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New excitation technique for the identification of flutter derivatives

*You-Chan Hwang[1], Seung-Heon Cha[2], Ho-Kyung Kim[3] and Hae-Sung Lee[4]

[1), 2), 3) ,4)] Department of Civil & Environmental Engineering, Seoul National University, Seoul 151-744, Korea
[3)] hokyungk@snu.ac.kr

ABSTRACT

This paper proposes a new excitation technique (Force-controlled steady-state excitation) for the identification of flutter derivatives. Forced vibration technique, that was used previously, is the method that the excitation system holds the model and excites it vertically or torsionally, so it restrains the interaction between model and wind inevitably. In contrast with the previous forced vibration technique, this method does not restrain the movement by using the spring support system and shaker, so that it can consider the interaction. To validate this new method, the flutter derivatives of the BD05 model with that of the previous method were compared.

1. INTRODUCTION

As long-span bridges are constructed more and more, the aerodynamic stability of the bridge has become important. To evaluate the aerodynamic stability, flutter derivatives are needed. Until now, extraction methods for the flutter derivatives are divided into 2 methods. One is the free-vibration test, and the other is forced-vibration test (Displacement-Controlled system). But, nowadays forced-vibration test is general method because free-vibration test has many weak points. Displacement-Controlled forced vibration keeps the basic assumption (Steady-state) well and makes it possible to collect as enough length of the experiment data as we want. However, this method cannot consider the interaction between the section model and wind owing to restraining the movement. Moreover the excitation equipment is heavy and fixed. So, it is hard to modify the section model and sophisticated setting is also required. In this situation, new excitation technique is needed to extract the flutter derivatives in accordance with the Scanlan's assumption.

2. NEW EXCITATION TECHNIQUE (FORCE-CONTROLLED EXCITATION)

New excitation technique should make the 2-D section model move as sinusoidal without restraining the motion. To realize these conditions, the rotating pendulum and spring support system as shown in Fig. 1 is needed. The direction and excitation

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[1), 2)] Graduate Student
[3), 4)] Professor

frequency of section model are controlled by phase and rotating frequency of pendulum (Fig. 2).

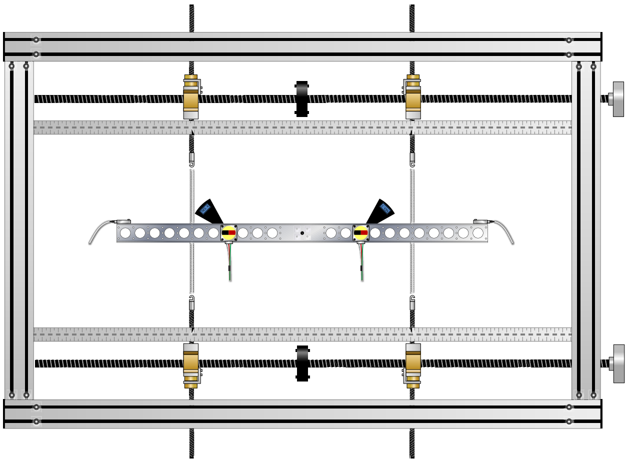

Fig. 1 Setting of New Excitation Technique

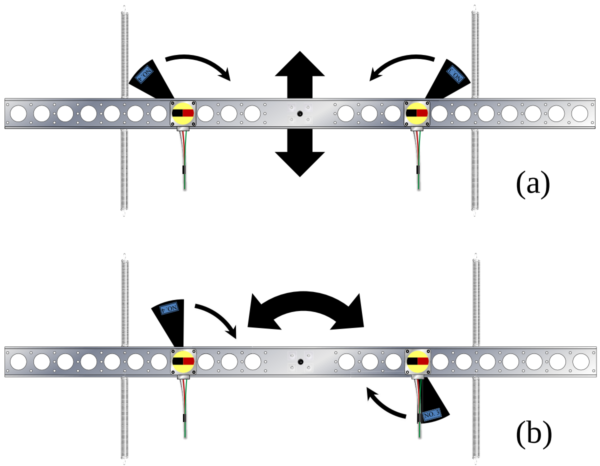

Fig. 2 Excitation Method
(a) Vertical mode (b) Torsional mode

We can get the acceleration information from the accelerometer attached at the side of the bar. With reconstruction method of dynamic displacement and velocity based on the measured acceleration and EEE (Equation Error Estimation, Hong(2012)) method, flutter derivatives can be extracted. The concept of EEE method is to minimize the relative error between known and unknown forces. Objective function is like Eq.(1) and known value and unknown value are defined as Eq. (2).

$$\underset{\mathbf{X}}{\mathrm{Min}}\,\Pi(\mathbf{X}) = \frac{1}{2}\sum_{i=1}^{nt}\left\|\mathbf{F}_{\mathbf{kn}}(t_i) - \mathbf{F}_{\mathbf{un}}(\mathbf{X}, t_i)\right\|_2^2 \tag{1}$$

$$\begin{gathered}\mathbf{F}_{\mathbf{kn}}(t_i) = \mathbf{M}\ddot{\mathbf{u}}(t_i) + \mathbf{C}\dot{\mathbf{u}}(t_i) + \mathbf{K}\mathbf{u}(t_i) - \mathbf{F}_{\mathbf{mot}}(t_i) \\ \mathbf{F}_{\mathbf{un}}(t_i) = \mathbf{C}_{ae}\dot{\mathbf{u}}(t_i) + \mathbf{K}_{ae}\mathbf{u}(t_i)\end{gathered} \tag{2}$$

where $\mathbf{M}$, $\mathbf{C}$ and $\mathbf{K}$ are the mass, damping and stiffness matrix, $\mathbf{F}_{\mathbf{mot}}(t_i)$ is the excitation force. $\mathbf{u}(t_i)$, $\mathbf{C}_{ae}$ and $\mathbf{K}_{ae}$ can be expressed as

$$\mathbf{u}(t_i) = \begin{bmatrix} h(t_i) \\ \alpha(t_i) \end{bmatrix},\ \mathbf{C}_{ae} = \frac{1}{2}\rho\omega_{ex}B^2\begin{bmatrix} H_1 & BH_2 \\ BA_1 & B^2A_2 \end{bmatrix},\ \mathbf{K}_{ae} = \frac{1}{2}\rho\omega_{ex}^2B^2\begin{bmatrix} H_4 & BH_3 \\ BA_4 & B^2A_3 \end{bmatrix} \tag{3}$$

where $H_i, A_i\ (i = 1\cdots4)$ are the flutter derivatives.

3. APPLYICATION OF NEW EXCITATION TECHNIQUE

In application of the new excitation technique to B/D=05 section model (Fig. 3). Experiments were conducted using the wind tunnel, Le Cachalot at the Seoul National University. The dynamic property of model is summarized in Table 1. To confirm the dependency of excitation frequency, the excitation frequency were changed 2 times. So, total test cases are 3; 2.0Hz, 2.5Hz and 3.0Hz excitation.

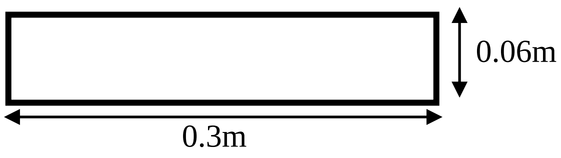

Fig. 3 Cross Section of B/D=5 model

Table. 1 Dynamic Property of B/D=5

Mass(kg/m)		6.02
Inertial moment(kg m^2/m)		0.09
Natural frequency (Hz)	Vertical	1.77
	Torsional	4.08
Excitation frequency(Hz)		2.0, 2.5, 3.0

Utilizing the experiment data of 3 cases, flutter derivatives were extracted. For the sake of consistency, each case performed 3 times independently. The results are shown in Fig. 4.

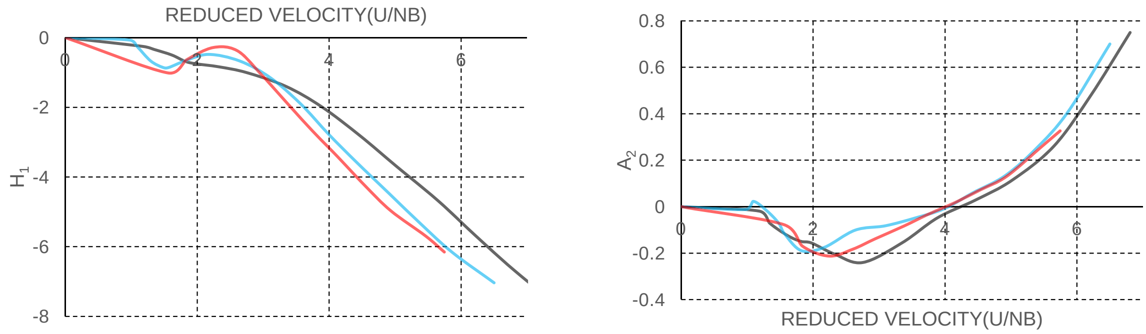

Fig. 4 Flutter Derivatives of B/D=5 (— 2.0Hz, — 2.5Hz, — 3.0Hz Excitation)

As you can see in the figure, a consistent tendency is identified for several excitation frequencies.

4. VALIDATE THE RESULT WITH DISPLACEMENT-CONTROLLED RESULT

To validate the result, comparison of the result with displacement-controlled result conducted by Matsumoto(1996) and calculation of aerodynamic damping and frequency are conducted. Single-mode flutter theory is used to perform this process.

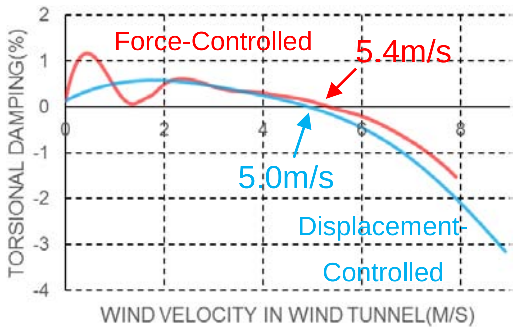

Fig.5 Aerodynamic Damping of B/D=5

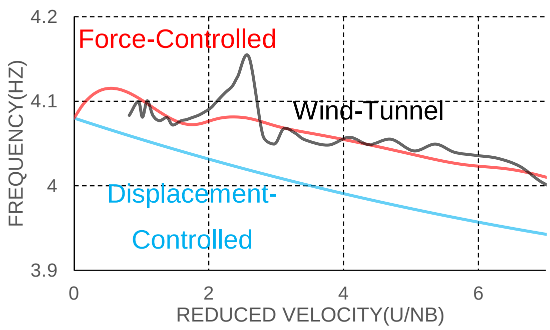

Fig.6 Aerodynamic Frequency of B/D=5

As shown in Fig.5, there is no big difference in flutter velocity between two methods. Actual flutter velocity was checked by wind-tunnel test result (5.2m/s). So, it can be concluded that both methods predict flutter velocity quite well. On the other hand, the result of aerodynamic frequency is quiet distinct to each other. The prediction from the force-controlled result is well matched with real wind-tunnel test results.

5. CONCLUSIONS

The force-controlled technique overcomes the weakness of the displacement-controlled technique. As the excitation technique is changed, different flutter derivatives are attained. It leads to the distinctive prediction of aerodynamic frequency and the result from force-controlled data is well matched with real wind tunnel data. Since force-controlled excitation system can manifest the interaction between wind and section model, these discrepancy can be explained by the interaction force. Based on the results so far archived, the force-controlled technique may provide profound insight in identifying the interaction force between wind and section model.

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