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Inspection Strategy for Steel Bridge Structures based on Probabilistic Computations

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Abstract

The paper discusses the current state of the development of a computation-driven inspection strategy for steel bridge structures. The approach is based on assumption that weak points of the structure can be identified and their behaviour can be simulated with use of fracture mechanics approaches. Then the time of the first in-depth inspection can be determined as a time when the issue (usually a crack) is developed to an unacceptable size with target probability. To determine this a probabilistic framework based on the Direct Optimized Probabilistic Computation method is used. The paper gives a general overview of the approach and discusses its main features and limitations int the point of view of the current knowledge.

Keywords: reliability, Monte Carlo, steel bridge, fatigue, inspections.

1 Introduction

Steel structures, including bridges, are among those often used in contemporary civil engineering. Steel structures, naturally, include many details which are prone to fatigue damage [1]. They include connections (especially welded or bolted ones) and many other geometric features like holes. To ensure that structure will be usable for whole expected service life it is necessary to conduct activities which will led to timely detection of development of any type of damage like cracks or corrosion.

Monitoring and repairs strategies have been continuously developed. The first steel bridges were inspected by naked eye with no elaborated plan of inspections and their repairs were done when problems were reported. These approaches have been evolved through introduction of fixed time plans to modern approaches which include continuous monitoring with on-line reporting in some cases [3].

However, there are large number of bridges which were build in the past and which have no facilities to accommodate effective on-line monitoring tools.

There are a number of efforts to define procedures and guidelines to extend bridges safety and lifespan by means of inspections and repairs [3], [6], [2]. Such approaches propose several levels of complexity of such procedures in accordance of a structure type, its importance and feasibility. Some of these approaches have been already adopted by various organisations. General rules for assessment of existing structures are already included in the ISO standard [7]. The above mentioned standard, nor other similar documents, however does not strictly define what particular approach have to be used. The best approach for a particular structure can be decided in several ways, as it is shown in the paper [12] where authors discuss use of several approaches (a probabilistic analysis with or without visual inspections and an analysis supported by extensive in situ diagnostics). It is clearly shown here that feasibility and costs play important role in decision what approach would be used.

In some parts of the Europe it is still common practice to inspections of bridges according to time plans. Such plans are based on previous experiences (and usually executed with constant time steps) and on recommendations of currently available frameworks [4], [6]. The reason for such conservative approach is mainly the high number of existing structures [3].

The probability of development of cracks in critical details is obviously non-constant. Moreover, cracks development may be induced by several factors. In this paper the classification used in [2] and in the database [16] is used:

- Cracks originating from weld defects that were introduced at the time of fabrication.
- Cracking due to an inappropriate structural component of low fatigue strength in terms of nominal stress.
- Cracks originating and/or fatigue crack growth due to out-of-plane stresses and deformations that were unforeseen in the design.
- Cracks originating and/or fatigue crack growth due to unexpected structural behaviour such as vibrations induced by wind or traffic.

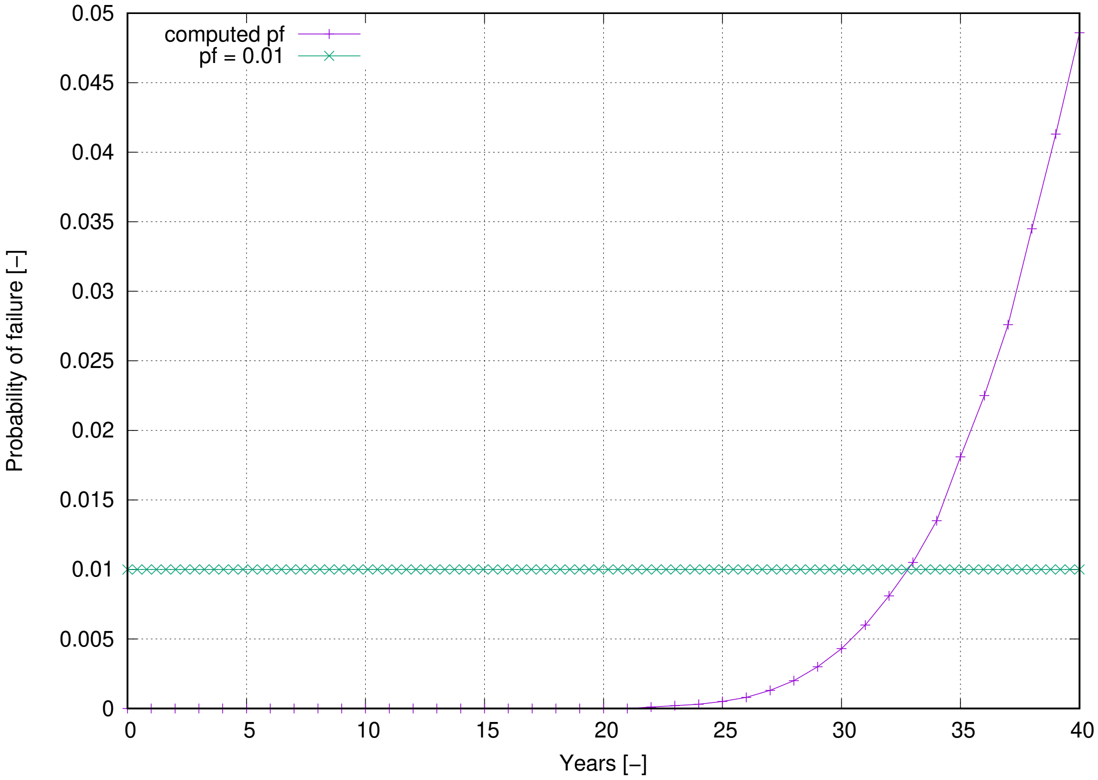

Figure 1: Probability of failure of a steel bridge detail with a value of the target probability marked by the green line [9].

The database [16] lists over 200 cases of damages and repairs of steel bridges around the world. The paper [2] draws some conclusions based on that database. It is shown there that causes 2 and 3 from the list above typically led to cracks before 25^{th} year of bridge service life and majority of all cracks is detected till the 45^{th} year of structural operation.

2 Aims

This paper thus aims to contribute to the goal of defining of an inspection plan strategy based on a computational analysis of weak points of the structure. This analysis corresponds with the crack initiation factors 2 and 3.

3 Methodology

The proposed approach is a development of previous works [8], [10] and [9]. The main assumption is that the critical points of the studied structure can be identified and the loads on the structure can be described as random variables. These variables are represented in form of so-called bounded histograms [13].

Based on the assumptions above it is possible to compute time (an year of service life) when the crack in a given critical point initiates with pre-defined probability. The computed time then can be used as the time of the first in-depth inspection. An illustration of such approach in shown in Figure 1 where the horizontal (green) line represents the pre-defined target probability of failure (0.01 in the presented case).

There are several possible scenarios when the inspection on the reals structure is conducted in the time determined by the computation:

- No fatigue crack is detected by available means.
- The detected crack is below the maximum allowed (acceptable) size (thus no ”failure” is considered).
- The crack reached the maximum allowed (acceptable) size. This is interpreted as a ”failure” and repair is necessary.

The next inspection is then determined with the same methodology. However, the new probability of failure level is determined on basis of identified scenario and with use of conditional probability. Detailed description how the new probability level is computed is given in [11].

Several simplification are used in the proposed approach:

- Computations use analytical formulas for fatigue crack propagation in studied critical details.
- The Paris-Erdogan [15] law is used.
- Loads, material properties and other necessary input data can be represented as random variables.
- Probabilistic solution based on the Monte Carlo [14], [13] or the Direct Optimized Probabilistic Computation (DOProC) method [8] is used.

A typical solution is based on an analysis of the crack length (crack size) a. The failure is defined as a probability that the a is equal or greater than the critical (acceptable) crack size a_{lim} for the studied detail.

In the most typical cases the main random parameters are the initial crack length a_0, the yield stress f_y, the load size often represented by the force F and the number of load cycles N.

The above mentioned approach is implemented if form of the MATLAB/Octave code.

4 Conclusions

The proposed approach has its strengths and weaknesses.

The main feature of the proposed approach is that it can be used for existing structures. These structures can be analysed and inspected to identify their structural deficiencies. Then it is possible to define input data (most importantly, their load history) and to execute the computation with respect to their actual state.

The obvious problem is that the approach cannot work with cracks originating from weld defects and similar issues. For initial stage of service life of bridge it is this important to supplement this method with other approaches. Also, identification of weak points is based on human factor and thus it can be source of errors. This can be improved by introduction of Finite Element Analysis – based identification of weak points and/or by supplementing it by identification based on Artificial Intelligence Approaches. For example, usability of the approach [5] is now being studied.

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