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Numerical simulation of temperature induced structural static responses for long-span suspension bridge

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Abstract

Temperature effect is one of the most significant and negative effects on bridges, even worse for long-span bridges. In this study, numerical simulation method of temperature induced structural static responses for long-span suspension bridge is investigated. The finite element (FE) models for transient thermal and structural analysis of a long-span suspension are developed, respectively. The thermal boundary conditions are calculated and applied on the thermal FE models for thermal analysis to obtain the variations and distributions of structural temperatures. Then, structural temperatures are loaded on the structural FE models for structural analysis to obtain the structural static responses such as vertical displacements, inclinations and strains. The results are compared with the field measurements to verify the validity and efficiency of this method. The method can provide a feasible and efficient way for analysis and assessment of the temperature effects on long-span suspension bridges.

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Keywords: Long-span suspension bridges; temperature effects; structural static responses; finite element

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1. Introduction

Bridges are key components in the national traffic systems. However, harsh service environment degenerates the performance of bridges even leads to catastrophic collapse. Temperature is one of the most negative effects on bridge. Bridges are exposed directly to the natural environment. The energy exchange between bridges and the surrounding environment by way of heat convection and heat radiation changes the temperatures of bridge and subsequently affects the structural responses. The structural responses of bridges, such as static and dynamical properties, are significantly affected by temperatures and their distributions[1-3].

The analysis of bridge temperature effects includes mainly two parts: structural temperature and induced structural responses. An accurate calculation of structural temperature is needed in the evaluation of temperature-induced structural responses on bridges. Zuk[4] was the first to study the temperature effects on bridges. Though the field data of several highway bridges, he identified the combined action of environmental conditions (e.g., solar radiation, air temperature, wind, humidity). Emanual and Hulsey[5] used the finite element (FE) models to calculate bridge temperatures as a function of time. Churchward and Yehuda[6] recorded the temperature of a poststressed twin-box concrete bridge at different instants of time and predicted the temperature profiles reasonably. Moorty and Roeder[7] succeeded in calculating the movements of a bridge affected by the temperature. Xu et al. [8] used the field monitoring data of Tsing Ma Bridge in 2005 to explore the temperature-displacement relationship of the bridge. Currently, investigations of temperature induced structural responses of bridges mostly base on the field measurements, which need to install a complete monitoring system on the bridge. It is laborious and expensive. What's more, it is not effective for long-term and real-time analysis of thermal analysis and assessments for bridges.

In this study, the numerical simulation method of temperature induced structural static responses for long-span suspension bridge is investigated. Firstly, the finite element (FE) models for transient thermal analysis and structural analysis of a long-span suspension are developed respectively. Secondly, the thermal boundary conditions are calculated and applied on the thermal FE models for thermal analysis to obtain the structural temperatures. Then, the structural temperatures are loaded on the structural FE models for structural analysis and the structural responses of bridge calculated. Finally, the results are compared with the field measurements to verify the validity and efficiency of this method. The proposed approach can provide a feasible and high effective method for analysis and assessment of the temperature effects on long-span suspension bridges.

2. Relation of temperature and physical properties

A long-span bridge is a complex flexible structural system. The changes of temperature and temperature variation significantly affect the structural behavior of bridges. The temperature-varying parameters of building materials mainly includes Young's modulus and coefficient of thermal expansion. After exploring the effect of temperature variation on physical property of materials, Yu et al. [9] summarized the relation of temperature and some physical properties.

(a) Coefficient of thermal expansion of steel

$$\alpha_s = (0.004T + 12)\times 10^{-6}[\mathrm{m/(m℃)}] \quad T \le 350℃ \tag{1}$$

(b) Coefficient of thermal expansion of concrete

$$\alpha_s = (0.008T + 6)\times 10^{-6}[\mathrm{m/(m℃)}] \tag{2}$$

(c) Young's modulus of steel

$$E = E_0[1 - \frac{13(T-20)}{33000}] \qquad T \le 350℃ \tag{3}$$