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Procedia Engineering 188 (2017) 163 – 169

Procedia Engineering

www.elsevier.com/locate/procedia

6th Asia Pacific Workshop on Structural Health Monitoring, 6th APWSHM

Automatic estimation of natural frequencies and damping ratios of building structures

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Abstract

Our laboratory has been working on developing a practical structural health monitoring (SHM) system consisting of digital sensor network and a cloud server. The usefulness of such a system has been recognized by real estate companies, construction companies and design firms. We estimate the number of systems exceeded one hundred.

In the SHM system, modal parameters such as natural frequency and damping ratio are important damage indicators to diagnose the condition of structures. However, existing conventional methods require the knowledge of expert to select the proper modal parameters. This is the barrier for promoting the system. Under an emergency event, we will not be able to have immediate help from the experts as they will be very busy to take care of so many buildings.

In this paper, we propose an automatic estimation method to extract fundamental modal frequencies and damping ratios under the assumption we have information on mass distribution and mode shapes. We use these information to filter out the necessary modal information only so that any system identification methods that are applicable to single-degree-of-freedom systems will work well.

To test the method, 40 story steel and RC building structural models were developed. They were simplified to tri-linear skeleton type nonlinear model to show the feasibility of the proposed method to nonlinear level as well. Finally, the method is applied to real tall buildings near Shinjuku Station. The building is 29 story and made of steel. It suffered nonstructural damage during Tohoku Earthquake of March 11, 2011.

Peer-review under responsibility of the organizing committee of the 6th APWSHM

1. Introduction

1.1. About modal estimation

Natural frequency and damping ratio reflect the variation of stiffness and mass. Then we can comprehend properties of structures. However, professionals are essential to estimate these parameters because of the difficulty understanding the complicated theory.

Keywords: Structural Health Monitoring; Inverse of mode matrix; ARX model; Modal estimation; Nonlinear analysis

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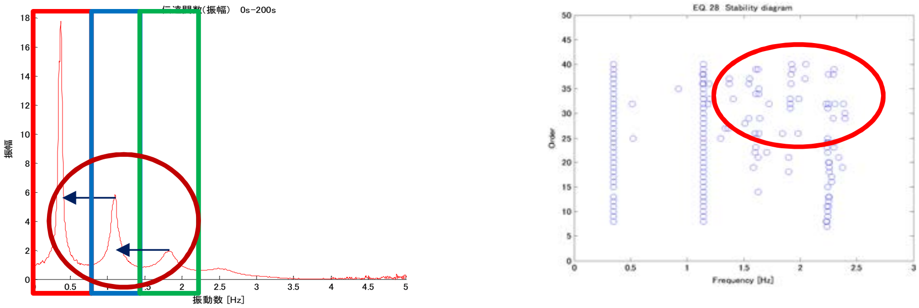
Peer-review under responsibility of the organizing committee of the 6th APWSHM
doi:10.1016/j.proeng.2017.04.470

1.2. Conventional researches and their problems

Conventional researches show that auto estimation is difficult. Many methods apply bandpass filter to divide the response per mode[1]. However, such theories can't follow the reduction of natural frequency as shown in Figure.1.3.1. (a).

Some methods apply stability diagram [2]. In stability diagram, poles of each system identification model order are plotted on the same straight line on model order-frequency graph, then target natural frequencies are derived. However, there are some fake poles in higher order as shown in Figure.1.3.1.(b).



(a)Using bandpass filter (b)Stability diagram

Fig.1.3.1.Conventional estimation method

1.3. Research objective

Due to these backgrounds, we focus on parameter estimation as my research. Our research objective is to estimate natural frequency and damping ratio automatically and accurately even if natural frequency reduction happens. In nonlinear analysis, we shape skeleton curve, and check stiffness shifting and mass shifting as the first step. Next, we check whether our method is applicable in nonlinear domain.

In modal estimation, I aim to propose easier and visible method.

2. Estimation method

2.1. Estimation procedure

First, we perform cleansing to the observed data to remove the unwanted gradient. Second, we acquire relative acceleration. Third, we multiply the inverse of mode matrix to the relative acceleration. The detail is mentioned in 2.2. Fourth, we perform system identification by ARX model and downsize the data (Resampling). In the end, we calculate transfer function and we can estimate modal parameters from the pole of ARX model.

2.2. Multiplying the inverse of mode matrix

When we divide the relative acceleration to each modal response, we multiply the inverse of mode matrix like equation(2.2.1)[3]. In eq(2.2.1), $\ddot{q}_i$ is ith modal acceleration response. $\ddot{x}_i$ is relative acceleration on the ith floor. u_{kl} is lth mode shape on the kth floor. Mode shapes are acquired beforehand by eigenvalue analysis or designed value. We can get the modal response by the third mode using four sensors at minimum.

$$\begin{Bmatrix} \ddot{q}_1 \\ \ddot{q}_2 \\ \ddot{q}_3 \end{Bmatrix} = \begin{bmatrix} u_{n1} & u_{n2} \\ u_{j1} & u_{j2} \\ u_{i1} & u_{i2} \end{bmatrix}^{-1} \begin{Bmatrix} \ddot{x}_n \\ \ddot{x}_j \\ \ddot{x}_i \end{Bmatrix} \tag{2.2.1}$$

3. Estimation results(Simulation)

3.1. Simulation model

We built 40-floor shear simulation model. Physical properties are descripted in Table 3.1.1. We used White Gauss Noise as input and added 10% RMS noise to input and output. Sampling time is 200s. Sampling frequency is 100Hz. Resampling frequency is 5Hz.