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Identification of Story Stiffness of Shear Buildings under Ambient Vibration Tests with Highly Noise polluted Data

R. Khodayari[1], O. Bahar[2,*]

[1] Department of Civil Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran
[2] Assistant Professor, Structural Engineering Research Center, International Institute of Earthquake Engineering and Seismology, Tehran, Iran

ABSTRACT: In recent years, Vibration Based System Identification (VBSI) as a powerful tool to disclosure a mathematical expression of dynamic behaviors of structures, is taken into consideration for structure engineers. Among developed strategies for VBSI, the strategies identifying under ambient vibration tests without using input data, with no limitation in serviceability and no need to complex excitation tools, have been more desirable. In some cases, regarding to high numbers of Degrees Of Freedom (DOFs) and impossibility of recording in whole DOFs, it is necessary to identify physical characteristics beside modal parameters with recording in limited numbers of DOFs. Among those physical characteristics, stiffness parameter is more important. The main goal of this paper is to present a method for identification of story stiffness in shear type buildings using incomplete structural responses. At the first, the sub matrix of structural stiffness matrix is identified by the proposed method based on the structural dynamics theory and the realization theory-based Stochastic Subspace Identification (SSI) method and then story stiffness will be available. Since the presence of noise is imaginable in ambient vibration tests, effects of noise also been investigated. To evaluate the proposed method, a five-story & twelve-story analytical shear buildings are studied. Extensive analysis show the high ability and accuracy of proposed method in correct identification of story stiffness from incomplete output records even in presence of noise.

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1. INTRODUCTION

In recent years, Vibration Based System Identification (VBSI) as a powerful tool to disclosure a mathematical expression of dynamic behaviors of structures is taken into consideration for structure engineers. Among developed strategies for VBSI, the strategies identifying under ambient vibration tests without using input data, with no limitation in serviceability and no need to complex excitation tools, have been more desirable [1]. In some cases, regarding to high numbers of Degrees Of Freedom (DOFs) and impossibility of recording in whole DOFs, it is necessary to identify physical characteristics beside modal parameters with recording in limited numbers of DOFs. Among those physical characteristics, knowing the real floor stiffness of a structure has a great important for damage detection.

In some damage detection cases, instead of extracting the whole matrices of the structure, identifying the stiffness parameter may be a great help. On the other hand, regarding to the large dimension of a structure and also due to impossibility of recording all DoFs, only a few DoFs of the structure will be inevitably measured, which is called incomplete measurement. The main goal of this paper is to present a method for identification of story stiffness in shear type buildings.

*Corresponding author's email: omidbahar@iiees.ac.ir

2. METHODOLOGY

The first order dynamic differential equation of motion of a linear time-invariant system in the state space with m input and l output are as follow:

$$\dot{x}(t) = A_c x(t) + B_c u(t) \tag{1}$$

$$\mathbf{y}(t) = Cx(t) + Gu(t) \tag{2}$$

where Ac is the n×n system matrix in the continuous-time state space, Bc is the n×n location matrix of input forces, C is the l×n location vector of sensors for measurement of structural responses, G is the l×n location vector of sensors for measurement of input forces, and n is the order of the system that is equal to the two times of the real Dofs of the considered system [2]. By replacing noise signals in Eq.s 1 and 2 and transform them into a discrete form in time, we will have [3]:

$$x_{k+1} = A_d x_k + w_k \tag{3}$$

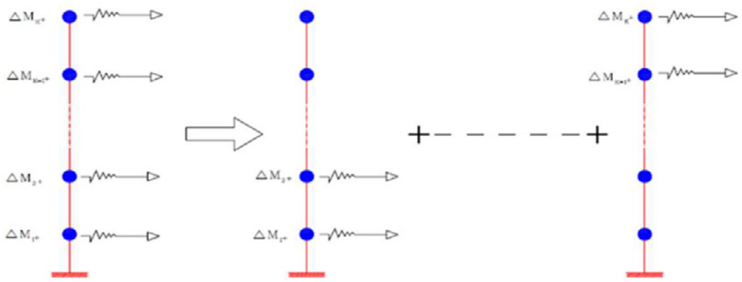

Fig. 1. Applying added mass and step by step identification of shear building

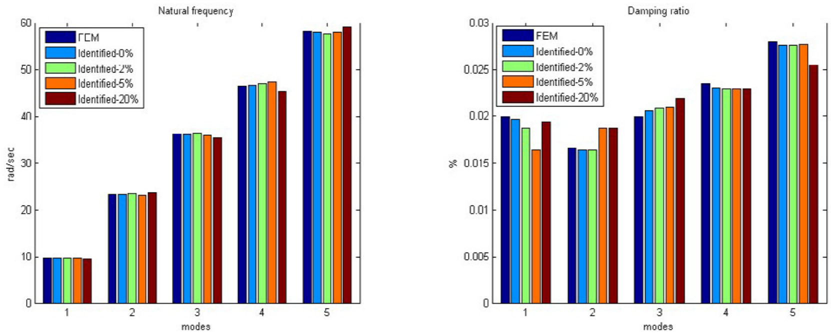

Fig. 2. Comparison of the modal frequencies and damping ratios

$$y_k = Cx_k + v_k \tag{4}$$

where Ad is the system matrix in the discrete-time state space. Modal parameters in continuous-time state space are determined from the following equations [2]:

$$\tilde{\Phi} = C\Psi \tag{5}$$

$$\lambda_j = \frac{\ln(\mu)}{\Delta T} \tag{6}$$

Where, μ and Ψ are Eigen value and Eigen vector of discrete-time system matrix. For under critical damping, $\lambda_j = -\zeta_j\omega_j \pm i\omega_j\sqrt{1-\zeta_j^2}$,assuming λ_j as complex number ($\lambda_j = a_j + ib_j$), mode shapes, Φ, is calculated from norm of vector $\tilde{\Phi}$, natural frequency and damping ratio of j th mode are derived from the following equations:

$$\omega_j = \sqrt{a_j^2 + b_j^2} \tag{7}$$

$$\zeta_j = \frac{-a_j}{\sqrt{a_j^2 + b_j^2}} \tag{8}$$

When we measure a few responses of the considered structure, order of C matrix is not full enough for extracting complete (full order) mode shapes of all DoFs. In other words, all identified mode shapes have only components related to that Dofs, which are measured but modal frequencies on equation (7) are full ordered

Regarding the relationship of mass scaled and normalized mode shapes ($\bar{\Phi}_{0j} = \alpha_{0j}\Phi_{0j}$), the scale factor would be:

$$\alpha_{0j} = \sqrt{\frac{\left(\omega_{0j}^{\ 2} - \omega_{1j}^{\ 2}\right)}{\omega_{1j}^{\ 2}\Phi_j^{\ T}\Delta M\Phi_j}} \tag{9}$$

After identification of correct but incomplete mode shapes, using the scale factor, the mode shapes should be changed to mass-scaled mode shapes in order to extract a substructure of stiffness matrix. As it was indicated, according to the possibility of extraction of all frequencies in incomplete measurement, by applying the mass change in master DOFs (measured DOFs), the scale factor obtained from equation (9) for incomplete measurement is equal to the scale factor obtained from complete measurement. Now, the simple dynamic relations of structure can be used to calculate the condensed stiffness matrix from the mass-scaled mode shapes in the master DOFs as follow:

$$K_R = \bar{\Phi}_m^{\ \dagger T}\Omega^2\bar{\Phi}_m^{\ \dagger} \tag{10}$$

Ω is the natural frequencies of real structure and $\bar{\Phi}_m^{\ \dagger}$ is

Table 1. Comparison of identified story stiffness and story stiffness in FEM model (KN/m)

	18th story	13th story	9th story
FEM model	1.50E+04	2.00E+04	2.50E+04
Identified without noise	1.47E+04	1.98E+04	2.51E+04
Identified with 20% noise	1.47E+04	1.97E+04	2.51E+04

pseudo-reverse or inverse matrix of Moore-Penrose, and bar indicates mass-scaled mode shapes.

$$[K]=\begin{bmatrix} \begin{bmatrix} K_1+K_2 & -K_2 \\ -K_2 & K_2+K_3 \end{bmatrix} & \cdots & \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} \\ \vdots & \ddots & \vdots \\ \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} & \cdots & \begin{bmatrix} K_{k-1}+K_k & -K_k \\ -K_k & K_k \end{bmatrix} \end{bmatrix} \quad (11)$$

As it is obviously shown in Fig 1, with measuring in two master DOFs, stiffness of three stories dependent to those DOFs can be easily identified. This is very practical in structural damage detection and with measurement in k and k-1 DOFs and applying added mass only in that DOFs, stiffness of three stories of k+1, k and k-1 can be identified according to equation (11).

3. EXAMPLES AND RESULTS

In order to evaluate applicability of the proposed analytical models of a five-story & twelve-story shear buildings are examined. For evaluation of noise effect, all output responses are polluted by white noise signals. In order to evaluate accuracy of the identified models, time history analysis of all identified models under the Tabas earthquake excitation are examined. Comparison of the modal frequencies and damping ratios for five-story building is shown in Fig 2.

For twelve-story building, story siffnesses are completely identified and in comparison with story stiffnesses in FEM model is indicated for noise polluted data (10%), table (1).

4. CONCLUSION

In this paper a method based on the realization theory and minimal realization principal as the bases for the SSI method is presented. This method aims to extract structural matrices of shear buildings using an ambient vibration test via a few limited measured structural responses. The advantage of the proposed method is that the story stiffness of the selected floors are simply determined, which is very practical in damage detection of stories of structures.

In order to evaluate applicability of this method, a four-story experimental model and a five-story & twelve-story shear buildings model incomplete measurement are studied. The results of all cases show that by even working with noise contaminated data, this method may accurately identify structural matrices in all cases with high precision.

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