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Verification of the repair effect for fatigue cracks in members of steel bridges based on thermoelastic stress measurement

Takahide Sakagami [a,*], Yoshiaki Mizokami [b], Daiki Shiozawa [a], Taisei Fujimoto [a], Yui Izumi [c], Taku Hanai [b], Akira Moriyama [b]

[a] Department of Mechanical Engineering, Kobe University, 1-1 Rokkodai-cho, Nada-ku, Kobe 657-8501, Japan
[b] Honshu-Shikoku Bridge Expressway Company Limited, 4-1-22 Onoe-dori, Chuo-ku, Kobe 651-0088, Japan
[c] Department of Mechanical Systems Engineering, University of Shiga Prefecture, 2500 Hassaka-cho, Hikone 522-0057, Japan

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ABSTRACT

Ageing steel bridges suffer fatigue cracks thereby necessitating immediate inspection, structural integrity evaluation or repair in the life cycle of steel bridges. We propose nondestructive evaluation techniques employing infrared thermography enabling us to remotely inspect the fatigue cracks in steel bridges and evaluate the structural integrity on the basis of thermoelastic stress measurement. This study presents a structural integrity assessment of steel bridges using remote measurement of the stress field around the fatigue cracks. We focus upon experimental results confirming reduction in the severity of the stress distribution around the fatigue cracks after the repair or reinforcement of members in steel bridges.

1. Introduction

Propagation of fatigue cracks from welded joints in steel bridges is one of the most serious problems associated with the deterioration of ageing infrastructure. Inspection of the deterioration such as fatigue damage or corrosion is necessary for ensuring safety and estimating the remaining strength of the steel bridges. In this respect, nondestructive testing (NDT) and nondestructive evaluation (NDE) techniques play important roles. Conventional NDT techniques for steel bridges include visual testing, eddy-current testing, magnetic-particle testing and ultrasonic testing. However, these are time- and labor-intensive techniques that require special equipment for inspection such as scaffoldings or vehicles for high-lift work. The Japan Ministry of Land, Infrastructure, Transport and Tourism has reported that there are over 0.7 million bridges requiring inspection [1]. This means that it is not realistically possible to employ conventional NDT techniques for ageing bridges; hence, a high-performance NDT method is essential for their effective maintenance. In addition, structural integrity evaluation is considered essential for the fitness for service evaluation of ageing steel bridges. For an accurate structural integrity evaluation, the actual applied-stress distribution around a fatigue crack and its history owing to the moving wheel load caused by vehicles on the bridge needs to be obtained. Conventional stress- and strain-measurement techniques are insufficient for these requirements.

Thermoelastic stress analysis (TSA) using infrared thermography has come into widespread use in the industry as an effective, experimental, full-field stress measurement technique [2–5]. Especially innovative research works on the TSA

* Corresponding author.
E-mail address: sakagami@mech.kobe-u.ac.jp (T. Sakagami).

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technique are found in structural integrity evaluations for steel structures as well as composite structures related with fracture mechanics evaluations and/or fatigue damage analyses. As for steel structural members, evaluation schemes of the fracture mechanics parameters have been investigated taking advantages of the TSA technique [6]. The fracture mechanics parameters such as stress intensity factor or *J*-integral were determined from the directly measured stress distribution around crack tips in objective structures [7–10]. These techniques have been successfully applied on the fatigue life assessment. Tomlinson et al. [11] investigated fatigue crack propagation under the mixed mode loading. Diaz et al. [12] applied their improved TSA technique for evaluating stress intensity factors in the fatigue test of weld specimen demonstrating the potential of TSA for crack growth analysis influenced by crack closure or residual stress field. Ummenhofer et al. [13] also investigated the applicability of the TSA technique for fatigue damage evaluation in welded joints. The TSA technique has been also employed as a powerful tool for evaluating impact or fatigue damages in composite materials and structures [14–17]. Emery et al. [18] showed the feasibility of the TSA for evaluating fiber breakage, matrix cracking and delamination damage in composites. Fruehmann et al. [19] applied the TSA technique for the assessment of fatigue damage evolution in woven composite materials. Paynter and Dutton [20] applied the TSA technique to wind turbine blade composite structure, in which successful results were obtained in damage evaluation using second harmonic signal correlation. Jones and Molent [21] showed the applicability of the TSA technique for in situ measurement during redesign, reinforcement or repair in aircraft structures.

These literatures showed the strong advantages of the TSA technique for the remote, noncontact, nondestructive and full-field stress measurement, as well as its applicability for various types of structural damages. Therefore, a useful and powerful technique for evaluating structural integrity related with fatigue damage evolution can be developed based on the TSA technique for the maintenance of ageing steel bridges.

This study focuses on the TSA-based in situ evaluation technique for stress reduction and restoration of structural integrity after repair or reinforcement. Fatigue cracks were found in the structural members of the Seto-Ohashi Bridges connecting the Honshu and Shikoku islands in Japan during their 21st-year inspection. Several repair methods have been investigated by experimental studies at the site. The stress distributions around the fatigue cracks were measured by employing the TSA technique when live loading acted on the bridge and the effectiveness of the severity reduction using these repair methods was investigated.

2. Fatigue crack evaluation in the life of steel bridges

The present authors [22] developed remote NDT- and NDE-techniques using infrared thermography for the maintenance of ageing steel structures. Fig. 1 shows a schematic of the proposed life cycle NDT- and NDE-techniques for steel bridges using infrared thermography. The first sign of deterioration in ageing steel bridges is the initiation of fatigue cracks. It would be beneficial to predict the occurrence and location of fatigue crack initiation. The feasibility of dissipated energy measurement was investigated for predicting the fatigue-crack initiation [23]. After the initiation of fatigue cracks, detection of these cracks is required for the maintenance of the steel bridges. The present authors [24] developed a relatively simple but useful

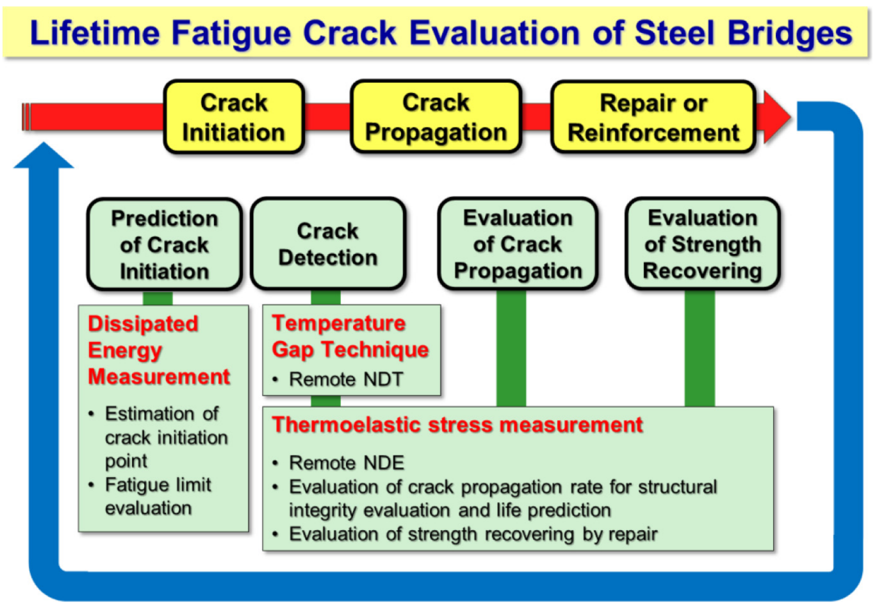

Fig. 1. Development of the NDT- and NDE-techniques using infrared thermography for fatigue cracks in steel bridges.

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