STUDY ON A METHOD TO IDENTIFY EXTERNAL FORCES AND DAMPING PARAMETERS OF STRUCTURE FROM RANDOM RESPONSE VALUES

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SUMMARY

Proposed in this paper is a method of identifying external forces and damping parameters of structure from random response values. This method estimates external forces acting on structure from response values by means of the inverse procedure of response analysis in the frequency range. An appropriate value of the damping parameter is identified by investigating the spectrum of external force for various damping parameters. This is very effective in cases of involving analyzing aerodynamic vibration tests in wind tunnels and field measurements of real structure vibration. The advantage of this method over other methods is that it can more accurately identify damping parameters even with less data.

INTRODUCTION

In order to accumulate basic data to improve structural design technique, many experiments and field measurements to identify damping parameters and external forces of structure are being carried out. Various methods of identifying damping parameters from field measurements were proposed, and got noteworthy results. Additionally apparent damping effects by external force such as aerodynamic damping were investigated by means of wind tunnel tests. Furthermore, acting forces on structures were also estimated from experiments and field measurements. However, these methods are necessary for measuring a large amount of data and for carrying out a large scale analyses when damping parameters are estimated. Moreover, the accuracy of identified values is limited. In particular, there might not be an appropriate method of identifying external wind force acting on structure. These facts prevent improvement in design technique of structure. Thus, the technique can be improved if the properties of the external forces and the damping parameters can be investigated easily.

Based on the above, the purpose of this paper is to propose a new method of identifying external forces and damping parameters from random response values of structure.

OUTLINE OF THIS METHOD

The basic concept underlying this method is shown in Figure1. This method estimates damping parameters and external forces by means of the inverse procedure of response analysis in the frequency range. The appropriate damping parameter is estimated from the spectra of external forces by trial and error. The basic principle and procedure are as follows:

If it is assumed that the orthogonality condition applies not only to the mass and stiffness but also the damping, it is convenient to invoke reduce down to a-single-degree-of-freedom. Based on the property, the equation of motion for a-single-degree-of-freedom system is expressed as follows:

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$$\ddot{X} + 2\xi\omega_0\dot{X} + \omega_0{}^2 X = f / M \quad (1)$$

where, M, ω_0 and ξ represent mass, natural circular frequency and damping parameter respectively. X, Xand X represent acceleration, velocity and displacement respectively. f represent external force. Generally, the response values derived from Equation. (1) are expressed as the sum of the harmonic vibration and the free vibration. With regard to the response values, the displacement is expressed as follows:

$$X = X_H + X_F \quad (2)$$

where, X_H represents the harmonic vibrations of displacement, and X_F represents the free vibration of displacement. It is assumed that external force f can be expressed by the summation of many sine waves. The amplitudes and phases of the sine waves of natural circular frequency ω_0 are expressed as α_k and ψ_k respectively. External force f(t) at time t can be expressed as follows:

$$f(t) = \sum_{k=1}^{n} \alpha_k e^{i(\omega_k t + \varphi_k)} \quad (3)$$

When the force acts on a vibration system of mass M, natural circular ferquency ω_0 and damping parameter ξ respectively, X_H (t) and X_F (t) of the vibration system can be expressed as follows:

$$X_H(t) = \sum_{k=1}^{n} \beta_k e^{i(\omega_k t + \varphi_k)} \quad (4)$$

$$X_F(t) = A_F e^{-\xi\omega_0 t} \cos(\sqrt{1-\xi^2}\,\omega_0 t - \phi_F) \quad (5)$$

where

$$\alpha_k = -M\omega_0{}^2 \beta_k \gamma_k \quad (6)$$

$$\varphi_k = \phi_k + \Phi_k \quad (7)$$

$$\gamma_k = \sqrt{(1-(\omega_k/\omega_0)^2)^2 + 4\xi^2(\omega_k/\omega_0)^2} \quad (8)$$

$$\Phi_k = \tan^{-1} 2\xi(\omega_k/\omega_0)/(1-(\omega_k/\omega_0)^2) \quad (9)$$

A_F and ψ_F are amplitude and phase of free vibration respectively. These are determined by the initial conditions. Real and imaginary number of Fourier spectra are represented by A_k and B_k respectively. Then, β_k and φ_k are expressed as follows:

$$\beta_k = \sqrt{A_k{}^2 + B_k{}^2} \quad (10)$$

$$\phi_k = \tan^{-1}(B_k / A_k) \quad (11)$$

Based on the principle of vibration system and equations, the procedure for identifying damping parameters and external forces from displacement response values is as follows:

1. Response values are obtained.

2. The free vibration values which are generated from the assumed initial values and the damping parameter are taken from the response values to evaluate the harmonic vibration values.

3. The harmonic vibration values obtained in 2 are Fourier transformed and the Fourier spectrum of harmonic vibration values is estimated.

4. The spectra of external force are derived from the spectra of harmonic vibration by means of the inverse transfer function of a-single-degree-of-freedom vibration system.

5. The aptitude of free vibration values is determined from the identified spectra of external forces.

6. Processes 2 to 5 are repeated until the appropriate free vibration values are determined. The damping parameter of the determined free vibration values becomes the appropriate damping parameter of the structure.

7. The external force on time history is evaluated from the spectra of external force by means of Fourier inverse transformation. Then, if apparent damping effects are included, it is necessary to add the effect to the the value of evaluated external forces.

The concept for determing the suitable value for the damping parameter in 5 is shown in Figure2 imitatively. The ordinary amplitude spectrum of external force doesn't have power in the high frequency range. On the other hand, the amplitude spectrum of external force, in the case when free vibration isn't reduced perfectly, increases as frequency increases. The free vibration value for which the increase in the high frequency range is smallest is considered suitable, and its damping parameter is considered suitable, too.

THE VALIDITY OF THIS METHOD

In order to verify the validity of this method, the damping parameters and external forces are identified from random response values of a-single-degree-of-freedom system by means of computer simulation and a wind tunnel vibration test .

In the computer simulation, the natural circular frequency and the mass of this vibration system are ω_0=66.57rad/sec and M=0.219Kgcm^2 respectively. The damping parameters areξ=0.1,1.0,2.0 and 5.0%. The number of sampling data is 1024 in the case of ξ=0.1,1.0 and 2.0%, and is 512 in the case of ξ=5.0%. The sampling time interval is 1000μsec.

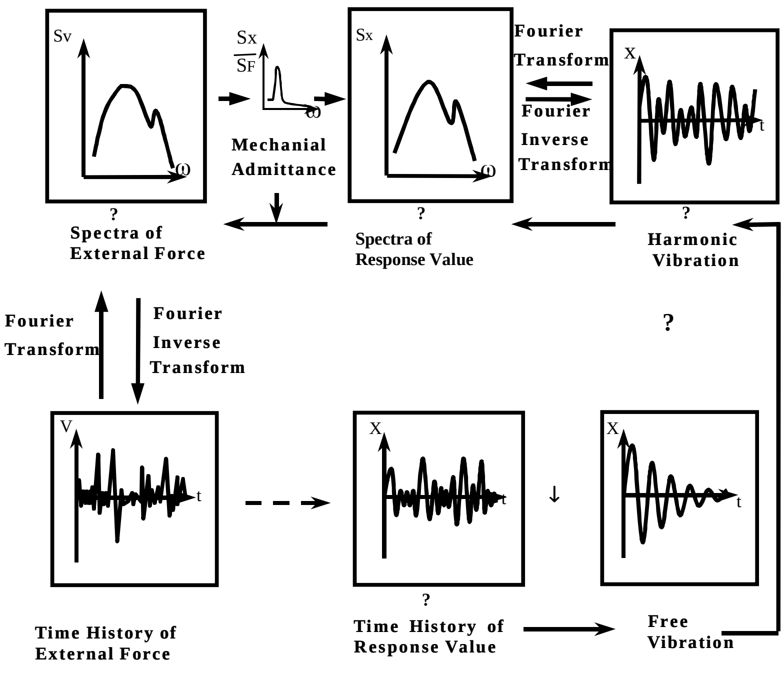

Figure 1: The Concept of This Method

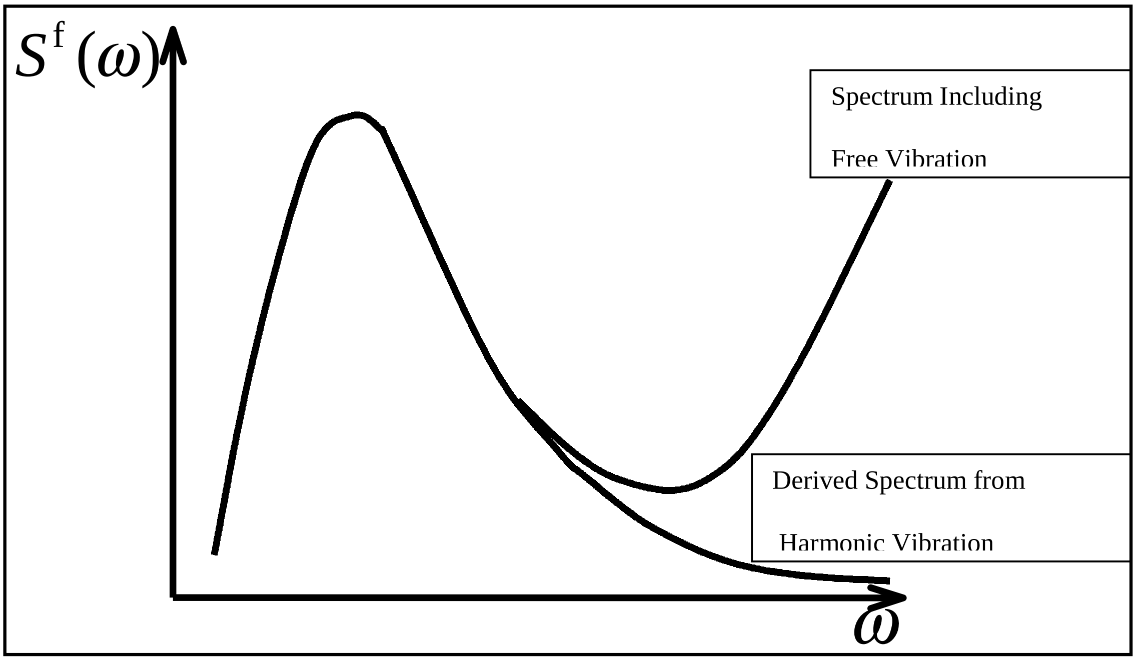

Figure2 : The Differences between the Spectra of External Forces

The estimated spectrum and time histories of the external forces in the case of ξ=1.0 and 2.0% are shown in Figure3 and Figure4 respectively. Every graphs in Figure3 indecats that increase of spectra in the high frequency ranges are suppresed as the assumed ξ approaches to input value. From Figure4, the estimated values of external force on time history correspond to the input values of external force very well in the case of ξ=2.0%. However, the estimated values don't correspond to the input values very well in the case of ξ=1.0%. There are some differences between the estimated value in the case of ξ=1.0% and 2.0%. The difference is especially remarkable at the beginning and end of the time histories.

The damping parameter and external forces are identified from the response values, which is obtained from the wind tunnel vibration test, in across wind direction. The natural circular frequency, mass, number of sampling and sampling time interval are similar to the previous case.ξ of the system is set at approximately 2%. The identified spectra from the response values are shown in Figure5. If the assumed ξ approaches the input value, the increase of the spectrum in high frequency ranges is suppressed as frequency increases in the previous case. So, the identified value of the damping parameter is determined to be 2.0%. The time history of total response value, free vibration, harmonic vibration and external wind force when damping parameter and initial parameter are considered as suitable is shown in Figure6. Especially, the time history of total response value is compared with the response value obtained from the estimeted external force by means of step-by-step integration analysis on time history. The total response value obtained from wind tunnel vibration tests corresponds very well to the response value obtained from the estimated external force.

CONCLUSION

The result obtained though this study can be summarized as follows:

1) A new method of identifying damping parameters and external forces is proposed.

2) The proposed method can identify the values accurately even if there is little data.

3) This method can be widely applied, for example, for analysis of the results of wind tunnel tests and field measurements of structure vibration.

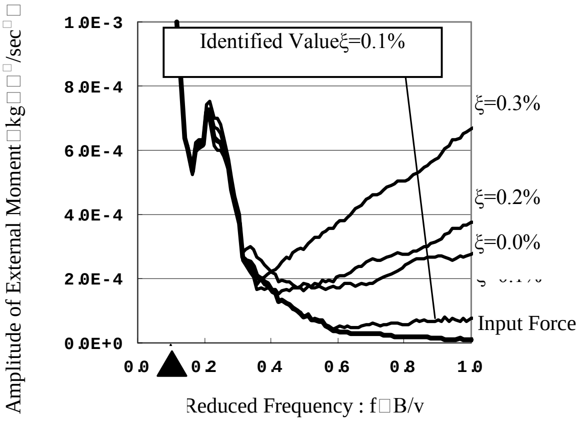

Figure 3-a : Spectrum of External Force (:ξ=0.1%)

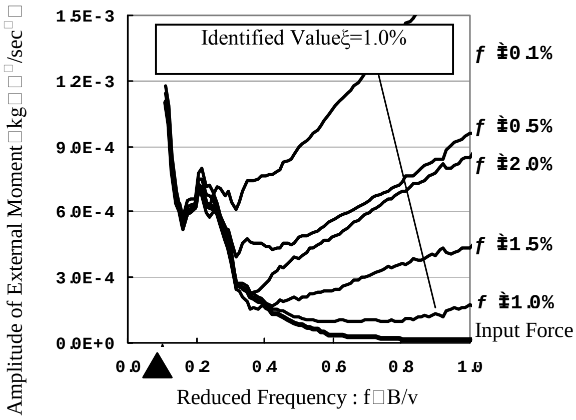

Figure 3-b : Spectrum of External Force (:ξ=1.0%)

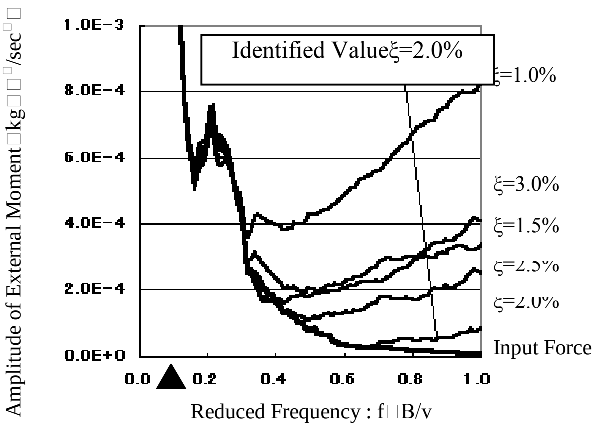

Figure 3-c : Spectrum of External Force (:ξ=2.0%

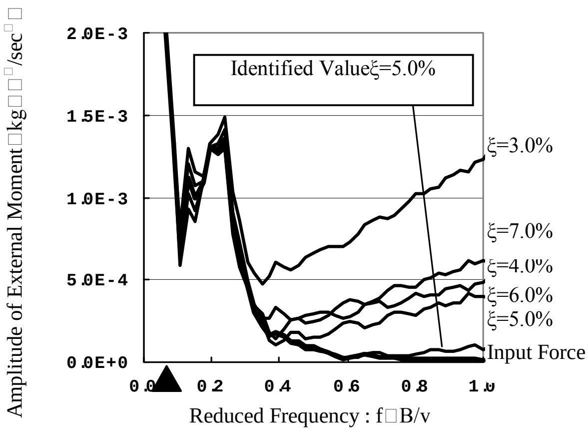

Figure 3-d : Spectrum of External Force (:ξ=5.0%)

▲ ***Reduced Natural Frequency***

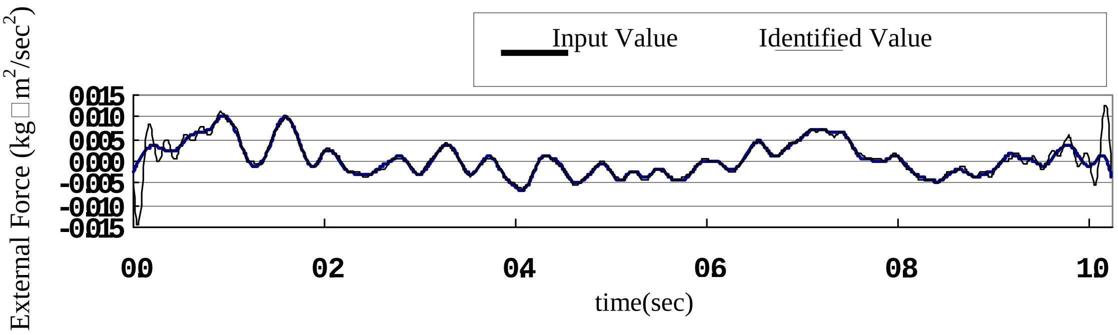

Figure4-a : Comparison Identified Value with Input Value (ξ=1.0%)

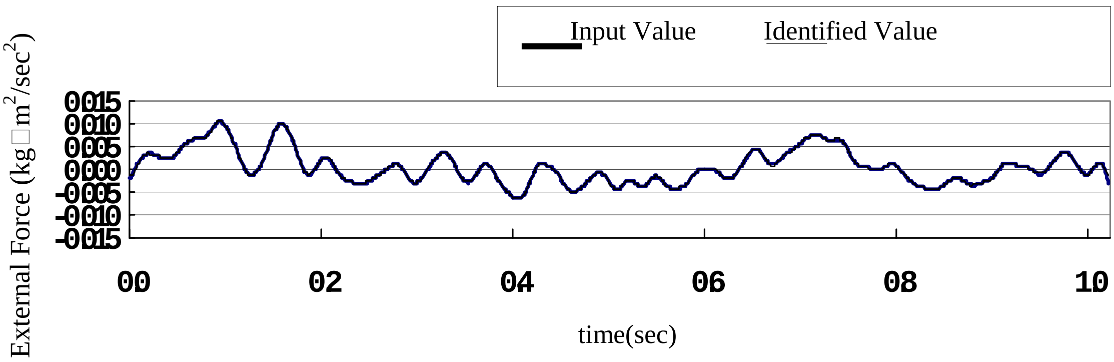

Figure4-b : Comparison Identified Value with Input Value (ξ=2.0%)

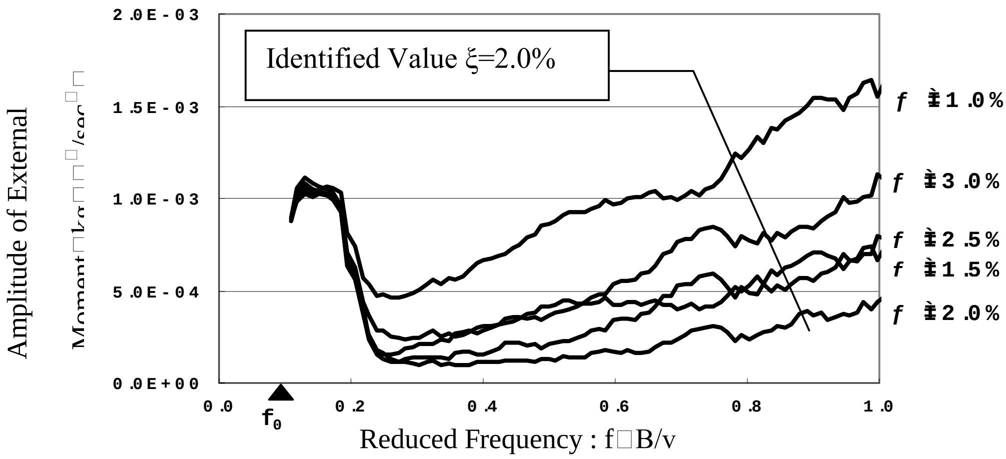

Figure 5 : Spectrum of External Force

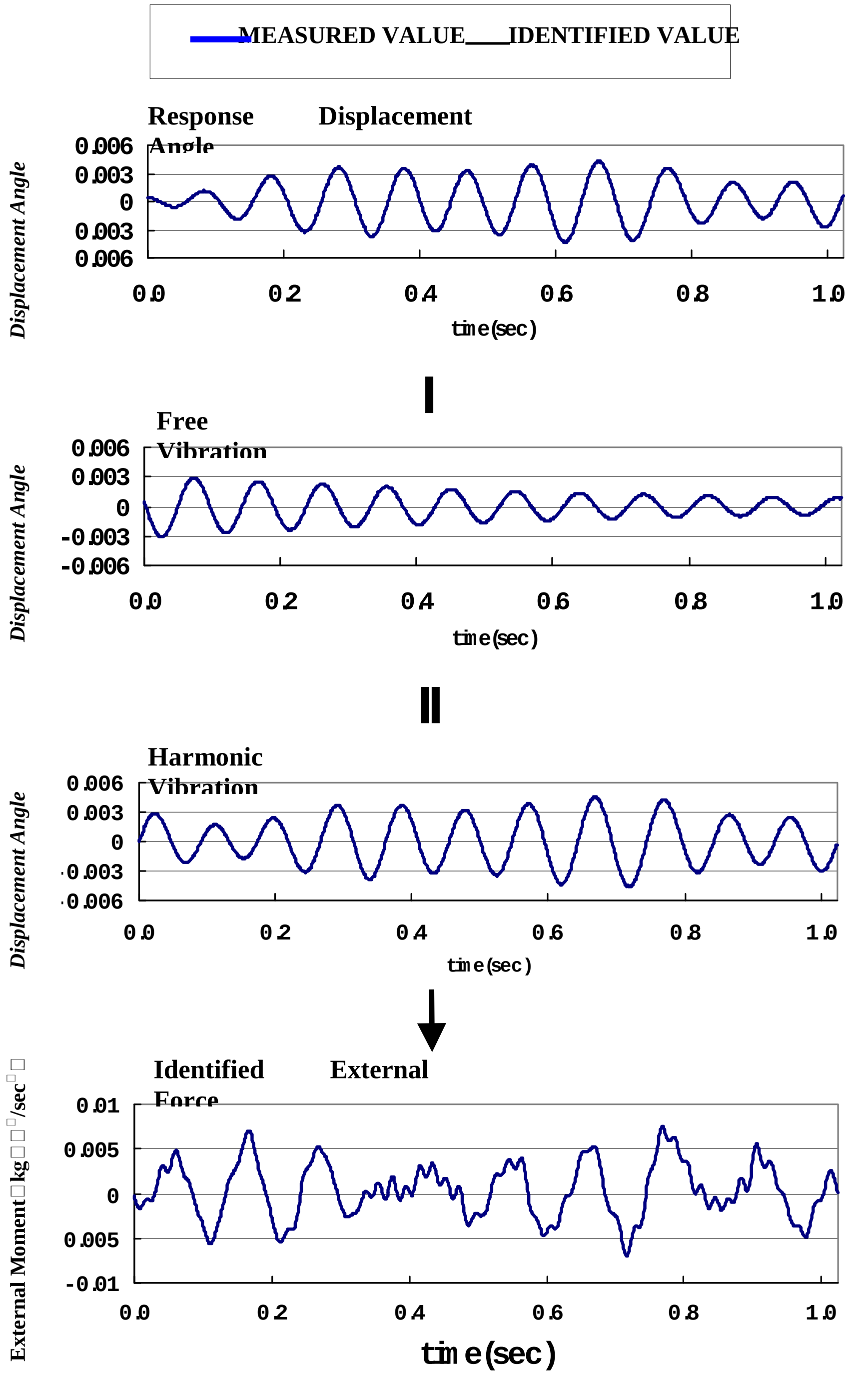

Figure 6 : Identification of External Force from Wind Tunnel Test

REFERENCE

TAMURA, Y. and JEARY, A. (1996), “Meeting on Structual Damping International Wind Engineering Fourum and Additional Paper”, *Journal of W*