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Fatigue reliability assessment for orthotropic steel deck details under traffic flow and temperature loading

Yang Liu [a], Haiping Zhang [a,*], Yongming Liu [b], Yang Deng [a], Nan Jiang [a], Naiwei Lu [a]

[a] School of Civil Engineering and Architecture, Changsha University of Science & Technology, Changsha 410014, China
[b] School for Engineering of Matter, Transport and Energy, Arizona State University, Tempe, AZ 85281, USA

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ABSTRACT

A new fatigue reliability assessment function which takes into account the vehicle and temperature loadings has been developed in this study. The vehicle and temperature loadings are important parameters as they can cause fatigue failure of the welds in a steel box girder. The temperature affects the traffic loading effect by changing the elastic modulus of asphalt pavement. The effect of the temperature difference has been considered based on the measured data and the finite element analysis. Linear regression equations between the equivalent stress and the temperature for different vehicle types have been developed. Using the thermal stress analysis and the rain-flow counting method, the temperature difference fatigue stress spectrum has been determined. Further, a limit equation for the fatigue reliability assessment, which takes into account both the vehicle and temperature loadings, has been developed. Finally, the effects of the temperature and the traffic growth rate on the fatigue reliability of two welding types of Nan-xi Yangtze River Suspension Bridge have been assessed.

1. Introduction

Flat steel box girder is widely used as a structural component in cable-stayed bridges and suspension bridges. However, there is the problem of fatigue damage under the vehicle load and environment factors. With the maturity of the coating process for steel box, corrosion of medium is no longer a concern. However, there is a strong correlation between ambient temperature and fatigue damage of steel box [1]. It is therefore meaningful to develop a limit equation by including the effects of the vehicle load and the temperature for fatigue reliability assessment.

Fatigue reliability assessment for orthotropic steel deck bridge has been well developed. Historically, the method of fatigue reliability analysis can be divided into fatigue strain statistical analysis according to the strain sensor data [2] and the fatigue element analysis (FEA) based on weigh-in-motion (WIM) data [3]. The strain sensors can measure the fatigue strain which contain various signals (vehicle signal, temperature signal and interference signal). However, it is harder to measure every stress in detail due to the limited numbers of strain sensors and the installation technology. The FEA method can calculate the focus stress at all the points. However, this approach does not include the effect of ambient temperature on the fatigue damage without the structure of temperature data.

There are two points which fatigue damage is affected by the temperature. (1) The fatigue strength of the material changes with changing temperature. The high ambient temperature lowers the fatigue strength of the material and the converse is true when the temperature is low [4]. However, in south China, the temperature range at the bridges is quite small (−5 °C to

* Corresponding author.
E-mail address: zhanghaipingbridge@163.com (H. Zhang).

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60 °C. Further, the fatigue strength of the welds at the bridges only changes a little with changing temperature, which is in contrast to the fatigue strength of the welds in aeronautical engineering [5]. (2) The fatigue stress is affected by the changing temperature. One of reasons is due to the stiffness of asphalt paving (AC) which is sensitive to temperature. The higher the temperature, the AC is less stiff. This means that the spreading load ability of the AC is weak in high temperature environment [6]. The other reason is the accumulation of fatigue stress produced by the temperature difference. Since the fatigue stress caused by the temperature difference is similar to that by the vehicle loads [7], it is therefore necessary to accumulate the temperature difference stress in the fatigue reliability assessment. Fig. 1 shows the fatigue reliability assessment for orthotropic steel details using the FEA method, which includes the effects of the vehicle and temperature loadings.

The objectives of this study are to analyze the effect of temperature on the fatigue reliability of weld in steel box, and to develop a fatigue reliability limit equation which includes both the effects of traffic loads and temperature loads. Using the structural health motoring measured data, the limit equation developed in this study has been applied to assess the steel box fatigue reliability of Nan-xi Yangtze River Suspension Bridge.

2. Health monitoring system of Yangtze River Suspension Bridge

As shown in Fig. 2, the main span of the Nan-xi Yangtze River Suspension Bridge is 820 m, which is the longest bridge in southwest China. As shown in Fig. 1, there are four types of monitoring data required for the fatigue reliability assessment: vehicle weight, AC pavement temperature, welds strain, and steel girder temperature. WIM system is mounted on an orthotropic deck plate to record the vehicle weight, as shown in Fig. 2. During 2014, using the weigh-in-motion (WIM) system, the vehicle parameter data, truck weight, axle weight and truck type, were collected. The fatigue damage to the bridge under the loading of sedan cars was considered negligible. Hence, only the truck data have been analyzed. They have been divided into six groups, according to the number of axles. The daily traffic flow ranges from 5000 to 6000 vehicles.

The temperature monitoring system sensors have been divided into steel structural temperature sensor, AC pavement temperature sensor and air ambient temperature sensor. The locations of these three types of temperature sensors are showed in Fig. 3. The sensors measured the data at a frequency of 5 Hz. For the measured data over a period of 10 min, a mean temperature has been calculated. Over one year, the number of average temperatures is 52,560.

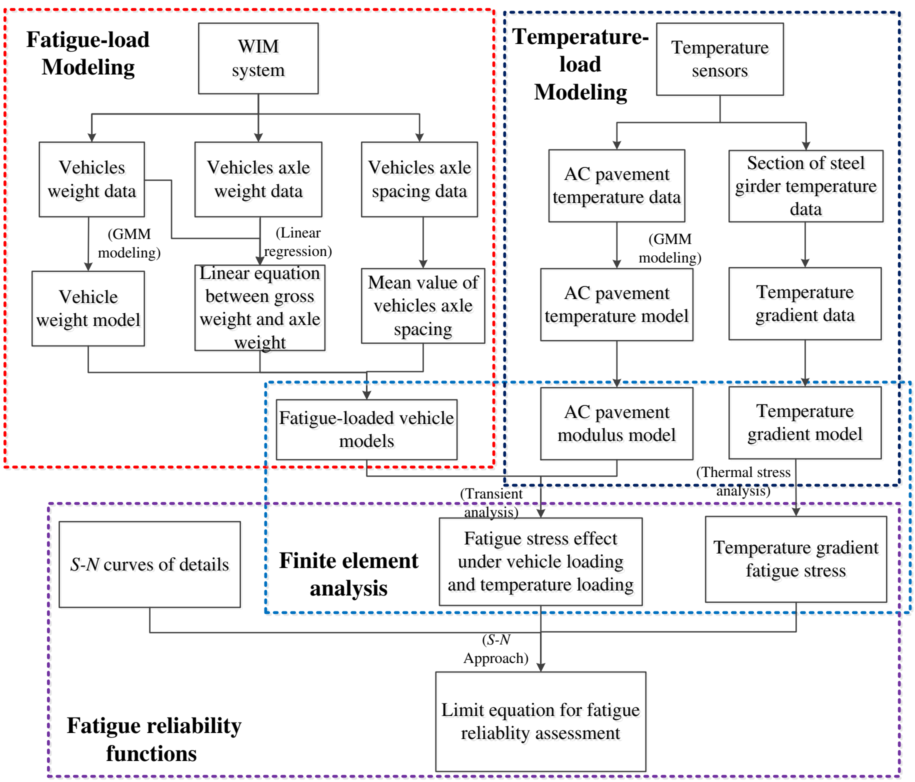

Fig. 1. Flowchart for fatigue reliability assessment including the effects of vehicle and temperature loadings.