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Unexpected Vibration Monitoring in a Suspension Bridge and Cause Investigation

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ABSTRACT

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. 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. At that time of vibration, for maintaining curing temperature of the replaced wearing surface, the temporal screens were applied on the bridge railings. Since the primary source was estimated as these temporal screens, wind tunnel tests were performed for the section model of the deck section with and without the screens. In addition to sectional shape change, the interesting aspect is that the bridge deck was oscillated as 4th vertical mode so that lower damping ratio of 4th vertical mode can be a factor of the development of unexpected VIV. This paper presents the screen effects on VIV with a series of two-dimensional wind tunnel tests and extracted modal damping ratio through various system identification schemes based on the field monitored data.

1. INTRODUCTION

On Oct. 26, 2014, a VIV is observed in the YSS Bridge for a duration of two hours. At that time, as shown in Fig. 1, the temporal screens were applied on the all over the bridge railings for maintaining curing temperature of the replaced wearing surface.

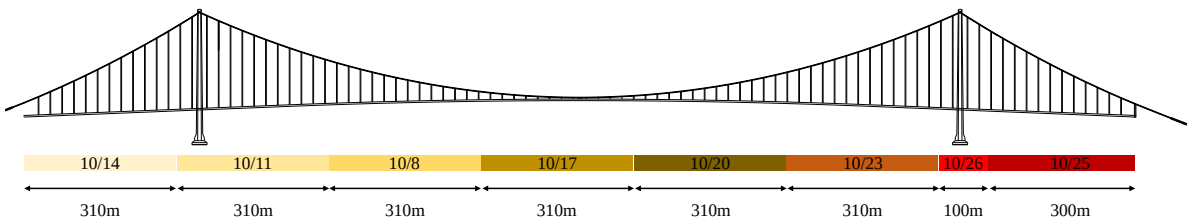

Fig. 1 Construction plan of temporal screens

From the Global Navigation Satellite System (GNSS) sensor installed at the mid-span of the bridge, the displacement of bridge was measured as shown in Fig. 2.

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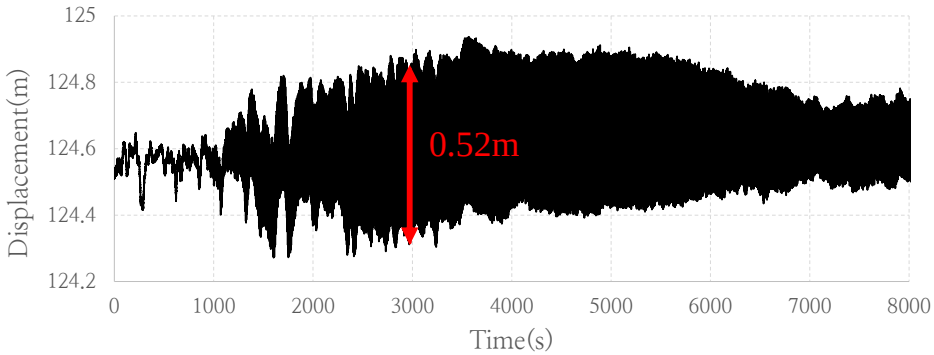

Fig. 2 Measured displacement data

PSD results of this vibration indicates the bridge deck oscillates with a 0.3176 Hz (the 4th symmetric vertical mode).

The purpose of the present study is to clarify the screen effects with a series of two-dimensional wind tunnel tests and extract modal damping ratio through various system identification schemes based on the field monitored data.

2. WIND TUNNEL TESTS

Spring supported tests were performed with scale model in the 2D wind tunnel at Seoul National University for reproduction of VIV. The test section is 1.0m in width, 1.5m in height and 4.0m in length as Shown in Fig. 3. The section model was manufactured as 1/70 length scale. As it was considered that temporal screens made the air flow change and caused VIV phenomena, not only original section was manufactured but also temporal screen model was built.

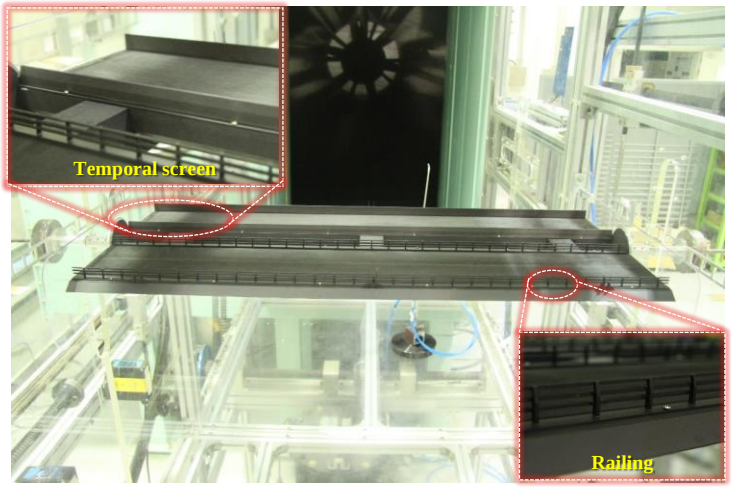

Fig. 3 Deck section model in a wind tunnel

To reproduce the vibration, tests were divided into 2 parts. To confirm the aerodynamic characteristic of original deck section, experiments started at low damping condition. As shown in Fig.4 (a), VIV phenomenon occurred in 6.5~7.8m/s range.

However, the amplitude of VIV is under the allowable amplitude and VIV disappeared as the damping ratio is increased to the design level. Thus, aerodynamic safety of YSS Bridge is re-verified through these tests.

In the case of temporal screens applied section at windward direction (Fig.4 (b)), the range of the VIV (4.4~8.3m/s) occurred is wider than original section (6.5~7.8m/s) and the maximum amplitude of VIV is also larger than allowable. In spite of the design damping level, VIV phenomenon still occurred ($\xi = 0.39\%$ case). The maximum VIV amplitude is 0.60m in real scale. To compare the VIV amplitude with measured displacement at center point (0.52m), 0.60m is almost the same as measured data. Therefore we can consider that the cause of VIV is the temporal screens.

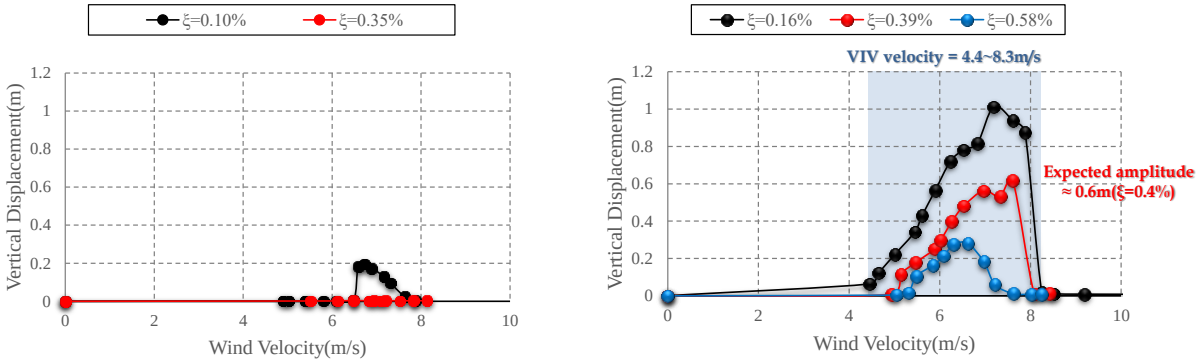

Fig. 4 V-A curve: (a) original section, (b) original section with temporal screens

3. IDENTIFICATION OF DAMPING BASED ON SYSTEM IDENTIFICATION SCHEMES

In order to study a reason for high mode VIV, modal damping ratios were identified by operational modal analysis. Fig. 5(a) illustrates 1-hour ambient vibration data utilized for damping identification. PSD of measured acceleration shown in Figs. 5(b)-(c) indicates that 4th vertical mode (0.32Hz), which is target mode, was well developed in measured data. The Frequency Domain Decomposition (Brinker, 2000) and Natural Excitation Technique – Eigensystem Realization Algorithm (Caicedo, 2004), were implemented as system identification method.

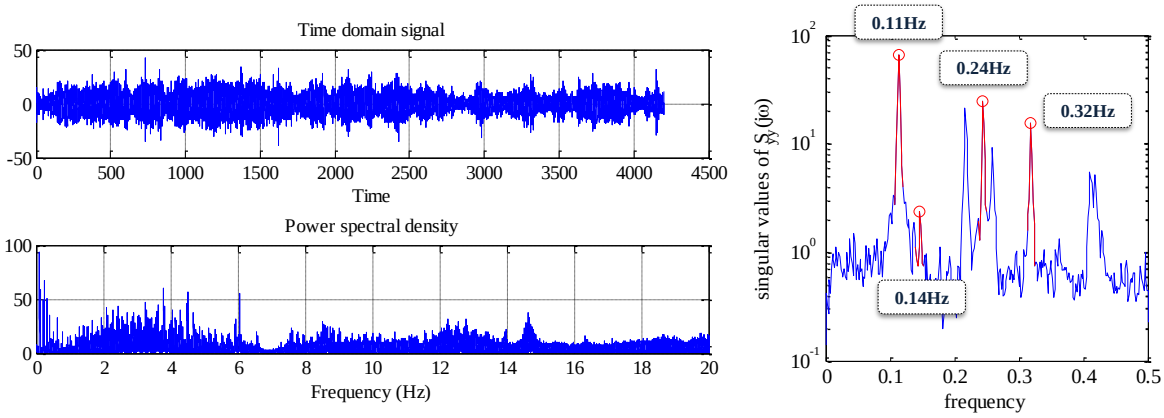

Fig. 5 Measured ambient vibration data: (a) acceleration, (b) PSD, (c) components of symmetric vertical modes.

Table 1 summarizes the results, in which VS1 denotes the “1st Vertical Symmetric mode”. It is clear that the modal damping ratio for VS4 is lower than that for VS1 or VS2, and it caused the VIV of a 4th symmetric vertical mode.

Table 1. Result of system identification (natural frequency / damping ratio)

Methodology	VS1	VS2	VS3	**VS4**
FDD	0.11Hz / 1.26%	0.15Hz / 2.42%	0.24Hz / 0.44%	**0.32Hz / 0.42%**
NExT-ERA	0.11Hz / 1.17%	-	0.24Hz / 0.45%	**0.32Hz / 0.38%**

4. CONCLUSIONS

The source of the unexpected VIV observed in 2014 on the YSS Bridge was the temporal screens. The bridge was subjected to the VIV tuned to the 4th vertical mode, for which the modal damping ratio was identified to be relatively small than other modes. The bridge at the current normal operational condition, without the temporal screens, is identified to be aerodynamically suitable as it was thoroughly verified via the wind tunnel tests at the design stage.

ACKNOWLEDGEMENT

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