Journal of Constructional Steel Research 112 (2015) 80–92

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Temperature variation in steel box girders of cable-stayed bridges during construction

Sang-Hyo Kim [a], Se-Jun Park [a], Jiaxu Wu [b], Jeong-Hun Won [c,*]

[a] School of Civil & Environmental Engineering, Yonsei University, 262 Seongsanno, Seodaemun-gu, Seoul 120–749, Republic of Korea
[b] Dasan Consultants, Dasan B/D, Munjeong-dong, Songpa-gu, Seoul 137–722, Republic of Korea
[c] Department of Safety Engineering, Chungbuk National University, 52 Naesudong-ro, Haungdeok-gu, Cheongju, Chungbuk 361–763, Republic of Korea

ARTICLE INFO

Article history:
Received 15 May 2014
Accepted 26 April 2015
Available online 19 May 2015

Keywords:
Temperature distribution
Steel box girder
Cable-stayed bridge
Construction
Numerical approach

ABSTRACT

This study investigated the variation of the temperature distribution in the steel box girder of a cable-stayed bridge during construction. Measured data were used to study the basic thermal characteristics because the thermal behavior of these bridges during construction is particularly difficult to predict and not well-known. In addition, a simple numerical approach was carried out to predict approximately the variation of the temperature distribution in a steel box girder. The temperature variation of the top flange showed a steep change, while the temperature variation of the bottom flange exhibited a smooth curve throughout the day because of the relative low amount of solar energy and encased internal air. At night, the bottom flange showed a higher temperature than the top flange and ambient temperature. In the top flange, the temperature decreased as the distance from the center increased, while the temperature in the bottom flange increased with the distance from the center. The time to reach the peak temperature at each location varied without correlation to the time of peak solar radiation because of the effect of the encased air. When compared with the measured data, the analysis results closely matched the temperature variations for different seasons in the center of the top flange, where the largest peak temperature and variation were observed. Thus, the adopted simple numerical approach can approximate the temperature variation of a steel box girder during construction in the planning and design phases.

1. Introduction

During construction, the flexibility of steel cable-stayed bridges means that they have more complicated structural behavior than other types of bridges and are more vulnerable to the surrounding environment. Among the various factors that affect the construction of steel cable-stayed bridges, the thermal behavior caused by environmental parameters such as solar radiation, air temperature, and wind speed is particularly difficult to predict [1]. For steel bridges, temperature variation can induce thermal stresses that are comparable to the stresses induced by dead and live loads [2,3].

In case of cable-stayed bridges, uneven temperature stresses may occur on the pylons, cables, and girders because of their geometry, which would cause more serious problems than on other types of bridges. Furthermore, a steel box girder of a cable-stayed bridge is exposed to environmental parameters over a long period during construction without pavement, which means that the heat transfer characteristics differ from those of the steel girder when the bridge is in operation. The uneven temperature variation causes vertical or horizontal displacements in the pylons, cables, and girders, which make it difficult to manage the bridge alignment. This can cause construction errors in the process of connecting key-segments. Thus, the temperature variation of steel cable-stayed bridges during construction needs to be predicted in order to consider changes in the temperature distribution in the planning and design phases.

Most recent studies on the thermal behavior of steel structures have focused on elevated temperatures because fire safety has become major issue in steel construction. The fire resistance of steel members such as columns, beams, and joints has been numerically and experimentally studied [4–8]. For steel bridges, some research groups have focused on predicting the temperature distribution in steel girders considering environmental parameters. Tong et al. [2] proposed a numerical model for analyzing the temperature distribution and compared the results with those obtained from scaled models. The effects of various parameters on the temperature distribution were studied by sensitivity analysis on both a box girder section and π-girder section. Kim et al. [9] developed a temperature prediction model to examine the thermal behavior of a curved steel box girder with a concrete slab. Liu et al. [3] experimentally and numerically investigated the temperature distribution in H-shaped steel members and conducted a parametric study. They developed a simplified approach to predict the temperature distribution. However, most studies on the thermal behavior of bridges caused by environmental parameters mainly focused on the bridge

* Corresponding author. Tel.: +82 43 261 2459; fax: +82 43 265 2457.
E-mail address: jhwon@chungbuk.ac.kr (J.-H. Won).

http://dx.doi.org/10.1016/j.jcsr.2015.04.016
0143-974X/

deck of composite steel-concrete girder bridges or Prestressed Concrete (PSC) girder bridges [1,10–13]. For the decks of these bridges, tensile cracks can occur because of the uneven stress from a nonlinear temperature distribution in the girder section. Conversely, there has been little research on the effects of the solar radiation, air temperature, and wind speed on the thermal behavior of cable-stayed bridges during construction.

For engineers involved in design and construction, they need to understand the thermal behavior to determine if the thermal effect during construction should be seriously considered. In order to estimate the thermal behavior of bridges, the temperature distributions in the girder section should first be predicted before detailed 3D nonlinear thermal stress analysis is performed. However, little data are available at construction sites for the temperature distributions in steel box girders affected by environmental parameters. In order to obtain temperature data, temperature measurement devices have been installed at some construction sites. The measurement locations are mainly determined empirically because correct information on the characteristics of the temperature distribution has not been disseminated.

The objective of this study was to provide the basic characteristics for the temperature distribution in a steel box girder of a cable-stayed bridge during construction based on the measured data. In addition, a simple numerical approach was developed to predict approximately the variation of the temperature distribution in the steel box girder by 2-D heat transfer analysis. This numerical approach considers not only the change in solar radiation but also the temperature change of the internal air and convective heat transfer phenomena from variations in the wind velocity.

2. Example bridge and measurement

As an example, Incheon Bridge in Korea was selected in order to evaluate the temperature distribution in the steel box girder of a cable-stayed bridge during construction. This is a well-known cable-stayed bridge with a main span length of 800 m (Fig. 1). The width of the steel box girder is 33.1 m, and the height is 3.0 m. Fig. 1(b) and Table 1 give the section dimensions of the steel box girder with the measured data (point A in Fig. 1(a)). The measurement positions were four points on the bottom flange (TH1–TH4) and three points on the top flange (TH5–TH7). The atmospheric temperature was measured at one point (TH9). The analyzed thermal data were taken from June and September-November 2008.

Table 1
Dimensions of section A.

Member			Dimension (mm)
Top flange		Thickness	14
(Deck plate)		U-rib plate	304x260x8
		Rib plate	170x16
Bottom flange		Thickness	16
		U-rib plate	400x240x8
		Rib plate	170x19
Web	LW2,	Thickness	14
	RW2	Rib plate	130x16
	LW1,	Thickness	19
	RW1	Rib plate	170x19

3. Heat transfer analysis

3.1. Finite element model

A 2-D heat transfer analysis was performed considering the solar radiation, internal air temperature, and change in wind velocity surrounding the steel girder, which were varied with time. Previously, authors used a simplified temperature prediction model based on the solar radiation energy equation with a finite element (FE) program in order to survey the nonlinear temperature distribution in a curved steel box bridge during operation [9]. In the present study, the convective energy

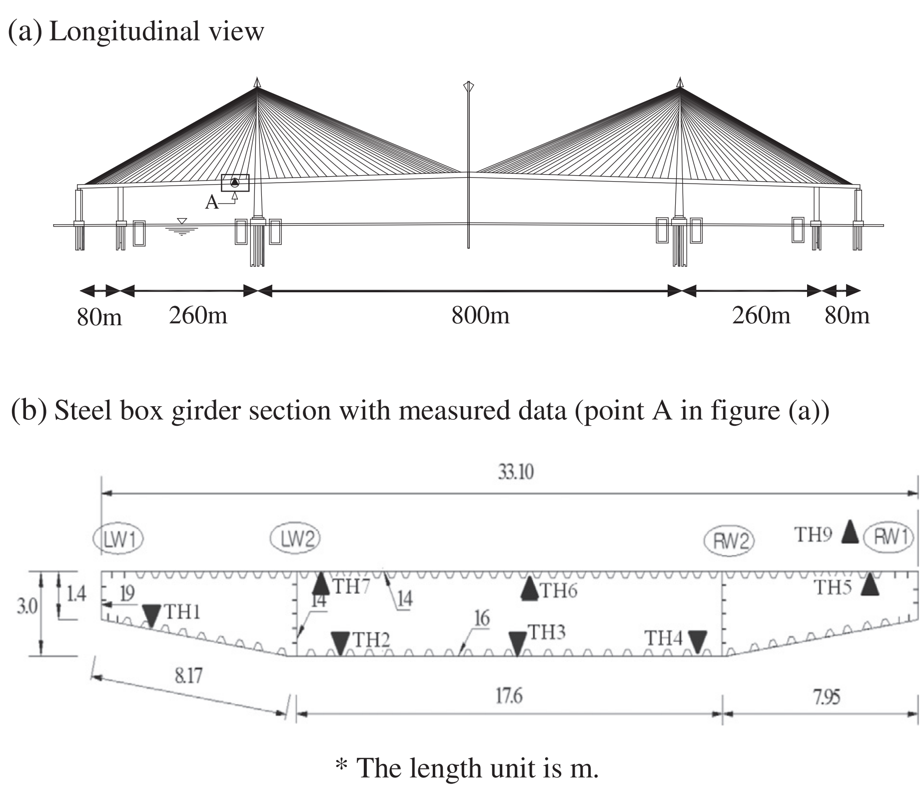

Fig. 1. Example bridge.