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Reliability and durability of concrete and pre-stressed concrete bridges, decision making processes and risks

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Summary

The paper deals with the reliability and durability of concrete and pre-stressed concrete bridges and with the decision-making processes and risks what to do with the bridge in a certain stage of life time. It describes the most frequently occurred failure causes within the realization, operation and reconstruction of the bridge structures. At the end there are mentioned some NDT methods, which are used in bridge diagnostics.

KEYWORDS: concrete bridges, reliability, durability, failures, safety, decision-making, NDT methods.

1. INTRODUCTION

Problems of the durability of concrete bridges and pursuit of the prolongation of their service life or optionally change in their usage is very topical matter today in particular from the following reasons:

- on considerable part of existing concrete bridges, evidences of ageing and damage start more and more to occur in the greater range that indicate oncoming exhaustion of load carrying capacity.

- demands on usability and resistance of bridges are growing rapidly today (the intensity of the traffic load is growing, axle loads of vehicles are increasing, by the damaging emission, the effects of environment on bridges are growing worse).

- construction of new objects is demanding on consumption of still rear raw materials and energies. Disposal of removed bridge structures is connected with a lot of technical and ecological problems.

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2. DURABILITY OF BRIDGES AND ITS SECURING (FACTORS INFLUENCING BRIDGE DURABILITY)

Durability of bridges is indivisible part of their reliability. The bridge has required durability, if it serves reliability conditions from the viewpoint of decisive limit states during the supposed life time T_∞ . These limit states are set down by actual codes and regulations. It can be possible only in that case if the initial bridge condition, given by the quality of project and realization, is on needed level and effects of load and environment will not during the time grow worse insomuch as the reliability system (structure, load and environment) will stop to work good due time $t < T_\infty$.

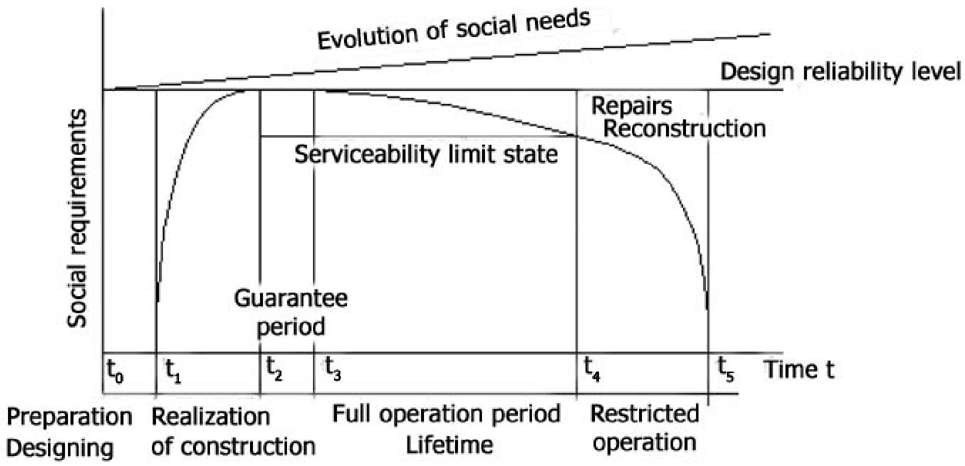

Fig. 1 Reliability and life time of bridge structure

On the basis of cause analysis of the bridge failures that occur the most frequently, it was found out the following percentage distribution of failure causes in the realization of bridge structure: according to the literature [1].

20% of failure causes are included already in the design of bridge structure (geological survey, project preparation and works connected with the preparation of realization).

50% of failure causes come directly under the process of bridge construction (material quality, wrong detail, lack of technological discipline).

15% of failure causes are possible to predicate directly to the operation.

15% of failure causes are possible to predicate to the other effects.

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If we analyse failure causes further we find the important fact that from all of the failure causes it is possible to predicate 80% of them to the human factor failure and only 20% are caused in the consequence of the bridge load.

From above mentioned it follows that construction of bridge object require high demands on qualification and quality of all the workers, namely during all stages of construction. On the Fig. 1 can be seen time intervals in life time of bridge structure.

The time t_2 to t_4 would meet our presumption about safe operational usage of bridge. Then decision-making process arrives what to do with bridge next.

3. RECONSTRUCTION OF BRIDGE

For user, it means to consider whether:

- modernisation of operation on the bridge is necessary and whether this arrangement will require intervention to carrying superstructure of bridge or

- reliability bridge condition (i. e. defects and failures) is of so much serious character that there is need to put a certain effort on its improvement within the framework of structure safety.

Basically it means two types of reconstruction that are joined together often in practise.

a) Reconstruction caused by change of operation is joined with the general repair of carrying bridge superstructure during that until now arisen failures are removed. In the same time, the needed durability of bridge is assured along further functional period with the same parameters of social needs.

b) Reconstruction caused by failures in carrying bridge superstructure can cause under specific conditions even such decision that can produce reduction of bridge usage (i. e. reduction of load carrying capacity), removing of substantial defects and leaving the bridge to serve to the end of the life time in limited operational conditions for some time only. Supposed period for this decision should not be more than 5 years.

Decision-making process about necessity or possibility, range and method of reconstruction is often very difficult because there is need to take into account set of many contradictorily acting factors namely above all:

- Purpose of reconstruction (including considerations about the social importance of the bridge).

- Economical aspects (the viewpoint of moral life time), rate of initial costs to maintenance costs.

- Possibilities of technical solutions (comparison of structure condition with available technical means).

In decision-making process it can not be omitted the fact that the condition of bridges built in the same period, by the same technology and at the same traffic load, can be substantially different, namely through the climatic impacts and through the effects of aggressive environment. They were not envisaged in complex in the bridge design in the past, but they were solved only by the taking into account of code requirements that set down maximum permissible crack widths, eventually the necessary depth of cover layer.

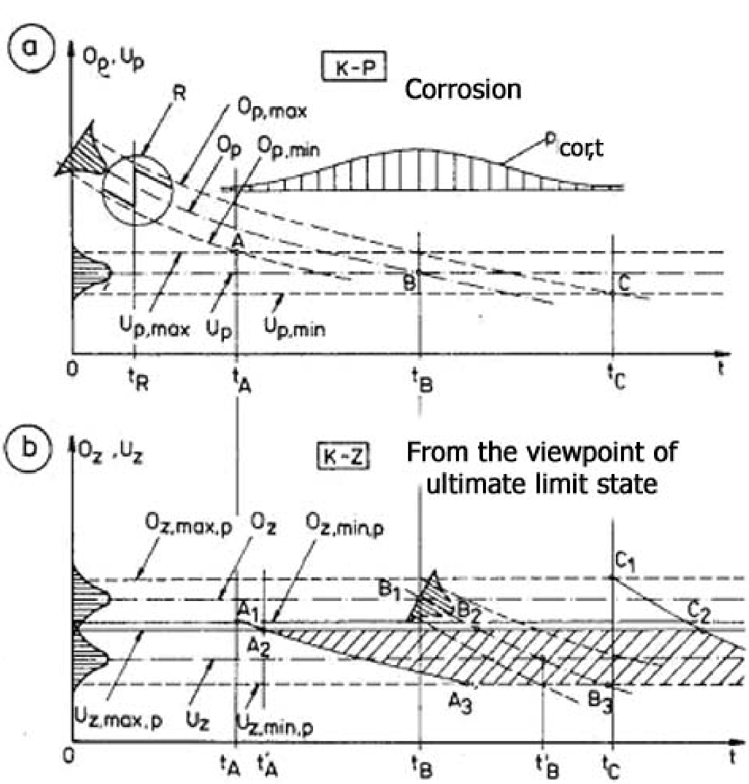

Fig. 2 Scheme of interaction of reliability system (structure, loads & environment in time t)

Both the effects of environment and the structure resistance against them are variable values, see [2], that can be influenced by many other factors both in

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project and in bridge construction and during its operation (e. g. by the shape of carrying bridge superstructure, surface structure, compactness of concrete, usage and arrangement of reinforcement, total level of production and its control, influences caused by shrinkage, strain, flow of interacting media, maintenance of operational devices).

On Fig. 2 the interaction of system (structure, loads and environment) is illustrated in simplified way during the time for the bridge that would demonstrate a long life time in favourable environment.

Fig. 2a shows the influence of random variability of environment impacts U_p and the influence of structure resistance O_p on the possible moment of the beginning of corrosion of concrete or reinforcement (degradation O_p by influence of U_p).

Fig. 2b further shows the course of reducing of the bridge structure resistance O_z from the viewpoint of ultimate limit state and eventual rise of failures from this viewpoint, which will come into being if $O_z < U_z$. It is evident that first failures can arise already much earlier than it is supposed ($t'_a < t'_b$), even though with the little probability.

Points marked out on Fig.2 (a, b) $A(t_a)$, $B(t_b)$, $C(t_c)$ show examples of possible moments of the beginning of corrosion and the $C_1 – C_3$ courses of reducing of the bridge structure resistance O_z against loading by the corrosion influence are connected with them.

From above mentioned examination it is evident that reliability and durability of bridge structure is complicated matter. There is need to proceed during the examination in a complex way and carry out always substantial analysis of all the possible causes under them it can come to the bridge failures. Only then, on the basis of complex analysis carried out in this way, we can come up to the decision-making process, how to proceed with bridge ahead. Even in a very careful approach, though for assessment and decision-making process we shall use results of diagnostic survey, eventually completed ones by loading test in any case we meet the certain risk.

4. RISK IN DECISION-MAKING PROCESS WHAT TO DO WITH THE BRIDGE IN A CERTAIN STAGE OF LIFE TIME

Each progress and each change bring the certain risk with themselves. We could understand it in connection with progress as a positive effect. We get information about risks that could be accurate, sometime less accurate and sometime even knowingly garbled. Risks remain often inexplicable and they produce fear and

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worries. There is need to assess the risks at construction and operation of bridge from various viewpoints, namely during the course of whole life time of bridges:

- collapse of carrying bridge superstructure can be an extreme case,
- total collapse of structure and its putting out of operation.

The risks in decision-making process, what to do with the bridge in a certain stage of life time, are important extraordinary. Just these risks should be the objective of other studies, because they can influence considerably the future of ever increasing number of built bridges.

5. NDT BRIDGE DIAGNOSTICS METHODS

Beside a classical bridge inspection methods, which are realized in regular periods (main, secondary, and control inspections) there are special inspections, which are carried out after disaster's occurrence, in case of detection of any change in soil body or after presence of rebar corrosion symptoms, etc.

The classical bridge inspection methods are visual inspection, carbonation depth survey, content of chloride survey, core analysis, etc.

New NDT methods like ground penetrating radar, ultrasound, acoustic emission, infrared thermography, radiography, vibration analysis are used more often today [3].

Bridge structure can be instrumented with structural testing system for medium and long-term monitoring. This way a structural movement or degradation over periods of time is monitored and the data can be downloaded via telephone modem and remotely viewed in real time or automatically stored on a periodic basis.

CDV- Transport Research Centre is dealing with two from above mentioned NDT methods (acoustic emission - AE and ground penetrating radar - GPR) [4].

CDV proposed the best practice guideline called Diagnostic survey of road bridges, monitoring methods and evaluation of rebar corrosion in concrete by acoustic emission method, which was submitted for an approval to the Czech Ministry of Transport.

Acoustic response of studied structure to an evoked loading is evaluated there.

Basically there are two possibilities for application of AE method. The first one is long term monitoring of a whole structure or its parts by array of AE sensors. The second one is one-shot investigation by AE method, which should be carried out periodically.

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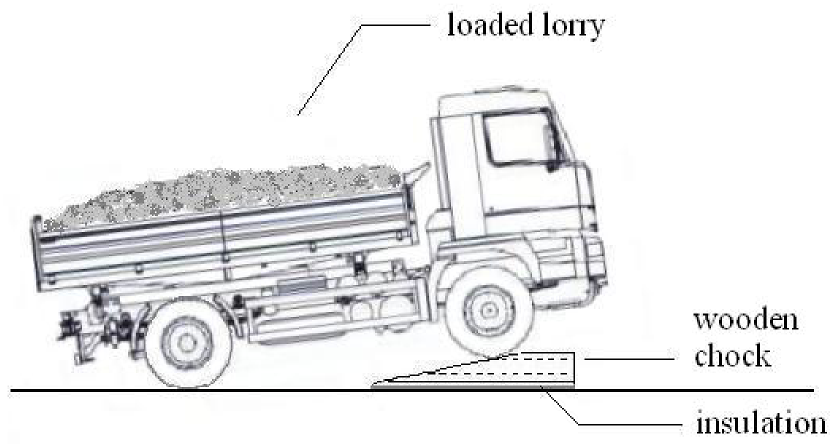


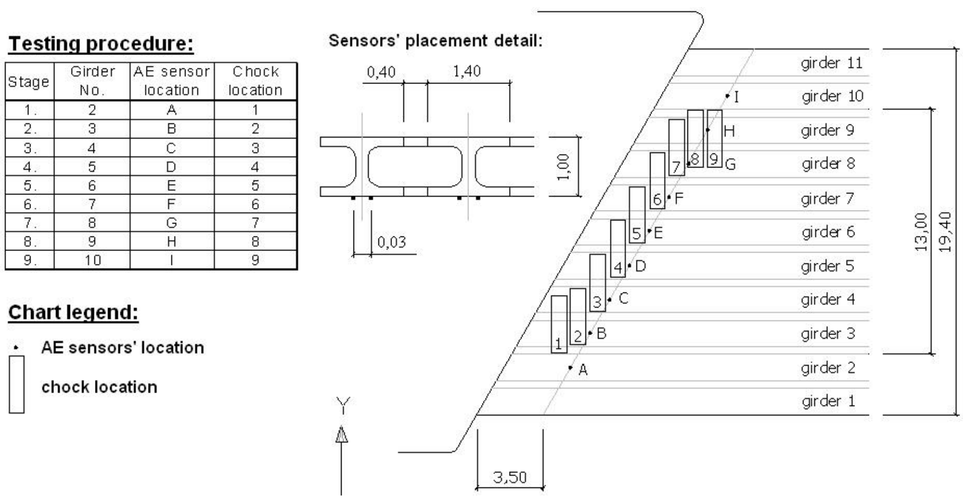
Fig. 3 Bridge dynamic loading with impact

In the proposal there are mentioned the following basic ways of a bridge loading:

static – loading vehicles are placed in the middle of the arch span,

dynamic without impact – loading vehicle or vehicles travelling along the bridge with constant speed 0,5 km/h,

dynamic with impact – loaded lorry travelling with constant speed across the wooden chock of constant high, see Fig. 3,
under traffic operation.



Stage	Girder No.	AE sensor location	Chock location
1.	2	A	1
2.	3	B	2
3.	4	C	3
4.	5	D	4
5.	6	E	5
6.	7	F	6
7.	8	G	7
8.	9	H	8
9.	10	I	9

Fig. 4 Bridge loading scheme

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The measurement is carried out on the base of prepared testing procedure, whose important part is a loading scheme. An example of loading scheme in case of dynamic loading with impact shows Fig. 4 (wooden chock placement, AE sensors location, etc.).

Recorded AE signals are analyzed (number of AE events and their parameters, frequency analysis, time-frequency analysis) and AE sources are classified.

Fig. 5 shows frequency spectra comparison of signals recorded during dynamic loading of the bridge with impact in the middle of the same girder before and after reconstruction of the bridge, where the original girders remained the same.

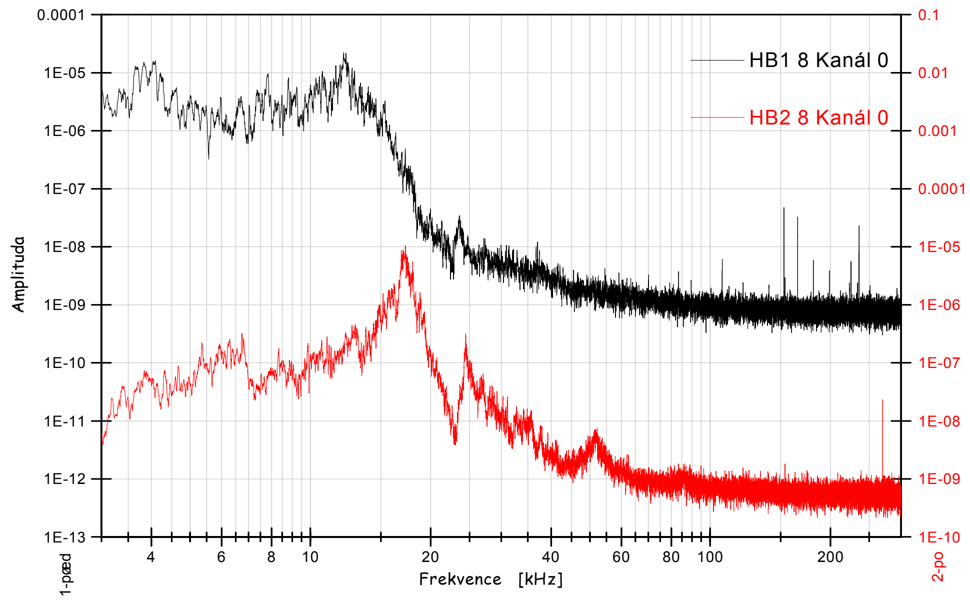

Fig 5 Girder evaluation: frequency spectra comparison (before and after reconstruction of the bridge)

CDV partakes on solving of some research projects where the Ground penetrating radar possibilities are studied in the field of road evaluation. Currently CDV concentrates its effort also to GPR usage in the bridge evaluation area [5].

In the Czech Republic the GPR diagnostics of bridges is limited to a pavement and a bridge deck control. The GPR problematic is not standardised in the Czech Republic in contrast to USA and UK.

Fig. 6 shows GPR radargram at the edge of Gutter bridge, which was subsequently reinforced and filled with concrete and its interpretation in the form of the graph.

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Usage of suitable combination of NDT methods gives more precise survey results. In the case of GPR it is appropriate combination with infrared thermography method.

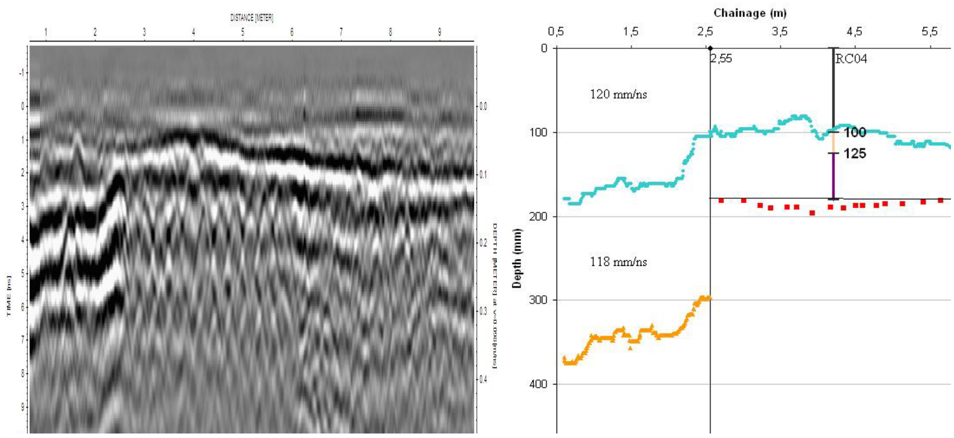

Fig. 6 Gutter bridge: GPR radargram, graph interpretation

6. CONCLUSIONS

The reliability and durability of the concrete and pre-stressed concrete bridges depend on their initial condition, on the quality of project and realization and further on the effects of operation and environment.

The durability of bridges is an indivisible part of their reliability. Important decisions are made just before the reconstruction of the bridge or after their failures.

In such decision-making processes some factors as purpose of reconstruction, economical aspects and possibilities of technical solutions and necessary risks too should have been taken into account.

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