The 2014 World Congress on
Advances in Civil, Environmental, and Materials Research (ACEM14)
Busan, Korea, August 24-28, 2014

Improvement of aerodynamic performance of bridges using small wind turbines

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ABSTRACT

This study proposes a methodology of using small wind turbines for dual purposes, improving the aerodynamic performance of flexible bridges and wind energy harvesting. A method for the proper placement of small wind turbines on flexible bridges was proposed according to the analogy of conventional aerodynamic appendages. The effectiveness of the proposed method was investigated from the wind tunnel tests for a bridge girder. It was found from the tests that the wind turbine attached analogously to a fairing was effective to decrease the vortex-induced vibration of a bridge girder. The results of the present study show the general availability of wind turbines for the improvement of aerodynamic performance and energy supply of flexible bridges, although the capacity of wind power generation was dependent on the wind characteristics at the bridge site

1. INTRODUCTION

Wind-induced vibrations are often critical in the safety and serviceability of flexible bridges. The wind tunnel testing technique has been commonly used to predict such vibrations. If undesirable vibrations were observed during the wind tunnel tests, the outer shape of the bridge section has been generally changed to improve the aerodynamic performance of bridges. Although wind tunnel testing has been performed prior to design, some bridges have suffered after completion because of vortex-induced vibration or poor aerodynamic stability.

In order to mitigate the wind-induced vibrations, while aerodynamic means have been commonly used in the design of new bridges, for the retrofit of existing structures either aerodynamic countermeasures or mechanical countermeasures have been adopted. For aerodynamic countermeasures, aerodynamic appendages such as faring, guide vane, splitter, etc have successfully been used for this purpose by streamlining the sections.

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This paper presents a solution whereby small wind turbines are used for dual purposes, improving the aerodynamic performance of flexible bridges and wind energy harvesting.

2. EXAMPLE BRIDGE AND WIND TURBINES

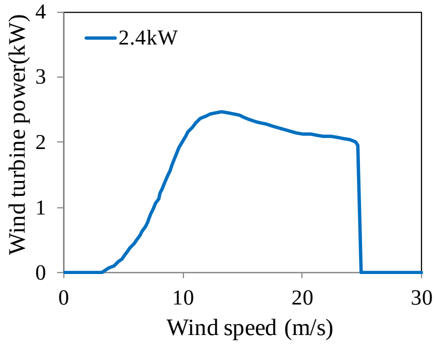
Long span bridges without supporting cables generally adopt a deep girder because of its flexural rigidity. The Rio-Niteroi Bridge in Brazil is a typical example of a deep girder (Battista and Pfeil 2000). For sustained cross winds around 15~16.5m/s, the Rio-Niteroi Bridge has for many years experienced vortex-induced vertical vibrations with amplitudes reaching ±25cm in the middle of the center span (Battista et al., 2008). Battista et al. (2008) reported the design and installation of tuned mass dampers to prevent the vibrations. As an alternative for the mechanical vibration control system, the wind turbines have been studied in the present study for both aerodynamic countermeasure and energy supply.

In the present study, it was assumed that small horizontal-axis wind turbines were attached to bridges. The technical data for the wind turbine was adopted from Skystream 3.7 (Xzeres Wind 2013), which specify rated powers of 2.4kW. Detail data for the wind turbine is given in Table 1. Fig. 1 shows the power performance curve for the wind turbine to assess wind energy potential.

Table 1. Specifications of wind turbine.

Specification	Data
Number of Blades	3
Rotor Diameter	3.72 m
Rated Power	2.4 kW
Cut-in Wind Speed	3.5 m/s
Rated Wind Speed	13 m/s

Fig. 1. Power performance curve



3. Wind Tunnel Test

The experiments were performed in a wind tunnel at the KOCED Wind Tunnel Center in Chonbuk National University, Korea. The wind tunnel is an open circuit blowing type tunnel with al rectangular test section of 1m x 1.5m. The free-stream velocity of the wind tunnel ranges from 0.3m/s to 20m/s, and the turbulence intensity of the uniform flow is less than 0.5%. The cross sectional shape of the wind tunnel model was simplified from that of the Rio-Niteroi Bridge. The model scale was 1:70 and the length of the bridge section model was 0.9m. Fig. 2 shows the bridge girder model equipped with turbine models and the measurement of wind field behind a model turbine.

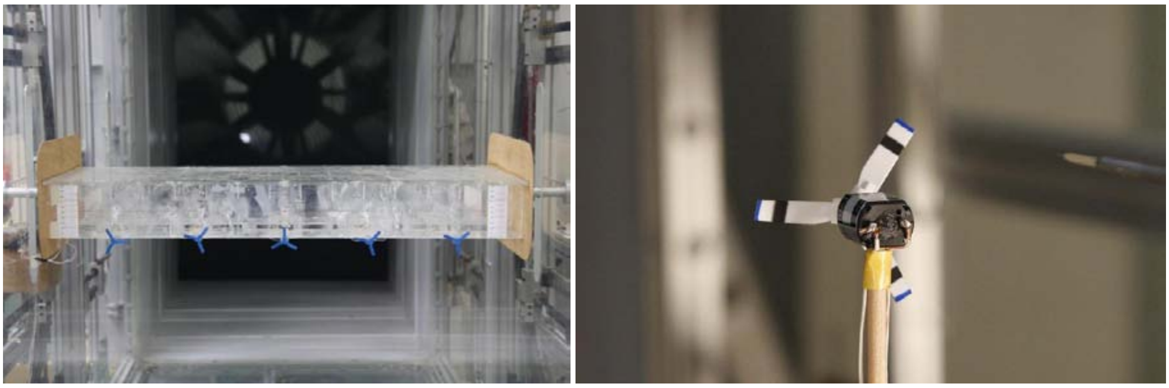


Fig. 2. Bridge section and turbine model in the wind tunnel

3.1 Model Turbine and Scaling Issues

The model turbine with a diameter of 53mm corresponding to the 2.4kW wind turbine was assumed to be installed at the bridge model. As shown in Fig. 2, each model turbine consisted of a three-blade rotor attached to a small DC generator. The turbine angular velocity was adjusted by changing the resistance of the generator (Chamorro and Porté-Agel 2009; Kang and Meneveau 2010). Okulov and Sorensen (2007) have showed that, although it is not possible to match the Reynolds number of real wind turbines, it is possible to reproduce the basic characteristics of the wakes (e.g., wake rotation, tip vortices, and helical tip vortices). Cal et al. (2010) also note that the tip Reynolds number effects are known to be less dominant at the wind turbine tests. The purpose of the present tests is not to model the performance of a particular full scale turbine, but to simulate turbine wakes for improving of aerodynamic performance of bridge girder.

3.2 Wind Turbine Wakes

In this study, the distributions of average wind speeds and turbulence intensities along downstream direction were measured using hotwire anemometer in order to validate the wind field behind a model turbine. The measured wind speeds and turbulence intensities were compared with existing wake models. Fig. 3 shows the measured streamwise wind speeds and turbulence intensities along downstream direction.

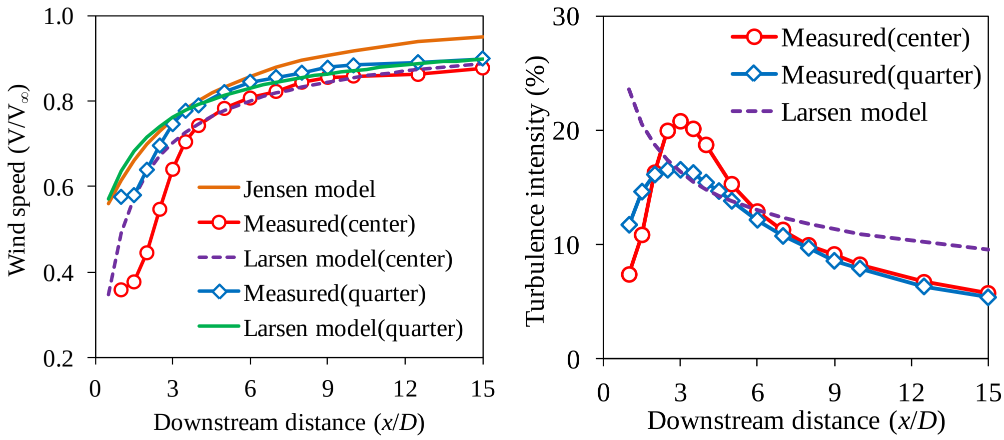


Fig. 3. Normalized streamwise mean wind speeds and turbulence intensities

4. Experimental Results

From the experimental results, it was found that the fairing turbine was effective to reduce the vortex-induced vibration of the bridge girder. A comprehensive study was performed for the fairing turbine. Fig. 4 shows the control efficiency of the fairing turbine according to the distance from the girder edge and the effects of a spanwise fairing interval. The optimal spanwise interval was 3D when fairing turbines were attached at 2D and 3D apart from the girder edge.

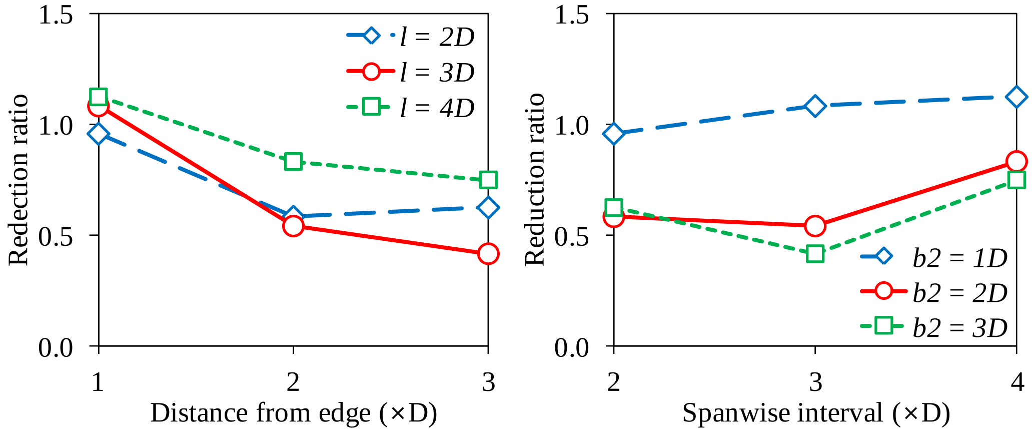


Fig. 4. Effects of distance from girder edge and spanwise interval

Approximately 40 wind turbines can be installed on a single side of a 700m span bridge based on the arrangement of fairing turbine in Table 2.

Table 2. Energy potential of wind turbine attached at a deep girder bridge.

Turbine location	Mean wind speed (m/s)	Rated power	AEP/ea (MWh)	Number of turbines	Total AEP (MWh)
Leading edge	5.11	2.4kW	6.97	40	278.6
Trailing edge	1.40	2.4kW	0.04	40	1.59

5. CONCLUSIONS

This paper proposes a methodology of using small wind turbines for improving the aerodynamic performance of flexible bridges as well as wind energy harvesting. The results of the present study show the general availability of wind turbines for the improvement of aerodynamic performance and energy supply of flexible bridges, although the capacity of wind power generation was dependent on the wind characteristics at the bridge site

Acknowledgments

This research was supported by the grant (13CCTI-A052604-07-000000) from the Ministry of Land, Transport and Maritime of Korean government through the Core

Research Institute at Seoul National University for Core Engineering Technology Development of Super Long Span Bridge R&D Center.

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