Target reliability levels for assessment of existing structures

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1 INTRODUCTION

At present existing structures are mostly verified using simplified deterministic procedures based on the partial factor method commonly applied in design of new structures. Such assessments are often conservative and may lead to expensive repairs. More realistic verification of actual performance of existing structures can be achieved by probabilistic methods when uncertainties of basic variables are described by appropriate probabilistic models.

Specification of the target reliability levels is required for the probabilistic assessment of existing structures. In addition the target reliabilities can be used to modify the partial factors for a deterministic assessment. It has been recognised that it would be uneconomical to specify for all existing structures the same reliability levels as for new structures.

The target reliability levels recommended in EN 1990 (2002) and ISO 13822 (2003) are related to consequences of failure only. More detailed classification is given in ISO 2394 (1998) where relative costs of safety measures are also taken into account. The target reliability levels provided in these documents are partly based on calibrations to previous practice and should be considered as indicative.

ISO 13822 (2003) indicates a possibility to specify the target reliability levels by optimisation of the total cost related to an assumed remaining working life. The submitted paper attempts to apply this approach for existing structures.

2 COST OPTIMISATION

According to Ang & De Leon (1997) the underlying economics is of concern and importance in the upgrading of existing structures. From an economic point of view, the objective may be to minimize the total working-life cost.

Based on previous studies concerning existing structures, the expected total costs C_{tot} may be generally considered as the sum of the expected costs of inspections, maintenance, repairs and costs related to failure of a structure. The decision parameters to be optimised in the assessment may influence resistance, serviceability, durability, maintenance, inspection, repair strategies etc.

3 REQUIREMENTS ON HUMAN SAFETY

The cost optimisation is aimed to find the optimum decision from the perspective of an owner of the structure. However, society commonly establishes limits for human safety. Steenbergen & Vrouwenvelder (2010) proposed to consider the acceptable maximum probability to become a victim of structural failure approximately 10^{-5} per year and derived the target reliability indices to assure minimum human safety. This procedure is adopted in the present study, but the acceptable maximum probability to become a victim of structural failure is here considered as 10^{-6} per year in accordance with ISO 2394 (1998).

4 NUMERICAL EXAMPLE

Application of the optimisation procedure is illustrated by the example of reliability assessment of a generic member of the existing building with the remaining working life t_r = 15 or 30 years, assuming moderate costs of safety measures and moderate failure consequences. The probabilistic models of basic variables recommended by JCSS (2006) are applied in the reliability analysis.

To derive generally applicable target reliability levels indicating whether the structure should be repaired or not, the limiting value of d_{0lim} of the rate d_0 (resistance before repair over resistance required by Eurocodes) is found from the following relationship:

Table 1. Overview of target reliabilities for the considered structure.

Code, method	Remaining working life	
	15 years	30 years
EN 1990	4.1	4.0
ISO 13822	3.8	3.8
ISO 2394	3.1	3.1
Optimisation β_0	3.3	3.1
Optimisation β_1	3.5	3.5

$$E[C_{tot}'(d_{0lim},t_r)] = E[C_{tot}''(d_{opt},t_r)] \quad (1)$$

where C_{tot}' = total costs in case of no repair; C_{tot}'' = total costs in case of repair; and d_{opt} = optimum value of decision parameter d (resistance after repair over resistance required by Eurocodes) minimising the total cost C_{tot}''. For $d_0 < d_{0lim}$ the reliability level of an existing structure is too low and the decision is to repair the structure as the optimum repair strategy yields a lower total cost. For $d_0 > d_{0lim}$ the present state is accepted from an economic point of view.

The minimum acceptable reliability index is:

$$\beta_0 = \max[\beta(d_{0lim},t_r);\ \beta_{hs}(t_r)] \quad (2)$$

where $\beta(\cdot)$ = reliability index; and $\beta_{hs}(\cdot)$ = reliability index for minimum human safety.

When the repair is necessary (actual reliability index is less than β_0), the total cost C_{tot}'' is optimised and the optimum value d_{opt} and optimum reliability index are found:

$$\beta_1 = \max[\beta(d_{opt},t_r);\ \beta_{hs}(t_r)] \quad (3)$$

Table 1 provides a comparison of the target reliabilities estimated for the considered structure using different procedures in structural codes, or based on the total cost optimisation and the requirements on human safety. A great scatter is observed, for instance for t_r = 15 years, the reliability index varies within the range from 2.5 to 4.1. It should be noted that EN 1990 (2002) recommends considerably greater values that seem to be applicable primarily for new structures. Also ISO 13822 (2003) provides a rather high reliability level. ISO 2394 (1998) indicates values similar to the target reliability levels obtained by the optimisation concerning the decision on repair of a structure (β_0).

5 CONCLUSIONS AND RECOMMENDATIONS FOR STANDARDISATION

The following conclusions may be drawn from the present study:

- It is uneconomical to require all existing structures comply fully with the target reliability levels for new structures. Lower target reliability levels can be used if they are justified on the basis of social, cultural, economical, and sustainable considerations,
- Decisions in the assessment can result in acceptance of an actual state or in the repair of a structure; two target reliability levels are thus needed - the minimum level below which the structure is unreliable and should be repaired (β_0), and the level indicating an optimum repair strategy (β_1),
- The probabilistic cost optimisation provides useful background information for specification of these levels,
- In the optimisation the total failure consequences including direct and indirect consequences should be taken into account,
- Minimum levels for human safety should not be exceeded,
- The target reliability levels are primarily dependent on the failure consequences and on the marginal cost per unit of a decision parameter; repair costs independent of the decision parameter and remaining working life are less significant.

The results of this study may be implemented in practical design using the partial factor method as follows:

- The characteristic values of the basic variables including time-variant loads remain independent of the remaining working life (in accordance with EN 1990 (2002));
- The design values are specified on the basis of an appropriate reliability index assessed for relevant costs of safety measures and failure consequences,
- The partial factors are determined considering specified design values and unchanged characteristic values of basic variables.

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