IOP Conference Series: Earth and Environmental Science

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To cite this article: M Holický 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **290** 012133

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# New European Document on Assessment of Existing Structures and Building Stock

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**Abstract**. The upcoming CEN Technical Specification (TS) on assessment of existing structures and building stock is related to the fundamental concepts and requirements of the current generation of EN Eurocodes. The final draft of the Technical Specification was already submitted to the technical committee CEN TC250 in April 2018. The document concerns all types of building stock, buildings, bridges and construction works, including geotechnical structures, exposed to all kinds of actions. It contains requirements, general framework of assessment, data updating, structural analysis, different verification methods (partial factors, probabilistic methods, risk assessment), past performance, interventions, annexes (flowchart, target reliability and partial factor methods, assessment of heritage building stock). The submitted contribution provides background information on the principles accepted in the final draft of TS and practical examples of applications to assessment of existing building stock. Particular attention is given to operational assessment methods of existing buildings taking into account actual material properties and actions.

## 1. Introduction

Assessment of existing structures is becoming an important and more and more frequent engineering task. Continued use of existing structures is of a great significance due to environmental, economic and socio-political assets, growing larger every year. These aspects are particularly relevant to public buildings that constitute a great social and economic value. General principles of sustainable development regularly lead to the need for extension of the life of a structure, in majority of practical cases in conjunction with severe economic constraints. That is why the assessment of existing structures often requires application of sophisticated methods, as a rule beyond the scope of traditional design procedures as stated in the recently developed Technical Specification (TS) [1]. This European document is based on a number of national codes related to assessment of existing structures (listed in JRC report [2]), International Standards ISO 2394 [3], ISO 13822 [4], ISO 12491 [5] and Eurocode EN 1990 and its revision prEN1990 [6]. Probability based procedures are related to scientific publications (listed in JRC report [2]) and other references (for example [7] to [13]).

The approach to assessment of an existing structure is in many aspects different from that taken in designing the structure of newly proposed buildings. 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 (as-designed) state, must be taken into account. However, even though the existing building may be investigated several times, some uncertainty in behaviour of the basic variables shall always remain. Therefore, similarly as in the design of new structures, actual variation in the basic variables describing actions, material properties, geometric data and model uncertainties

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are to be taken into account by any verification method. Differences between the design of new structures and the assessment of existing structures as indicated in table 1 should be considered when making decision [9].

**Table 1.** Differences between the design of new structures and the assessment of existing structures, reliability implications.

| Aspect | Design of new structures | Assessment of existing structures | Reliability implications |
|---|---|---|---|
| Economic | Additional costs of reliability improvements are usually low | Additional costs of reliability improvements of existing structures are usually high | Reduction of additional costs may require decrease of the reliability level |
| Social | Restrictions are usually less significant than in existing structures | Restriction of the use and damage of existing cultural assets are significant | Mitigation of negative cultural aspects may involve decrease of the reliability level |
| Sustainability | New materials are often used and the aspect of sustainability is difficult | Allowance for sustainability is provided by using original materials | The use of original materials may allow to decrease the reliability level |

In general an existing structure could be subjected to assessment in case of:

- rehabilitation of an existing constructed facility, during which new structural members are added to the existing load-carrying system;
- adequacy checking in order to establish whether the existing structure can resist loads associated with the anticipated change in use of the facility, operational changes or extension of its design working life;
- repair of an existing structure that has deteriorated due to time dependent environmental effects or that has suffered damage from accidental actions, for example, earthquake;
- doubts concerning actual reliability of the structure.

In some circumstances, assessments may also be required by authorities, insurance companies or owners or may be demanded by a maintenance plan.

## 2. General Framework of Assessment

Two main principles are usually accepted when assessing existing structures:

- Currently valid codes for the verification of structural reliability should be applied; historic codes valid in the period when the structure was designed should be used only as guidance documents.
- Actual characteristics of structural materials, actions, geometric data and structural behaviour should be considered; the original design documentation including drawings should be used as guidance documents only.

The first principle should be applied in order to achieve similar reliability level as in case of newly designed structures. The second principle should avoid negligence of any structural condition that may affect actual reliability (in favourable or unfavourable way) of a given structure. Most of the current codes are developed assuming the concept of limit states in conjunction with the partial factor method. In accordance with this method that is mostly considered here, basic variables are specified by characteristic or representative values. The design values of the basic variables could be determined from the characteristic (representative) values and appropriate partial factors or on the basis of more advanced reliability methods.

It follows from the second principle that a visual inspection of the assessed structure should be made whenever possible. Practical experience shows that inspection of the site is also useful to obtain a good feel for actual situation and state of the structure. As a rule the assessment need not be performed for those parts of the existing structure that will not be affected by structural changes, rehabilitation, repair, change in use or which are not obviously damaged or are not suspected of having insufficient reliability.

In general, the assessment procedure consists of the following steps:

- specification of the assessment objectives required by the client or authority;
- scenarios related to structural conditions and actions;
- preliminary assessment:
  - study of available documentation;
  - preliminary inspection;
  - preliminary checks;
  - decision on immediate actions;
  - recommendation for detailed assessment;
- detailed assessment:
  - detailed documentary search;
  - detailed inspection;
  - material testing and determination of actions;
  - determination of structural properties;
  - structural analysis;
- verification of structural reliability;
- report including proposal for construction intervention;
- repeat of the sequence if necessary.

When the preliminary assessment indicates that the structure is reliable for its intended use over the remaining life, a detailed assessment may not be required. Conversely, if the structure seems to be in dangerous or uncertain condition, immediate interventions and detailed assessment may be necessary.

## 3. General Framework of Assessment

In accordance with the above mentioned general principles, characteristic and representative values of all basic variables $X_i$ shall be determined taking into account the actual situation and state of the structure. Available design documentation is used as a guidance material only. The actual state of the structure should be verified by its inspection to an adequate extent. If appropriate, destructive or non-destructive inspections should be performed and evaluated using statistical methods.

For the verification of the structural reliability using partial factor method, the characteristic and representative values of basic variables shall be considered as follows:

- Dimensions of the structural elements shall be determined on the basis of adequate measurements. However, when the original design documentation is available and no changes in dimensions have taken place, the nominal dimensions given in the documentation may be used in the analysis.
- Load characteristics shall be introduced with the values corresponding with the actual situation verified by destructive or non-destructive inspections. When some loads have been reduced or removed completely, the representative values can be reduced or appropriate partial factors can be adjusted. When overloading has been observed in the past, it may be appropriate to increase adequately the representative values.
- Material properties shall be considered according to the actual state of the structure verified by destructive or non-destructive inspections. When the original design documentation is available

and no serious deterioration, design errors or construction errors are suspected, the characteristic values given in original design may be used.

- Model uncertainties shall be considered in the same way as in the design stage unless previous structural behaviour (especially damage) indicates otherwise. In some cases model factors, coefficients and other design assumptions may be established from measurements on the existing structure (e.g. wind pressure coefficient, effective width values, etc.).

Thus the reliability verification of an existing structure should be backed up by inspection of the structure including collection of appropriate data. Evaluation of prior information and its updating using newly obtained measurements is one of the most important steps of the assessment.

## 4. Reliability verification

### *4.1. General*

Reliability verification of an existing structure shall be made using valid codes of practice, as a rule based on the limit state concept. Attention should be paid to both the ultimate and serviceability limit states. Verification may be carried out using partial safety factor or structural reliability methods with consideration of the structural system and ductility of components. The reliability assessment shall be made taking into account the remaining working life of the structure, the reference period, and anticipated changes in the environment of the structure.

The conclusion from the assessment shall withstand a plausibility check. In particular, discrepancies between the results of structural analysis (e.g. insufficient safety) and the real structural condition (e.g. no sign of distress or failure, satisfactory structural performance) must be explained. It should be kept in mind that many engineering models are conservative and cannot be always used directly to explain an actual situation [7].

The target reliability level used for verification can be taken as the level of reliability implied by the acceptance criteria provided in valid design codes. The target reliability level shall be stated together with clearly defined limit state functions and specific models of the basic variables. The target reliability level can also be established taking into account the required performance level for the structure, the reference period and possible failure consequences. In accordance with ISO 2394 [3], the performance requirements applied in the assessment of existing structures are the same as those used in the design of new structures. Lower reliability targets for existing structures may be used if they can be justified on the basis of economic, social and sustainable consideration (see Annex F to ISO 13822 [4]).

An adequate value of the reliability index $\beta$ should be generally determined considering the appropriate reference period. For serviceability and fatigue the reference period equals the remaining working life, while for the ultimate limit states the reference period is in principle the same as the design working life specified for new structures (50 years for buildings). This general approach should be in specific cases supplemented by a detailed consideration of the character of serviceability limit states (reversible, irreversible), fatigue (detectable, not detectable) and consequences of ultimate limit states (economic consequences, number of endangered people).

Reliability of a structure given by condition $\mathrm{g}(X_i) > 0$, where $X_i$ denote the basic variables (in a simplified form $R - E > 0$) can be verified by various methods. The following procedures are included in the Technical Specification [1].

### *4.2. Partial factor method*

The reliability requirement $\mathrm{g}(X_i) > 0$ is exchanged by the condition

$$\mathrm{g}(x_{\mathrm{d}i}) = \mathrm{g}(x_{\mathrm{d}1}, x_{\mathrm{d}2}, x_{\mathrm{d}3}, ...) > 0,\ \ x_{\mathrm{d}i} = x_{\mathrm{k}i} \text{ or } x_{\mathrm{d}i} = x_{\mathrm{k}i}\,\gamma \text{ or } x_{\mathrm{d}i} = x_{\mathrm{k}i}/\gamma \tag{1}$$

Here $x_{\mathrm{d}i}$ denotes the design values of basic variables $X_i$ determined using their characteristic values $x_{\mathrm{k}i}$ and relevant partial factors $\gamma$.

### 4.3. *Design value method*
The condition (1) is modified by the requirement

$$g(x_{di}) = g(x_{d2}, x_{d2}, x_{d3}, ...) > 0,\ \Phi_{Xi}\,(x_{di}) = \Phi(-\alpha_i\,\beta) \quad (2)$$

Here $\alpha_i$ denotes the FORM sensitivity factors and Φ the normal distribution function.

### 4.4. *Probabilistic method*
The requirement $g(X_i) > 0$ is examined by the failure probability

$$Pf = P\{g(Xi) < 0\} < P_{f,t} \quad (3)$$

Here $P_{f,t}$ denotes the target probability of failure that is to be specified taking into account economic and societal consequences of failure and the costs of improving structural reliability.

### 4.5. *Risk assessment approach*
The reliability is examined by acceptable risk expressed in a symbolic form as

$$R = P_f\,C = P\{g(X_i) < 0\}\;C < R_t \quad (4)$$

Here $C$ generally represents any type of economic and societal consequences and $R_t$ the relevant target risk level. Appropriate target risk level $R_t$ is to be specified individually taking into account the specific condition of an assessed structure. This may be a complicated task, particularly in case of heritage buildings, where historical and artistic aspects are usually also involved. A general flowchart of the risk assessment procedure is shown in the Technical Specification [1].

## 5. Reliability requirements
Basic requirements emphasize the necessity for the compliance with all the assumptions made in Eurocodes. Additional clauses on robustness and sustainability are supplemented. National choice of the levels of reliability should take account of the relevant factors, including:

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

Consequences of structural failure are split into five subsequent classes, denoted CC0 to CC4, depending on societal and economic aspects as indicated in table 2. Provisions for the subsequent classes CC0 and CC4 are outside of the scope of the Eurocodes.

**Table 2.** Definition of consequences classes.

| Consequences Class | | The more severe of loss of human life | The more severe of 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 |

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 annual reliability indices $\beta_1$ and failure probability $P_f$ related to ultimate limit state,

IOP Conf. Series: Earth and Environmental Science **290** (2019) 012133 doi:10.1088/1755-1315/290/1/012133

consequence classes CC1, CC2 and CC3, and to one year reference period are indicated in table 2. These values are based on previous studies [7] and Annex C of the draft prEN 1990 [6]; seismic situations are explicitly excluded. It is not specified whether the values in table 3 are applicable for accidental and fire design situations and recommendations for Serviceability Limit States are missing.

**Table 3.** Tentative reliability levels related to one year and ultimate limit states in accordance with prEN 1990 from 2018 [6].

| CC1 | CC2 | CC3 |
|---|---|---|
| $P_f = 10^{-5}$ | $P_f = 10^{-6}$ | $P_f = 10^{-7}$ |
| $\beta_1 = 4{,}2$ | $\beta_1 = 4{,}7$ | $\beta_1 = 5{,}2$ |

The final draft prEN 1990 [6] does not include possible transformation of the reliability level related to one year to levels related to other reference periods even though this is needed to specify reliability elements for design and assessment of common structures. Such a tool is proposed in the final draft of the upcoming Technical Specification [1] and in the recent publications ([9] to [12]).

## 6. Adjustment of the target reliability to different reference periods

Transformation of target reliability index $\beta$ related to different reference periods of $n$ years is well known when the main uncertainty comes from actions that have statistically independent maxima in each year. Then the reliability (complementary to failure probabilities) $\Phi(\beta_n)$ related to the reference period of $n$ years is determined from annual reliability $\Phi(\beta_1)$, where the index $\beta_1$ is related to one year, as the product of $n$ annual reliabilities, thus in average as $[\Phi(\beta_1)]^n$. Consequently, the reliability index $\beta_n$ can be assessed from $\beta_1$ using the expression indicated in the Eurocode EN 1990 from 2002 [6]:

$$\Phi(\beta_{\mathbf{n}}) = [\Phi(\beta_1)]^n \tag{5}$$

Equation (5) indicates that for mutually independent occurrence of failures in subsequent years the commonly used reliability index $\beta_n = 3{,}8$ for $n = 50$ corresponds to $\beta_1 = 4{,}7$.

However, the statistical maxima of actions (and other time dependent variables) in subsequent years are usually correlated. Consequently, the occurrences of failures in subsequent years are dependent. Then the relationship (5) should be generalized to take into account the correlation of failure events in subsequent years. The following proposal for adjustment of reliability to different reference periods provides an operational tool to solve the problem.

Assume that the variation of annual failure probabilities with time is approximated by rectangular wave process with the mean duration of rectangles of $k$ years. When the mean duration $k = 1$, then the failures in subsequent years are assumed to be independent and the relation (5) can be used. If $k = n$, then the annual failures within the whole reference period of $n$ years are fully dependent and the annual target reliability will be valid for the whole reference period of $n$ years. In general, the reliability index $\beta_{nk}$, related to the reference period of $n$ years and independence interval of $k$ years, can be derived from reliability index $\beta_1$, assuming that the resulting reliability is the product of annual reliabilities $\Phi(\beta_1)$ in $n/k$ years, thus $[\Phi(\beta_1)]^{n/k}$, and can be assessed by the following approximate formula (accepted in the Technical Specification [1]):

$$\Phi(\beta_{\mathbf{nk}}) = [\Phi(\beta_1)]^{n/k} \tag{6}$$

Here the independence interval $k \le n$ corresponds to the mean time period for which the failures in subsequent periods of $k$ years are assumed to be mutually independent. Variation of the reliability index $\beta_{nk}$ with the reference period $n$ and the independence interval $k$ given by expression (6) assuming $\beta_1 = 4{,}7$ is shown in figure 1. This figure 1 also indicates the annual reliability index $\beta_1 = 4{,}7$ and the reliability index $\beta_{50} = 3{,}8$ specified by equation (5) in EN 1990 from 2002 [6]. The reliability index $\beta_{50}$ equals to $\beta_{50,1} = 3{,}8$ given by equation (6) for the independence interval $k = 1$ year.

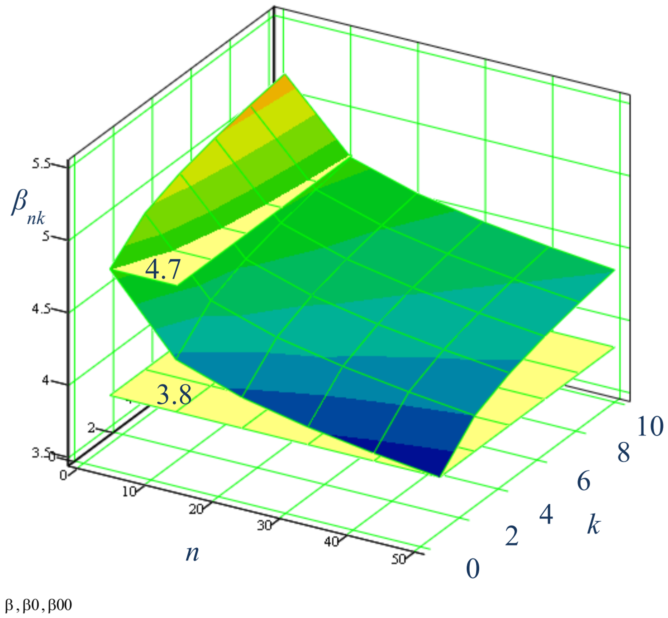


**Figure 1.** Variation $\beta_{\mathrm{nk}}$ with the reference period $n$ and independence interval $k$ for $\beta_1$ = 4,7

It follows from figure 1 that the independence interval $k$ may affect the reliability index $\beta_{nk}$ and should be considered when specifying the target reliability level. It depends on the characteristics of time variant basic variables, particularly on dominant actions. Informative values of the independence intervals $k$ related to dominant actions are indicated in table 4.

**Table 4.** Informative values of independence intervals $k$ related to the dominant actions.

| Dominant actions | Examples of dominant actions | Examples of structural members | Independence intervals $k$ |
|---|---|---|---|
| Permanent | Self-weight of structures and fixed equipment | Beams, walls and columns | ≈ reference period $n$ |
| Imposed | Loads on floors in residential, office and small buildings | Floors, walls, columns | 5 to 10 years |
| Climatic | Wind, snow, temperature | Claddings, tanks, silos, bridges | 1 to 7 years |

## 7. Concluding remarks

The main principles of the upcoming European document on assessment of existing structures and building stock can be summarized as follows:

- Currently valid codes for the verification of structural reliability should be applied, codes valid in the period when the structure was designed, should be used as guidance documents;
- Actual characteristics of structural material, action, geometric data and structural behaviour should be considered; the original design documentation including drawings should be used as guidance information only.

The most important step of the whole assessment procedure is the evaluation of available data and updating of prior information concerning actions, strength and structural reliability. Typically, assessment of existing structures is a cyclic process in which the first preliminary assessment is often supplemented by subsequent detailed investigations, data evaluation and updating. The report on structural assessment prepared by an engineer assessing the structure should include a recommendation on possible structural and operational interventions. However, the client in collaboration with the relevant authority should make the final decision concerning interventions.

The following conclusions are related to the target reliability level:

- The target reliability levels recommended in various national and international documents are inconsistent in terms of the values and reference periods.
- In the latest draft prEN 1990 from 2018 [6] of the revision of Eurocode EN 1990 the target reliability level is indicated only for 1 year and 50 years reference periods.
- Transformation formulae for adjustment of reliability level to different reference periods taking into account mutual dependence of failure probabilities in subsequent years are missing.
- The proposed transformation formula for reliability index $\beta_{nk}$ depends on the reference period $n$ and independence interval $k$.
- Reliability index $\beta_{nk}$ decreases with the reference period $n$ and increases with the independence interval $k$.
- When determining the target reliability index, the assumption of annual independency of failures ($k = 1$) may be unsafe.

**Acknowledgement**
This work was supported by the Ministry of Culture of the Czech Republic under Grant DG16P02M050 ‘‘Optimisation of Observations and Assessment of Heritage Structures”.

**References**

[1] CEN, M515 WG2.T1, April 2018, Technical Specification, *Assessment of existing structures* (Brussels)

[2] JRC, 2015 Scientific and Policy Report (N1247) *New European Technical Rules for the Assessment and Retrofitting of Existing Structures* (Luxembourg)

[3] ISO 2394, 2015 *General principles on reliability of structures*. ISO, Geneva, Switzerland.

[4] ISO 13822, 2010 *Basis for design of structures -Assessment of existing structures.* ISO, Geneva, Switzerland.

[5] ISO 12491, 1998 *Statistical methods for quality control of building materials and componens*. ISO, Geneva, Switzerland.

[6] EN 1990, 2002 *Eurocode – Basis of structural design*.
prEN 1990, 2018, Draft of Eurocode – Basis of structural design.

[7] Diamantidis D, Holický M et al 2009 Reliability differentiation *Guidebook 1, Load effects on Buildings* (CTU in Prague, Klokner Institute) ISBN 978-80-01-04468-1 pp 48–61

[8] Ellingwood B R 1996 Reliability-based condition assessment and LRFD for existing structures *Struct.l Saf.* **18(2+3)** 67–80

[9] Holický M 2005 Assessment of existing structures (Chapter 9) *Structural safety and its quality assurance*, ed B R Ellingwood and J Kanda (ASCE)

[10] Holický M 2009 *Reliability analysis for structural design* (SUN MeDIA Stellenbosch) ZA, ISBN 978-1-920338-11-4, 199 pages.

[11] Holický M 2013 *Introduction to Probability and Statistics for Engineers* (Springer, Heidelberg, New York, London)

[12] Holický M 2017 *Operational approach to assessment of existing structures* (ICOSSAR, Vienna)

[13] JCSS, 2001 Joint Committee for Structural Safety *Probabilistic Model Code* http://www.jcss.ethz.ch/.