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EFFECT OF SEISMIC STRENGTHENING OF WOODEN BUILDING AS DETERMINED WITH MICRO-TREMOR MEASUREMENTS

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In Japan, it is important to be able to determine the factors affecting changes in the vibration characteristics of wooden buildings resulting from their seismic strengthening, so as to ensure their seismic resilience. This study set out to determine the effect of seismic strengthening on the vibration characteristics of a wooden building and to clarify the factors affecting the changes in the vibration characteristics based on micro-tremor measurements. The results of the micro-tremor measurements were compared with the results of a seismic diagnosis. The main findings were as follows; 1) The installation of seismic strengthening increases the natural frequency. 2) The amplitude of the structure plane in which the steel columns and structural plywood were installed was reduced. 3) The results of micro-tremor measurements and a seismic diagnosis exhibited the same tendency regarding the effects of seismic strengthening.

Keywords: Natural frequency, Vibration mode, Deformation angle, Seismic diagnosis.

1 INTRODUCTION

Many large earthquakes have occurred in Japan since the Great Hanshin earthquake of 1995 when many wooden buildings were very badly damaged. Powerful earthquakes are very likely to occur in Japan; previous examples of such earthquakes include the Nankai, Tōnankai, and Tōkai earthquakes. Many Japanese live in wooden buildings that are vulnerable to such earthquakes. Therefore, ensuring their seismic resilience has become very important, making it essential to fully understand their vibration characteristics so that we can evaluate the effect of any seismic strengthening. However, few studies have focused on the factors affecting the changes in the vibration characteristics resulting from seismic strengthening.

This study set out to determine the change in the vibration characteristics of a wooden building resulting from seismic strengthening and to clarify the factors affecting the change in the vibration characteristics based on the results of micro-tremor measurements. The micro-tremor measurements were conducted on a wooden temple before and after seismic strengthening. The seismic strengthening was performed using steel columns, a steel frame in the horizontal plane, structural plywood inside the hanging walls, and steel plates at the points at which the wooden braces connect. The results of the micro-tremor measurements were compared with the results of a seismic diagnosis. The effects of the seismic strengthening of the building were examined by comparing with the natural frequency, vibration mode, and deformation angle, as determined by a seismic diagnosis, with the measured results.

2 MICRO-TREMOR MEASUREMENTS

2.1 Overview of Wooden Temple

The subject of this study was a single-story wooden temple in Asakura City, Fukuoka Prefecture. It is shown in Figures 1 and 2. The length and width of the structure were approximately 27.4 m and 21.6 m, respectively. The height was approximately 9.0 m, given the large size of the prayer space. The temple was constructed using a wooden frame with columns and beams, infilled with mud walls. The exterior and interior finishes were plaster. The roof was covered with copper sheathing.

Figure 3 shows the arrangement of the seismic strengthening for the temple. Steel columns were installed at the entrance and in the middle of the prayer space, as shown in Figure 4. Steel braces were installed in the attic space to prevent the deformation of entrance wall due to the eccentricity of the seismic walls, as shown in Figure 5. The hanging walls of the corridors were strengthened using structural plywood to transfer any seismic forces to the steel columns. The connections between the wooden braces were strengthened with metal plates for the same reason.

Figure 1. Exterior of temple.

Figure 2. Interior of temple.

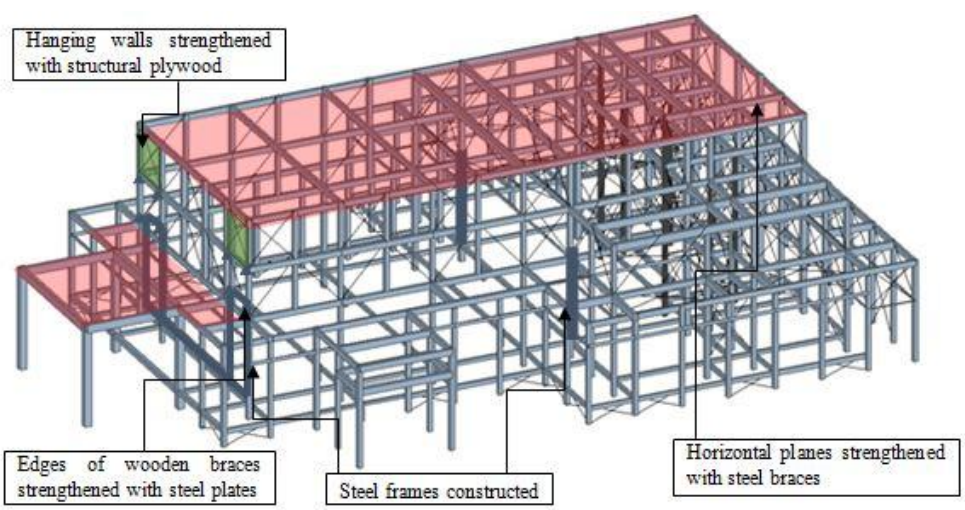

Figure 3. Arrangement of seismic strengthening.

Figure 4. Steel column.

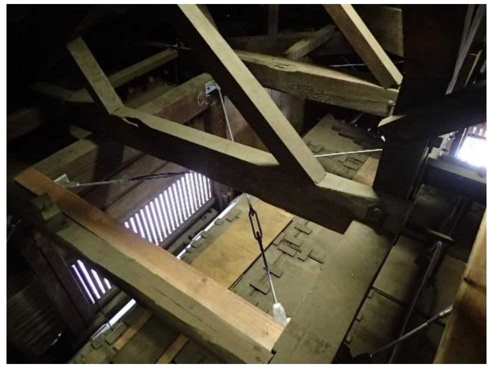

Figure 5. Steel braces in horizontal plane.

2.2 Measurement Method

To estimate the vibration properties of the wooden temple before and after seismic strengthening, we carried out micro-tremor measurements. Figures 6 and 7 show the locations of each sensor. Ch one was established at ground level, while Ch two to six were at the roof level. To examine the effects of seismic strengthening, the locations of each sensor were the same before and after the seismic strengthening. The micro-tremors were measured one times over 250 sec, at a sampling frequency of 200 Hz. The measured values were divided by 40.96 s. Those portions with less noise (such as that caused by traffic) were subjected to ensemble-averaging and smoothing (Hanning Window: 50). The obtained values were Fourier-transformed and, from the ratio of the Fourier spectra to the ground surface at each measurement point inside the temple, the natural frequency and vibration mode of the temple were estimated.

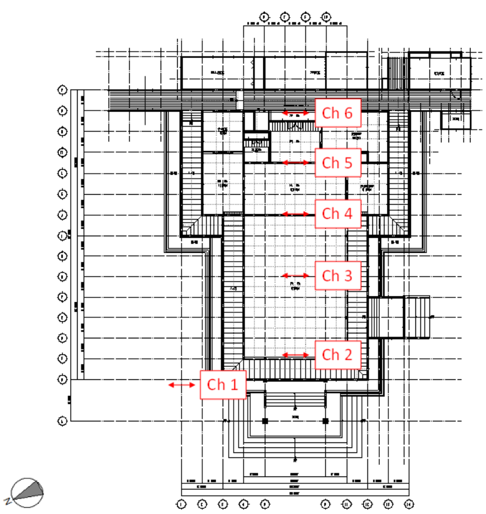

Figure 6. Locations of transverse-direction sensors.

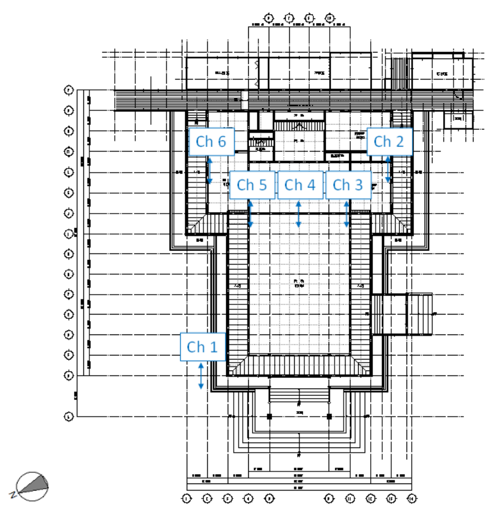

Figure 7. Locations of longitudinal-direction sensors.

2.3 Measured Results

Figures 8 to 11 show the measured results, obtained before and after seismic strengthening in each direction. The first peak frequency in the transverse direction changes from 1.95 Hz to 2.22

Hz. Installing the seismic strengthening increased the natural frequency of the temple by approximately 1.1 times in the transverse direction. In the longitudinal direction, on the other hand, the natural frequency of the temple was almost the same as that before the seismic strengthening.

Figures 12 and 13 show the first vibration mode before and after seismic strengthening in each direction. The amplitude of the structure plane for Ch 2 and 4 is reduced because of the effect of the steel columns and structural plywood. On the other hand, the amplitude of the structural plane for Ch 3 became large so that the effect of the steel braces in the attic space is small. The first vibration mode in the longitudinal direction is almost the same before and after the seismic strengthening.

2.4 Comparison between Micro-Tremor Measurements and Seismic Diagnosis Results

To examine the relationship between the results of micro-tremor measurements and a seismic diagnosis, Figures 14 and 15 show the deformation angle ratio during a large earthquake, as determined by the seismic diagnosis. Before seismic strengthening, the amplitude of the structure plane for Ch two in the micro-tremor measurements was largest, as was the deformation angle at the entrance (west side) in the seismic diagnosis.

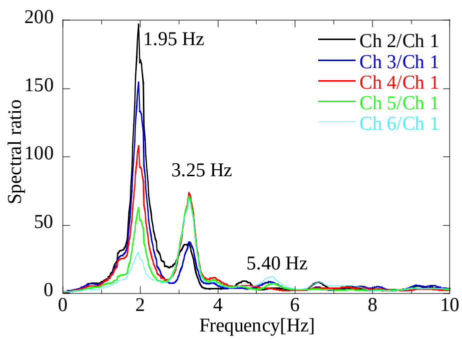

Figure 8. Fourier spectra ratio in transverse direction (before seismic strengthening).

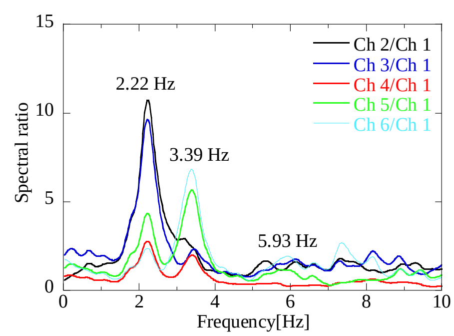

Figure 9. Fourier spectra ratio in transverse direction (after seismic strengthening).

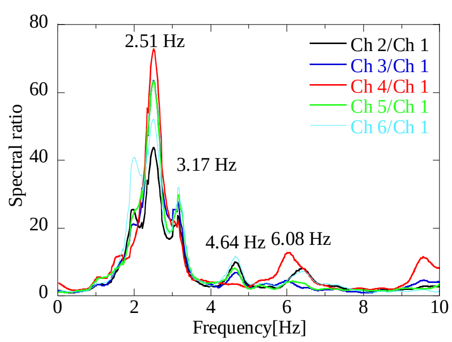

Figure 10. Fourier spectra ratio in longitudinal direction (before seismic strengthening).

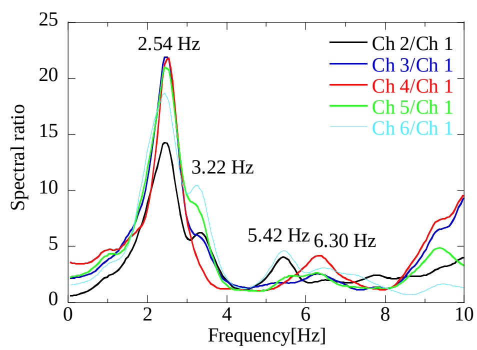

Figure 11. Fourier spectra ratio in longitudinal direction (after seismic strengthening).

After seismic strengthening, the amplitude of the structure plane where the steel columns and structural plywood were installed was found to be smaller than that before seismic strengthening. The results of the seismic diagnosis indicate that the deformation angle of same structure plane becomes small. The longitudinal direction exhibits the same tendency as the transverse direction. We noted the same trend regarding the effects of seismic strengthening in both the micro-tremor measurements and the results of the seismic diagnosis.

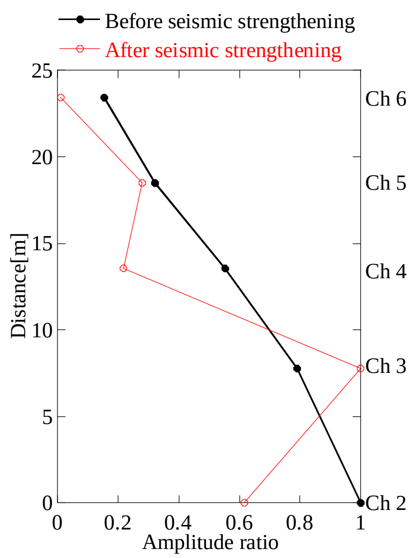

Figure 12. Effect of seismic strengthening on results of micro-tremor measurements (transverse direction).

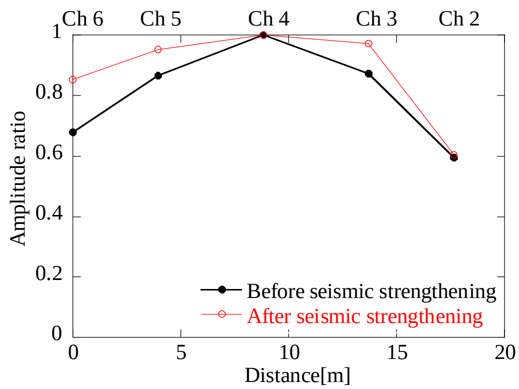

Figure 13. Effect of reinforcement on results of micro-tremor measurements (longitudinal direction).

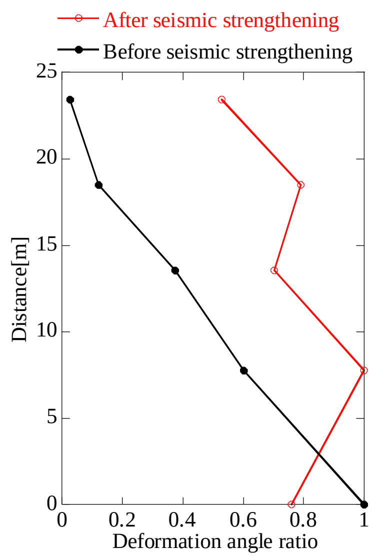

Figure 14. Effect of seismic strengthening on seismic diagnosis (transverse direction).

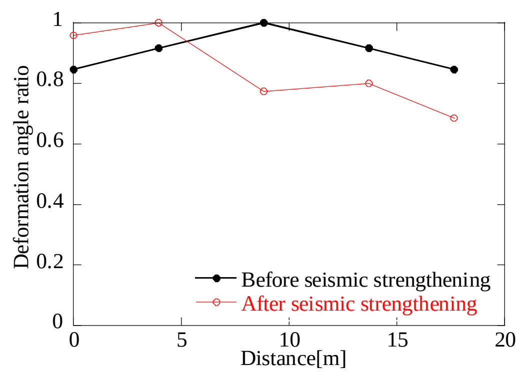

Figure 15. Effect of seismic strengthening on seismic diagnosis (longitudinal direction).

3 CONCLUSIONS

In this study, micro-tremor measurements were conducted for a wooden temple before and after seismic strengthening. The results of the micro-tremor measurements were compared with the results of a seismic diagnosis. Based on the measured results, we examined the effect of the seismic strengthening by comparing the natural frequency, vibration mode, and deformation angle in the seismic diagnosis. The main findings were as follows:

1) The installation of seismic strengthening increased the natural frequency of the temple by approximately 1.1 times in the transverse direction. In the longitudinal direction, on the other hand, the natural frequency was found to be almost same before and after the seismic strengthening.

2) The amplitude of structure plane in which the steel columns and structural plywood were installed was reduced. On the other hand, the effect of the steel braces in the attic space proved to be small.

3) We found that, regarding the effects of the seismic strengthening, the same tendency could be observed in the results of both the micro-tremor measurements and seismic diagnosis.

Acknowledgments

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