The 2014 World Congress on
Advances in Civil, Environmental, and Materials Research (ACEM14)
Busan, Korea, August 24-28, 2014

The effect of nonstationary condition on the identification of damping ratio from ambient vibration data

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ABSTRACT

Identification of damping ratio of twin cable stayed bridge ispresented from ambient vibration data in nonstationary condition. A series of previous studies have identified the damping ratio of investigated bridge by the Natural Excitation Technique (NExT) – Eigensystem Realization Algorithm (ERA) which has been successfully applied to the identification of modal parameters of bridges utilizing ambient vibration data.However, an operational monitored data from bridges isnot a fully stationary condition due tothe traffic induced vibration, which could be one of the reasons for the scattering in the estimated damping ratios. This paper considered the effect of nonstationarity on the estimated damping ratio by the implementation of system identification method for nonstationary ambient vibration.

1. INTRODUCTION

A severe vortex-induced vibration was observed at the investigated bridge, Jindo bridge, a twin cable-stayed bridge. Seo et al. (2013) performed a series of wind tunnel tests to find thereason of this unexpected vibration and pointed out the low structural damping ratio as a main reason. Actual damping ratio was estimated using field monitored data as 0.28% which is lower than the design guideline (Kim et al., 2013).

One unusual feature of identified result is that estimated damping ratio was excessively scattered as can be seen in Fig. 1. The assumption of modal identification from ambient vibration data wasthat the input loading is a stationary process such as a white noise (Caicedo, 2011). However, most bridges are under nonstationary ambient excitations such as a combination of wind and vehicle as shown in Fig. 2. This non-stationarity can be a reason for the observed scattering.

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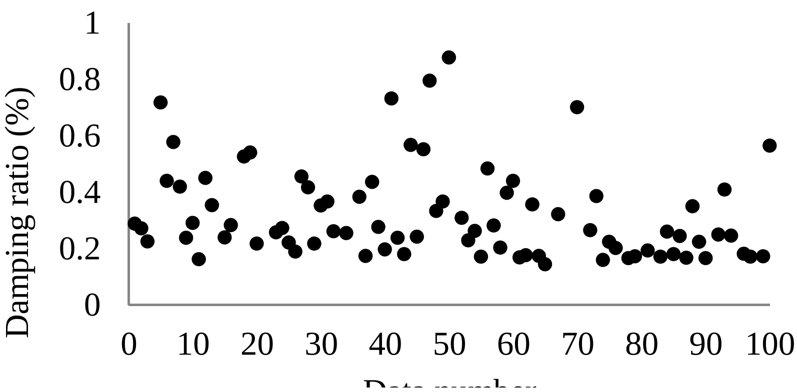

Fig. 1Scattered damping ratio under nonstationary ambient vibration

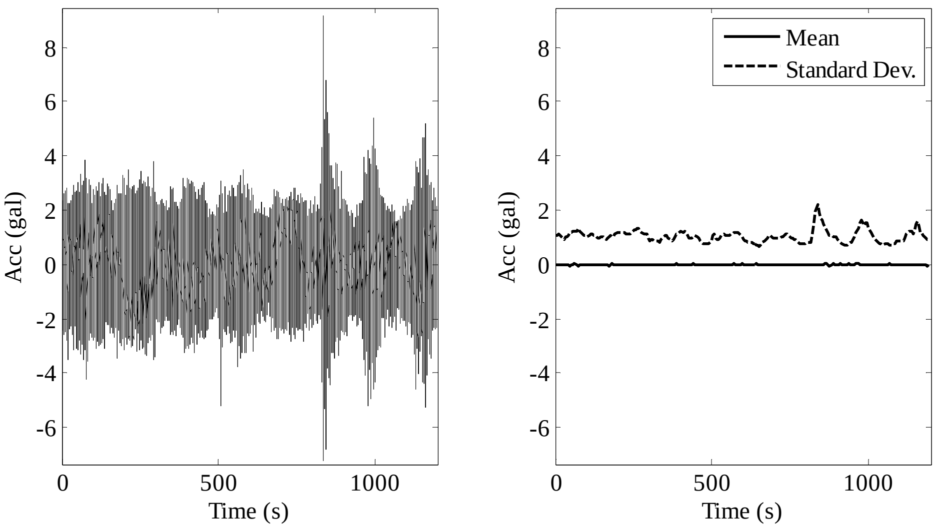

Fig. 2Representative record: (a) Acceleration and (b)mean and standard deviation

This paper considered the effect of nonstationarity on the estimated damping ratio by the implementation of modified correlation technique (Chiang and Lin, 2008) for nonstationary ambient vibration paired with Eigensystem Realization Algorithm.

2. SYSTEM IDENFICIATION FOR NONSTATIONARY DATA

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

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

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

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

where*C* is the expectation of square root forthe ergodic process part. Finally, we can obtain the approximate stationary process by dividing the sample record by envelop amplitude-modulating function.

to verify the proposed scheme, a 6-DOF shear building model is simulated. The sample function of nonstationary white noise and the response at the top of the building is shown in Fig. 3 (a) and (b), respectively. $\Gamma(t)$is calculated from Fig. 3(b) using the moving averaging, and the curve fitting is applied to obtain a smoothed line. The original input and fitted $\Gamma(t)$ are well matched as can be seen in Fig. 4

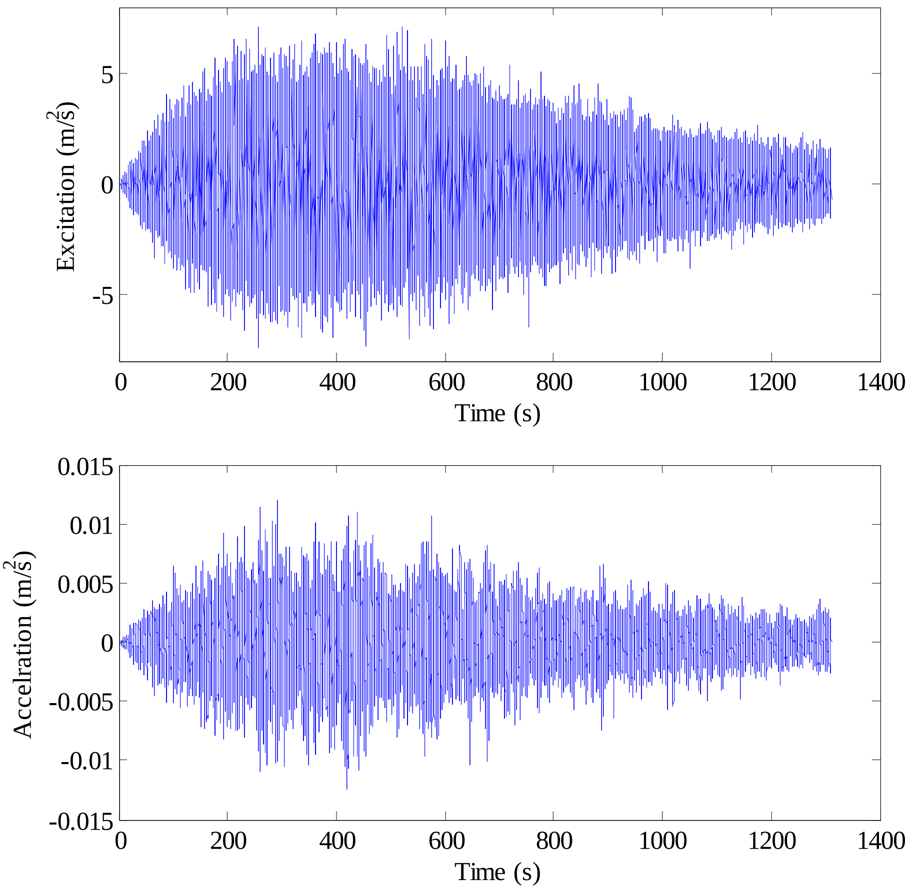

Fig. 3Numerical simulation: (a) Input excitation and (b) calculated acceleration

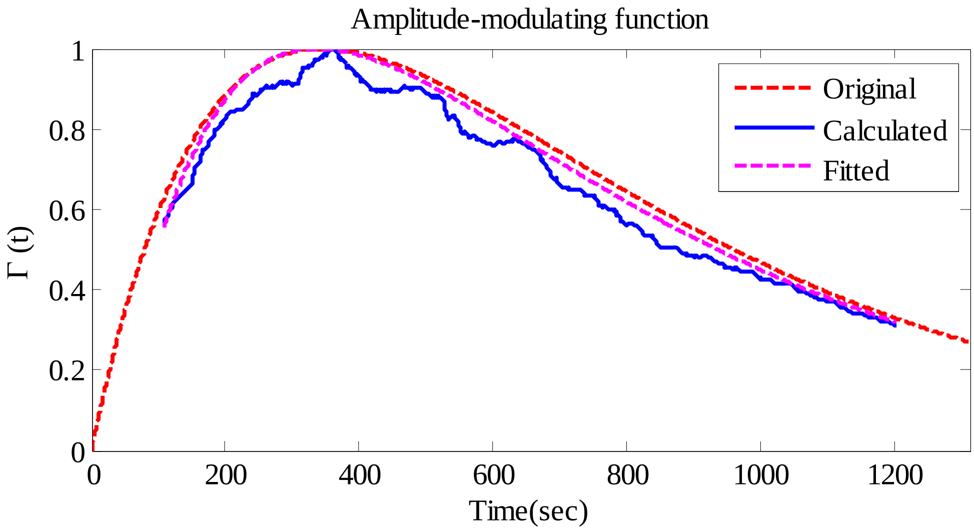

Fig. 4Amplitude-modulating function obtained by moving-average

3. APPLICATIONS FOR JINDO BRIDGES

The amplitude-modulating function of the measured acceleration of Jindo Bridge is calculated and the approximate stationary ambient vibration data is also obtained by dividing the measured acceleration by the calculated amplitude-modulating function,$\Gamma(t)$. All results are shown in Fig. 5.

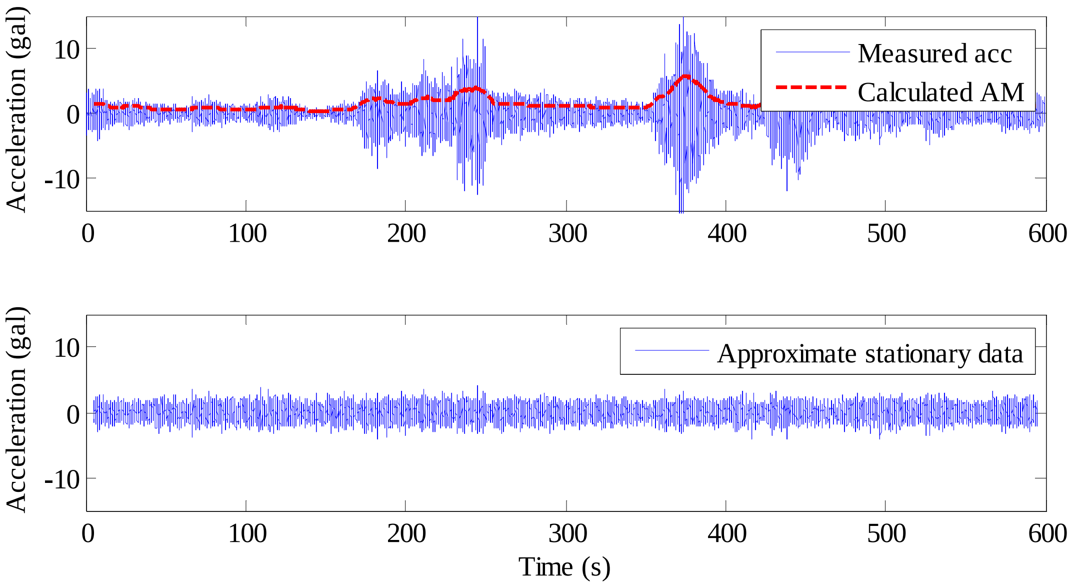

Fig. 5Application for monitored data: (a) Measured acceleration and calculated amplitude-modulating function and (b) approximate stationary data

NExT-ERA is 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. 6. As can be seen, the stationary data shows less scattering than the nonstationary case in terms of standard deviation, but the stabilizing effect for the damping ratio remains little with no dramatic change.

Fig. 7 presents the estimated damping ratio according to the considered mode which one of the important analysis parameters for the NExT-ERA. If the 1st mode is dominant, 1 or 2 considered modesare enough to estimate the exact damping ratio. However, if it is hard to find the first mode in the PSD of the measured acceleration, considered mode has to be increased one by one. Therefore, a small considered mode means that the 1st mode is dominant while a large one means the 1st mode is not fully governing. As can be seen, the considered mode of stationary data decreases compared to the raw data and it can be said that the approximation of stationarity strongly contributes to average out high modesdue to traffic-induced vibration. Fig. 7 also shows that these higher modes could be one of the reasonsofthe scattering.

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

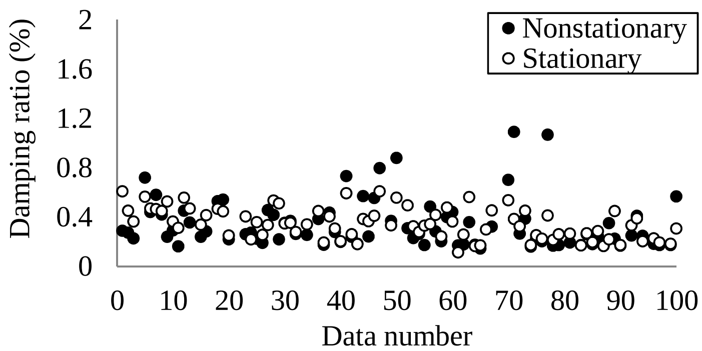

Fig. 6Estimated 1st vertical damping ratio of Jindo Bridges

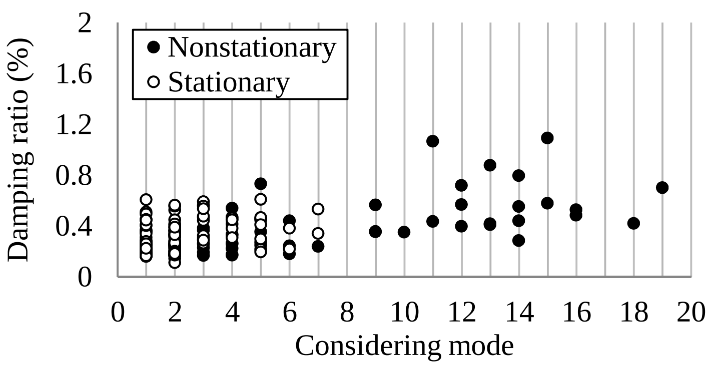

Fig. 7Estimated 1st vertical damping ratio according to considered mode

4. CONCLUSIONS

The approximation method for stationary process from nonstationary ambient vibration data is proposed. Numerical example shows good result to estimate the amplitude-modulating function by moving average. By the application for actual bridge, the approximation of stationary process stabilized to some extent the scattering of estimated damping ratio. The proposed scheme is rather effective to weaken the higher mode by decreasing the traffic induced vibration. By decreasinghigher modal participation, the scattering of damping ratio is slightly removed.

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