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Variation of structural vibration characteristics versus non-uniform temperature distribution

Yong Xia [a,*], You-Lin Xu [a], Ze-Long Wei [a], Hong-Ping Zhu [b], Xiao-Qing Zhou [c]

[a] Department of Civil and Structural Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, China
[b] School of Civil Engineering & Mechanics, Huazhong University of Science & Technology, Wuhan, Hubei, 430074, China
[c] College of Civil Engineering, Shenzhen University, Shenzhen, Guangdong, China

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ABSTRACT

In vibration-based condition assessment exercises, it is necessary to discriminate the variation of structural properties due to environmental changes from those caused by structural damages. Some efforts have been made to correlate the structural vibration characteristics and the air temperature or temperatures at the structural surface. As the temperature of an entire structure is generally non-uniformly distributed, using the air temperature or surface temperatures alone may not sufficiently capture the relation between the structural responses and temperatures. The present paper aims to investigate the variation of the structural vibration characteristics versus the non-uniform temperature field of the structure. Thermodynamic models are employed to estimate the temperature at different components of the structure at different times. As the material mechanical properties are temperature dependent, the structure can be regarded as a composite structure consisting of elements with different Young's moduli. Consequently, the natural frequencies of the structure can be calculated with the finite element method. The procedures are repeated for different times and thus variation of the frequencies with respect to time is obtained. A simply supported RC slab was constructed and used as a proof-of-concept example. The temperatures at different points of the slab were recorded continuously in one day, together with a series of forced modal testing to extract its modal properties. On the other hand, a finite element model was established to conduct a transient thermal analysis and estimate the temperature distribution of the slab, which shows a good agreement with the measurement counterpart. The temperature data at all components and thermal properties of the material were then inputted to the model to calculate the frequencies, which also matched the measured frequencies very well. Moreover, a good linear correlation between the natural frequencies measured and the structural temperatures other than the air temperature or surface temperatures is observed. The present study provides a new approach to quantifying the environmental effect on the structural vibration characteristics.

1. Introduction

In structural condition monitoring assessment [1–4], a practical difficulty exists because the structural responses vary with the changing environmental conditions, particularly the temperature. Some studies have found that the changes in structural responses due to temperature variation could be more significant than the changes due to normal structural damage [5]. If the temperature effect is not fully understood, structural condition cannot be evaluated reliably [6].

During the past 20 years, quite a few studies have been conducted to investigate the environmental effect on structural vibration properties. Askegaard and Mossing [7] studied a three-span RC footbridge and observed a 10% seasonal change in frequency over a three-year period. Researchers from the Los Alamos National Laboratory [8] found that the first three natural frequencies of the Alamosa Canyon Bridge varied about 5% during a 24 h period as the temperature of the bridge deck changed by approximately 22 °C. Peeters and De Roeck [9] continuously monitored the Z24-Bridge for nearly a year and they reported that the frequencies decreased with increase in temperature. Desjardins et al. [10]studied the modal data and the average girder temperatures collected over a six-month period in the Confederation Bridge. The first two modal frequencies identified from the Bill Emerson Memorial Bridge [11] monotonically decreased as the temperature increased in a linear way, while the mode shapes did not experience a significant change. Ni et al. [12,13] investigated the effect of temperature and wind speed on modal parameters in the Ting Kau Bridge in Hong Kong using one-year monitoring data. Fu and DeWolf [14] found

* Corresponding author. Tel.: +852 2766 6066; fax: +852 2334 6389.
E-mail address: ceyxia@polyu.edu.hk (Y. Xia).

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