A SIMPLE APPARATUS FOR MEASURING SELF-EXCITED WIND FORCES ON BRIDGES

Seung Ho Lee\(^1\) and Soon-Duck Kwon\(^2\)

\(^1\) Ph.D. student, Dept. of Civil Engineering, Chonbuk National University  
Chonju, Chonbuk, Korea, guide1th@chonbuk.ac.kr
\(^2\) Director, KOCED Wind Tunnel Center, Chonbuk National University  
Chonju, Chonbuk, Korea, sdkwon@chonbuk.ac.kr

ABSTRACT

A simple vibration system consist of stepping motors and force transducers was designed and fabricated to measure the self excited wind loads acting on bridge sections. The bridge section model installed on the system was harmonically excited either vertical or torsional at a time. Then the measured forces were converted to the flutter derivatives by applying the Fourier and Hilbert transform. From the wind tunnel tests, the effects of the frequencies, amplitudes and angles of attack on flutter derivatives were investigated. Moreover the flutter derivatives for six bridge sections were provided.

KEYWORDS: FLUTTER DERIVATIVE, FORCED VIBRATION, BRIDGE VIBRATION, WIND EFFECT

Introduction

The self-excited wind forces which are generally expressed by the flutter derivatives are caused by the structural motion of bridge itself, and affect the stability of the coupled system between bridge and wind. The extraction of the flutter derivatives from the free vibration signal has been studied by many researchers because of its relatively simple mechanism to excite the bridge model. However the flutter derivatives extracted by the free vibration method are generally dispersed along its average value at certain wind speed, and sometimes need to be expressed in terms of probabilistic manner. Moreover the choice of initial conditions is important in order to produce meaningful results.

The forced excitation method has advantages compared with the free vibration method. The forced vibration method can simulate a steady-state sinusoidal motion which is basic assumption of flutter analysis. The oscillation amplitude and frequency can be controlled in the forced vibration method. Finally the forced vibration method provides consistent results at repeated tests. This study presents a simple excitation apparatus consist of stepping motors and force transducers as well as signal processing algorithm to extract the flutter derivatives acting on bridge sections. The effects of the frequencies, amplitudes and angles of attack on flutter derivatives have been investigated from the wind tunnel tests.

Forced excitation apparatus

The forced excitation system developed in present study is shown in Figure 1. Basically the apparatus consist of two parts. The first is a part to provide the harmonic excitations to a bridge model for simulating the steady state structural responses. As shown in Figure 1, the bridge model is upheld by three vertical supporting members. Two supporting members at upstream and one at downstream are attached at linear guides and independently driven by two stepping motors. The cam and crank system converts the motor rotation to the
vertical motion of the supporting members. The rotating frequency of the motor is easily adjusted at the motor controller. The amplitude of vertical motion at each supporting members can be adjustable by changing the eccentricity at cam and crank system. The pitching motion for the bridge modes are realized by giving opposite phase to upstream and downstream motors. The amplitude of pitching motion is adjusted by changing the amplitude of supporting members and/or changing the gap between upstream and downstream members. The motor controller used in this study, National Instruments PCI-7342 and UMI-7764, is capable of independent 2-axes control.

The second part is measurement of the forces acting on the bridge model by three single-axis loadcells installed between the bridge model and supporting members. The displacements of the bridge model are measured by using the noncontract optical system. The forces and displacements are simultaneously recorded by the data acquisition card, National Instruments PCI-6024. The interactive program for motor control and data acquisition has been made by the LabVIEW, and further data processing has been done by the MATLAB.

![Figure 1: Forced Excitation System](attachment:image1.png)

![Figure 2: Bridge Sections](attachment:image2.png)

**Data process for extraction of flutter derivatives**

When we gives a sinusoidal pitching motion, \( \alpha(t) = \alpha_0 \cos(\omega_0 t) \), to the bridge model, the following measured lift and pitching moment contains aerodynamic force as well as inertia forces.

\[
L_\alpha(t) = \overline{L_\alpha} \cos(\omega_0 t + \varphi_{L\alpha}) \\
M_\alpha(t) = \overline{M_\alpha} \cos(\omega_0 t + \varphi_{M\alpha})
\]

(1a)  
(1b)

The amplitudes of the forces, \( \overline{L_\alpha} \) and \( \overline{M_\alpha} \), can be obtained by finding the maximum Fourier spectral amplitude. The phase angles of the signal, \( \varphi_{L\alpha} \) and \( \varphi_{M\alpha} \), can be acquired from the Hilbert transform. The authors found that the Hilbert transform provided consistent results in computation of the phase angle compared with other methods.

The process for removing the inertia forces from total measured forces is as follows. At first step, the amplitudes and phase angles for the lift and pitching moment without wind
which are denoted as $T_{a_0}$, $M_{a_0}$, $\varphi_{La_0}$ and $\varphi_{Ma_0}$ respectively, can be obtained by giving the forced pitching motion. In this case, the forces contain inertia terms only. At second step, the amplitudes and phase angles for the lift and pitching moment under certain wind velocity, $T_{a_1}$, $M_{a_1}$, $\varphi_{La_1}$ and $\varphi_{Ma_1}$, can be also obtained. The amplitude and phase angle for pure aerodynamic forces can be computed by extracting the inertia terms from the total ones.

Finally the flutter derivatives can be obtained as follows. The flutter derivatives related to the vertical motion also can be computed by the same manner.

$$H_2^* = \frac{T_{a_0}}{2} \frac{\sin \varphi_{La_0}}{\alpha_0} \rho U^2 B K^2$$

$$H_3^* = \frac{T_{a_0}}{2} \frac{\cos \varphi_{La_0}}{\alpha_0} \rho U^2 B K^2$$

Experimental results

Figure 3 provides the analytical results for flat plate and the measured flutter derivatives for thin rectangular section with aspect ratio 20. It can be seen from the figure that the measured flutter derivatives are close to those evaluated from analytical results. This indirectly confirms the validity of the present apparatus and data processing algorithm.

The effects of the frequencies and amplitudes on flutter derivatives were investigated for the rectangle. As shown in Figure 4, the oscillation frequencies and amplitudes give minor effect on the flutter derivatives within the practical range of wind speed.
The flutter derivatives for four more actual bridge sections shown Figure 2 were tested in the wind tunnel using the system in present study. The results may not be provided at here because of page limitation.

Concluding remarks

This study presents a simple apparatus consist of stepping motors and force transducers as well as a signal processing algorithm to measure the flutter derivatives acting on bridge sections. The validity of the present system has been confirmed from the wind tunnel tests. It is also found that the oscillation frequencies and amplitudes give minor effect on the flutter derivatives within the practical range of wind speed.

References

