A heuristic model for performance assessment of welded joints in orthotropic steel decks based on monitoring data

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Summary

Orthotropic steel decks can present fatigue issues at welded joints, the assessment of which turns out to be a complex task due to their intricate geometry, the uncertain nature of the primary live load (traffic flow) and the temperature-driven composite action between the pavement and the steel deck. Current assessment methods tend to disregard the joint effect of traffic levels and pavement temperatures and rely on relatively long-term monitoring periods to capture strain responses and the overall associated uncertainty. This limits the ability to interpret short-term monitoring data, since failure to quantify this temperature-traffic interaction makes it impossible to understand short-term variations in the monitored strain responses. To overcome current limitations, a heuristic model is presented to predict stress-related performance indicators monitored at welded joints in orthotropic steel decks considering pavement temperatures and traffic levels as input parameters. Model parameters are determined through multiple linear regression and can be regarded as the set of health-related features to perform local Structural Health Monitoring (SHM). Model simulations are benchmarked with real monitoring data from the Great Belt Bridge (Denmark). In general, good agreement is found between model simulations and monitoring data. Current research efforts to improve the limitations of the proposed model are outlined.

Keywords: Orthotropic Decks, Structural Health Monitoring, Fatigue Assessment, Monitoring-based Predictive Models

1. Abstract

Orthotropic steel decks are a preferred structural element of long-span bridges due to their reduced weight and high stiffness. As a main drawback these elements can present fatigue issues at welded joints, the assessment of which turns out to be a complex task due to their intricate geometry, the uncertain nature of the primary live load (traffic flow) and the temperature-driven composite action between the pavement and the steel deck. Current assessment methods based on structural monitoring tend to rely on relatively long-term monitoring periods to capture strain responses and the overall associated uncertainty. In many cases emphasis is given to the final strain and stress response, without paying much attention to the underlying factors that combine in producing the final stress, such as the joint effect of the pavement temperature and the traffic load. This can be an important drawback, since failure to quantify this combined effect makes it impossible to understand short-term variations in strain response or compare monitoring data obtained at different points in time. This limits the ability to interpret relatively short-term monitoring data and perform local Structural Health Monitoring by extracting health-related features from the monitoring data.

In order to overcome current limitations and make proper use of monitoring campaigns, the present paper proposes a heuristic model to predict stress-related performance indicators pertinent to welded joints of those structural components as a function of hourly-averaged pavement temperatures (T) and hourly levels of heavy traffic (B). The stress-related performance indicator is

https://doi.org/10.2749/222137813806521252
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defined as:

$$D(t) = \sum_{i=1}^{N} (\Delta\sigma_i)^3 \quad (1)$$

Where $\Delta\sigma_i$ is the i^{th} stress range out of the N calculated within the t^{th} monitored hour by applying the rainflow counting algorithm to the monitored strains. D is a performance indicator proportional to S-N fatigue damage (considering the fatigue parameter m equal to 3 for many typical fatigue details).

As a first formulation of a general model linking B, T and D, a heuristic approach has been considered consisting of the following model:

$$D = B \cdot \left(\theta_0 + \theta_1 \cdot T + \theta_2 \cdot T^2 + \theta_3 \cdot T^3\right) \quad (2)$$

The set of model parameters, $\vec{\theta}$, can be seen as a local signature of the combined effect of the traffic load, the environment, and the structural performance of the particular monitored point including its interaction with the pavement layer. In principle, changes in the attributes or composition of any of the abovementioned elements should be captured and reflected in the set of model parameters. In consequence, the local performance of a monitored welded joint could be assessed by analyzing the set of model parameters $\vec{\theta}$ in time, which could be used to detect time-varying effects. It is therefore believed that such predictive model (or extensions of it) could constitute a quantitative tool to perform local Structural Health Monitoring. Other potential applications could be to define temporal requirements for current monitoring systems, according to the time needed to obtain reliable estimates of model parameters, and to simulate future realizations of SN-fatigue damages under a range of future traffic and temperature scenarios.

Model parameters are regressed using the curve fitting tool of Matlab R2011b. The proposed approach is illustrated using real monitored data from the Great Belt Bridge (Denmark), as it is shown in figure 1. Simulations of the parameter D based on the model are benchmarked against monitored data. Although some discrepancies are observed, model predictions and monitored performance profiles present in general a good agreement, provided ambient conditions and traffic flow data are available. This can be regarded as a promising hint for further developing predictive models for the performance assessment of welded joints in orthotropic steel decks considering monitoring data in order to enhance current local SHM approaches. Nevertheless, some further issues need to be addressed in order to fully benefit from the outlined approach, such as the expected bias and scatter in the model predictions, the determination of appropriate 'training' intervals in order to minimize these factors as well as the probabilistic extension of the proposed model.

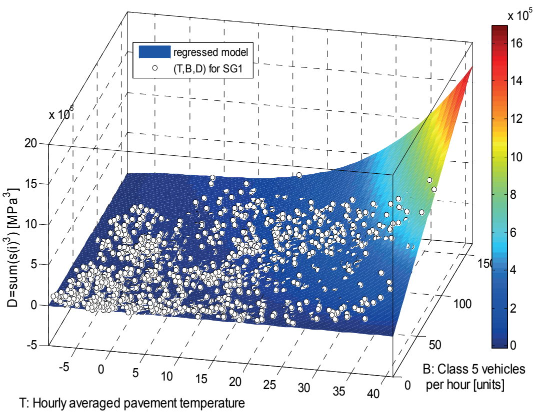

Fig. 1: The heuristic regression model for one monitored welded joint of the Great Belt Bridge (Denmark).