{\mathrm{k}} / \gamma_{\mathrm{m}}; a_{\mathrm{d}}...\} / \gamma_{Rd}. \quad (9)$$

Here η denotes a conversion factor appropriate to the material property. The factor ψ, which takes account of reductions in the design values of variable actions, is applied as ψ_0, ψ_1 or ψ_2 to simultaneously occurring accompanying variable actions. The following simplifications may be made to Eqn. (8) and (9).

a) On the loading side (for a single action or where linearity of action effects exists):

$$E_{\mathrm{d}} = E\ \{\gamma_{F,\mathrm{i}} F_{\mathrm{rep},i}, a_{\mathrm{d}}\}. \quad (10)$$

b) On the resistance side the general format is given in Eqn. (9), and further simplifications may be given in the relevant material-oriented documents.

The relation between individual partial factors in Eurocodes is schematically indicated in Fig. 1. The partial factor γ_F may be split into the load intensity uncertainty factor γ_f and model uncertainty factor γ_{Ed}. Similarly, the partial factor γ_{M} may be split into the material property factor γ_{m} and resistance model uncertainty factor γ_{Rd}.

Generally, it holds that

$$\gamma_F = \gamma_{\mathrm{f}}\, \gamma_{Ed;} \quad (11)$$

$$\gamma_{\mathrm{M}} = \gamma_{\mathrm{m}}\, \gamma_{Rd.} \quad (12)$$

Numerical values of both factors of model uncertainty depend on particular conditions and should be derived from previous experience and available experimental data. The factor of load effect g_{Ed} may be expected within the interval from 1,05 to 1,15. The resistance factor g_{Rd} depends on the construction materials and behaviour of the structural member. For example, uncertainty of the bending capacity of a steel beam will be lower (about 1,05) than uncertainty of a welded connection capacity (about 1,15).

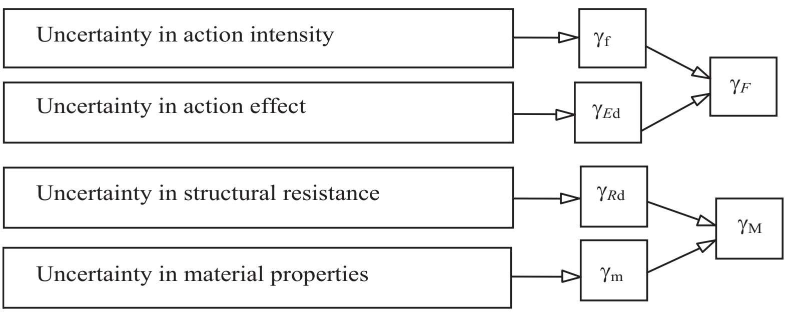

Fig. 1. Partial factors in EN 1990 [8]

2.3. Partial factors for permanent actions. Consider a permanent load *G* (self-weight) having a normal distribution. It is assumed that the characteristic value G_{k} of *G* is equal to the mean μ_G:

$$G_k = \mu_G \quad (13)$$

Then the design value G_{d} is given as

$$G_{\mathrm{d}} = \mu_G - \alpha_F \times \beta \times \sigma_G = \mu_G(1 + 0{,}7 \times \beta \times V_G). \quad (14)$$

In equation (14) μ_G denotes the mean, σ_G the standard deviation, V_G the coefficient of variation and $\alpha_E = -0{,}7$ the sensitivity factor of actions as recommended in EN 1990 [8]. The partial factor g_G of *G* can be then determined from the ratio

$$\gamma_G = G_d / G_k \quad (15)$$

Taking into account equation (13) and (14) it follows from (15) that

$$\gamma_G = (1 + 0{,}7 \times \beta \times V_G) \quad (16)$$

Fig. 2 shows the variation of the partial factor γ_G with the reliability index β for selected coefficients of variation V_G. If $V_G = 0{,}1$ and $\beta = 3{,}8$, then the partial factor $\gamma_G = 1{,}27$. However, if $V_G = 0{,}03$ (a safe value for self-weight and massive structures), then $\gamma_G = 1{,}08$. Obviously, a single partial factor $\gamma_G = 1{,}35$ recommended in [8] is a conservative value. A series of realistic values $\gamma_G \geq 1{,}05$ are provided in [9] e.g. for self-weight of different materials (concrete, steel, soil). Similar values of partial factors were also recommended in original Czech standards.

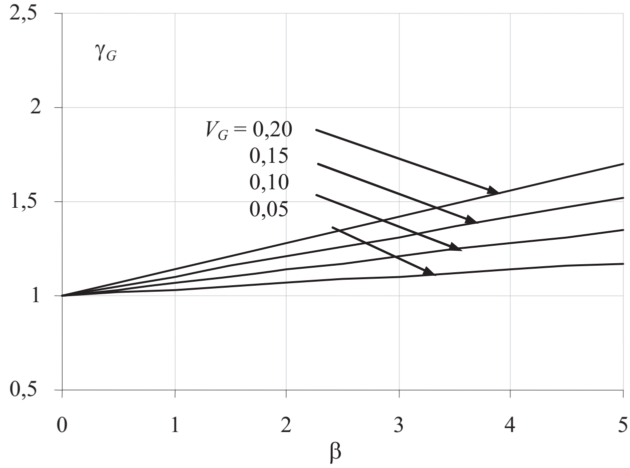

Fig. 2. Variation of the partial factor g$_G$ with the reliability index b for selected values of the coefficient of variation V_G

2.4. Partial factors for variable actions. A similar procedure as in the case of the permanent load G can be used for estimation of the partial factors g$_Q$ for variable loads Q. Assuming the Gumbel distribution, the characteristic value of action is usually defined as 0,98 fractile of annual extremes (or extremes related to a certain basic reference period) and is given as

$$Q_k = \mu_Q\,(1 - V_Q\,(0{,}45 + 0{,}78\,\ln(-\ln(0{,}98)))). \tag{17}$$

The design value Q_d related to the working life described by period ratio N is given as

$$Q_\mathrm{d} = \mu_Q\,(1 - w_Q\,(0{,}45 - 0{,}78\alpha_T\,\ln(\mathrm{N}) + 0{,}78\ln(-\ln(\mathrm{F}^{-1}(-\alpha_E\beta))))). \tag{18}$$

In Eqn. (17) and (18) μ_Q denotes the mean, w_Q the coefficient of variation of extreme values of Q determined for the basic reference periods (for 1 or 5 years), N denotes the ratio of the working design life, for example 50 years, and the basic reference period. As an example, the period ratio $N = 10$ (= 50/5) is considered below. Finally, $\alpha_E = -\,0{,}7$ is the sensitivity factor of Q and α_T is the time-sensitivity factor given by the ratio w'_Q / w_Q, where w'_Q denotes the coefficient of variation of the time-dependent component of Q and w_Q denotes the coefficient of variation of the total Q. When Q depends on time-dependent components only, $w'_Q = w_Q$ and $\alpha_T = 1$. Note that the reliability index β in Eqn. (18) is related to the design working life (for example to 50 years) and not to the basic reference period (for example to 1 or 5 years). The partial factor γ_Q of Q is given as

$$\gamma_Q = Q_d / Q_k \tag{19}$$

The partial factor γ_Q of a variable action Q defined by Eqn. (19) depends on five parameters. In addition to w_Q, α_E, β (used also in the case of time-invariant basic variables), the partial factor of variable actions γ_Q depends also on the period ratio N and on the time-sensitivity factor α_T. Fig. 3 shows the variation of γ_Q with the coefficients of variation w_Q for selected values of β assuming a Gumbel distribution of Q, and the period ratio $N = 10$ (the design working life 10 times greater than the basic reference period) and the time-sensitivity factor $\alpha_T = 1$ (no time-independent components).

It should be noted that the time-variant component may have a considerably lower variability than the total action Q, and, therefore, a reduced coefficient of variation should be considered in Eqn. (20) for estimating time-variant effects ($\alpha_T < 1$). Consequently, the predicted design value Q_d and the partial factor γ_Q would decrease. Without going into details, it appears that the value $\gamma_Q = 1{,}5$, which is recommended in EN 1990 [8], is a reasonable approximation corresponding to the reliability index $\beta = 3{,}8$, the coefficient of variation $w_Q = 0{,}3$ (that may be considered as a reduced coefficient of variation of the extremes of Q) and to the period ratio $N = 10$ (the design working life being 10 times of the basic reference period).

The factor $\gamma_Q = 1{,}5$ appears to be conservative for $V_Q < 0{,}3$ and unsafe for $V_Q > 0{,}3$. Note that $\gamma_Q = 1{,}4$ is given in Russian code [13] for snow and wind actions ($\gamma_Q = 1{,}4$ for snow and $\gamma_Q = 1{,}2$ to 1,3 for wind actions in original Czech standards).

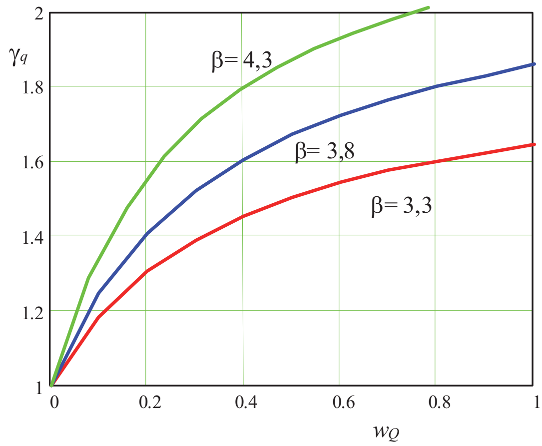

Fig. 3. Variation of γ_Q with the coefficients of variation w_Q for selected values of β assuming a Gumbel distribution of Q, period ratio N =10 and $\alpha_T = 1$

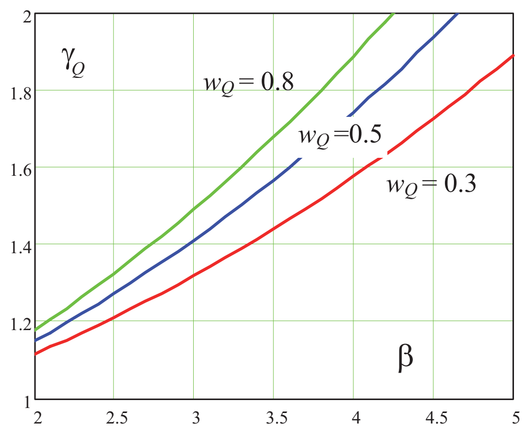

Fig. 4. Variation of γ_Q with the reliability index b for selected values of the coefficients of variation w_Q assuming a Gumbel distribution of Q, ratio $N = 10$ and $\alpha_T = 1$

2.5. Load combination rules. Two alternative procedures are given in EN 1990 [8] for verification of EQU. The first procedure is based on separate verification of EQU and application of STR (if needed), the second approach is based on combined verification and appears to be in some cases less safe.

Load combination rules for verification of Ultimate limit states (ULS) of type strength (STR) described in EN 1990 [8] by expression (6.10) and its modification (6.10a) and (6.10b) offer two alternatives which may lead to significant differences in load effects (commonly about 15—20 %). This problem is well known and already thoroughly analysed in [6, 7]. As a result of these investigations it is strongly recommended to specify in national implementation a unique (unambiguous) variant, similarly as in recently revised Russian standard [9].

Load combination rules for verification of geotechnical design (ULS of type GEO) give three alternative approaches leading in some cases to considerably different results. For example resulting dimensions of common footing may have differences about 20 to 40 %.

3. Other technical problems

Other technical problems of implementation include lack of guidance for application of different design situations. For example a structure under fire should be verified according to the accidental design situation for which alternative combination factors are indicated in EN 1990 [8]. During subsequent repair the structure should comply with the requirements for the transient design situation, for which, up to now, there are no explicit rules for existing structures provided by Eurocodes.

Another problem is a unified definition of the characteristic values for variable actions, particularly for imposed and climatic actions, when 0,98 fractile for time dependent components should be supplemented by probabilistic specification of resulting action effect (for example for imposed load and wind, [9, 10]).

Concerning imposed load provided in EN 1991-1-1 [9], a more detail guidance on the specification of the load intensity from recommended intervals is needed. Clarification of when the partitions and parapets are acting as barriers and should be exposed to horizontal loads is to be provided.

The document on accidental loads EN 1991-1-7 [11] should be further elaborated and supplemented by other sources of accidental loads (explosion of various chemicals). The procedure of risk assessment should be provided by appropriate risk criteria.

4. Editorial problems

The formal editorial problems including terminology and translation cause significant difficulties in many countries, particularly in those countries (including the Czech Republic and Russia) where the concept of limit states in conjunction with the partial factor method have been used for a long time. Eurocodes were developed much later, and, consequently, are based on new scientific basis available at that time. Unfortunately, in those days available documents on partial factor methods (as earlier versions of recently revised standard [2]) have not been taken into account.

New terminology and translation of English versions of Eurocodes cause sometimes difficulties and misunderstanding. Translations to different European languages may be in some cases confusing and misleading and should be prepared with help of experts on structural design. To avoid future ambiguity it is recommended to adopt the terminology and adapt the translation to the sense of the original English versions. For facilitation of national implementation of European standards, several Czech technical vocabularies have been prepared which are focused on loading, reliability of structures and material oriented structures.

5. Evolution of eurocodes

Further evolution of Eurocodes proposed in document [12] includes simplifications and clarification of provisions, revision of serviceability criteria (imperfections, deflections, vibrations), incorporation of the latest results of research including structural glass, FRP polymers, membrane structures, guidance for existing structures, re-consideration of the status of certain clauses or annexes, improvement of the liaison with other European standards, evaluation of contents with regards to mainly first two basic requirements of the Construction Product Directive (CPR). The basis of design rules will be transferred from several parts of EN 1991 and EN 1993 to Annexes A3 to A5 of EN 1990 [8].

It is foreseen to reduce the number of NDPs on the basis of analysis of JRC database and review possible need for changes in the National Annexes in comparison to recommended values provided in Eurocodes.

It is proposed to develop requirements for robustness of structures, for design of fatigue, for application of non-linear approach and to introduce criteria for displacement and vibration of structures in EN 1990 [8].

6. Conclusions

(1) System of Eurocodes constitutes a great achievement in harmonization of European standards for structural design.

(2) The main technical problems of implementation with regards to the basis of design include specification of the target reliability level, definition of the characteristic values, partial and combination factors and load combination rules for various types of structures and geotechnical design.

(3) In national implementation, it is strongly recommended to specify a unique (unambiguous) variant chosen from recommended options.

(4) Terminology and translation should be adapted to the sense of the original English version. Other manner of translations may be confusing or misleading.

(5) Next generation of Eurocodes should be drafted with regards to the need for further harmonization and reduction of NDPs, for simplification and user-friendly applications.

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ВВЕДЕНИЕ ЕВРОКОДОВ В СОСТАВ НАЦИОНАЛЬНЫХ СТАНДАРТОВ И ИХ ПРИМЕНЕНИЕ

Введение Еврокодов в состав систем национальных строительных стандартов может сопровождаться проблемами как лингвистического, так и технического характера. Основные технические проблемы представляют собой определение необходимых уровней надежности различных видов строительных конструкций, числовых значений всевозможных параметров, частичных и комбинированных коэффициентов, правил сочетаемости нагрузок на конструкции, а также требований к геотехническому проектированию. Следующее поколение Еврокодов будет характеризоваться более высокой степенью гармонизации и сокращением численности параметров, значения которых будут устанавливаться на внутринациональном уровне.

Ключевые слова: основы проектирования, требования к надежности, частичные коэффициенты, национальный выбор.

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