Thermal Environmental Effects on Modal Parameters and Health Monitoring of Bridge Structures

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Summary

Often changes in the frequencies extracted from the vibration response are used for the detection of damage. However, these structural characteristics are also affected by the outside thermal envonment; this effect could be large enough to mask the changes caused by the damage. So it is important to understand and predict the effect of the environmental variations on these characteristics to separate them from those caused by the damage. In this paper, we examine the trends in the frequencies variations of a reinforced concrete box girder bridge structure subjected to a nine-year long record of measured temperature, radiation, and wind speed. It is observed that the major trends in the frequency variations are parallel to the major trends in thermal environment. The paper then presents and validates an identification approach to estimate the system frequencies directly from a few measured temperature values without a detailed finite element analysis.

Keywords: Structural Health Monitoring; Bridges; Structural frequencies; environmental effect; system identification.

1. Introduction

For health monitoring of bridge structures modal parameter-based methods have been considered for use wherein the changes in the parameters are used to predict the damage. However, it is well known that the modal parameters are affected not only by the damage but also by environmental temperature and humidity changes. It is, thus, necessary to separate these two effects for damage detection. In this paper, we first examine how the environmental thermal variations affect the modal properties and then examine if these trends can be estimated by using simple models.

2. Thermal-Structural analysis

Environmental thermal conditions affect the modal properties due to changes in material properties such as Young's modulus and also due to internal thermal stresses that cause geometric stiffness effects. To incorporate these effects here, we first calculate the temperature distribution inside the structure by heat conduction analysis and then use it to calculate the temperature dependent material properties and the pre-stress effects due to differential temperature distribution. For a civil structure with irregular boundaries, it is necessary to solve the heat conduction problem by discretization methods such as finite element method with due consideration of radiation and convection effects

https://doi.org/10.2749/222137809796078423
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on the boundaries. Reference [1] provides the details of conducting such analyses and to calculate stiffness matrix that includes the temperature dependent material properties and geometric stiffness effects. The eigenvalue analysis with this stiffness provides the modal properties that reflect the effect of the thermal environment.

This analysis procedure was applied to a representative concrete box girder bridge model for the thermal environment defined by temperature, solar radiation and wind velocity measurements made at Elizabeth city, NC, USA [2]. The effects of including or ignoring various thermal conditions as well as including or excluding the asphalt layer on the frequencies were analyzed. There was a significant difference in the frequency for the summer and winter conditions. The radiation effect was relatively more strong than the convection. The asphalt contributed to the system stiffness and thus the frequencies significantly in winter months. The frequencies had similar seasonal and diurnal harmonic trends as the environmental temperature. The future study will use these trends in predicting the frequency changes to incorporate the seasonal and daily change effects.

3. System Identification

The possibility of just using a few representative temperature measurements on the structure to estimate frequencies without a detailed finite element analysis was also explored. To accommodate the dynamic nature of frequency-temperature relationship, the state space representation was used. The state space model was identifed using the stochastic subspace identification approach employing N4SID code in MATLAB. The mathematical underpinnings of the algorithm are explained in [7] and [8]. To calculate the model matrices, the temperature and corresponding frequency data obtained by finite element analysis was used. (In practice, the temperature will be recorded and the frequencies will be obtained from the measured bridge reponse.) The model was validated using a different set of temperature and frequency data and was found to be very good.

4. Conclusion

The paper presents a finite element approach for investigating the effect of thermal environment on the modal parameters of a bridge structure. The detailed analysis shows that the frequencies are susceptible to the outside thermal environment. It is, thus, necessary to include this effect in health monitoring schemes that utilize the modal parameters. Herein a state-space model is proposed to estimate the frequencies from the measured temperature values. For health monitoring purposes, one will estimate such frequencies and compare them with the frequencies extracted from the vibration response of the system. A significant differences beyond a certain threshold would indicate a change in the system or presence of damage.

5. Acknowledgement

This research is supported by National Science Foundation through grant no. CMMI-0700558. This support is gratefully acknowledged. Any opinion, findings, and conclusions or recommendations expressed in this study are those of the writers and do not necessarily reflect the views of the National Science Foundation.

6. References

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