ARTICLE IN PRESS

Theoretical and Applied Fracture Mechanics xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Theoretical and Applied Fracture Mechanics

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

Life cycle analysis of steel railway bridges

D. Peng [a], R. Jones [a,b,*], K. Cairns [a], J. Baker [a], A. McMillan [b]

[a] Centre of Expertise in Structural Mechanics, Department of Mechanical and Aeronautical Engineering, Monash University, Wellington Rd, Clayton, Vic 3800, Australia
[b] School of Applied Sciences, Computing and Engineering, Wrexham Glyndwr University, Mold Road, Wrexham LL11 2AW, UK

ARTICLE INFO

Article history:
Received 11 May 2017
Revised 30 June 2017
Accepted 30 June 2017
Available online xxxx

Keywords:
Steel bridges
Corrosion
Fatigue crack growth
Remaining life

ABSTRACT

This paper focuses on the growth of cracks that arise from natural corrosion in steel bridges. It is shown that these two effects of corrosion and stress, need to be simultaneously analysed. A methodology used to compute the growth of such cracks in bridge steels is presented. A better understanding of the remaining life of steel bridges would help establish an assessment procedure and guide engineers when deciding between reinforcement and replacement.

1. Introduction

Bridge condition can typically be expressed in two ways: condition appraisal (which is subjective) and analytical load rating. Condition appraisal is perhaps the most commonly used approach. The appraisal is a subjective rating based on established guidelines such as the National Bridge Inspection Standards (NBIS) and the inspector's judgment. Analytical load rating is also used to evaluate railroad bridges. The American Railway Engineering and Maintenance-of-Way Association (AREMA) publishes the Manual for Railway Engineering, which provides standards for railroad bridge evaluation [1]. In general, steel bridge structures must not only comply with enough strength but also behave satisfactorily under services loads.[1]

The assessment of the safety, durability and remaining life of steel bridges requires an understanding of the interaction of fatigue and corrosion degradation processes. In tension dominated members, there is a competition between the rate at which material is lost due to corrosion and the rate of fatigue crack growth. However, at present there is little information about the environments seen by Australian and Norwegian bridges or the associated rates of corrosion. In Australia the fatigue analysis of new and existing steel structures is based on the use of standardized S-N curves. To be able to provide an estimated life remaining for corroded steel bridge is very important for the infrastructure industry. A better understanding of the real behaviour of steel bridges would help establish an assessment procedure and guide engineers, when deciding between reinforcement and replacement.

Numerous publications can be found on corrosion fatigue, and a detailed discussion is provided in [2]. There are only a few available publications for solving the problems of fatigue-corrosion interaction in steel bridges. A probabilistic approach and damage stress model to evaluate fatigue lives was developed in [8]. Many of the methods used focus on the use S-N curves for different atmospheric conditions coupled with assumed corrosion rates and simple cumulative fatigue damage laws [9,10]. A fatigue crack growth evaluation method based on linear elastic fracture mechanics was developed in [11–15]. No available solutions can be found in the literature for corrosion-fatigue interaction where the section stress changes as material is lost due to corrosion.

Fatigue life prediction of corroded bridge steel beam is exceptionally difficult and computationally demanding, as calculations need to be made at each stage of the life of a beam. This is due to compute the stress intensity factor computations for each crack configuration that are needed to calculate the amount of crack growth, update the crack geometry, and then re-compute the stress intensity factors for this new geometry. To meet this challenge, this paper will discuss the issues associated with fatigue crack growth within corroded steel beam. The methodology addresses the following areas and develops the tools and procedures needed by industry:

* Corresponding author at: Centre of Expertise in Structural Mechanics, Department of Mechanical and Aeronautical Engineering, Monash University, Wellington Rd, Clayton, Vic 3800, Australia.

E-mail address: rhys.jones@monash.edu (R. Jones).

[1] In this context it should be noted that there are numerous approaches to repair cracking and degradation in steel bridges. Many different methods ranging from the stop drilling of holes [3–6] to the use of composite doublers [6,7] are used.

http://dx.doi.org/10.1016/j.tafmec.2017.06.023
0167-8442/

Please cite this article in press as: D. Peng et al., Life cycle analysis of steel railway bridges, Theor. Appl. Fract. Mech. (2017), http://dx.doi.org/10.1016/j.tafmec.2017.06.023

(1) A methodology for determining the load environment seen by steel bridges (i.e. the load spectra or load time history). It is illustrated by examining two bridges, viz: V/Line Brides 62 and Brides 44.
(2) Tools for determining the operational environment seen by bridges.
(3) A methodology for determining the corresponding rates of corrosion.
(4) Tools for assessing the damage state of a bridge and for assessing the interaction of corrosion with the structure and the operational load spectra.
(5) The fatigue crack growth tools which when coupled with an ability to monitor the rate of corrosion enable the operator to assess whether a bridge will fail via reduction in the net section or by fatigue crack growth. This then enables the operator to determine the appropriate maintenance periods.

In steps (4) and (5), a 3D model of the steel bridge beam without corrosion is created and the region of interest analysed. In this model, the crack is not explicitly modelled. Having determined the stress field with a semi-analytical solution technique [14,17], conjunction with crack size modification factor and geometry evolution factor (varied with corrosion rate), was used to determine the stress intensity factors (K) for any given crack length. These stress intensity factors were used in conjunction with the Hartman-Schijve crack growth equation [15,16] to compute the crack growth history which can be thought of as a variant of the strain energy density formulation presented in [17,18] and discussed in more detail in the Appendix A. An advantage of this approach is that cracks in the structure do not need to be explicitly modelled. A crack of any size can be analysed using the original (uncracked) finite element model. As cracks are not modelled explicitly, a coarser mesh can be used to minimise the number of degrees of freedom, thereby reducing the analysis time. Solutions for the stress-intensity factors can then be obtained for a variety of cracks using the original finite element analysis quickly and easily.

The data presented in this paper supports the ASHTO recommended metal loss model. The paper also reveals that the failure

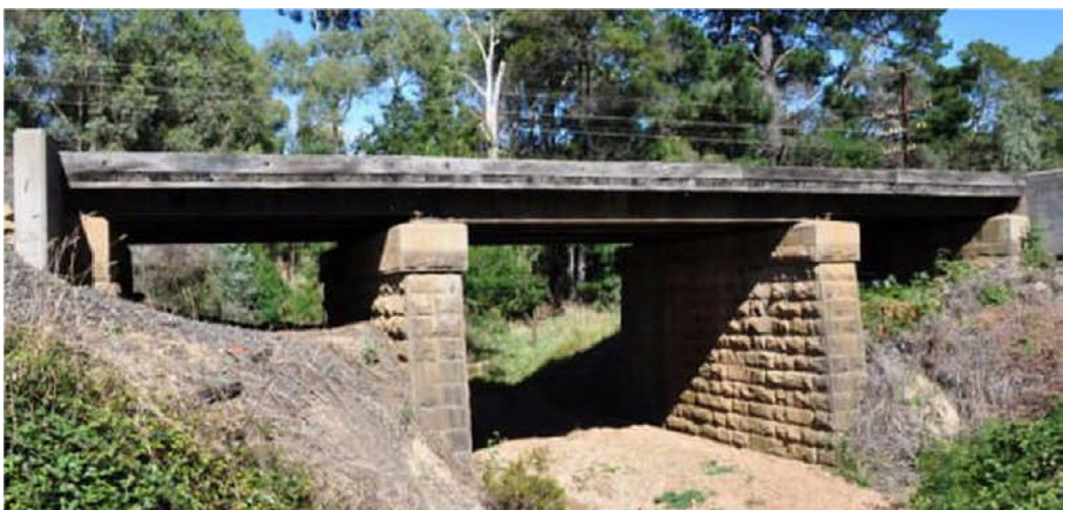

Fig. 1. Bridge 62 near Kilmore East, Victoria.

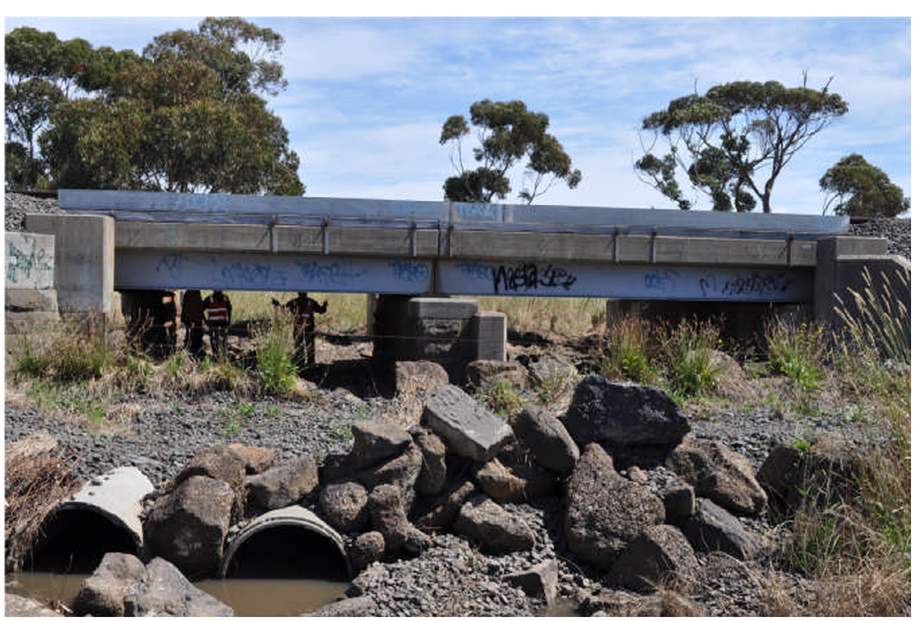

Fig. 2. Bridge 44 near Little River, Victoria.