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Numerical simulation method of thermal analysis for bridges without using field measurements

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Abstract

Structural temperatures have significantly negative effects on the performances of bridges. In this study, a numerical method of thermal analysis for bridges without using field measurements is proposed and investigated based on a long-span suspension bridge under weather conditions of a sunny day. Firstly, basic theory and methods of bridge thermal analysis are discussed. Secondly, the long-span suspension bridge and the structural health monitoring system are briefly introduced. Then, the finite element model of a typical section of the box girder of the long-span suspension bridge is constructed for transient thermal analysis to calculate the temperature variation and distributions. The thermal boundary conditions are calculated using the meteorological information from the nearby airport rather than the field measurements for thermal analysis. At last, the thermal boundary conditions are applied on the FF model to obtain the structural temperatures using transient thermal analysis. Besides, the conventional method using the bridge field meteorological measurements is also carried out for comparison. All the simulated results of structural temperatures are compared with the field measurements. All of them have good agreements. It is demonstrated that the proposed method is reliable and effective.

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Keywords: Bridges; temperature behavior; numerical simulation; transient thermal analysis

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1. Introduction

Bridges play a very important role in the transportation system. However, the long-term overload operation and harsh service environment result in damages even accidents on bridges. Temperature has been widely recognized as one of the most significant and negative environmental effects on bridges. The environmental thermal effects may have a more significant impact on structural behavior than the external operational loads[1-3].

Considerable efforts have been devoted to investigating temperature distribution and thermal effects on bridges based on field monitoring, laboratory test and numerical simulation. Zuk[4] discussed the effects of solar radiation, air temperature, wind, humidity, and material types on temperature distribution by investigating several highway bridges. Emanual[5] performed a finite element analysis used to calculate bridge temperatures as a function of time and investigated the temperature variations of a composite-girder highway bridge. Priestley[1-2] identified the vertical temperature gradients of prestressed and reinforced concrete bridges and compared the analytical results with those from laboratory and field experiment. Kennedy[3] explored the temperature distribution in composite bridges and proposed the linear temperature distribution through the depth of the slab and uniform distribution through the depth of the steel beam by synthesizing several theoretical and experimental studies on prototype bridges. Churchward[6] conducted a long-term field measurement on a post stressed twin-box concrete bridge. An analytical expression of the vertical temperature profile as a function of the maximum differential temperature and environmental parameter insolation was presented.

With the rapid developments in computer techniques, the structural temperature distribution and thermal effects have been widely investigated using finite element method [2]. The one-dimensional approaches were firstly studied. Emerson[7] established a finite difference model based on the assumption that the flow of heat through the bridge was linear. Kehlbeck[8] found a theoretical solution to temperature distribution of bridge. Hunt and Cooked[9] calculated temperature distribution of bridge by the way of the one dimensional unsteady heat conduction. Elbadry[10] presented a two-dimensional FE method to determine the time-dependent temperature variation of a concrete box-girder bridge. Xia et al[11] investigated the temperature distribution and associated responses of a long-span suspension bridge through field monitoring and numerical analysis. Zhou et al[12] conducted such a study on a long-span suspension bridge and explored the transversal temperature difference.

The finite element method can provides a higher efficiency and lower cost way for thermal analysis of bridges. The thermal boundaries are calculated based on lots of field meteorological measurements such as solar radiation, air temperature, humidity, wind speed and direction. Hence, a weather station should be established on the field of bridges. It is costly and lower efficiency. In this study, a numerical method of thermal analysis for bridges without using field measurements is proposed and discussed.

2. Basic theory for thermal analysis

The heat transfer processes of a bridge consist of heat conduction, heat convection, and thermal radiation[8,12]. Heat conduction exists in the interior of the box girder and is governed by the Fourier heat-transfer equation. Heat convection is a kind of energy exchange between solid surface and surrounding fluid. Thermal radiation is a kind of energy transfer caused by the emitting and absorbing radiation of the structural surface.

2.1. Solar radiation effects

Several types of radiations are given off or absorbed by a surface of bridge, such as direct solar radiation, atmospheric radiation, diffuse radiation, reflected radiation, environmental radiation and structural irradiation [13]. The solar radiation is affected by several factors such as dates, the latitude and the altitude of the bridge, atmospheric turbidity and the cloudiness of the sky [8]. The calculation method of each type of radiation can refer to relevant literatures [8, 10, 14].