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Discussion on the Applicability of Using Random Decrement Technique to Identify the Aerodynamic Damping under Vortex-Induced Resonance

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Abstract

The random decrement technique is an efficient method to extract the modal parameters based on the white-noise input assumption. However, for the crosswind aerodynamic force of high rise building, its non-white noise character can't be ignored (especially for the vortex-induced resonance) because its power spectral has obvious peak. Based on four categories of crosswind aerodynamic force inputs, the application of random decrement technique on the aerodynamic damping identification was investigated by the Matlab numerical simulation. Some suggestions are given for the crosswind aerodynamic damping identification with random decrement technique.

1. Introduction

The random decrement technique is a system identification method which can obtain the free vibration signal from the response of the structure based on the white-noise input assumption [1,2]. Because of its speed and accuracy, the random decrement method is widely used in the system identification for wind tunnel tests and full-scale measurements. However, the exciting force in many cases (such as the crosswind aerodynamic force of high-rise building) does not meet the white-noise input assumption. Then, what is the result if we still use the random decrement method for non-white noise input cases? Spanos and Zeldin [5] pointed that the Random Decrement signature is not the system free vibration curve unless the corresponding input excitation is white. The crosswind aerodynamic force of high-rise building is a typical non-white noise. In this study, the suitable of random decrement method on aerodynamic damping identification for a single degree linear system under the crosswind aerodynamic excitation is investigated by Matlab numerical simulation.

2. Numerical Simulation

The numerical simulation of aerodynamic damping identification for a single degree linear system is mainly divided into the following 3 steps.

2.1 Aerodynamic Force Simulation

The crosswind aerodynamic force spectrum were obtained from the generalized force spectral formula proposed by Chinese load code for the design of building structures (GB50009-2012) [3]. Firstly, different aerodynamic force spectrum S_{Fi} under four different terrain categories (A, B, C and D) and different reduced wind speeds ($U_r = 4.6 \sim 13.1$) were calculated according to the code. Then the aerodynamic force spectrum were transformed into time series by inverse Fourier transform. In order to get accurate random decrement signatures, the sampling frequency of aerodynamic force is 312.5Hz and the simulation length of each time series is 14 minutes. Figure 1 shows the simulation aerodynamic force spectrum and their time series in the terrain category A and reduced wind speed $U_r = 4.6$.

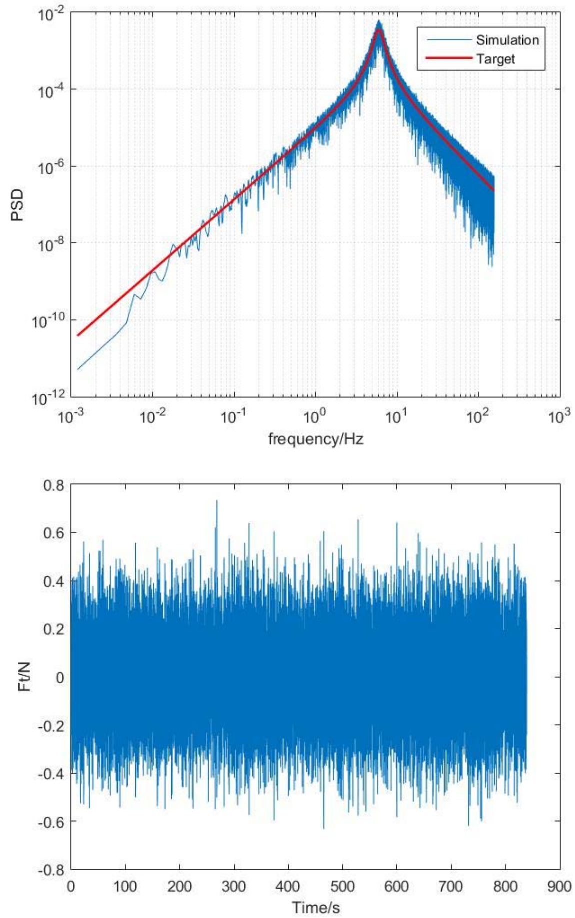

Figure 1. Simulation aerodynamic force spectrum and their time series (Terrain category A, $U_r = 4.6$)

2.2 Simulation of Random Vibration Response

Base on the dynamic characteristics of an aeroelastic model ($m = 0.225kg$, $f_0 = 13Hz$, $\xi_s = 0.02$) and the aerodynamic force $F(t)$ obtained from last step, the wind induced responses were calculated with Newmark- β method. The calculated responses were checked by comparing them with the results calculated with the Duhamel integral. The results calculated with the two methods are almost the same as shown in Figure 2.

In order to facilitate analysis, the aerodynamic damping ratio were set to vary in gradient: $\xi_a = -0.015, -0.01, ..., 0.02$. After ignoring the aerodynamic stiffness force and the aerodynamic inertia force, the random vibration equation can be simplified as: $m\ddot{x} + 2(\zeta_s + \zeta_a)w\dot{x} + mw^2 x = F(t)$.

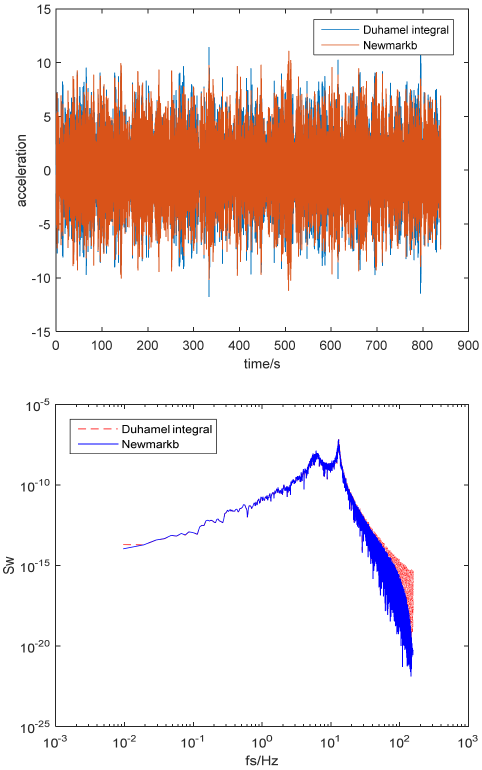

Figure 2. The acceleration response time series and their power spectrum

2.3 Aerodynamic Damping Identification

Usually the measured response data will contain noise and system deviation, so researchers need to pretreat the response data for eliminating the trend item and filtering the noise before system identification. There was no trend and noise item since this study was based on the numerical simulation. Therefore, we needn't pretreat the data under this ideal condition. After testing some cases, we chose suitable initial acceleration and signature length to apply the improved random decrement technique to get the random decrement signature $D(t)$ by both positive and negative level crossing triggering condition [1]. The ensemble average times of each random decrement signature is more than 27000 in this simulation. Finally, the damping was obtained by the nonlinear least square fitting of the random decrement signature by Tamura's four parameters method [6], i.e. $\min\left\{\left[Ae^{-\xi\omega_0 t}\left(\cos\omega_d t + B\sin\omega_d t\right) - D(t)\right]^2\right\}$, where A, B, ξ, ω_0 are the parameters been fitted. The damping ratio obtained from the nonlinear least square fitting is the total damping ratio and the total damping minus the structural damping is the aerodynamic damping.

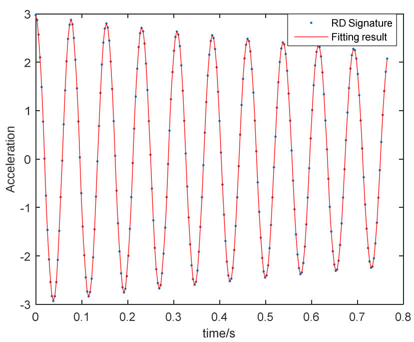

Figure 3. Fitting of the random decrement signature

3. Result

Figure 4 shows the variation of identified aerodynamic damping ratio with the change of reduced wind speeds under terrain categories A, B, C and D, respectively.

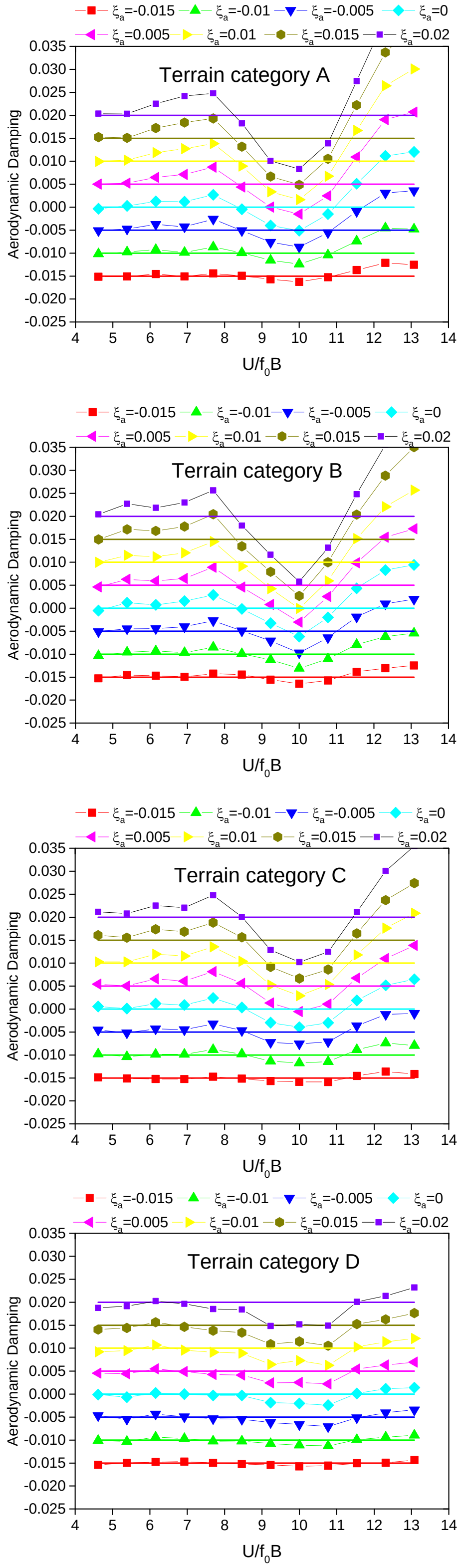

Figure 4. The results of aerodynamic damping identification

For terrain category A, the aerodynamic damping ratio identification results are accurate under low reduced wind speeds ($U_r = 4 \sim 6$). With the increase of the reduced wind speed, the identification deviations of high damping ratios increase gradually and reach a small peak at $U_r = 7.7$. When the reduced wind speed continues to increase, it will come to the vortex-induced resonance region. The identification results in this region （$U_r = 8 \sim 12$） will show a clear 'V' shape which has a bottom at the critical reduced wind speed $U_r = 10$. This means that the identified damping ratio values are smaller than the real values in the region, especially for the positive aerodynamic damping ratio. The maximum identification deviation is about -0.15 in the critical reduced wind speed $U_r = 10$. With the real aerodynamic damping ratio decreases, the deviations gradually fall down. For the negative aerodynamic damping, the identification deviation is less than 0.002. When the aerodynamic damping ratio is -0.015, the identification deviation is the minimum (only about 0.001).

When terrain category changes from A to D, the identification deviation mainly shows a descent trend, especially for the vortex-induced resonance region. For terrain category D and critical reduced wind speed, the maximum identification deviation is about 0.005 which appear in the case $\xi_a = 0.02$ which is decreased 97% than the correspondence case in terrain category A. In order to explain this phenomenon, Table 1 describes the deviations of identification aerodynamic damping ratio under the critical wind speed. The index χ in the table is the bandwidth parameter of input aerodynamic force, which is calculated as following:

$$\chi = \frac{f_2 - f_1}{2 f_0} \tag{1}$$

where f_1 and f_2 are the half-power points (two frequency points at the $1/\sqrt{2}$ height of the power spectral peak of crosswind aerodynamic force), f_0 is the frequency of aerodynamic power spectra's peak. This index reflects the bandwidth and peak value of aerodynamic spectrum. The smaller value of χ indicates that the aerodynamic spectral energy is more concentrate and the non-white noise character is more obvious. The larger value of χ indicates that the aerodynamic spectral is closer to the white noise. As the table shows, the values of χ for A, B, C, D four terrain categories are 0.0865, 0.0903, 0.1130 and 0.1988. Therefore, the value of χ become large gradually when the terrain category change from A to D. Meanwhile, the effect of non-white noise is more and more weak which result in the reduced identification deviation.

Terrain category		A	B	C	D
χ		0.086	0.09	0.113	0.199
ξ_a	-0.015	-0.0013	-0.0015	-0.0008	-0.0007
	-0.01	-0.0024	-0.0031	-0.0017	-0.0011
	-0.005	-0.0037	-0.0047	-0.0026	-0.0016
	0	-0.0051	-0.0062	-0.0039	-0.002
	0.005	-0.0065	-0.008	-0.0055	-0.0025
	0.01	-0.0084	-0.0101	-0.0071	-0.0027
	0.015	-0.0101	-0.0123	-0.0083	-0.0035
	0.02	-0.0117	-0.0142	-0.0098	-0.0048

Table 1. The deviations of identification aerodynamic damping under the critical wind speed (vortex induced resonance)

In general, for the vortex-induced resonance region, the identification of positive aerodynamic damping have severe deviation. But for the negative aerodynamic damping the deviation is less than 0.002 which is an acceptable deviation for projects. In fact, in addition to cases in the high turbulence or corner modified buildings, it won't appear the positive aerodynamic damping in the vortex-induced resonance region [4]. In most cases, the aerodynamic damping ratio usually is negative value in this region. So, the random decrement method is still applicable to identify the aerodynamic damping in the vortex-induced resonance region for the conventional rectangle-section building.

4. Conclusions

The applicability of the random decrement technique to identify the crosswind aerodynamic damping was studied in detail based on the numerical simulation. The results show that: in the low reduced wind speed region, the identification results are accurate. In vortex-induced resonance region, the identification of positive aerodynamic damping ratio has severe deviation but that for the negative aerodynamic damping ratio has acceptable deviation. The parameter of aerodynamic power spectrum bandwidth χ affects the identification results. The larger the value of χ is (closer to white noise), the more accurate the identification results by random decrement technique will be.

However, we must know that the simulation had ignored the nonlinearity behaviour during the vortex shedding and this should be studied further.

Acknowledgments

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