(136) Localized Identification of Linear MDOF Systems in Frequency Domain

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INTRODUCTION

The identification of parameters of a structure from recorded structural responses is useful for an analytical model. When the number of degree-of-freedom of the structure becomes greater, the accuracy of indentified parameters and the convergency degrade or deteriorate seriously. In previous studies, modal analysis method, in which the equation of motion of a structure is decomposed into uncoupled single DOF modal equations of motion, were utilized (Mcverry[1] in frequency domain and Beck[2]in time domain) to deal with this problem. Recently, the substructure technique, in which the structure is divided into smaller substructures with a fewer of parameters, was used to estimate the stiffness and damping coefficients of a MDOF structure in time domain (Koh, et al.[3]).   Besides, from an engineering point of view, the parameters of the critical part in a structure is only of interest. The suitable approach is thus expected to be developed.

In this paper, an identification approach to estimate the parameters of a local part in a structure involving many degrees of freedom is formulated through substructuring in frquency domain. The formulation is then solved by Modified Successive Linear Programming (MSLP)[4]. The numerical investigations are performed for simulated data with and without noises. For noise contaminated data, the technique of spectra smoothing is used to reduce the noise effect. The faster convergency and considerably higher accuracy are achieved. Although this approach is for localized identification, it certainly can be applied to complete structure identification if enough response records are available.

FORMULATION

Consider a substructure(Fig.1(b)), which is extracted from the complete structure(Fig.1(a)).The vector-matrix equation of motion can be written as

$$[M] \{\ddot{y}(t)\} + [C]\{\dot{y}(t)\} + [K]\{y(t)\} = \{f(t)\} \quad (1)$$

where $\{y(t)\}$ is relative displacement vector;[M],[C]and [K] are mass,damping and stiffness matrix as follows:

$$\{y(t)\} = \begin{Bmatrix} y_{p+1}(t) \\ \cdots \\ y_r(t) \\ \cdots \\ y_q(t) \end{Bmatrix} \quad (2) \; ; \; [M] = \begin{bmatrix} m_{p+1} & & & 0 \\ & \cdots & & \\ & & m_r & \\ & & & \cdots \\ 0 & & & m_q \end{bmatrix} \quad (3)$$

$$[K] = \begin{bmatrix} k_p+k_{p+1} & -k_{p+1} & & & 0 \\ -k_{p+1} & k_{p+1}+k_{p+2} & -k_{p+2} & & \\ & \cdots & \cdots & & \\ & & -k_{r-1} & k_{r-1}+k_r & -k_r \\ & & & \cdots & \cdots \\ 0 & & & & -k_{q-1} & k_{q-1}+k_q \end{bmatrix} \quad (4)$$
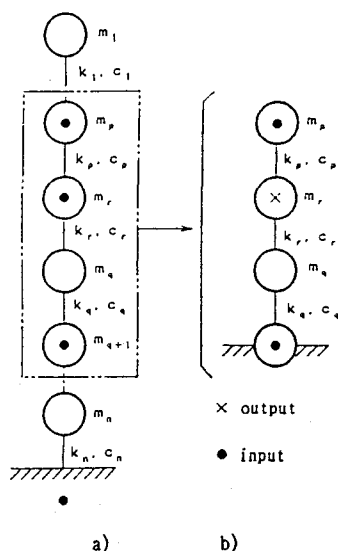
$$[C] = same\ as\ [K] \quad (5)$$

Fig.1 A MDOF lumped mass-
spring-doshpot system

× output
● input

a)   b)

and $\{f(t)\}$ is the excitation force vector:

$$\{f(t)\}=\begin{Bmatrix} -m_{p+1}\ddot{z}_{q+1}(t)+c_p\dot{y}_p(t)+k_py_p(t) \\ -m_{p+2}\ddot{z}_{q+1}(t) \\ \cdots\cdots\cdots \\ -m_r\ddot{z}_{q+1}(t) \\ \cdots\cdots\cdots \\ -m_q\ddot{z}_{q+1}(t) \end{Bmatrix} \qquad (6)$$

in which, $\ddot{z}_{q+1}(t)$ is the absolute acceleration record of the $(q+1)$-th mass that is the lowest mass of the substructure.

Solving Eq. (1) in frequency domain results in:

$$\{\ddot{Y}(\omega)\}=[A(\omega)]^{-1}(\{B(\omega)\}+\{F(\omega)\}) \qquad (7)$$

where $\{\ddot{Y}(\omega)\}$ is the Fourier transform of $\{\ddot{y}(t)\}$, and $\{F(\omega)\}$, $[A(\omega)]$ and $\{B(\omega)\}$ are as follows:

$$\{F(\omega)\}=\begin{Bmatrix} \omega^2m_{p+1}\ddot{z}_{q+1}(\omega)+(i\omega c_p+k_p)\{\ddot{Y}_p(\omega)+v_p\}+i\omega k_pd_p \\ \omega^2m_{p+2}\ddot{z}_{q+1}(\omega) \\ \cdots\cdots\cdots \\ \omega^2m_r\ddot{z}_{q+1}(\omega) \\ \cdots\cdots\cdots \\ \omega^2m_q\ddot{z}_{q+1}(\omega) \end{Bmatrix} \qquad (8)$$

$$[A(\omega)]=-\omega^2[M]+i\omega[C]+[K] \qquad (9) \; ; \qquad \{B(\omega)\}=-(i\omega[C]+[K])\{V\}-i\omega[K]\{D\} \qquad (10)$$

in which, the vector $\{V\}=\{(v_p(0)-v_p(T)),\cdots(v_r(0)-v_r(T))\cdots(v_q(0)-v_q(T))\}^T$ and $\{D\}=\{(d_p(0)-d_p(T)),\cdots(d_r(0)-d_r(T))\cdots(d_q(0)-d_q(T))\}^T$ are the differences of the velocity and displacement between the beginning and the end of the record duration T for each mass. In practical calculation the solving is carried out at discrete frequency, ω_k, using FFT. Difining parameter vector $\alpha=\{k_p,\cdots k_r,\cdots k_q,c_p,\cdots c_r,\cdots c_q,v_p,\cdots v_r,\cdots v_q,d_p,\cdots d_r,\cdots d_q\}^T$, the acceleration response $\ddot{Y}_r(\omega_k)$ at an arbitrary mass is written as $\ddot{Y}_r(\omega_k:\alpha)$ if $\ddot{z}_{q+1}(t)$ and $\ddot{y}_p(t)$ are measured.

CRITERION FOR IDENTIFICATION

The identification is performed by selecting the parameters to obtain a least-squares fit between the analytical acceleration response $\ddot{Y}_r(\omega_k:\alpha)$ and the corresponding recorded acceleration response $\ddot{Y}_{ro}(\omega_k)$ of the r-th mass over a specified frequency band. In practice, the measured responses and groud motion are generally crrupted by noise. One way dealing with this problem is to use a window to smooth the noise crrupted spectra. Here, Parzen window, in which spectra amplitudes within a specified frequency band width are weighted averaged, is used. The criterion for identification is summarized in the following expression:

$$\varepsilon(\alpha) = \sum_{k=1}^{Nf} \{ \left| \overline{\overline{Y}}_r(\omega_k : \alpha) \right| - \left| \overline{\overline{Y}}_{ro}(\omega_k) \right| \}^2 \quad \rightarrow \quad \min \tag{11}$$

where N_f is the number of the specified frequencies and the variables with "—" represent smoothed spectra i.e.,

$$\left| \overline{\overline{Y}}_r(\omega_k : \alpha) \right| = \sum_{L=-m}^{m} W_L \left| \ddot{Y}_r(\omega_{k-L} : \alpha) \right| \tag{12}$$

$$\left| \overline{\overline{Y}}_{ro}(\omega_k) \right| = \sum_{L=-m}^{m} W_L \left| \ddot{Y}_{ro}(\omega_{k-L}) \right| \tag{13}$$

where W_L is the weighting coefficient of Parzen window. Each substructure is identified independently from Eq. (11) using Modified Successive Linear Programming[4].

NUMERICAL INVESTIGATION

As an example, the approach is applied to a ten-mass system with mass m=100kg, stiffness K=1.2x10⁵ N/cm and damping coefficient C= 2x10³ N·s/cm for all masses. The response measurements are generated on the assumption that the system is excited by 1940 El Centro earthquake ground motion. In the identification process, the mass matrix is assumed to be known and stiffness and damping coefficients of the lower three masses, i.e., masses from 8 to 10 are estimated with the initial values being 1.3 times of the true values. The specified frequency band in the criterion is taken from 0.1 to 20.0 Hz and divided into 100 equal intervals.

The results of the localized identification
The identified stiffness and damping coefficients are given in Figure 2. It can be seen that the good agreements are obtained between the identified and the true values.
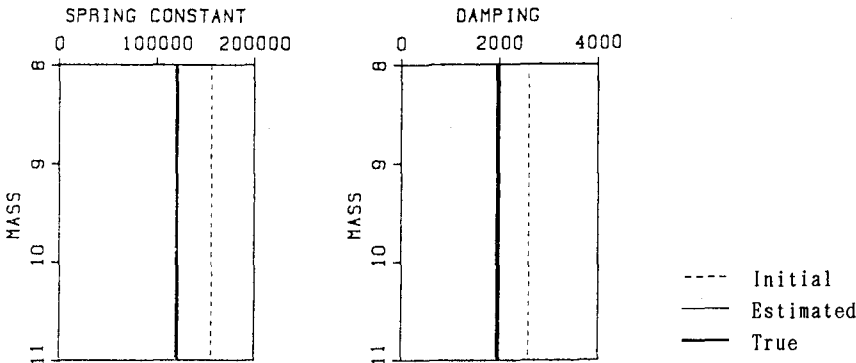
Figure 2. The identified results

The influence of measurement noises
A white noise with frequency bandwidth of 0.1-20.Hz and the amplitude of 5% in root mean square are added to the responses and earthquake ground motion to simulate noise-contaminated measurement records. The identified results are shown in Fig.3. It is clear that the accuracy is deteriorated by the noise, especially for damping. In order to reduce the influence of noise, the Parzen window with 1.0Hz bandwidth is used in spectra smoothing. The results are given in Figure 4. The effects of spectra smoothing on reducing the influence of noise and improving accuracy are significant.
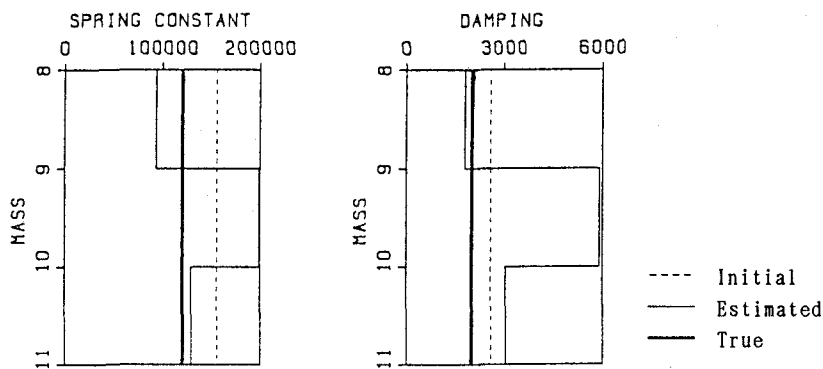
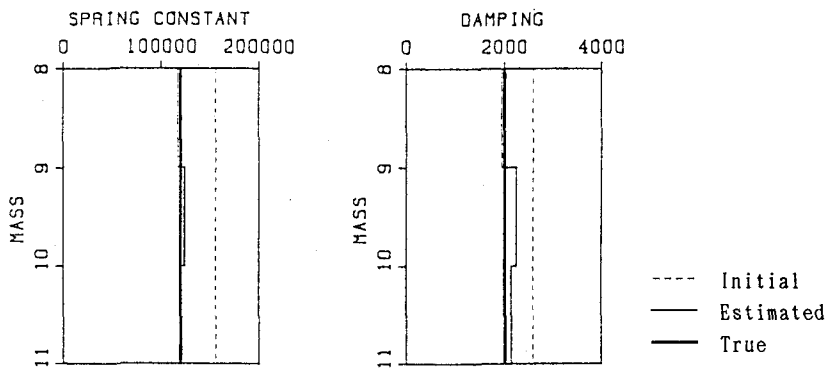Fig. 3 The influence of measurement noises (noise level 5%)

Fig. 4 The effects of spectra smoothing (noise level 5%, band width 1.0Hz)

CONCLUSIONS

A localized identification approach to estimate the parameters of a structure involving many degrees of freedom is formulated through substructuring in frquency domain. The developed approach is applied to a linear multi-degree-of-freedom system for simulated data with and without noises. The considerably higher accuracy is achieved for data without noise. For noise contaminated data, the accuracy is deteriorated, especially for the damping. The technique of spectra smoothing is effective in reducing the influence of noise and improving accuracy.

REFERENCE

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