System Identification of a Five-Storied Steel-Frame Structure Based on Natural Frequency Deviation with Known Mass Loading

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Summary

In this study, we observe microtremors on each story of a five-storied steel-frame structure, and obtain the natural frequencies up to 5^{th} modes. By loading an added mass of pre-determined amount (2% of the total mass) to each story of the structure one by one, we observe significant changes of natural frequencies as independent information. Using these six cases of natural frequencies we identified physical parameters of each story. As a result we obtained reasonable parameters that can reproduce observed natural frequencies and modes quite well.

Keywords: dynamic response, system identification, natural frequency, MDOF.

1. Introduction

To predict a response of a structure during an earthquake and to monitor any resulting damage of the structure after a large earthquake, we need to identify the physical parameters (mass and stiffness) of the target structure in advance. However, it is not easy to directly estimate the real mass and stiffness as a simplified (equivalent) dynamic model since structures have many non-structural elements. For that purpose Mori and Kawase (2002) [1] proved that mass-loading experiment is quite effective to determine both stiffness and mass at the same time. However, in their study only once they put mass on the roof of the building so that they need to fix the mass and stiffness distribution along the vertical axis.

In this study, first we observe microtremors (i.e., ambient vibrations) on each story of a five-storied steel-frame structure (Fig.1), and obtain its natural frequencies up to fifth modes. Then by loading an added mass of pre-determined amount to each story of the structure one by one, we observe deviations of five natural frequencies as the five sets of independent information. Using these six sets of natural frequency values with and without an added mass we identified physical parameters of each story by using a shear-bending multi-degrees-of-freedom (MDOF) system.

We used 100 steel plates as added weights, each of which weigh 30kg, so the total weight at each floor is 3 tons. This corresponds to about 2% of the whole building weight. The experiment was conducted from October to December 2012 by putting weight first on the roof floor only, then move to the fifth floor, then to the fourth floor, and so on, until on the second floor and remove entirely. In each mass loading experiment we measured microtremors and identified natural frequencies up to fifth modes by using conventional FFT technique. Since we did independent measurements six times, we have 30 target natural frequencies. First we used a simple shear spring-mass model (10 parameters) to reproduce observed natural frequencies but it turned out to be impossible to explain observed values within a reasonable range of parameters. Then we assume a bending-shear spring model (15 parameters, initial model parameters are shown in Table 1.) and use the so-called hybrid heuristic search (HHS) method to determine these parameters. As a result we can obtain reasonable stiffnesses and masses that can reproduce observed natural frequencies and modes quite well.

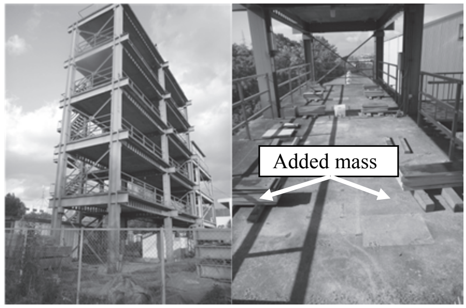

Fig. 1: The target structure with mass

2. System Identification

We used an equivalent mass-shear and bending stiffness model to reproduce observed natural frequencies without considering damping. The system identification was performed by using the so-called “Hybrid Heuristic Search”, where we use Genetic Algorithm with Simulated Annealing (Nagashima et al., 2013 [2]). The advantage of the method is that it searches a wider space of solution in the beginning to avoid local minima and then tries to find a better solution later within a smaller space of search. Our target function to minimize is as follows:

$$\Omega = \sum_{j=1,6} \sum_{i=1,5} w_{(i,j)} \frac{\left(f_{(i,j)} - f^{0}_{(i,j)}\right)^2}{\left(f^{0}_{(i,j)}\right)^2} \qquad (1)$$

where $f_{(i,j)}$ is the i-th mode observed frequency with a mass on the j-th floor, $f^{0}_{(i,j)}$ is the i-th mode calculated frequency with a mass on the j-th floor, and $w_{(i,j)}$ is the weighting function, usually 1.0.

The resultant identified model shows natural frequencies very close to the observed ones, as shown in Fig.2 by gray solid diamonds. We should note that the third mode frequency before (black circle) and after (gray solid square at weight level 1) the mass loading experiment yielded significantly different values. We have no idea why only the third mode had such a large difference of about 0.2 Hz but we use the value after the experiment because its date was closer to the dates of the mass loading experiment. The resultant model parameters are shown in Table 2. It turns out that the floor weights of the structure are larger than the calculated initial values while the inverted stiffnesses are smaller than the initial values except for the shear stiffnesses of the third and the first floors.

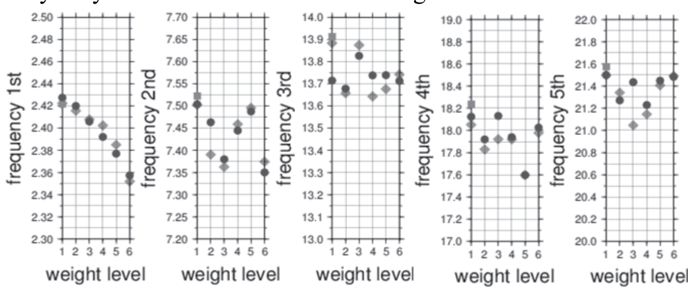

Fig. 2: Comparison between observation (●) and theory (◆) for natural frequencies of five modes with known mass loading on the weight

Table 1: Initial model parameters.

	Bending stiffness [N·m/rad]	Shear stiffness [kN/mm]	Mass [ton]
5	8.58×10⁹	131	23.3
4	8.51×10⁹	127	27.2
3	8.51×10⁹	127	26.8
2	12.8×10⁹	192	28.6
1	12.3×10⁹	171	27.2

Table 2: Identified model parameters.

	Bending stiffness [N·m/rad]	Shear stiffness [kN/mm]	Mass [ton]
5	4.4×10⁹	113	25.4
4	3.8×10⁹	109	26.0
3	4.7×10⁹	142	29.6
2	10.2×10⁹	165	29.7
1	10.8×10⁹	201	30.2