J. Wind Eng. Ind. Aerodyn. 116 (2013) 7–20

Contents lists available at SciVerse ScienceDirect

Journal of Wind Engineering and Industrial Aerodynamics

journal homepage: www.elsevier.com/locate/jweia

Interference effect on vortex-induced vibration in a parallel twin cable-stayed bridge

Ju-Won Seo [a], Ho-Kyung Kim [b,*], Jin Park [b], Kwon-Taek Kim [c], Gi-Nam Kim [a]

[a] Hyundai Institute of Construction Technology, Yongin-si, Gyeonggi-do, South Korea
[b] Department of Civil and Environmental Engineering, Seoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul 151-744, South Korea
[c] Korea Bridge Design & Engineering Research Center, Seoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul 151-744, South Korea

ARTICLE INFO

Article history:
Received 26 July 2012
Received in revised form
22 November 2012
Accepted 26 January 2013
Available online 19 March 2013

Keywords:
Parallel bridge
Vortex-induced vibration (VIV)
Interference
Cable-stayed bridge
Particle image velocimetry (PIV)
Flow visualization
Damping

ABSTRACT

A vortex-induced vibration (VIV), amplified by an interference effect caused by two parallel decks, was observed in the upstream deck of a twin cable stayed-bridge. This represents the first case of such an observation in an actual long-span cable-supported bridge. The observed VIV was successfully reproduced in a wind tunnel. Both decks were equipped with vanes and the single deck alone showed an allowable performance, in terms of VIV, based on wind tunnel tests that were carried out. It therefore appears that the observed vibration was affected by the parallel arrangement of the decks. A particle image velocimetry technique was successfully applied to investigate the complicated flow field between the upstream and downstream decks. Alternating eddies were formed in phase with the upstream deck motion and were transmitted to the downstream deck introducing "Ω" and "℧" shaped flow fields as a result. Following the alternating eddies, upward and downward wind streams were in turn fed into the gap and these flows amplified the vibration in the upstream deck of the bridge. Several modifications of aerodynamic additives were not effective in reducing this VIV. However, an increase in structural damping effectively mitigated the vibration.

1. Introduction

The aerodynamic performance of long-span bridges is typically evaluated from the standpoints of both stability and serviceability. One of the important issues in serviceability performance is the mitigation of vortex-induced vibration (VIV), which is traditionally suppressed by applying several types of aerodynamic additives such as fairings or guide vanes. However, the majority of previous studies have focused on the VIV associated with single bridge decks.

Owing to the increase of traffic volume, an additional bridge could be added in parallel to an existing bridge. In this case, the second bridge is usually spaced with a minimal gap distance to increase economy and efficiency from the standpoint of road planning. Sometimes, two or more bridges are constructed in parallel from the initial design stage. For these types of parallel bridges, an interference effect on VIV is typically issued in the design stage for a slender box girder bridge (Honda et al., 1993) as well as small to medium sized cable-stayed bridges (Grillaud et al., 1992; Larsen et al., 2000a).

The planning of a parallel bridge, especially a long span cable-stayed bridge, requires that interference effects between adjacent structures be studied more intensively than usual. Kimura et al. (2008) reported that the interference effect could be significant even with a separation distance as large as 8 times the deck width in parallel cable-stayed bridges. Meng et al. (2011) proposed a strategy for mitigating the aerodynamic interference effect on VIV of two adjacent cable-stayed bridges. They applied a computational fluid dynamics approach to trace interference flow fields between two parallel decks. Both studies concluded that the interference effects were dependent on gap distance as well as deck shape. However the overall phenomena were quite complicated and more intensive studies were recommended to draw a general conclusion related to the interference effect on VIV.

Recently, VIV, magnified due to an interference effect caused by two parallel decks (hereafter referred to as interference VIV even though the parallel disposition may be one of the sources of the vibration), was observed in a twin cable-stayed bridge that is currently in service. The bridge was subjected to a steady wind of 9.8–11.5 m/s for two hours in the normal direction to the bridge axis. A lock-in heaving motion was monitored in the windward deck that exceeded the allowable limit for serviceability performance. Since the actual observation of the interference VIV in a parallel cable-stayed bridge that was in service was the first such case, a series of investigations were carried out in a wind tunnel

* Corresponding author. Tel.: +82 2 880 7365; fax: +82 2 873 2684.
E-mail addresses: jwseo@hdec.co.kr (J.-W. Seo), hokyungk@snu.ac.kr (H.-K. Kim), az22@snu.ac.kr (J. Park), teagi@snu.ac.kr (K.-T. Kim), gnkim@hdec.co.kr (G.-N. Kim).

0167-6105/$ - see front matter
http://dx.doi.org/10.1016/j.jweia.2013.01.014

in an attempt to identify the main sources of the vibration as well as possible measures that could be used for mitigation. Particle image velocimetry (PIV) tests were utilized to investigate the complicated flow field between the two decks.

2. Field observation of interference VIV

2.1. The bridge investigated

The Jindo Bridge, shown in Fig. 1, is composed of two parallel cable-stayed bridges with a main span length of 340 m. The 1st Jindo Bridge shown in the left side of Fig. 1 was opened to traffic in 1984 while the 2nd Jindo Bridge on the right side of Fig. 1 was built in 2005. These bridges are hereafter referred to as Bridge 1 (older bridge) and Bridge 2 (newer bridge). The decks of the two bridges are similar in cross-sectional shape as shown in Fig. 2, and closely spaced with a net distance of 10 m between them, as shown in Fig. 3. Bridge 1 was equipped with vanes to mitigate conventional VIV from the beginning of the bridge design.

The vanes are different with those adopted for the Storebælt suspension bridge (Larsen et al., 2000b) in terms of the shape and position. Based on the configuration of the vane, two different contributions would be expected for mitigating VIV. One function is as a fairing which modifies the corner shape with a rounded curve and the other function as an actual guide vane with a provided gap. However, each contribution is not confirmed in the present study and the attachments are simply referred to as vanes according to the design report (Hyundai Engineering and Construction (HDEC), 2000a).

2.2. Identified natural frequencies of the bridges

An international test-bed application of a smart wireless sensor network has been ongoing for Bridge 2. The sensor network consists of a total of 113 sensors and the natural frequencies of Bridge 2 were identified as shown in Table 1 (Jang et al., 2010; Spencer et al., 2011). The natural frequencies of Bridge 1 were identified from a built-in monitoring system and are also included in Table 1 (Hyundai Engineering and Construction (HDEC), 2000b). The fundamental vertical frequencies of both bridges are similar but the frequency of Bridge 2 (0.45 Hz) is slightly lower than that of Bridge 1 (0.513 Hz).

2.3. The observed interference VIV

On April 19, 2011, a significant vibration was observed on the deck of Bridge 2 for a duration of two hours. The onsite wind velocity and the vibration of the deck were recorded with the built-in monitoring system installed in two bridges, as shown in Fig. 4. The wind velocity was measured by the ultrasonic anemometer installed on one side of the deck of Bridge 1 since the anemometer on Bridge 2 was temporarily unavailable. The anemometer was placed at a height of 3 m from the deck and the maximum sampling frequency was 10 Hz. The response of the deck was measured by accelerometers installed on both sides of the deck at the center of main span. The displacement at the same position was also monitored by a set of the laser displacement transducer located on the crossbeam of a pylon and the target

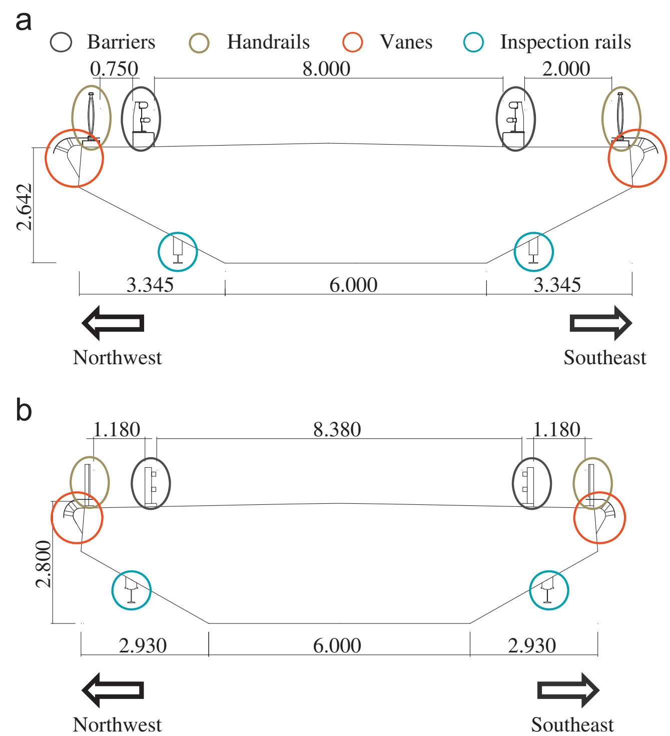

Fig. 2. Cross sections of (a) Bridge 2 (newer) and (b) Bridge 1 (older) (unit: m).

Table 1
Identified natural frequencies (Hz) of bridges.

Modes	Bridge 2 (Jang et al., 2010; Spencer et al., 2011)	Bridge 1 (Hyundai Engineering and Construction (HDEC), 2000b)
Vertical (first)	0.45	0.513
Vertical (second)	0.66	–
Vertical (third)	1.03	–
Torsional (first)	1.87	1.490

Fig. 1. Parallel twin Jindo Bridge.