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Standards for the Assessment of Existing Structures: Real Need or Caprice of Code Makers?

Normas para la evaluación de las estructuras existentes: ¿necesidad real o capricho de la furia reguladora?

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ABSTRACT

The assessment of existing structures is an urgent issue of great economic importance in an increasing number of countries around the globe, as in many places a growing part of the total construction activity involves existing buildings, bridges and other civil engineering works. Currently, the Eurocodes, which will be used in all member states of the European Committee for Standardization, CEN, and possibly in more and more countries outside this space, are mainly focused on designing new structures. The use of design-oriented methods to assess existing structures often leads to a high degree of conservatism. This has serious economic, ecological and socio-political consequences if satisfactory structures are condemned as unsafe, thereby leading to an unnecessary investment of resources in their retrofitting or replacement, including the associated dismantling. For this reason, assessing existing structures often requires the use of refined methods that go beyond the scope of the design codes for new structures. Therefore, in the last 20 years, methods for assessing existing structures have been developed in many countries on a national level. However, they have not yet been coordinated and are not widely used in daily practice. There is therefore an urgent need to merge the various national approaches into a generally accepted, coherent and harmonized set of rules for existing structures that complement those for the design of new structures. CEN therefore took the initiative to start a project to develop new European technical rules for the assessment and retrofitting of existing structures. The development of the corresponding part of the Eurocode should be achieved in three steps. Two of these steps have already been completed, namely the preparation of a Scientific and Policy Report and, once adopted by the National Standardization Bodies of the member states, the conversion into a CEN Technical Specification. The third step, the conversion of the Technical Specification into an EN Eurocode Part, is currently in progress. Against this background, relevant differences between assessment and design from the point of view of structural reliability are discussed in this paper and some needs for further code provisions with regard to existing structures are identified.

KEYWORDS: Existing structures, deterioration, reliability, robustness, assessment, uncertainty, updating, probabilistic methods, partial factors, codes.

RESUMEN

La evaluación de las estructuras existentes es un tema prioritario, de gran importancia económica, en un número creciente de países de todo el mundo ya que en muchos lugares una parte cada vez mayor del mercado de la construcción se centra en las actuaciones relacionadas con edificios, puentes y otras obras de ingeniería civil que ya existen. Actualmente, los Eurocódigos, que se utilizarán en todos los estados miembro del Comité Europeo de Normalización, CEN, y posiblemente en más y más países fuera de este espacio, están principalmente enfocados al proyecto de nuevas estructuras. El empleo de métodos orientados al dimensionado para evaluar las estructuras existentes a menudo conduce a un alto grado de conservadurismo. Las consecuencias económicas, ecológicas y sociopolíticas podrían ser significativas si se condenaran como inseguras unas estructuras cuyas prestaciones son satisfactorias, llevando a una inversión innecesaria de recursos en su rehabilitación o desmantelamiento y sustitución. Por esta razón, la evaluación de las estructuras existentes a menudo requiere el uso de métodos refinados que van más allá del alcance de las reglas normalizadas para el proyecto de nuevas estructuras. Consecuentemente, en los últimos 20 años, se han desarrollado métodos para la evaluación de las estructuras existentes en muchos países a nivel nacional. Sin embargo, estos métodos aún no se han coordinado entre sí y su implementación en →

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la práctica diaria suele ser escasa. Existe por ello una necesidad urgente de fusionar los diversos enfoques nacionales en un conjunto de reglas generalmente aceptadas, coherentes y armonizadas para las estructuras existentes que complementen las reglas para el proyecto de nuevas estructuras. CEN tomó la iniciativa de iniciar un proyecto para desarrollar nuevas normas técnicas europeas para la evaluación y la rehabilitación de las estructuras existentes. Está previsto que el desarrollo de la parte correspondiente del Eurocódigo se logre en tres pasos. Ya se han completado dos de estos pasos, a saber, la preparación de un Informe Científico y de Política y, una vez adoptado por los Organismos Nacionales de Normalización de los estados miembro, la conversión de este documento en una Especificación Técnica de CEN. El tercer paso, la evolución de la Especificación Técnica en una Parte del Eurocódigo, EN, está actualmente en progreso. Sobre este trasfondo, en el presente artículo se analizan las diferencias más relevantes entre la evaluación y el proyecto desde el punto de vista de la fiabilidad estructural y se identifican algunos aspectos que deberían dar lugar a unas reglas adicionales en futuras normas dedicadas a las estructuras existentes.

PALABRAS CLAVE: Estructuras existentes, deterioro, fiabilidad, robustez, evaluación, incertidumbre, actualización, métodos probabilistas, coeficientes parciales, normas.

1. INTRODUCTION

1.1. Motivation

Current and future activities related to the development of cities, industrial areas and infrastructures should be determined by sustainability goals [1]. New needs are therefore not simply answered by adding new buildings and infrastructures to the existing built environment or by replacing existing with new engineering works. Rather, ways are being explored to modify existing systems to meet new demands, or simply to extend their service life. For this purpose, the reliability of existing structures must be verified, activity that is usually denominated as assessment [2, 3].

In general, an assessment of an existing structure may be required in the case of [4]:

- a change in the purpose of the structure compared to that for which it was originally designed or previously assessed;
- deviations in the properties of the structure from those adopted in the original design or in the previous assessment.

Examples of changes in the purpose of a structure include:

- change of use;
- increase of actions;
- extension of the originally intended design service life;
- increase in reliability requirements (e.g. due to higher consequences in case of failure).

Deviations in the properties of a structure can be due to the following causes, among others:

- modifications of the structural system (e.g. extension, upgrading, repair);
- deterioration induced by time-dependent actions and environmental influences (e.g. corrosion, fatigue);
- damage induced by accidental events, overloads, changes of the boundary conditions (e.g. differential settlements);
- defects resulting from previously undetected errors during design, construction or use.

The general principles of structural reliability laid down in the Eurocode for structural design [5] also apply to the assessment of existing structures. However, there are important differences between assessing existing and designing new structures. The use of design-oriented methods to assess existing structures therefore often leads to a high degree of conservatism with serious economic, ecological and socio-political consequences if resources are invested in the unnecessary strengthening or replacement of existing structures with the associated disruptions [1]. This paper briefly discusses relevant differences between assessment and design.

Widely divergent approaches exist to deal with these differences. Such approaches are characterized not only by national choices and preferences, but also by differences depending on the type of structure being assessed [6]. There is therefore an urgent need to merge the various options into a generally accepted, coherent and harmonized set of rules for the assessment of existing structures that complement those for the design of new structures. The Technical Specification [3] recently published by the European Committee for Standardization, addresses these differences but provides only general principles for the assessment of existing structures which are currently being further developed [7, 8] for their effective operational use in practice (Section 7).

1.2. Scope

The main difference between assessing the performance in existing and design phase structures is that many characteristics whose values are merely anticipated in the latter can be measured in the former, taking also into account the effects of the construction process and subsequent life of the structure, during which it may have undergone alteration, deterioration, misuse and other changes to its as-built (or as-designed) state. The accuracy of the assessment results obtained by applying load and strength models can usually be improved by collecting more data about the structure under analysis and about the actions and influences to which it is exposed (Sections 3, 4). This does not mean, however, that the uncertainties can be completely resolved: in-service inspection and testing are also associated with uncertainties [4]. Therefore, assessment is conducted by stages [3], raising the quality of the information available from stage to stage.

Another relevant difference between the design of new structures and the assessment of existing ones concerns the level of reliability required (Section 2). The choice of this level depends, among other parameters, on the amount and expense of effort needed to reduce the risks associated with a structure. The cost of achieving a higher level of performance (i.e. increased safety) is usually high in existing structures compared to the cost of improving the same performance in the design phase of a new structure. This aspect should be considered when choosing the level of reliability required for an existing structure [1], along with the influence of the remaining service life.

Deterioration due to environmental influences, repeated actions or use-induced wear is typically a cumulative process that can adversely affect structural reliability. Differences between existing and new structures also evolve from the treatment of the possible combination of cumulative deterioration and extreme action effects (Section 5).

Although the detailed design of any engineering structure requires multiple iterative steps, the ultimate result is a clear definition of the type, layout and dimensions of the load bearing system and its individual elements and details, as well as an appropriate selection of construction materials. This can be fundamentally different in an existing structure in which different approaches may be advisable, depending on the results and conclusions from the assessment with regard to the relevant requirements for the system (Section 6). Appropriate recommendations should be formulated to the owner, taking into account the conditions for possible intervention and future operation of the construction work. Such recommendations can therefore include constructional or operational intervention measures that belong to different categories.

After discussing the main differences between assessment and design, further needs for code provisions in relation to existing structures are identified (Section 7). These provisions should go beyond the general principles of the current documents on the basis of assessment and retrofitting [2, 3].

2. TARGET RELIABILITY LEVEL

Significant aspects that must be considered when determining the target value of the reliability index for the assessment situations relevant to an existing structure include the following [3]:

- the possible cause and the mode of reaching a limit state;
- the possible direct and indirect consequences of failure in terms of risk to life, injury, potential environmental and economic losses, social and political consequences, loss of cultural heritage value, etc.;
- the relative cost of safety measures to increase reliability;
- the reference period.

The acceptable reliability levels for existing structures can be different from those required for new structures. The following types of considerations can justify lower levels for existing structures:

- economic: the relative cost of safety measures to increase the reliability of an existing structure can be very high, while the additional cost of increasing the reliability in the design phase of new structures is generally low;
- societal: the strengthening or replacement of existing structures can lead to the resettlement of residents, the interruption of activities or may influence the values of cultural heritage, circumstances that normally do not play a role in the design of new structures;
- sustainability: sustainability goals are of fundamental importance when deciding to extend the service life of existing buildings and infrastructures, or when adapting such systems to new needs, as this implies a reduction in resource consumption compared to replacement with new structures or structural elements (see 1.1); likewise, the rehabilitation of existing structures usually allows the selection of the most suitable solutions and materials from the point of view of sustainability.

Target reliability levels can be derived based on explicit risk analysis or economic optimization, meeting acceptable human safety levels, for example in relation to current best practice [7]. When selecting target reliability levels, it should be taken into account that the intended remaining service life of an existing structure often may be shorter than the design service life of new structures. In any case, the reference period to which the target reliability is related can be selected independently of the remaining service life. However, the same reference period should be adopted as for the statistical parameters of the relevant variable actions. If annual target reliabilities are used, the corresponding structural performance should be achieved in each subsequent year of the remaining service life. This is particularly relevant in the case of deteriorating structures (Section 5), in which the final year of the remaining service life is decisive (see 5.2).

3. UPDATING INFORMATION

3.1. General

The acquisition of new data about an existing structure by means of inspections, measurements or tests is intended to supplement the available prior information, which may often be vague, with respect to aspects such as geometrical properties, actions and environmental influences, construction material and geotechnical properties, as well as the actual condition of the structure, its behaviour or deformation capacity [3]. When new information becomes available, all relevant data need to be evaluated, taking into account the uncertain prior information. This process is known as updating information, which is one of the main tasks of any assessment.

Two complementary approaches can be considered to update information about the properties of a structure and its performance under the actions and influences to which it is exposed [4]:

- the updating of the probability of structural failure by using information from load testing or about the performance of the structure in the past;
- the collection of data on individual basic variables by performing on-site inspections to update previously available uncertain information.

3.2. *Updating the failure probabilities*

Formally, the direct update of the probability of failure can be carried out using fundamental relationships from probability theory [4, 7], together with the information that an existing structure or structural component has withstood an applied load effect. In practice, load effects are known in the case of load tests or, to a lesser extent, if the maximum load applied over the past service life can be estimated.

In this context it should be noted that the observation that a structure or structural component has withstood a load test does not reveal its actual resistance, nor does it provide a direct measure of structural reliability. Such an observation only indicates that the minimum resistance of the structure at the time of the test is greater than the effect of the applied load. Therefore, in order to update the probability of failure of a structure on the basis of a known load, the original cumulative distribution function for the structural resistance used for this purpose can be cut off at the level of the known deterministic or random action effects, allowing for the relevant model uncertainties including those associated with the conversion from an action to its effects. If no knowledge on the resistance is available, the probability of failure may be assessed based on the effects of the known action and its statistical distribution.

Similarly, satisfactory performance of a structure during T years of service indicates that, in the absence of significant degradation, its minimum resistance is greater than the maximum action effect applied over that period. To quantify the probability of failure, the distribution function for the structural resistance can be updated taking into account the known deterministic or the estimated random maximum action effect over the same period of T years.

3.3. *Updating the basic variables*

When updating the probability distribution function of a basic variable, X_i, its parameters (e.g., mean value, standard deviation, coefficient of skewness, lower bound, etc.) may be considered as random variables [4, 7, 9]. Prior distribution functions for the unknown parameters of the investigated variable should reflect all the information available before the in-service data acquisition is carried out. Given such prior distributions and statistical data from new observations, posterior distributions can be derived, e.g. by applying a Bayesian method [9]. In general, the following assumptions are appropriate for the type of distribution in most applications:

- for dimensions and material properties, respectively a Gaussian and a log-normal distribution may be adopted;
- a Gaussian distribution may be appropriate for permanent action effects;
- an extreme value distribution may be suitable if it is intended to represent a maximum value within a chosen reference time (e.g., effects due to variable or accidental actions).

The choice of probability distribution functions should be made with caution, considering possible bias and skewness. The coefficients of asymmetry and kurtosis may provide valuable information for determining the appropriate theoretical model (i.e., probability distribution function).

It is important to note that any method used for inspection, measurement or testing has a limited resolution (see 1.2). Uncertainties associated with such methods include [4]:

- measurement error;
- inherent variability of a measured parameter;
- model uncertainty when a parameter cannot be measured directly so that a relationship is needed between it and the corresponding measured parameter;
- statistical uncertainty due to a limited number of measurements.

These uncertainties should be taken into account when determining the statistical data that describe the measured parameter. This can be achieved, for example, by increasing the coefficient of variation of the corresponding parameter [7]. In this context, it should also be taken into account that the uncertainties associated with non-destructive testing methods are generally higher than with destructive methods.

4. VERIFICATION

4.1. *Overview*

Similar to the design of new structures, when assessing existing structures it should be verified that no limit state is exceeded for all relevant assessment situations [7]. The most accurate way of assessment would be to explicitly consider updated load and strength variables through the use of reliability methods or risk-based decision procedures. However, such methods and procedures are time-consuming, calling for a specific working knowledge of probabilistic methods, and are only applied in special cases. For example:

- if using the partial factor method it cannot be demonstrated that the structure or element achieves the required reliability;
- when uncertainties are outside the usual ranges;
- in cases with severe failure consequences or insufficient robustness;
- for decisions regarding a whole group of similar structures (e.g. calibration of partial factors);
- when evaluating the efficiency of different options for intervention (e.g. monitoring and maintenance strategies).

To verify whether an existing structure meets the relevant reliability requirements for all assessment situations, the partial factor format is normally used, equivalent to the format specified for structural design [5]. The difference is that the relevant parameters, including the characteristic values of the basic variables and partial factors, can be modified based on updated information [7].

4.2. *Partial factor format*

When using the partial factor format, the assessment values for the action effects, E_a, are compared to the assessment values for the respective strengths, R_a. The so-called assessment values [7] are equivalent to the design values for new structures

[5]. Structural reliability requirements are met if inequality (1) is fulfilled for all relevant assessment situations:

$$E_a \leq R_a \tag{1}$$

E_a and R_a can be expressed as functions of the assessment values of the basic variables, x_{ai}, as in formulas (2) and (3):

$$E_a = E\{x_{a1}; x_{a2}; x_{a3}; \dots; x_{ai}\} \tag{2}$$

$$E_a = R\{x_{a1}; x_{a2}; x_{a3}; \dots; x_{ai}\} \tag{3}$$

The assessment values for the effects of actions, E_a, and the corresponding strengths, R_a, should be determined in a manner comparable to the design values E_d and R_d, respectively, using the rules for the design of new structures [5] where applicable, but substituting the values of all design parameters –including basic variables, partial factors, ψ factors and conversion factors–, with the corresponding values for assessment. As an example, for the reliability verification of an existing structure at ultimate limit states for persistent and transient assessment situations, inequality (1) can be expressed using the general format of formula (4):

$$E_a = \gamma_{Sa}\, E\{\sum(\gamma_f\, \psi F_k); a_a; X_{Ra}\} \leq R_a = \frac{1}{\gamma_{Ra}}\, R\{\frac{\eta X_k}{\gamma_m}; a_a; \sum F_{Ea}\} \tag{4}$$

F_{Ea} assessment values of actions used in determining E_a.
F_k characteristic value of an action.
X_k characteristic value of a material or product property.
X_{Ra} assessment values of material properties used in determining R_a.
a_a assessment value of geometrical parameters.
γ_f partial factor that takes account of unfavourable deviations of an action value from its characteristic value.
γ_m partial factor accounting for unfavourable deviations of the material properties from their characteristic values and the random part of η.
γ_{Ra} partial factor for assessment accounting for the uncertainties in modelling the resistance and for geometric deviations, if these are not modelled explicitly.
γ_{Sa} partial factor for assessment accounting for the uncertainties in modelling the effects of actions.
η mean value of the conversion factor.
ψ combination factor for assessment.

Strength or resistance models are specified in the material-oriented Eurocodes for the design of new structures. The assumptions underlying the structural resistance clauses are not always explicitly stated in the current Eurocodes and can generally not be assumed to be fulfilled for existing structures. Resistance models for design may therefore not be directly applicable to assess existing structures (Section 7).

4.3. *Assessment values of the basic variables*

Provided that the basic variables relevant for the reliability verification of an existing structure are specified by suitable probability distribution functions (see 3.3), their characteristic values, x_{ki}, the associated partial factors, γ_{xi}, and the assessment values, x_{ai}, can be determined. By way of example, consider a log-normally distributed resistance variable x_i, associated with a non-deteriorated structure, with updated mean value, μ_{xi}, standard deviation, σ_{xi} and coefficient of variation, V_{xi}. The updated characteristic value, x_{ki}, is obtained as the lower 5% fractile of the updated probability distribution function of x_i. For relatively small coefficients of variation, $V_{xi} \leq 0.25$, the updated partial factor, γ_{xi}, may be obtained from formula (5) using, as a first approximation, the value recommended in the Eurocode [5] for the FORM sensitivity factor for resistance, α_R:

$$\gamma_{xi} = \frac{x_{ki}}{\mu_{xi}}\, e^{\alpha_R \beta_t V_{xi}} \tag{5}$$

The assessment value of the same variable, x_{ai}, to be applied in the reliability verification of the existing structure analysed, is obtained from formula (6):

$$x_{ai} = \frac{x_{ki}}{\gamma_{xi}} \tag{6}$$

Similarly, for a normally distributed action variable, x_i, with updated parameters μ_{xi}, σ_{xi} and V_{xi}, the updated partial factor, γ_{xi}, can be obtained from formula (7). As in the previous case, the value recommended in the Eurocode [5] for the FORM sensitivity factor for effects of actions, α_E, may be used as a first approximation:

$$\gamma_{xi} = \frac{\mu_{ki}}{x_{ki}}\,(1 - \alpha_E \beta_t V_{xi}) \tag{7}$$

The updated assessment value of the action variable, x_{ai}, can be derived as follows from the updated characteristic value, x_{ki}:

$$x_{ai} = \gamma_{xi}\, x_{ki} \tag{8}$$

For permanent actions, the updated characteristic value, x_{ki}, is normally considered to be equivalent to the updated mean value, μ_{xi}.

Variable actions are usually modelled as the product of a time-variant part and a time-invariant part. According to the Eurocode [5], for climatic actions the characteristic value of the time-variant part is chosen as the 98% fractile of the annual maximum. The characteristic value of the time-invariant part is tuned in such a way that for the product of the two characteristic values the exceedance probability for a one-year period again is 2%. For imposed loads, no specific statement is included in the Eurocode [5]. Assuming that the uncertainties associated with the time-invariant part are not relevant, for the effects of variable actions with a Gumbel distribution, the updated partial factor, γ_{xi}, may be determined on the basis of formula (9), where ϕ is the cumulative distribution function of the standardised normal distribution, σ_{xi} represents the updated standard deviation and the other parameters correspond to those of formula (7). As already mentioned (Section 2), all these parameters should relate to the chosen reference period. In the absence of a specific reliability analysis, the sensitivity factor, α_E, may again be approximated by using recommended values [5]. Finally, the updated assessment value of the action variable, x_{ai}, is obtained by applying formula (8). The latter also applies to the general case if the uncertainties associated with the time-invariant part of the action are relevant, although the updated partial factor, γ_{xi}, cannot be represented with a closed formula.

$$\gamma_{xi} = \frac{1}{x_{ki}} \left(\mu_{xi} - \sigma_{xi} \frac{\sqrt{6}}{\pi} \left(0.577 + ln \left(-ln \, \phi(-\alpha_E \, \beta_t) \right) \right) \right) \tag{9}$$

The above examples of updated partial factors and assessment values take no account of additional effects, e.g. due to model uncertainties. Further information on general procedures for taking such uncertainties into account can be found in the Eurocode [5].

5. DETERIORATION

5.1. General

Deterioration due to environmental influences, repeated actions or use-induced wear is typically a cumulative process that can adversely affect the reliability of existing structures. When designing new structures according to the Eurocodes, the possible combination of cumulative deterioration and extreme action effects is often neglected: durability design is usually considered separately from the design for ultimate and serviceability limit states. In some material-oriented Eurocodes, the design to prevent deterioration is based on verifications of well-defined and controllable limit states without direct negative consequences. These are often approximations to real limit states with direct consequences that are difficult to quantify and are therefore referred to as condition or proxy limit states [4]. Such simplifications are not appropriate for the assessment of existing structures that are affected by deterioration mechanisms:

- reliability requirements should be verified for the combined effects of cumulative deterioration and the relevant actions likely to occur during the remaining service life;
- condition limit states intended to prevent deterioration from affecting the performance of a new structure may not apply to existing structures that are affected by ongoing deterioration;
- indicators that are not based on measurable quantities cannot be used for inspection and maintenance planning.

5.2. Remaining structural resistance and verification

Resistance models are usually based on a combination of mechanical principles and empirical relationships. Models that explicitly take into account the effects of deterioration on resistance, adjusted or newly developed (Section 7), should preferably be based on mechanical principles. The scope of such models should include all relevant material-specific deterioration mechanisms and the associated uncertainties should be quantified.

Models should also be developed to describe the propagation of deterioration as a function of time, with the aim of predicting the condition of an existing structure over the remaining service life, going out from its actual condition at the time of assessment. Depending on the conditions to which the structure is exposed (e.g. environmental influences, repeated actions), these models should describe the onset and the rate of the cumulative processes that affect the parameters influencing the remaining structural resistance. The spatial distribution of the processes should be accounted for if relevant.

In deteriorating structures, the reliability requirements should be based on a reference period of one year (Section 2) and verifications should be carried out for the final year of the intended remaining service life. The uncertainties associated with the models that describe the propagation of deterioration as a function of time may be reduced by implementing structural health monitoring techniques to provide information about environmental influences on the structure, degradation processes or structural performance and their variation over time [7]. Such uncertainties should be taken into account, however, along with those associated with the resistance models for deteriorated structures (Section 7).

6. CONCLUSIONS FROM THE ASSESSMENT

The staged assessment process (see 1.2) of an existing structure can be completed if clear conclusions can be drawn from the findings regarding the assessment objectives, or if an additional assessment step is unlikely to provide relevant new knowledge. Depending on the assessment findings, the structure or a structural member may, within the scope of the assessment:

- achieve the reliability required, assuming adequate inspection and maintenance during the remaining service life;
- achieve the reliability required at the time of the assessment, but not for the complete period of time during which the existing structure is intended to remain operational, taking into account the anticipated development of its condition and the planned level of maintenance;
- fail to achieve the reliability required;
- need immediate correction of the existing condition by means of urgent risk mitigation measures.

If the required degree of reliability is not achieved with regard to structural safety, robustness, serviceability or durability, intervention is needed. Appropriate interventions should be defined case-specifically, taking account of the following:

- the type and importance of the structure;
- the type of basic requirement [5] that is not met;
- possible cause and mode of attaining a limit state;
- expected consequences of failure;
- options of interventions that are available.

7. CLOSURE

7.1. General

The recently published Technical Specification of the European Committee for Standardization [3] is not intended to establish independent rules on the assessment and retrofitting of existing structures. Rather, these rules complement those laid down in the Eurocode for structural design [5]. Consequently, there is a strong interaction between both documents, with the Technical Specification focusing on the general principles for assessing existing structures, which differ from the basis for designing new structures, as explained in the previous sections. On the occasion of the conversion of the Technical Specification into an EN Eurocode Part [7], some further guidance needs to be provided to avoid inconsistencies between the two sets of rules for design and assessment, respectively, and to enable the consistent application of more advanced approaches than the partial factor format in verifying the reliability of an existing structure. It is not the aim of this article to provide a complete list of issues to consider in future code developments (see 1.1). However, some hints are given below as representative examples.

7.2. Reliability requirements

The first aspect to be considered is the reliability level. Indicative values for the target reliability index for the one-year and 50-year reference periods, $\beta_{t,1}$ and $\beta_{t,50}$, respectively, are assumed within the Eurocode [5] for the Ultimate Limit State design of building structures and bridges, belonging to different consequence classes and exposed to persistent, transient and fatigue design situations. The requirements for the one-year reference period are, in general, considerably higher than the corresponding values indicated in the international standard on reliability for structures [4]. The reason is that the annual values in the Eurocode [5] are based on the assumption that possible failure events in each year of the design lifetime are independent. In most cases, however, there is some correlation in failure events due to the constant presence of variables that do not change with time, like self-weight and also strength when measures are taken to avoid deterioration. In the international standard on reliability of structures [4], this correlation has been taken into account, for a better consistency of verifications related to, respectively, the one-year reference period, where the target should be met for every year of the chosen design life (or the remaining working life) of the structure, and those related to the 50-year reference period. The aforementioned inconsistency in the Eurocode [5] can be corrected when setting target reliability levels in the National Annex for use in a country. In addition to the failure consequences, the relative cost of safety measures should also be taken into account when establishing target reliabilities. Finally, indicative values should be given for serviceability limit states.

7.3. Uncertainties

Acceptability of an existing structure should be checked by comparing the outcome of the assessment to established reliability requirements as those mentioned before. Such requirements in turn depend on the level of uncertainty associated with standardized rules. Since the assessment of existing structures should be carried out considering their actual conditions and updating information entails a change in the uncertainties associated with structural analysis variables, the difficulty lies in the want of any explicitly established degree of uncertainty associated with the standardized rules in force for structural design. The following information is therefore needed in relation with the Eurocodes:

- the state of uncertainty associated with the rules for structural design, i.e. the probabilistic models for actions and resistances, used for the calibration of partial factors;
- the partial factor format adopted for calibration purposes.

7.4. Structural resistance

In the same vein, material-specific Eurocodes currently provide models that are often based on a number of assumptions which, although not always explicitly stated, are only compatible with the design of new structures (see 4.2). Resistance models that cannot be used for the assessment of all existing structures should therefore be adjusted so that the effects of structural condition, including deterioration (Section 5), on the load bearing capacity can be modelled explicitly. Such assessment-specific provisions should be developed for future editions of material-oriented Eurocodes [8]. In some cases, it may be advisable to develop new models. If resistance models for the design are adjusted or expanded in their scope in order to enable the assessment of existing structures, partial factors for resistance, γ_{Ra}, should cover the degree of uncertainty associated with these models. When developing models to evaluate structural resistance after rehabilitation (e.g. for certain methods of repair or strengthening), partial factors for resistance should cover the degree of uncertainty associated with these models.

7.5. Robustness

In order to reach an adequate level of robustness, many modern codes, such as the Eurocode [5], require that the consequences of damage to structures due to an unforeseen adverse event must not be disproportionate to the original cause. Although the relevance of this feature of structures is well recognised, the clauses in structural codes and standards that seek to achieve this design goal are generally vague [10], mainly limited to general statements and intended to satisfy rules. To improve structural performance in terms of robustness, most known strategies require the adoption of measures in the conceptual design phase. A major problem in this regard is the lack of a general design philosophy for robustness. Therefore, any particular conceptual solution used may improve the structural performance for some hazard scenarios and worsen it for others [11]. Given this situation, even for apparently robust solutions, it is of the utmost importance to unequivocally identify all relevant hazards and hazard scenarios and to take them into account appropriately in the analysis. This is particularly relevant in the context of existing structures, where the adoption of measures related to the conceptual layout is normally not possible without constructional intervention. In addition, more operational rules are needed for providing structural robustness, beyond a list of general strategies, such as those included in current codes [5, 7, 12]. These rules should comprise quantitative decision criteria for the acceptance of the robustness of structures.

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