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Effect of the relative differences in the natural frequencies of parallel cable-stayed bridges during interactive vortex-induced vibration

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ABSTRACT

This study was focused on the effects of vortex-induced vibration (VIV) in parallel twin cable-stayed bridges. A series of wind tunnel tests were performed to investigate the effect of the relative differences in the setup of the natural frequencies of parallel decks during VIV. The differences in the natural frequencies of the two decks are represented in terms of the frequency ratio (FR) as defined by the ratio of the natural frequency of the upstream deck to that of the downstream deck. Six FRs were examined to cover all the potential ranges of relative differences in the natural frequencies of the two decks. The interactive motions of the two decks were examined with normalization parameters to demonstrate the fundamental mechanics of complicated VIV of parallel twin cable-stayed bridges from the viewpoints of fluid and structural dynamics.

1. Introduction

Owing to a series of successful planning and construction projects for long-span bridges around the world over the past three decades, knowledge on bridge aerodynamics has broadened considerably. The shapes of bridge decks have evolved for the suppression of flutter instability even for bridges with main spans of more than 3 km. Even though one could carefully state that the modern prototypes of aerodynamic deck sections are prepared for flutter-related issues, the issue of vortex-induced vibration (VIV) is case dependent, and continues to command attention.

Recently, VIV in parallel bridges has drawn attention because of the complicated interactions between the decks. The potential for VIV in parallel bridges was described by Kimura et al. (2008), but in-depth investigations followed only after the actual observation of VIV in the upstream deck of parallel cable-stayed bridges in 2011. Seo et al. (2013) successfully reproduced VIV in a wind tunnel and demonstrated that VIV was magnified by the parallel arrangement of decks. In a follow-up study, Kim et al. (2013) successfully demonstrated the existence of interactive VIV based on the field monitoring of data obtained from the bridges and described the low-level inherent damping ratio in the upstream deck as another potential contribution to high-level vibrations. Meng et al. (2011), Argentini et al. (2015), and Dallaire et al. (2016) have also reported studies of the interactive VIV of parallel decks.

Since one of the parameters in this sort of vibration is the distance of the gap between the two decks, Park et al. (2017) demonstrated that gap distances of five to seven times the depth of the upstream deck critically affected the interactive VIV in parallel cable-stayed bridges, which agreed with the results found by Kimura et al. (2008). Park et al. (2017), however, successfully demonstrated how the vulnerable gap distance was closely related to the moving distance of one vortex during a period of deck oscillation.

Another potential parameter that can play an important role in interactive VIV would be the relative differences in the natural frequencies of the two decks. For the VIV in the 2011 study, the natural frequency of the upstream deck was a bit lower than that of the downstream deck. According to Kim et al. (2013), the complicated interactions that can occur between two decks have been identified in operational field monitoring as well as in a wind tunnel and seem to be critically influenced by the relative differences in the frequencies of both decks.

Based on these results, we examined the interactive VIV in parallel decks by focusing on the relative differences in the natural frequencies of each. The examined frequency difference covered all the meaningful cases so that the fundamental mechanism of the interactive VIV could

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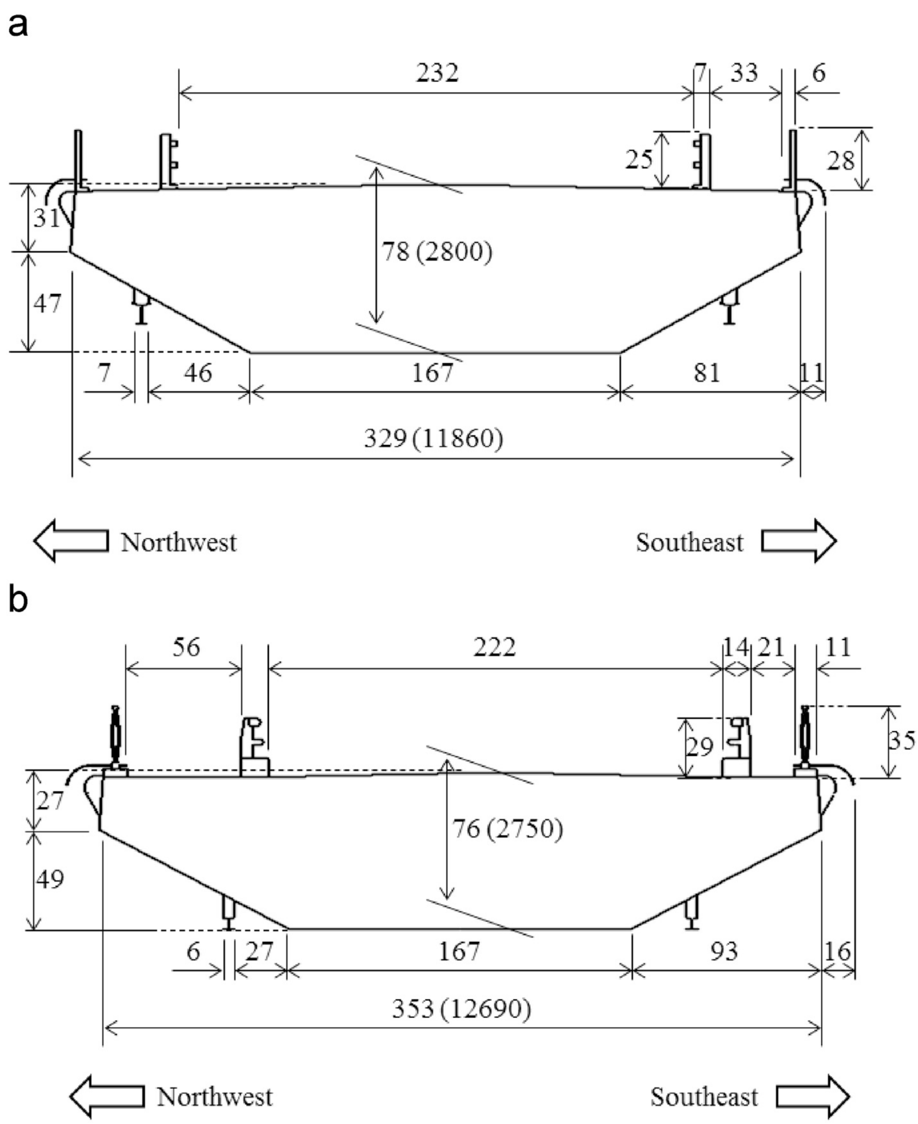

Fig. 1. Dimension (mm) of section models (Values in parentheses represent the dimensions for the prototype): (a) B1in downstream and (b) B2 in upstream.

be identified.

2. Experimental set-up

The investigated bridges had parallel cable-stayed decks exposed to crosswinds. The downstream and upstream decks will be referred to as B1 and B2, respectively, because B1 was built first in 1984 and B2 was later added in 2005, which fulfilled a concept for twin bridges. A northwestern wind prevails in the area of these bridges.

The two sectional models for the wind tunnel tests were identical to those used in several of the previous studies (Seo et al., 2013; Kim et al., 2013; Park et al., 2017). The sectional models were fabricated of balsa with the following length scale: $\lambda_L = L_m/L_P = 1/36$, where L_m and L_p represent the lengths of the model and prototype, respectively. The length of the model was 0.9 m, which was equivalent to a length of 32 m for the prototype. Both decks were equipped with barriers, handrails, inspection rails, guide vanes, and cable anchorage. All details were correctly reflected in the model to a consistent scale. Each sectional model was equipped with two end plates 0.40 m in width and 0.13 m in height for securing two-dimensional flow conditions along the sectional model. The geometries and dimensions of the sectional models are shown in Fig. 1.

The two decks were placed in a wind tunnel, as shown in Fig. 2. B2 was set in the upstream position. The center-to-center distance between the decks was 618 mm, which corresponded to an as-built distance of 22.25 m for the prototype. This setup conformed to the conditions of the unexpected VIVs in the 2011 study, which prompted an investigation of the bridges (Seo et al., 2013). The two sectional models were each