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Letter to the Editor

A method for monitoring invisible changes in a structure using its non-stationary vibration

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One of the major problems after an earthquake is the investigation of structural damage which causes certain changes in the dynamic property of a structure [1]. In principle, we can check the change using a Shaker to obtain the frequency response of a structure. However, it is difficult and not practical to shake a big structure before and after an earthquake to detect the change. Regardless of size or weight, all structures such as buildings, towers and bridges are vibrating due to the natural force of winds, ground motions or both of them. Thus, if we can solve the blind problem of estimating the dynamic property of a structure from vibrations which are caused by the force of unknown characteristics, we can develop a non-destructive method for investigating the structural damage of many types of structures.

The short-interval period of the forced vibration of a structure which is excited by winds or ground motions fluctuates around its natural vibration period. So it might be expected that the frequency distribution of short-interval period, the SIP distribution, reflects the dynamic property of a structure. This idea was validated by numerical experiments where short-interval periods were obtained with a non-harmonic Fourier analysis which entrails a three-step procedure to get each short-interval period [2]. First, obtain all sinusoids whose Fourier coefficients $a(T)$ and $b(T)$ are given by

$$a(T) = (1/nD)\left\{\sum_{m=1}^{nD} W_k(m)\sin(2\pi m/D) + \sum_{m=M-nD+1}^{M} W_k(m)\sin(2\pi m/D)\right\}, \tag{1}$$

$$b(T) = (1/nD)\left\{\sum_{m-1}^{nD} W_k(m)\cos(2\pi m/D) + \sum_{m=M-nD+1}^{M} W_k(m)\cos(2\pi m/D)\right\} \tag{2}$$

for $m = 1, 2, \ldots, M$, where $W_k(m)$ are short data samples, the fraction of a waveform $W(t)$ sampled by the frequency F, T is the period and n is an integer such that $n \leqslant M/D$ where $D = FT$. Next, get all residual wave data by removing a sinusoid from $W_k(m)$, such that

$$\varepsilon(m, T) = W_k(m) - a(T)\sin(2\pi m/D) - b(T)\cos(2\pi m/D). \tag{3}$$

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Finally, find a period T_k that minimizes the power of the residual wave data:

$$E(T) = \sum_{m=1}^{M} \varepsilon(m, T)^2. \quad (4)$$

The same procedure is carried out for $k = 1, 2, \ldots, N$ to find each period T_k and we get N short-interval periods which give the SIP distribution of $W(t)$.

Numerical experiments were conducted to get the SIP distribution of the one-degree-of-freedom system with the natural vibration period of $T_0 = 0.3$ s and the damping ratio h from 0.02 to 0.12, which was excited by the force of random vibration. The duration of forced vibration is 32 min, which was sampled by 100 Hz and divided into 2400 frame data to obtain an SIP distribution. Results of the numerical experiments are illustrated in Fig. 1 where four SIP distribution curves and DFT spectrums are shown for each damping ratio to check the stability of the method. The SIP distribution is not affected strongly by the spectrum of forced vibration, which is of great advantage to the health monitoring of structures. The maximum point of an SIP distribution gives the estimation of T_0 and the sharpness of distribution is related to the damping ratio h which is proportional to $(\Delta T/T_0)^2$, where ΔT is the width of an SIP distribution at the middle point.

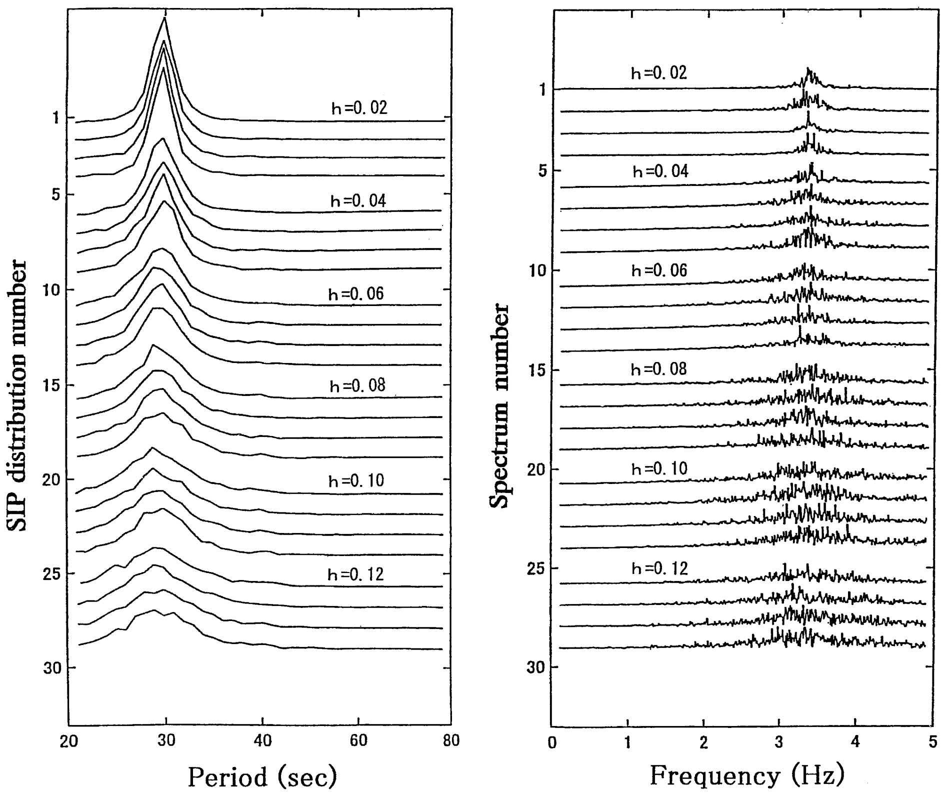

Fig. 1. SIP distribution curves and DFT spectrums of the forced vibration of the one-degree-of-freedom system which was excited by the force of random vibration. The natural vibration period of the system T_0 is 0.3 s and damping ratio h is from 0.02 to 0.12.

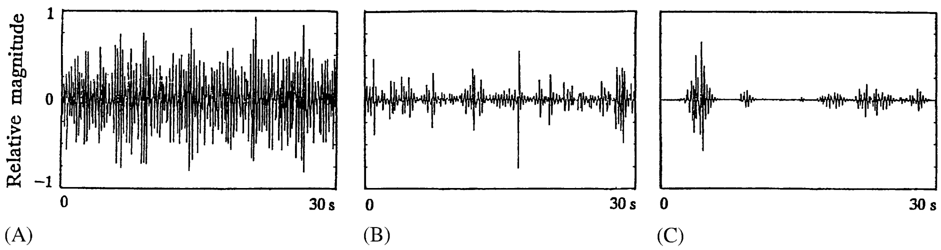

Fig. 2. Examples of non-stationary vibration of the one-degree-of-freedom system A, B and C in the interval of 30 s.

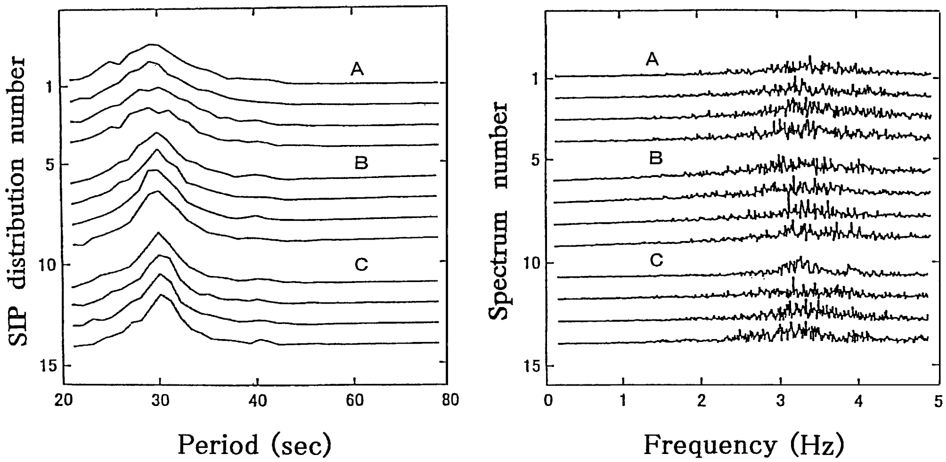

Fig. 3. SIP distribution curves and DFT spectrums of the non-stationary vibrations A, B and C, where $T_0 = 0.3$ s and $h = 0.12$.

Since the free vibration of a system is excited immediately after an impulsive force was applied to the system, the SIP distribution of a system becomes sharp when the non-stationary force of vibration applied to the system involves impulsive forces. Fig. 2 shows examples of forced vibration A, B and C, where A is excited by random force of vibration and B, C are by random force mixed with impulsive one. Relative magnitudes of the free vibration in respective cases are C > B > A. SIP distributions and DFT spectrums of the non-stationary vibrations A, B and C are shown in Fig. 3, where the duration of each vibration is 32 min and the parameters of the system are $T_0 = 0.3$ s and $h = 0.12$ (c.f. Fig. 1).

Structural changes due to degradation or damage after an earthquake, for example, are attributed to the decrease of stiffness which is generally accompanied with the increase of damping ratio. Cumulative curves of SIP distribution, as they are shown in Fig. 1 where T_0 is fixed, may be applied to the detection of such changes in a structure.

The method of investigating damage without destructing a structure is desired in many fields such as the building, ship and airplane industry. If the non-destructive method of investigating structural changes is available under the circumstance of big noise and vibration, we can reduce the cost of inspection and prevent accidents.

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