Damping identification of bridges from nonstatioary ambient vibration data

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ABSTRACT

This research focused on the assessment of vortex-induced vibration on cablestayed bridge with identification of damping ratio using nonstationary ambient vibration data. The damping ratio has a strong effect on the vortex-induced vibration of longspan bridge. It can be identified by operational modal analysis based on the assumption of stationary white noise input. However, most bridges are generally subjected to a nonstationary excitation in service, and it can be a reason of random uncertainty. To deal with this nonstationarity, an amplitude-modulating function is calculated from measured responses to eliminate global trends caused by a nonstationary part. The Bind Source Separation is also implemented to extract the stationary process from the raw signal. In order to estimate the damping ratio, Natural Excitation Technique-Eigensystem Realization Algorithm is applied to the extracted stationary process and nonstationary data to assess the effect of elimination of nonstationarity on damping estimation.

1. INTRODUCTION

The damping ratio has a strong effect on the occurrence of vortex-induced vibration of long-span bridge (Kim et al., 2013). For a damping identification, many researchers have utilized operational modal analysis. One of the important assumptions of outputonly modal analysis is that a structural system should be under stationary ambient vibration. However, in most cases, large civil structures are not under a strictly stationary excitation, especially in service condition. For example, a traffic-induced vibration, which is the one of dominant vibration sources for bridges, is not a perfect stationary process as shown in Fig. 1. This nonstationarity can also be a reason of variance/bias observed in damping estimation.

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Fig. 1 Representative record: (a) Acceleration and (b) mean and standard deviation

This research focused on accurate identification of damping ratio with nonstationary responses. The amplitude-modulating function was calculated from measured responses to eliminate global trends caused by a nonstationary part. The Bind Source Separation (BSS) based on Second-Order-Blind-Identification (SOBI) was implemented to extract a stationary process from the measured response. Natural Excitation Technique (NExT) was applied to calculate the impulse response function from separated stationary process by SOBI algorithm and Eigensystem Realization Algorithm (ERA) was utilized to estimate a damping ratio.

2. AMPLITUDE-MODULATING FUNCTINON TO REMOVE A NONSTATIONARITY FROM MIXED SOURCE

Chiang and Lin (2008) proposed an identification method of modal parameter from response data from structure under nonstationary ambient vibration. The ambient excitation is assumed as a product of white noise and an amplitude-modulating function (AM function), $\Gamma(t)$, as follows.

$$f(t) = \Gamma(t)w(t) \tag{1}$$

To transform the nonstationary response into stationary process, $\Gamma(t)$ should be extracted so that the temporal root-mean-square function from the real data is evaluated (Newland, 1993). This temporal root-mean-square function can be evaluated by moving averaging method for the squared sample record as

$$\Gamma(t) = C_{\sqrt{\frac{1}{T} \int_{t-\frac{T}{2}}^{t+\frac{T}{2}} u^{2}(\tau) d\tau}}$$
(2)

where C is the expectation of square root for ergodic process part. Finally, The approximate stationary process is acquired to divide the sample record by envelop of AM function.

The amplitude-modulating function of measured acceleration of Jindo Bridges was calculated, and the corresponding approximate stationary ambient vibration data was also obtained to divide the measured acceleration by the calculated AM function, $\Gamma(t)$. All results are shown in Fig. 2.



Fig. 2 Application for monitored data: (a) Measured acceleration and calculated amplitude-modulating function and (b) approximate stationary data

NExT-ERA was implemented to extract the damping ratio from raw data denoted as "Nonstationary" and approximate stationary data as "Stationary". The result is summarized in Table 1 and shown in Fig. 3. As can be seen, the stationary data shows less scattering than nonstationary case in terms of standard deviation, but the stabilizing effect for the damping ratio is not dramatic but a little.

Table 1. Mean and standard deviation according to nonstationarity

Stationary process		Nonstationary process		
Mean value	Standard deviation	Mean value	Standard deviation	
0.3459%	0.1250	0.3327%	0.2002	



Fig. 3 Estimated 1st vertical damping ratio of Jindo Bridges

Fig. 4 presents the estimated damping ratio according to considering mode indicating required system order to estimate a target mode. A small considering mode means that a target mode is dominant while large modes means a target mode is not fully governed and hard to find. As can be seen, the considering mode of stationary data decreased compared to the raw data. A process of approximation of stationary using AM function contributed to filter high modes caused by traffic-induced vibration. It also explains that these higher modes could be one of the reasons for scattering.



Fig. 4 Estimated 1st vertical damping ratio according to considering mode

3. EFFECT OF NONSTATIONARY LOADING ON DAMPING ESTIMATION

In order to evaluate the effect of nonstationary loading on the error of damping estimation, a series of numerical simulation was performed with various loading conditions. A three of loading condition (stationary white noise, sinusoidal and pulse loading) shown in Figs. 5 (a)-(c) was applied, respectively. Figs. 5 (d)-(f) illustrates corresponding accelerations according to each loading condition. These calculated accelerations were mixed linearly as shown in Fig. 6.

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Fig. 5 Time histories of (a) stationary loading (b) sinusoidal loading, (c) pulse loading and corresponding accelerations from (d) stationary (e) sinusoidal and (f) pulse loading



Fig. 6 Time history of mixed acceleration

BSS was utilized to recover the independent sources from only the output measurements. Among the various BSS algorithm, SOBI, which was proposed to employ time coherence of the source signals (Belouchrani et al., 1997), was applied to mixtures. As can be seen in Fig. 7, original source and identified sources shows good agreements for three loading conditions.

Fig. 8 shows correlation functions calculated by the NExT using stationary source, mixture and identified stationary source, respectively. The result of mixture was significantly distorted compared to that of stationary source while the identified source shows good coincidence.



Fig. 7 Original acceleration and separated source corresponding to (a) stationary, (b) sinusoidal and (c) pulse loading



Fig. 8 Correlation function of stationary source, mixture and identified stationary source

In order to study the influence of nonstationary process on damping estimation, 200 simulations were performed with variation of mixing matrix. The simulation time is set to as 3,600 seconds. The coefficients of mixing matrix for sinusoidal and pulse loading is relatively larger than that of stationary loading in order to increase nonstationarity on the mixture. The number of pulse loading was modified from 0, 40 and 60.

Fig. 9 synthesizes identified damping ratio from the 200 simulations performed for identified stationary source and two of mixtures, respectively. The result of identified stationary source was close to the input value while the damping ratio estimates from mixture turned into relatively incorrect with increasing the number of pulse loading.



Fig. 9 Identified damping ratio according to the number of pulse

Table 2 summarizes the mean value of damping ratio according to the number of pulse loading. As can be seen, a nonstationarity clearly affect the accuracy of damping estimation. The result of identified stationary source is more close to the actual damping ratio of 0.5% compare to the result of mixture.

Table 2. Mean v	alue of identified	damping ratio	according to the	number of pulse
			3	

	Mean value	
Input value	0.50%	
Identified stationary source	0.56%	
Mixture (# of pulses = 40)	0.81%	
Mixture (# of pulses = 60)	1.95%	

4. CONCLUSIONS

This research presents damping estimation from of nonstationary ambient vibrations by NExT-ERA combined with AM function and SOBI. The approximation of stationary process stabilized the scattering of estimated damping ratio a little. The proposed scheme is rather effective to weaken the higher modes by decreasing the trafficinduced vibration. By decreasing of higher modal participation, the scattering of

damping ratio is slightly removed. A series of numerical simulation showed that a strong pulse loading distorted an estimated impulse response function, and this distortion caused a large error in damping estimation. 200 simulations also demonstrated that higher nonstationarity increased a bias of estimates. In such a case, the recovering stationary source by SOBI provided more accurate estimation compared to the result of mixtures.

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