Variation of Natural Frequencies for 3F Wooden Structures in Fresh, Damaged and Reinforced States

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ABSTRACT:

Natural frequency of a structure certainly becomes an important index to identify the toughness of the structure. In other words variation of natural frequency can be utilized to indicate the health state of a structure, especially for a complicated structure. Many researchers believed that following the increase of damage, the stiffness of the structure will decrease, which means the natural frequency will decrease.

This paper is to report our recent research on a 3F wooden structure. Comparisons of the variations of natural frequencies have been clearly shown for the fresh structure, structures with slight and heavy damages, and reinforced structure. Real structure is that in the campus of Kinki University.

Natural frequencies of fresh structure, structures with slight and heavy damages decreased following the increase of damage for real structure, simulation and model structure in general. But in some stages natural frequency remains unchanged or increased even the damage increases. In the same time, comparisons between damaged structures and reinforced structures also have shown that the natural frequency increase in general but in some cases remains unchanged, after reinforcement.

INTRODUCTION

Earthquakes frequently occur recently which needs us, at one hand to build strong or vibration-controllable new buildings, on the other hand to check or to predict the strength or the possible future life cycle for old and under-using buildings. Structural health monitoring system for buildings appears to be a good way to solve such problems, as the system have been expected to predict the degree and the place of the strength-variation (generally strength-reduction).

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Usually, natural frequencies are used to catch the mere occurrence of structural damage, because natural frequencies are a global measure of structural characteristics. Damage detection typically involves analysis of acceleration data to search for changes in the structure's natural frequencies. Damage identification using the information of natural frequency shift (before and after damage occurrence) has been studied extensively [1]. Since damage normally means a loss in the stiffness, and the natural frequency is directly related to the stiffness, it is logical to use the change in natural frequencies as a damage indicator. Damage detection involves analyses of acceleration records to see if there are any changes in the frequency content of the record. Many methods for health monitoring systems have been developed based on the variation of the natural frequencies of the building [2]-[5]. However, damage does not always change the natural frequencies of a structure. The dynamic response of a damaged structure is nonlinear, and in most cases, hysteretic. Data from damaged structures have shown that, due to the hysteretic variations in the stiffness (i.e., the slope of the force-displacement curve), the natural frequencies fluctuate rapidly during damaging vibrations and cannot always be tracked from the records [6]. In some cases, although the structure is damaged, the pre- and post-earthquake natural frequencies may not be that much different because the damage occurs in the form of permanent displacements.

Recently some simulations and vibration experiments have been carried out [7]. Two real buildings have been used for the study. Until now simulation results from ANSYS soft on the real buildings and the shaking table results experiments used the model have been obtained. Some results of the model experiment and ANSYS simulations have shown that the damage of some columns and beams does not always lead to the natural frequency change of building.

Conversely, a change in a frequency does not always represent damage. The analyses of six different sets of earthquake records, as well as ambient vibration records, from a 40-story steel building in Los Angeles have shown that, although there was no damage, the natural frequencies of the building changed as much as 30% due to nonlinearities in the building's response and the soil-structure interaction effects [6]. Similar observations were made in other buildings by Kohler et al. [8] and Todorovska et al. [9]. In another study, Clinton et al. [10] have shown, by analyzing two-year-long continuous records from the Caltech's Millikan Library that the natural frequencies of a building can change significantly due to environmental factors, such as rainfall, wind speed, and temperature. In an analytical investigation of a 10-story building, Safak[6]has shown that in order to see a 10% reduction in the fundamental frequency more than 40% reduction in one of the story stiffness is required. Such a large reduction in stiffness would normally cause clearly visible damage.

The story is, if the strength varies (in general, decreases), then the natural frequency will certainly varies (in general, decreases). In turn in real buildings we can obtain the natural frequency variations (in general reduction) through sensors and based on these data to simulate the strength, thus to check the health of the building. Such story is correct theoretically, if the natural frequency really decreases. For real buildings the problem becomes: will the natural frequency really decrease? This paper is to report our recent research on vibration tests of a real 3F wooden structure in the campus of Kinki University. Comparisons of the variations of natural frequencies have been clearly shown for the fresh structure, structures with slight and heavy damages, and reinforced structure.

EXPERIMENT ARRANGEMENT

In 2001 we have built two buildings in the campus of Kinki University, wooden material, three stories, one traditional construction method and one newly developed method. The purposes of the two buildings are to predict possible recycle material rate after five years use. And thus these two buildings will be destroyed at the end of 2005, to check the recycle rate. In the same time we will take vibration experiments, which will certainly predict the variation of the natural frequency while one or more columns or beams will be cut off. The two real three-story wooden frame buildings are shown in Fig. 1. The right one is used for our tests. The wooden frame building consisted of sills, beams, columns with different rectangular cross section sizes, wood floor plates and wood shear walls. The sills, beams and columns were properly connected to form rigid joints. Overall dimensions of the building were measured as 10.942m×4.55 m×8.715m (Fig.2). We made our tests under the following conditions: manmade pushing was added to roof of the building considering the initial displacement load of the structure. Each building floor was equipped with two accelerometers (one is wire sensor the other is wireless sensor) in the x direction.


Fig.1 Real wooden frame building

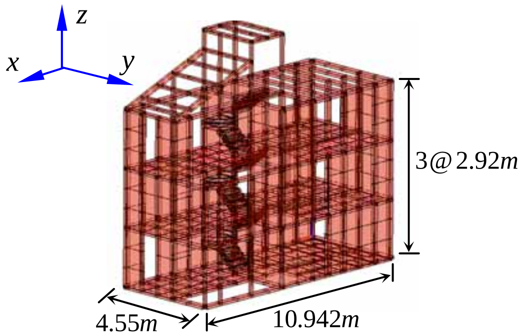

Fig.2 Configuration of the building model

DAMAGE AND REINFORCEMENT SIMULATIONS

To simulate different damage cases of structure, the wall, floor plate, beam and column were removed. The damage severity is simulated by removing each floor plate, wall, beam and column step by step during experiments. To simulate reinforcement, the removed columns will be replaced by braces. These braces were jointed with sill/beam and column. The reinforced structure has two braces in the wall of the first and second stories. Fig.3 shows the damage case of the wall and floor removing. Fig.4 and Fig.5 show the damage case of the 2nd floor's beam removing. To fully utilize removing or adding of the column and brace for generating different damage and reinforcement patterns, the three columns and four braces in the first floor and the second floor were removed or added either simultaneously or successively during the experiments. The configurations of the columns and braces of one side as shown in the Fig.6, the other side is same. Symbols D_f_w (floor and wall are removed), D_b (beam is removed), D_c (column is removed) and R_br (brace is added) are used hereafter to represent the different damage cases and reinforcement respectively. Settings of simulated damages and reinforcements are described as fellow.

Case 1: Wall and floor plates are removed step by step (D_f_w).

Case 2: Beams of the second floor are removed step by step (D_b).

Case 3: columns are removed or braces are added step by step (D_c, R_br). The detailed descriptions of this test are shown in Table 1.


(a) (b)

Fig.3 Wall and floor plates removed cases (D_f_w)

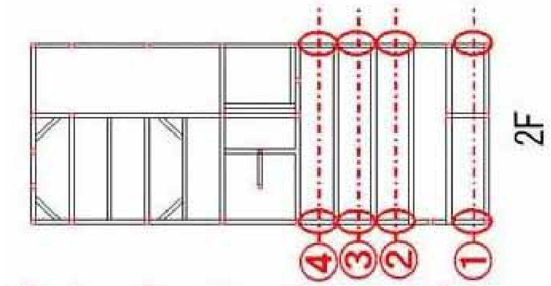

Fig.4 Configuration of the 2nd floor's plan


(a) beam②removed (b) beam①③removed


(c) beam①②③removed (d) beam①②③④removed

Fig.5 The 2nd floor's beams removed cases (D_b)

Table 1 Description of the experiment of case 3

stage	state		date	description
1	no damage		5.31	
2	damage		5.31	column①②removed
3	reinforce		6.21	brace①②③④added
4	damage	2	6.21	brace①②③④removed
5	reinforce	3	9.27	brace①②③④added
6	damage		9.27	brace②removed
7	damage	2,4	10.4	brace①②removed
8	reinforce	3,5	10.4	brace①②③④added
9	damage		10.4	beam①removed
10	damage		10.6	beam①②removed
11	reinforce		10.6	beam①added
12	damage & reinforce		10.18	column③removed, beam①②added, brace①②③④added
13	damage		10.18	brace③④added, brace①②removed
14	damage		10.21	brace①②③④removed
15	reinforce		10.21	brace①②③removed, brace④added
16	reinforce		10.21	brace①②removed, brace③④added
17	reinforce		10.21	brace②removed, brace①③④added
18	reinforce	12	10.21	brace①②③④added

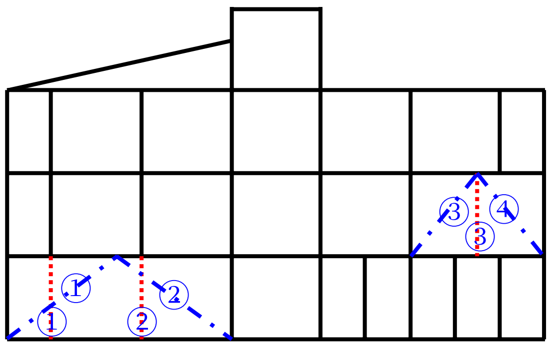

Fig.6 Configuration of side elevation

EXPERIMENTAL RESULTS AND DISCUSSIONS

The change of natural frequencies of the building with different damage cases was also calculated, and the results are given in Fig.7, Fig.8 and Fig. 9. It is seen from Fig. 7 (case 1) that even if the degree of damages increases, the natural frequency remains unchanged or increased. Various environmental factors can alter frequencies without damage, because we took this test in many days. Statically indeterminate condition and mass reduction of this building also can lead to this phenomenon. Hence, data from instrumented structures have clearly shown that changes in natural frequencies are not always a reliable indicator of damage because various environmental factors can change frequencies without damage. The changes in natural frequencies, a commonly used criterion for damage detection, are not always a reliable indicator of damage. Differ from the case 1, Fig.8 (case 2) shows that parts of the building damaged, the stiffness will decrease, which will cause the decrease of the first natural frequency. Fig.9 shows the results of the case 3. Theoretically, the frequencies of stages 2, 4 and 7 should be same; stages 3, 5, and 8 should be same; stages 12 and 18 also should be same. Because there have same physical mechanic conditions each other. Unfortunately, the Fig. 9 clearly shows different results. All these examples indicate that the changes in natural frequencies alone are not sufficient to reach conclusions about damage.

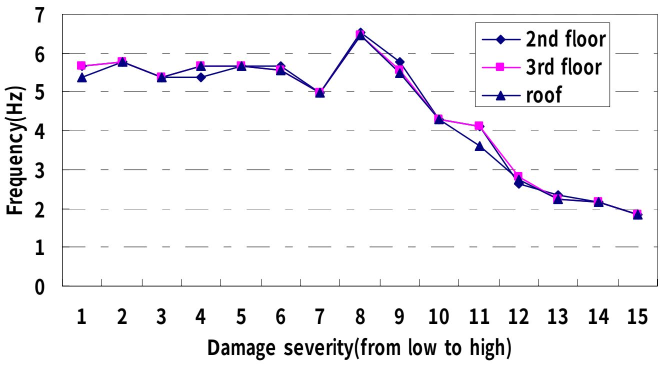

Fig.7 Experiment Results of the wall and floor removed cases

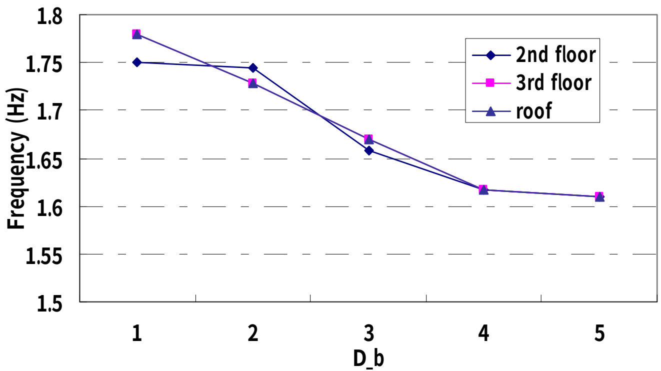

Fig.8 Experiment Results of the beam removed cases (D_b1: no damage; D_b2: beam ② removed; D_b3: beam ①③ removed; D_b4: beam ①②③ removed; D_b5: beam①②③④removed).

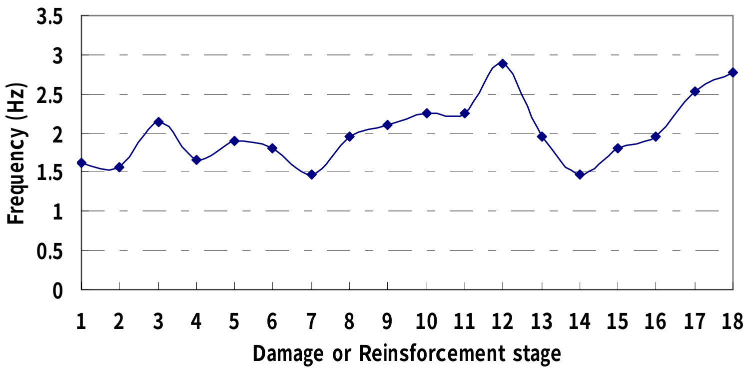

Fig.9 Experiment Results of the column removed or brace added cases (D_b&R_br)

CONCLUSIONS

The damages and reinforcements have been obtained by removing the walls, floor plates, columns and beams and adding the braces step by step. Data from instrumented structures have clearly shown that changes in natural frequencies are not always a reliable indicator of damage because various environmental factors can change frequencies without damage. The changes in natural frequencies, a commonly used criterion for damage detection, are not always a reliable indicator of damage. Various environmental factors can alter frequencies without damage.

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