ASSESSMENT AND REHABILITATION OF EXISTING BRIDGES

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Summary

Existing bridges are gradually deteriorating due to the effects of various adverse factors or they might be accidentally damaged by lorries leading to significant decrease of their reliability level. Before each bridge rehabilitation, the plan of exploitation, technical and economic analyses should be developed. The costs of bridge rehabilitation should not exceed the value of investment in a new bridge. In cases of heritage structures the co-operation with preservationists is needed.

Keywords: existing bridge, failure probability, remaining working life, rehabilitation

1 Introduction

Various existing bridges provide a vital transport function and specific character to cities and their surroundings. A number of bridges built of different materials including stone arch bridges across watercourses or railways may serve their purposes for a long time. However, a lack of maintenance may lead to gradual deterioration of bridges which increases doubts about their reliability. The assessment of bridges, estimation of their remaining working-life and consideration of their further exploitation should be based on the international standard ISO 13822 [1]. For the verification of existing bridges, the partial factor method or probabilistic methods may be used.

Application of probabilistic methods for specification of reliability and working life of a bridge is illustrated in Figure 1. It is assumed that the assessment (inspection) of an existing bridge is performed in time t_{pr} from the beginning of the bridge completion. In case that the time-dependent resistance $R(t)$ of a bridge or its member and load effects $E(t)$ are known, the remaining working life may be specified.

For estimation of residual working life, the following expression is given as

$$P_f(t_{res}) = \mathrm{P}\{R(t_{res}) - E(t_{res}) < 0\} = P_{f,t} \quad (1)$$

where t_{res} is the bridge residual working life and $P_{f,t}$ is the target failure probability. The probability of failure P_f may be expressed by the reliability index $\beta = -\Phi^{-1}(P_f)$, where Φ is the distribution function of standardised normal variable.

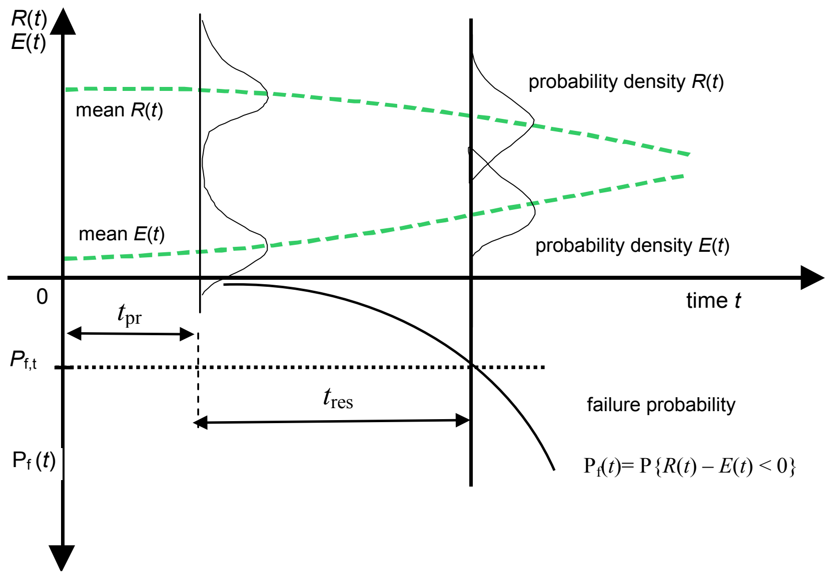

Fig. 1 *Probabilistic assessment of bridge working life*

Assessment of structural reliability and consideration about further exploitation is illustrated by the example of an existing stone road bridge. Final decision on rehabilitation of the bridge is also presented.

2 Stone arch bridge

Stone arch bridge built in the second half of 19th century spans across an international single-line railway in the South-West Bohemia. The length of the bridge is about 28 m, its width is 5 m. A 3rd class road having one lane for both directions of local traffic is crossing the bridge. On the basis of inspection the bridge is classified to IV class according to CSN 73 6221 [2]. The last main inspection was made in 2002 year; two successive main bridge inspections were skipped. A regular bridge inspection made in May 2010 also confirmed the bridge state in IV class. The bridge classified to this class may include defects in masonry, partial lack of mortar, existence of plants, local cracks of width greater than 0,4 mm, however without influence on bridge reliability. For estimation of the load bearing capacity, the coefficient α = 0,8 may be applied for class IV according to CSN 73 6221 [1]. The normal bridge bearing capacity was estimated to 5 t.

Shortly after the regular inspection of the bridge, its stone railing was accidentally impacted by a lorry with failed breaks (Fig. 2). About half of a stone railing and part of a breast wall fell down on a railway and the lorry finally crashed into a nearby dwelling house (fortunately with a minor injury of a driver only).

Several issues had to be addressed after the collision including assessment of the safety of traffic on the bridge, the reliability of the bridge with respect to traffic on railway and estimation of bridge residual working life. It was necessary to decide on further exploitation of existing bridge or its demolition and investment into a new one.

3 Reliability analysis of a bridge

For the assessment of the load-bearing capacity of the existing stone bridge, the nationally implemented international standard ISO 13822 [1], CSN 73 6222 [3] and Technical requirements TP 199 [4] are applied.

An obligatory extraordinary inspection of the bridge including material tests was not made after the accident. Therefore, the characteristic values of material properties of mortar, stones, backfill and road pavement and degree of their deterioration were based on available information and original Czech standards.

For estimation of the load-bearing capacity, the limit eccentricity $e_{\lim}$ (0,08 m) is determined according to TP 199 [4] and compared with eccentricity caused in stone arch by internal forces due to the self-weight, permanent loads, backfill and traffic loads. The traffic load models for common and exclusive bearing capacity are applied with a recommended value of dynamic factor $\delta = 1,4$ according to CSN 73 6222 [3]. For distribution of traffic loads on stone arch through backfill, the Boussinesq theory of elastic half-space is applied. The arch beam is divided in several parts where the internal forces are specified and loaded by traffic loads in such a way that the reliability condition for the limit eccentricity and strength of masonry is not exceeded.

Based on the analysis, the bridge capacity of 9 t is newly specified being about one time greater than the bridge capacity of 5 t introduced on the road traffic signs.

The probabilistic assessment according to ISO 13822 [1] is also conducted using the condition (1). The models of basic variables are considered according to the JCSS Probabilistic Model Code and previous research developed in the Klokner Institute CTU.

The probabilistic analyses reveals that the reliability index of the bridge for the considered traffic load model of 9 t is $\beta = 5,3$ what is considerably greater than it is recommended in Eurocodes for the ultimate limit states ($\beta_t = 3,8$).

It should be noted that in case that the bridge capacity would be specified according to probabilistic methods, the bridge capacity might be estimated to 10 t.

Fig. 2 *Damaged road stone bridge*

Fig. 3 *Rehabilitated bridge*

4 Economic considerations

Costs of a bridge repair due to the accidental impact of a lorry are estimated to 21.200 EUR. The actual remaining price of an existing bridge before the accident (including depreciation costs) is about 90.800 EUR. In case that a new bridge of similar geometry is built, its price may be estimated to 455.000 EUR (without demolition costs).

Finally it was decided to make a complex rehabilitation of a bridge where the total costs achieved 465.600 EUR. A heavy reinforced concrete deck was built, the masonry arch was tied and masonry grouted. New steel railing was installed on bridge which together with the heavy concrete deck adversely changed the original historic character of the stone bridge near the centre of the town. Despite of the complex rehabilitation, the bridge load bearing capacity of 5 t remained surprisingly unchanged (Fig. 3).

5 Concluding remarks

The stone arch bridge was superficially inspected only after the collision. Shortly after the accident an excessive rehabilitation of the bridge was proposed and executed. Application of a new reinforced concrete deck and steel railings unsuitably influenced the original historic character of the bridge. Moreover, the expensive rehabilitation did not lead to the enhancement of the low bridge bearing capacity of 5 t.

The presented example is focused on decision making and procedure concerning rehabilitation of the bridge. The bridge bearing capacity before rehabilitation is verified according to ISO 13822. The actual capacity of the bridge based on the partial factor method is 9 tons. In case that the probabilistic assessment of the bridge is provided, the reliability index β is about 5,3 which is greater than the target value (β_t = 3,8) recommended in Eurocodes. Moreover, in case that the probabilistic assessment is performed then the bridge capacity may be increased to 10 tons.

For assurance of further bridge serviceability, it could be sufficient to repair the damaged stone railing, to provide a new road pavement with insulation against moisture, to clean plants and grout mortar in masonry.

It is shown that before the rehabilitation of each existing bridge, the plan of exploitation, technical and economic analyses should be developed. The costs spend on the bridge rehabilitation should not exceed the value of investment in a new bridge. In cases of heritage structures co-operation with preservationists is also needed.

Acknowledgement

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