Report of an Unexpected Vortex-Induced Vibration in an Actual Suspension Bridge

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Abstract

An unexpected vibration was observed on the Yi Sun-sin Bridge on October 26th, 2014. Since the bridge was subjected to a single mode vibration in limited amplitude for one and a half hours, it was regarded as a vortex-induced vibration (VIV). Since the bridge was aerodynamically well designed for the VIV as well as flutter instability, the cause of the vibration was investigated via a series of two-dimensional wind tunnel tests. The one-side lanes were closed to traffics and the epoxy-coated wearing surface was being replaced at the time of the VIV. Since the primary source was estimated as the temporal screens applied on the bridge railings for maintaining curing temperature of the replaced wearing surface, wind tunnel tests were carried out for the section model of the deck section with and without the screens. This paper presents the screen effects on VIV of the investigated bridge and the illustration of the observed vibration based on in-depth investigation with a series of two-dimensional wind tunnel.

Keywords: Suspension bridge, Vortex-induced vibration, Screens, Wind tunnel test.

1 Introduction

On Oct. 26, 2014, an unexpected huge vortex-induced vibration (VIV) was observed in Yi Sun-sin Bridge (YSS Bridge) for a duration of one and half hours [1]. Since the bridge was aerodynamically well designed for the VIV as well as flutter instability, it is needed to reveal the cause of the vibration and dispel public disquiet. At that time of vibration, for maintaining curing temperature of the replaced wearing surface, the temporal screens were applied on the bridge railings as Figure 1. Therefore, wind tunnel tests were carried out for the section model of the deck section with and without the screens. The purpose of the present study is to understand the source of the unexpected VIV based on wind tunnel experiments result at various Scruton number.

Figure 1. Comparison of section (Left: Original section, Right: Original section with temporal screens)
2 Analysis of the VIV data

Global Navigation Satellite System (GNSS) sensor was installed at the mid-span of the bridge (sampling frequency: 10Hz). So, vibration was recorded in the format of displacement. Figure 2 shows the measured VIV data and Figure 3 is the corresponding PSD result. The maximum vibration amplitude is 0.52m and vibration frequency is 0.3176Hz. If the allowable acceleration of deck is set as 0.5m/s², the serviceability level displacement can be calculated as 0.25m (Eq. 1) and according to this value, the VIV amplitude exceeded the limit by over two times.

\[ d_{max} = \frac{0.5m/s^2}{(2\pi f_{vib})^2} \times 2 = 0.25m \]  

The frequency equal to 0.3176Hz is the 4th symmetric vertical mode frequency. If the maximum magnitude of mode shape vector set as 1, the value at the mid-span is 0.88. Therefore, to convert the wind-tunnel experiment data to displacement that vibrate at the mid-span with 4th symmetric vertical frequency, multiply the data by 0.88.

3 Wind tunnel test

3.1 General description

Wind tunnel experiments were conducted in a wind tunnel operated by the Department of Civil and Environmental Engineering at Seoul National University (Figure 4).

![Figure 4. Wind tunnel](image)

The test section is 1.5m in height, 1.0m in width and 4.0m in length. Manufactured the section model as Figure 5. Length scale is 1/70 and the length of the model is 0.9m. Two types of section were tested. One is original section shape and the other is with applied temporal screens.

![Figure 5. Section model of YSS Bridge in wind tunnel](image)

Since vibration phenomenon at real bridge oscillated with 4th symmetric vertical frequency, mass should also be considered effective mass of 4th symmetric vertical mode. Effective mass of deck is calculated as Eq. (2) and the value is 19.34ton/m.
To evaluate the damping ratio effect, wind-tunnel tests were performed at various Scrucuton number. Scrucuton number is defined as Eq. (3). Assume that design damping ratio of real bridge is 0.4%, Scrucuton number is calculated as 0.46.

\[ S_c = 2\pi \xi m / \rho B^2 \]  

(3)

3.2 Original section

To confirm the aerodynamic characteristic of YSS Bridge, experiments started at low Scrucuton number and checked the damping ratio effect as raising Scrucuton number. VIV phenomenon occurred at low damping condition (Figure 6, \( S_c = 0.13 \) case). However, the amplitude of VIV is under the allowable amplitude and VIV disappeared as the damping ratio is increased to the design level (Figure 6, \( S_c = 0.43 \) case). Thus, aerodynamic safety of YSS Bridge is re-verified through these tests.

3.3 Temporal screens applied section

In the case of temporal screens applied section at windward direction, the range of the VIV (4.4~8.5m/s) occurred is wider than original section (6.5~7.8m/s) and the maximum amplitude of VIV is also larger than allowable amplitude (Figure 7, \( S_c = 0.19 \)). In spite of the design damping level, VIV phenomenon still occurred (Figure 7, \( S_c = 0.47 \) case). The maximum VIV amplitude is 0.63m in real scale. To compare the VIV amplitude with measured displacement at mid-span (0.52m), converts amplitude by multiplying 0.88. This value is 0.55m and it is almost the same as measured data. Therefore we can consider that the cause of VIV are the temporal screens.

4 Conclusions

VIV which occurred on Oct. 26th for one and half hour was vibrated with 4th symmetric vertical frequency (0.3176Hz). The maximum amplitude is 0.52m and maximum acceleration is 1.0m/s². Temporal screens applied at the windward deck was pointed out as the probable cause of VIV. To confirm that, wind-tunnel tests were conducted. From the wind-tunnel test results, original section is stable for the VIV phenomenon at design damping level, on the other hand, huge VIV occurred at temporal screens applied case. Through the reproduction VIV experiments in the wind-tunnel, we can check temporal screens caused the VIV.
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6 References