Microtremor Measurement of Medium Scale Wooden Architecture

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Abstract

In recent years in Japan, the relaxation of regulations, enlightened policies around revitalizing forestry, and a growing consideration for the environment has resulted in low-rise and non-residential buildings such as public facilities and medical facilities, where reinforced concrete structures and steel structures have been mainstream, being increasingly built with wooden structures. Wooden low-rise and non-residential buildings (hereinafter called "medium scale wooden architecture") have many benefits, such as environment friendliness, low-cost, and short construction cycles. On the other hand, in Japan where earthquakes occur frequently, ensuring the seismic performance of buildings is a most important issue. Although there are various matters that need to be considered in examining seismic performance, not much work has been done in evaluating the vibration characteristics (natural frequency, vibration mode, etc.) of medium scale wooden architecture by performing vibration tests on such structures. Therefore, we are working on a series of studies focused on the vibration characteristics that directly affect the response of such structures.

In this study, in order to understand the vibration characteristics of medium scale wooden architecture, we carried out microtremor measurement on a full-size medium scale wooden architecture and examined its vibration characteristics.
Keywords: microtremor, vibration characteristics, medium scale wooden architecture

1. Introduction

In Japan, where earthquakes are a common occurrence, understanding the seismic behavior of buildings is extremely important. In recent years, with the development of seismic design and structural health monitoring technology, analysis of the vibration characteristics has been performed on various types of buildings.
Structural health monitoring is a monitoring system that evaluates the degree of damage to a building, to ensure its safety and continuous use in the event of a large-scale earthquake disaster. A seismometer is installed in the building to analyze its response waveform during an earthquake, and to estimate its soundness by estimating the fluctuation of vibration characteristics and maximum story deformation angle. Understanding the measured vibration characteristics is extremely useful, and the need for such information is increasing important following the reality of the Tohoku-Pacific Ocean earthquake [1] and the Kumamoto earthquake (with seismic intensity 7) occurring unremittingly in a short period of time. Consequently, research is being actively conducted.

On the other hand, in Japan, after the war, a large number of trees were planted, and subsequently logging became a necessity. For this reason, with the aim of growing the demand for timber as a whole and revitalizing domestic forestry, a law on promoting the use of timber in public buildings was enacted. In light of the above, the number of new buildings currently being constructed using the two-by-four method (mainly medical and welfare facilities) is on the rise (Figure. 1 [2]). However, there are not many empirical studies on the vibration characteristics of these buildings. In this report, in order to understand the basic vibration characteristics of medium scale wooden architecture built using the two-by-four method, we perform microtremor measurement on an actual building (Building A) and study its vibration characteristics at the microtremor amplitude level (natural frequency, dynamic interaction, etc.).

2. Target building A

Table 1 shows the outline of Building A constructed using the two-by-four method targeted in this study. Fig. 2 shows Building A's floor plan. This building is considered to be significantly affected by torsion because both its plane and the elevation are relatively irregular. In addition, since the two-by-four method is a wall type, the rigidity is large with respect to the ground, and it is possible that the vibration characteristics cannot be appropriately evaluated using a general foundation fixed model.

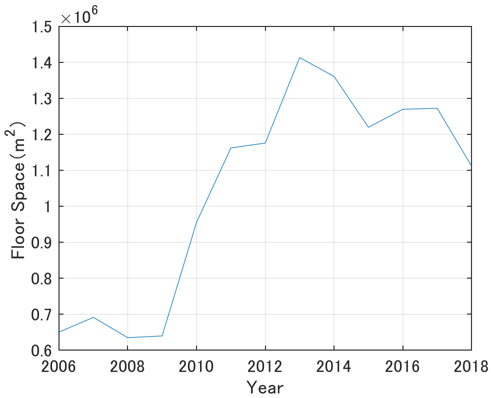
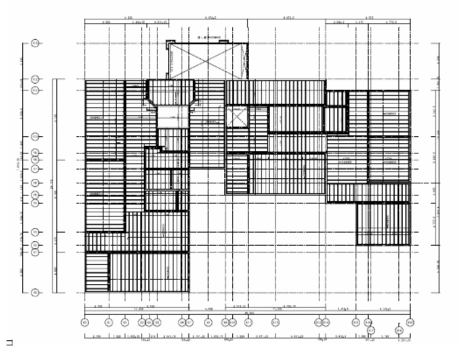


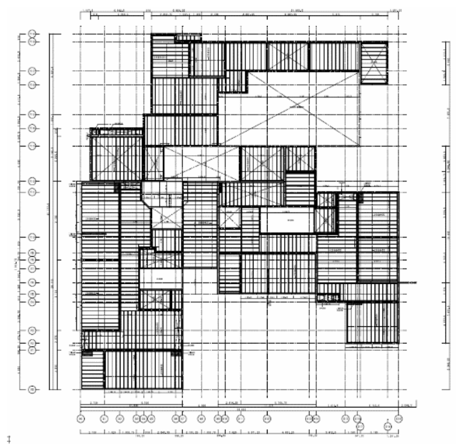
Figure. 1 – Yearly trends in the floor area for welfare facilities using the two-by-four method

Table 1 – Building A outline

location	Sagamihara, Kanagawa Prefecture
Completion	2013
Use	welfare facility
Construction method	Two-by-four method
Basic form	Direct foundation
Total floor area	1,694 m^2



(a) 2F



(b) 1F

Figure. 2 – Floor plan

3. Analytical method

3.1 Microtremor measurement

In order to evaluate the vibration characteristics at the minute amplitude level, a microtremor measurement was conducted on the target building, Building A, on July 7, 2019. Multi-point simultaneous measurements were performed with a sampling frequency of 100 Hz and a measurement time of 500 seconds. Since the target Building A is a building that is used on a daily basis, the measurement is performed in a state where a person is active in the building. However, the analysis is performed using data at moments with as little movement as possible.

Figure 3 shows the sensor layout. The location and measurement direction are as follows: the surface ground and the center of rigidity on the first floor are two horizontal directions and the vertical direction: the diagonal on each floor level; the center of rigidity on the second floor and the attic surface is two horizontal directions; and the center of each side on the first floor is the vertical direction. The equipment used was a portable vibration meter system SPC-52 and a servo type speed meter VSE-15D manufactured by Tokyo Sokushin Co., Ltd.

3.2 Vibration model

The vibration model assumes the following (a) and (b) [3].
(a) SR Model: Sway Rocking Model
(b) R Model: Rocking Model

Table 2 shows the input/output components corresponding to each vibration model, and Fig. 4 shows an outline of the Sway Rocking Model [4]. Fourier spectrum ratio of the Top to the GL corresponds to the SR model, the Fourier spectrum ratio of the Top to the 1F is compatible with the R model. The rocking rotation angle θ is calculated by taking the difference between the vertical displacements of the sensors at both ends on the same plane and dividing the difference by the distance between the sensors.

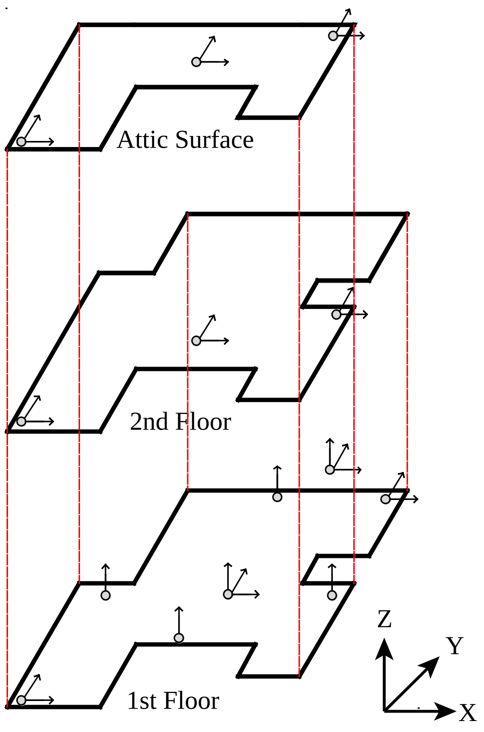


Figure. 3 – Sensor layout

Table 2 – Input/output for each vibration model

Model	Input	Output
SR	GL	Top
R	1F	Top

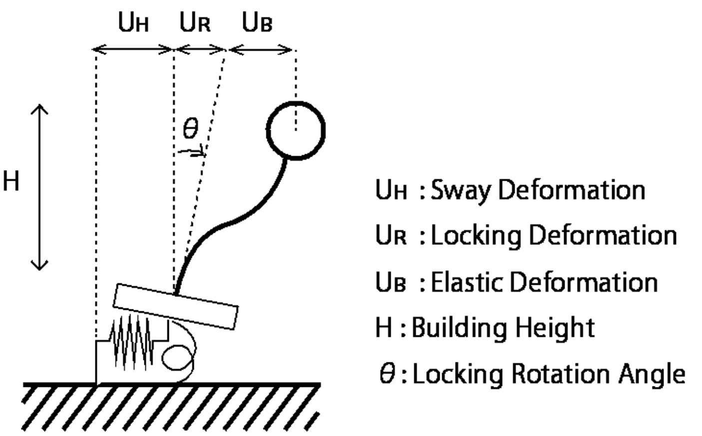


Figure. 4 – Sway Locking Model outline

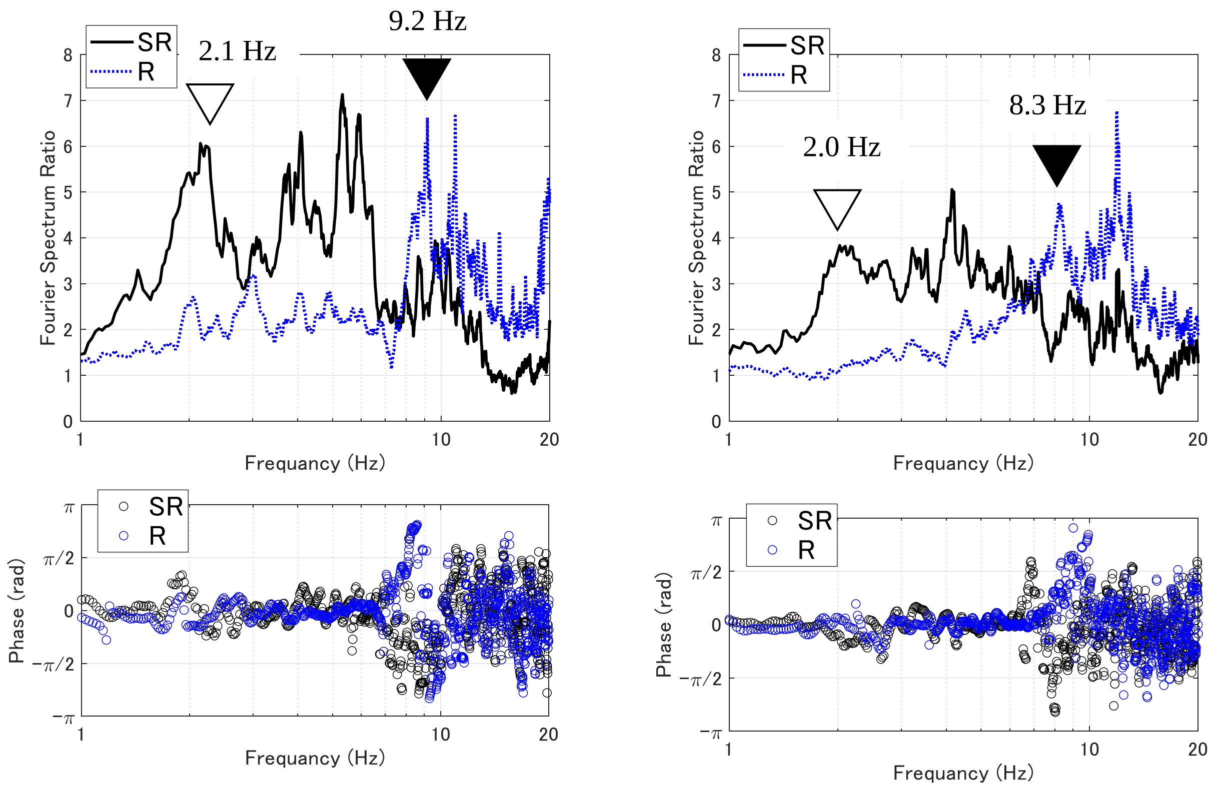
4. Result of analysis

In terms of the data processing, first, a Fourier transform was performed on the time history waveform obtained, and a Fourier spectrum at each point was obtained. Next, smoothing was performed using a Parzen-window method having a bandwidth of 0.2 Hz, and ensemble averaging. Subsequently, a value obtained by dividing the Fourier spectrum at the measurement point in the building by the Fourier spectrum at the measurement point on the ground or the first floor was used as a Fourier spectrum ratio, and the peak value was estimated as each natural frequency. In addition, vibration characteristics such as dynamic interaction were also analyzed.

4.1 Natural frequency

Fig. 5 shows the Fourier spectrum ratio and the phase difference of the SR Model (Top/GL) and the R Model (Top/1F). The natural frequency was estimated from the peak value of the Fourier spectrum ratio and the phase information. For output component, the one obtained by the sensor at the rigidity position on Attic surface is used.

The primary natural frequency of the SR Model was 2.1 Hz in the X-direction and 2.0 Hz in the Y-direction, judging from the peak frequency. On the other hand, the peak of the R Model clearly appears. The primary natural frequency was 9.2 Hz in the X-direction, 8.3 Hz in the Y-direction, and the secondary natural frequency was 11 Hz in the X-direction and 11.5 Hz in the Y-direction. Since the peaks of the Fourier spectrum ratio are considerably different between the SR Model and the R Model, it can be confirmed that the influence of the sway is large. Therefore, it is appropriate to evaluate the vibration characteristics of Building A using the SR Model.



(a) X-direction (b) Y-direction

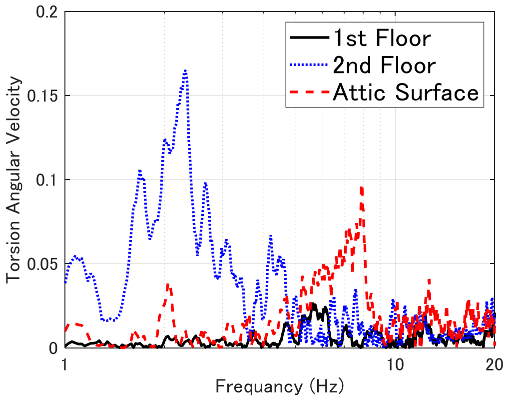
Figure. 5 – Fourier spectrum ratio and Phase (Top / GL or 1F)

4.2 Distortion

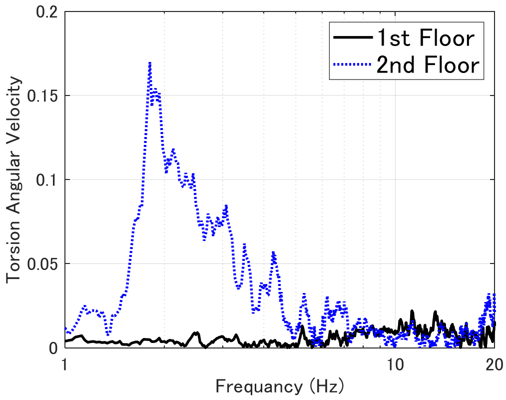
The difference between the Fourier spectra of the measurement points arranged diagonally on the same plane was obtained, and the difference was divided by the distance between the sensors to calculate the torsional angular velocity. Fig. 6 shows the torsional angular velocity spectrum of SR Model. Note that the measurement point on the second floor ceiling level in the Y-direction, for which measurements failed, is not handled. Also Fig. 7 shows a primary vibration mode diagram in the X-direction of SR Model. A peak is seen near the primary natural frequency of the SR Model, and twist can be confirmed from the primary vibration mode diagram. And in the X-direction, the peak frequency differs between the second-floor floor level and the second-floor ceiling level.

4.3 Dynamic interaction

Fig. 8 shows the Fourier spectrum ratio of the first horizontal and vertical component to the ground. The ratio does not become 1 in both directions, and amplification is observed on the low frequency side (up to 7 Hz), and input loss is seen on the high frequency side (above 7 Hz). The peak of the amplification corresponds to the peak of the SR Model. From this, it can be considered that the dynamic interaction effect between the ground and the building is large.



(a) X-direction



(b) Y-direction

Figure. 6 – Torsion angular velocity spectrum (SR Model)

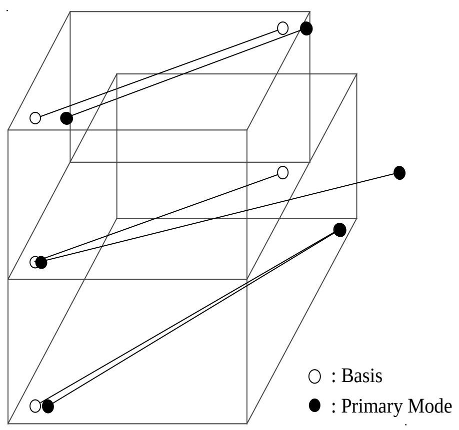


Figure. 7 – X-direction primary mode

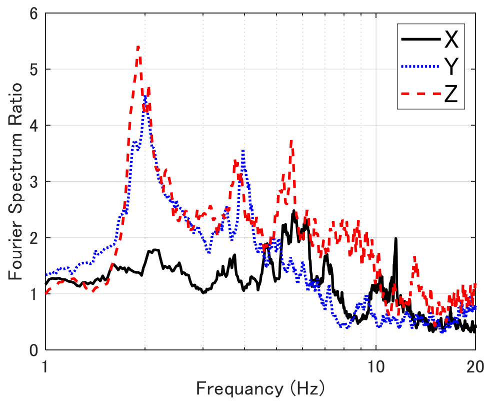


Figure. 8 – Fourier spectrum ratio (1F / GL)

4.4 Sway Rocking

Table 3 shows the sway rate and rocking rate calculated by dividing the sway displacement (first floor horizontal component) and the rocking displacement (Hθ) by the Top displacement at the primary natural frequency. It can be seen that the influence of the sway in both directions is considerable. Also, it can be seen that the influence of rocking is smaller than that of sway.

Table 3 – Sway Rocking rate at Primary Natural Frequency

(a) X-direction

Model	Primary natural frequency (Hz)	Sway rate	Rocking rate
SR	2.1	0.41	0.29
R	9.2		0.12

(b) Y-direction

Model	Primary natural frequency (Hz)	Sway rate	Rocking rate
SR	2.0	0.6	0.33
R	8.3		0.07

5. Conclusion

In this report, microtremor measurement was performed to understand the basic vibration characteristics at the microtremor amplitude level of the medium-sized wooden Building A, constructed using the two-by-four construction method, and the analysis results were shown. The obtained findings are as follows.

a) The primary natural frequency of the SR Model is around 2 Hz and around 8.6 Hz in the R Model in both directions.
b) Since the predominant frequencies of the SR Model and the R Model are significantly different, it is considered that the influence of the dynamic interaction (mainly sway) is large.
c) Sway vibration is dominant in the vibration characteristics of the SR Model.
d) The torsion can be confirmed in the primary vibration mode of the SR Model.

In the future, a three-dimensional analysis model will be created from the design documents, and eigenvalue analysis and seismic response analysis will be performed. We will also analyze the vibration characteristics of other medium scale wooden architecture and collect data.

Acknowledgements

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