ASSESSMENT OF RESIDUAL WORKING LIFE FOR EXISTING BRIDGES

Marková Jana
Klokner Institute CTU in Prague, Czech Republic, markova@klok.cvut.cz

Holický Milan
Klokner Institute CTU in Prague, Czech Republic, holicky@klok.cvut.cz

Summary

The remaining working life of an existing reinforced concrete bridge is analysed using the probabilistic methods of structural reliability. The serviceability limit states of crack width are considered as decisive conditions. The initial reliability of the bridge with respect to the crack width seems to satisfy the required target level recommended in EN 1990. However, the reliability index significantly decreases with the reduction of the area of reinforcement due to corrosion. The probabilistic methods of structural reliability are applied to assess the remaining working life of existing bridges.

Keywords: existing bridges, working life, target reliability, crack width, failure probability

1 Introduction

An extended use of existing structures is of a great importance in many countries. It has significant economic, social and cultural impacts. Many buildings and bridges, built in the Czech Republic and in other European countries in the 1960s, are now reaching the end of their working life. They require assessment and rehabilitation to assure their further safe and economical exploitation.

The assessment of an existing structure differs in many aspects from procedures taken during the design of a new structure and may require the application of sophisticated methods. In many cases these methods are beyond the scope of common standards for structural design. The prescriptive documents cannot be directly applied for the assessment, as the actual state of the structure and its materials must be taken into account. Moreover, the current standards have often more conservative requirements than the standards applied at the time of the original design. Although some existing structures appear to have a lower reliability level than is presently required for new structures, they may still comply with the performance requirements.

The requirements for safety and serviceability specified ISO 13822 [1] are in principle the same as for the design of new structures. There are however, some fundamental differences between the criteria for design of new structures and assessment of existing structures indicated in Tab. 1.

It is generally required to minimize structural intervention to existing structures and to use as much as possible the existing materials. Actual properties of existing materials should be, however, carefully verified.

Tab. 1 Differences in the criteria for existing and new structures

Criteria	Existing structures	New structures
Economical	incremental cost of increasing the structural safety is commonly high	incremental cost of increasing the structural safety is commonly lower
Social	may be significant due to reduction or disruption of serviceability and preservation of heritage values	commonly less significant than for existing structures
Sustainability	in large measure existing materials are used, leading to reduction of waste and recycling	commonly new materials are applied

The differences in criteria for assessment of existing structures and design of new structures affect decision concerning a suitable reliability level for an existing structure. For the specification of the optimum reliability level of rehabilitated structures, the principles of the theory of structural reliability, the risk assessment and methods of cost-benefit optimization should be applied.

2 Reliability verification of existing bridges

The design of existing bridges is as a rule based on different approaches given in previous standards, based on the method of allowable stresses or the safety factor method. Present suite of Eurocodes offer the most advanced partial factor method, supported by the theory of structural reliability.

Eurocode EN 1990 [2] for the basis of structural design gives indicative values of the design working life for several categories of structures (50 years working life for buildings and 100 years for bridges).

In case of existing bridges the decision on the required reliability level affects not only the safety aspects but also social and economic criteria.

3 Verification of the serviceability limit states

Verification of the serviceability limit states of an existing bridge is commonly based on estimation of the remaining working life. Recently developed Czech standard CSN 73 6222 [3] provides basic guidance for determination of the load-bearing capacity and estimation of the remaining working life of existing bridges. Six bridge categories of prestressed and reinforced concrete bridges are distinguished and limiting values of their crack width are recommended.

For the specification of the load-bearing capacity of prestressed and reinforced concrete bridges in serviceability conditions, the limit states of decompression and limit states of crack width have to be verified. The procedure for the assessment of the remaining working life of an existing reinforced concrete bridge based on crack width limit as proposed in the new prescriptive document [3] is analysed in detail below.

The indicative remaining working life of a reinforced concrete bridge is estimated on the basis of crack width limit given in Table 2.

Tab. 2 Indicative remaining working life of bridge based on crack width limit

Remaining working life (in years)	Post-tensioned bridges with tendons bonded	non-bonded	Reinforced bridges
50	0,2 mm	0,2 mm	0,3 mm
25	0,2 mm	0,3 mm	0,4 mm
10	0,3 mm	0,4 mm	0,5 mm

4 Reliability analysis of existing bridge

The probabilistic methods are applied for the verification of the reliability of an existing bridge affected by corrosion with respect to the serviceability limit states of crack width. A homogeneous (uniform) corrosion and also localized (pitting) corrosion are considered.

Further, the prescriptive criteria for crack width limits recommended in Table 2 for estimation of the residual life-time of reinforced concrete bridges are analyzed.

The probability P_F of a random crack width $w(\boldsymbol{X}, t)$ exceeding the crack width limit w_{lim} for the time dependent problem may be assessed as

$$P_F(\boldsymbol{X}, t) = P\{ w_{lim} - w(\boldsymbol{X}, t) < 0\} \quad (1)$$

where $\boldsymbol{X}$ is the vector of basic variables. Another reliability indicator is the generalized reliability index β, given as $\beta(\boldsymbol{X}, t) = -\Phi^{-1}(P_F(\boldsymbol{X}, t))$. The bridge may be considered as reliable if the inequality $\beta(\boldsymbol{X}, t) \geq \beta_t$ is satisfied. The recommended target reliability index β_t for verification of the irreversible serviceability limit states is $\beta_t = 1{,}5$.

The probabilistic reliability analyses indicate that the initial reliability index (β = 1,65) of the bridge with respect to the crack width complies with the required target value β_t = 1,5. The reliability of the bridge decreases in time due to the corrosion process. It is shown in **Fig. 1** that the reliability index decreases below the required reliability level in about 30 years of the bridge working life for assumed models of corrosion.

Thus, the decrease of the reliability caused by the pitting corrosion is going on with considerably greater speed than the uniform corrosion. For the bridge working life from 50 to 75 years, the reliability index significantly decreases below the target value due to the reinforcement reduction caused by pitting corrosion (in 75 years up to β = 0,6).

In case that the crack width limit w_{lim} = 0,004 mm may be considered in 75 years of the bridge working life (remaining 25 years in Table 2) as recommended in the national provisions [3], the reliability index of the bridge affected by the pitting corrosion increases up to β = 1,5 meeting the required target value. However, the reliability of the bridge is again significantly decreasing in time.

If 90 years of the bridge working life (remaining 10 years) is assumed, the crack width limit w_{lim} = 0,005 may be applied. Then the reliability index increases up to β = 1,7 for the pitting corrosion.

In case of the uniform corrosion of bridge reinforcement, the reliability index decreases less than in the case of pitting corrosion. The reliability index from 50 to 70 year working life of a bridge decreases from 1,35 to 1,2. The crack width limit 0,004 mm, resp. 0,005 mm, accepted in CSN 73 6222 [3] for the bridge remaining working life of 25 years, resp. 10 years, seems to be selected rather high leading to high values of the reliability index. It appears that the recommended values of crack width limits provided in national prescriptive provisions should also take into account the type of deterioration process.

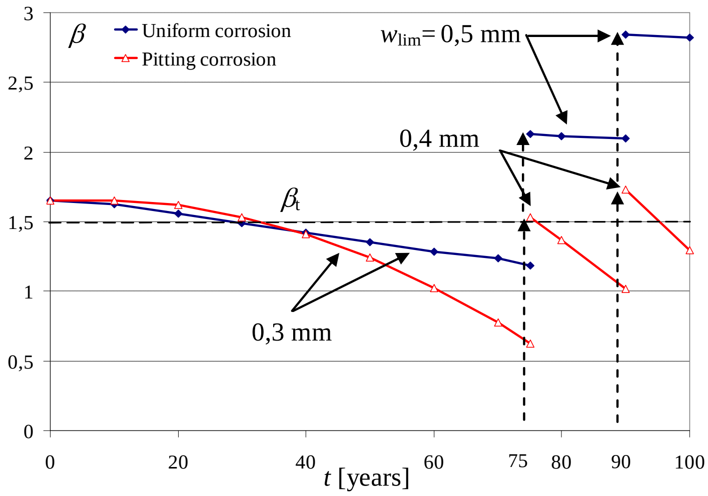

Fig. 1 Variation of the reliability index β for uniform and pitting corrosion with time t for selected crack width limits w_{lim}.

5 Concluding remarks

The reliability analysis of a reinforced concrete bridge with respect to the crack width shows that the uniform corrosion leads to a smaller reduction of the reinforcement area, and also to higher reliability indices than the pitting corrosion.

The results of probabilistic analysis of selected deteriorating bridge indicate that its reliability after about half of the working life (50 years) may be rather low (β < 1,3). Thus, for the achievement of the recommended target reliability level during the whole working life of the bridge and considered degradation processes, additional provisions need to be accepted in the design (e.g. increase of reinforcement cover, protection against corrosion).

It appears that the type of corrosion (uniform, pitting) and potential consequences of failure should be taken into account in the recommendations concerning the crack width limits given in current prescriptive documents. The crack width limits recommended for the assessment of the residual working life of a bridge should be further analyzed.

The development of procedures for the probabilistic assessment of existing bridges should contribute to optimal decision regarding their safety and serviceability supporting their further sustainability.

Acknowledgements

This study has been conducted at the Klokner Institute CTU within the framework of the research project A/CZ0046/2/0013 Assessment of historical immovable, supported by a grant from Iceland, Liechtenstein and Norway through the EEA Financial Mechanism and the Norwegian Financial Mechanism.

References

[1] ISO 13822. *Bases for design of structures – Assessment of existing structures*, 2001.

[2] EN 1990. *Eurocode, Basis of structural design*, CEN, 2004.

[3] CSN 73 6222 *Load bearing capacity of the road bridges*, UNMZ, 2008