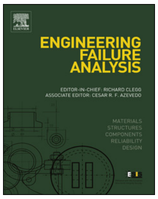
Engineering Failure Analysis 91 (2018) 306–314

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal



A decision support framework for fatigue assessment of steel bridges

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ARTICLE INFO

Keywords:
Bridges
Fatigue
Risk
Decisions
Monitoring

ABSTRACT

Many bridges are approaching or have already passed their expected service life. For steel bridges, fatigue is often the decisive degradation phenomenon that theoretically puts restrictions on a continued use. At the same time, fatigue is also afflicted with large uncertainties on the resistance side as well as on the action effect side. An accurate assessment of the service life will require measures outside the governing regulations but understanding what steps to take and how to consider the outcome for decisions on interventions can be a difficult task for a non-expert. This paper presents possible assessment actions and a decision support framework for rational decisions on interventions to extend the theoretical service life of existing bridges. A case study of a critical railway bridge is incorporated to demonstrate the framework. The aim is to provide a tool for bridge managers on how to evaluate and procure different assessment actions.

1. Introduction

There is an ever growing need to make decisions on interventions to keep existing bridges in service. Several investigations have shown that most countries with a developed transport infrastructure are facing challenges with a growing number of bridges approaching their expected service life [1, 2]. These bridges cannot be upgraded or replaced within reasonable budget restraints and, for sustainability reasons, their service life should be extended as far as possible. This will require the use of sophisticated methods for assessment and service life prediction. Guidelines can be found in, e.g., [1] and [3], where different assessment levels are suggested ranging from a conventional assessment following the regulations to advanced methods using fracture mechanics and probabilistic evaluation. Both publications suggest a consecutive approach with a stepwise increase of complexity and sophistication. This development of the assessment model will presumably increase the ability to predict a more realistic structural behaviour. On the other hand, models describing more complex phenomena will typically require more input variables and modelling choices afflicted with uncertainty. This leads to a greater need for reliable information concerning the properties and actual condition of the structure.

As an alternative to a consecutive assessment approach, a framework for classification of assessment actions and decision support has been suggested by Björnsson et al. [4]. The attributes of assessment actions are visualized as a cube in Fig. 1 hereafter called the MUK approach. This model allows a distinction between the contributions of different actions in connection with the prediction accuracy. The first attribute of the MUK approach is defined as the modelling sophistication (M), which measures how detailed the theoretical model for condition assessment is. The second factor represents the uncertainty consideration (U), that is how the uncertainties of the assessment are considered. The third factor represents the knowledge content (K), considering how information

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https://doi.org/10.1016/j.engfailanal.2018.04.033
Received 31 January 2018; Received in revised form 27 March 2018; Accepted 22 April 2018

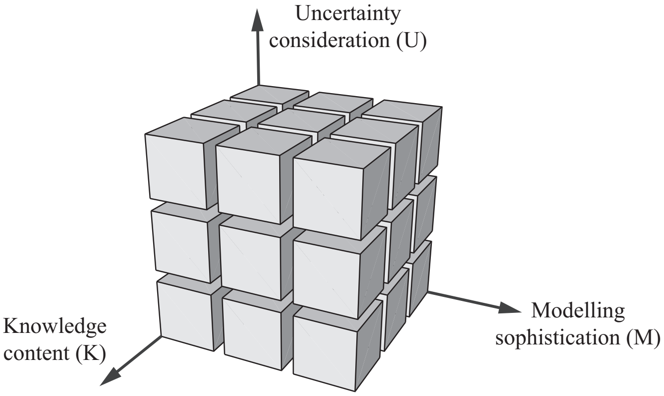

Fig. 1. A model for classification of assessment actions (MUK approach).

about the structure have been acquired and used in the assessment. The three attributes of the MUK approach can be visualized as a cube with each axis corresponding to one of the attributes; see Fig. 1. An assessment can be improved by proceeding along one axis but preferably by progressing in a three-dimensional sense along all axes. The origin of the cube can be interpreted as a preliminary assessment in accordance with the regulations. Moving away from the origin is expected to give an improved accuracy of results but, it also entails more complex methods requiring a greater number of variables [4]. The different attributes and levels of the MUK approach are explained in more detail in Section 2 considering fatigue assessments.

If a preliminary assessment indicates an exhausted service life, the bridge manager has to decide on more exhaustive assessment actions or possible interventions such as repair, rehabilitation, and demolition, to reduce the danger with respect to public safety [5]. The MUK approach combined with Bayesian decision theory under uncertainty is suggested as a tool to aid the decision maker in this navigation. It enables a rational consideration of uncertainties of the input variables and an evaluation of decision alternatives by minimizing expected costs or other negative consequences. An approach using influence diagrams, a Bayesian network augmented with decision and utility nodes [6], as suggested in [4] is implemented in this study. An influence diagram allows an evaluation of expected utilities of different decision options based on the information known at the time of the decision. The decision model is explained in Section 3.

The use of influence diagrams for decision support is suggested also in [7] and [8] where the deterioration of offshore structures is treated. These studies are focused on optimal planning of operation and maintenance (O&M) actions, which for offshore structures can constitute a significant part of the total life cycle cost [9]. For bridges, the relation between maintenance costs and consequences of failure is typically different. A considerable service life, up to 100 years or more, and large consequences of failure necessitate robust designs and low probabilities of failure. Actions to ascertain the resistance of a deteriorating bridge must be taken before obvious damages emerge. Hence, this study is focused on assessment actions rather than on O&M strategies. The purpose is to support rational decisions on procurement of measures to improve the accuracy of the predicted service life, with an overall aim to extend the service life of existing bridges.

The application of the MUK approach and the decision framework for fatigue assessment of existing steel bridges is elaborated in this paper. First, available methods for fatigue assessment are reviewed and a classification according to the model in Fig. 1 is suggested. Secondly, the decision model based on an influence diagram is described. Finally, a case study of a steel bridge subjected to fatigue deterioration is presented to demonstrate the approach.

2. Fatigue assessment

The assessment of an existing bridge considering fatigue is typically performed using the same methods as for the design of new bridges. Simplified characteristic load models are used and the verification is performed using a deterministic safety format. This is denominated as *Phase I: Preliminary evaluation* in [3]. Different attributes to consider in subsequent more detailed assessments can be classified according to Fig. 1. The three attributes; model sophistication (M), uncertainty consideration (U), and knowledge content (K), are described considering fatigue assessment in the following sections.

2.1. Model sophistication

For a condition assessment, a theoretical model to predict the structural behaviour due to loading is needed and, furthermore, a model reflecting the deterioration process. The model sophistication (M) is an attribute describing the complexity of the theoretical model, typically based on how many variables it contains and how accurately it reflects the performance of the bridge. However, increasing the level of complexity can be time-consuming, require additional data, introduce errors, etc. Therefore, the expected costs and benefits of moving to a higher level of sophistication should be evaluated and compared with options of moving along the other two axes in Fig. 1.

Considering fatigue, the accuracy of the service life prediction depends on the estimated load effect, described as a stress range