RESEARCH ARTICLE OPEN ACCESS

Vibration Characteristics of a Building Structure from a Natural Frequency Point of View

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ABSTRACT
To investigate vibration characteristics of the building, the natural frequency of the building was estimated using microtoremor and strong motion. In case estimated using microtoremor data, the natural frequency was 2.40Hz in the minor axis of the building. However, in case estimated using strong motion data, the average of them was 2.28Hz that is lower than that of microtremor. From a time series analysis on strong motion data, the natural frequency indicates high value before the part of principal motion, it drops to a lower on the part of principal motion. And it goes back with the decreasing acceleration amplitude of motion. It means that the natural frequency of the structure depends on the peak acceleration amplitude. Therefore, it is difficult to evaluate a health index only using the change of the natural frequency estimated by strong motion data. It means that it needs to use another parameter together.

Keywords – Building structure, Microtoremor, Natural frequency, Strong motion

I. INTRODUCTION

After a natural disaster, such as a big earthquake or a typhoon, occurred, some structures may be serious or slight damaged. In case with a visible damage, it is easy to maintain the health of them, if the damaged area is repaired. In case with a no visual damage, it is difficult to know the damaged area. Buildings with no visual damages may bring about second disaster. It is important to know a soundness of building structures that was affected by a natural disaster.

One of investigation methods is the structural health monitoring system. In case for structural buildings, change of a natural frequency [1][2], vibration mode [3], stiffness [4], transfer function of vibration data [5][6] is used for analysis. According to the study by Kashima [7], the natural frequency of a new building without damages indicates a secular change until a few years. Therefore, it needs for the soundness estimation to understand vibration characteristics of target buildings.

We start a strong motion observation inside the target building from 2011. In this study, vibration characteristics of the building from the natural frequency point of view were investigated using microtoremor and strong motion.

II. TARGET STRUCTURE

The building used in this study is a west building of Tokyo Metropolitan College of Industrial Technology, Shinagawa campus, located at Shinagawa, Tokyo. The structure is seven-story steel-reinforced concrete building constructed on January 1991. The floor plain is shown in Fig. 1. Each building plain shape of west, east and center buildings is rectangle.

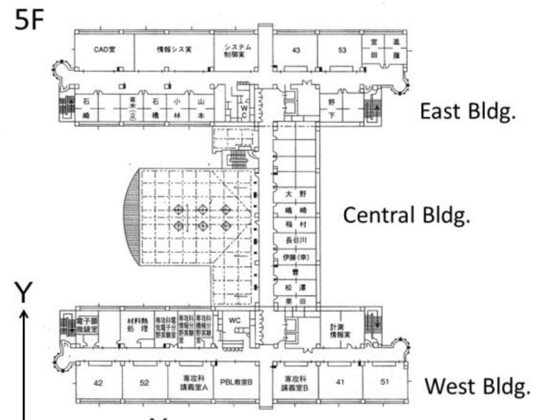

Fig. 1 Floor plain of the target building (5F)

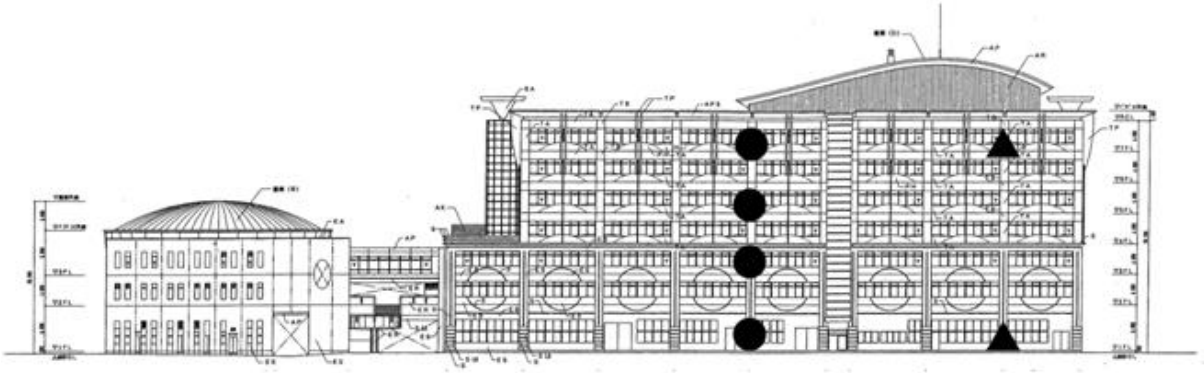

Fig. 2 Location of seismograms on the target building
●: Microtremor observation ▲: Strong motion observation

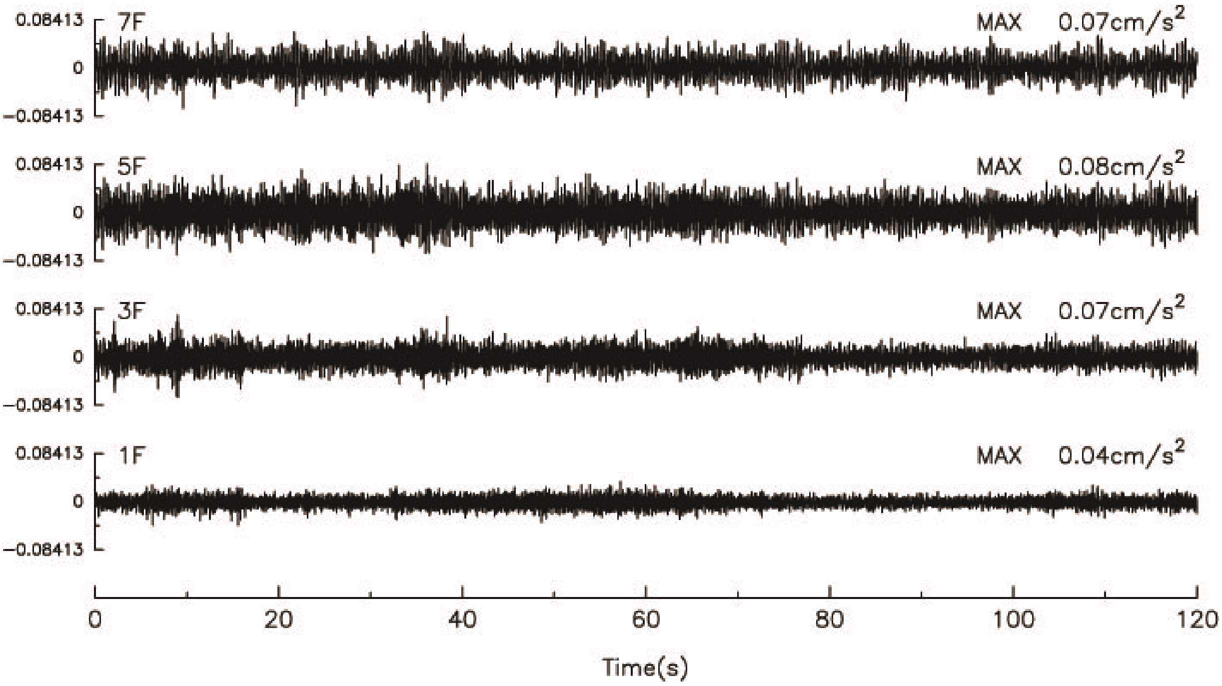

Fig. 3 An example of microtremor waveforms on the each floor

III. Vibration Characteristics Estimated by Microtremor

To estimate the natural frequency of the target building, microtremor observation was done on August 2011. The location of seismometers is shown in Fig. 2. To understand a change of vibration characteristics depending on increase of floors number, the sensors were put on 1F, 3F, 5F and 7F. A portable seismic recorder system (Akashi GPL 6A3P) was used for this observation. A signal from the sensor was amplified by a factor of 200 and recorded as a digital data with a sampling interval 0.01s. The data set was composed with a time window of 60 sec without traffic noise, a Fourier spectrum was calculated. And spectral ratios of 3F, 5F, 7F to 1F were calculated. For the analysis, an average of 5 data sets was used.

An example of observed waveforms is shown in Fig. 3. As some noise generated by traffic vibration was included in waveforms, most part of them is building vibration generated by microtremor. The spectral ratios are shown in Fig. 4. In the minor axis of the building (Y direction), a clear spectral peak at the frequency of 2.4Hz can be identified, and is getting big increasing of floors number. It means the peak of fundamental natural frequency. On the other hand, in the major axis of the building (X direction), two peaks at the frequency of 2.3Hz and of 2.8Hz that are the natural frequency can be identified. It indicates that the vibration mode in the X direction is complex.

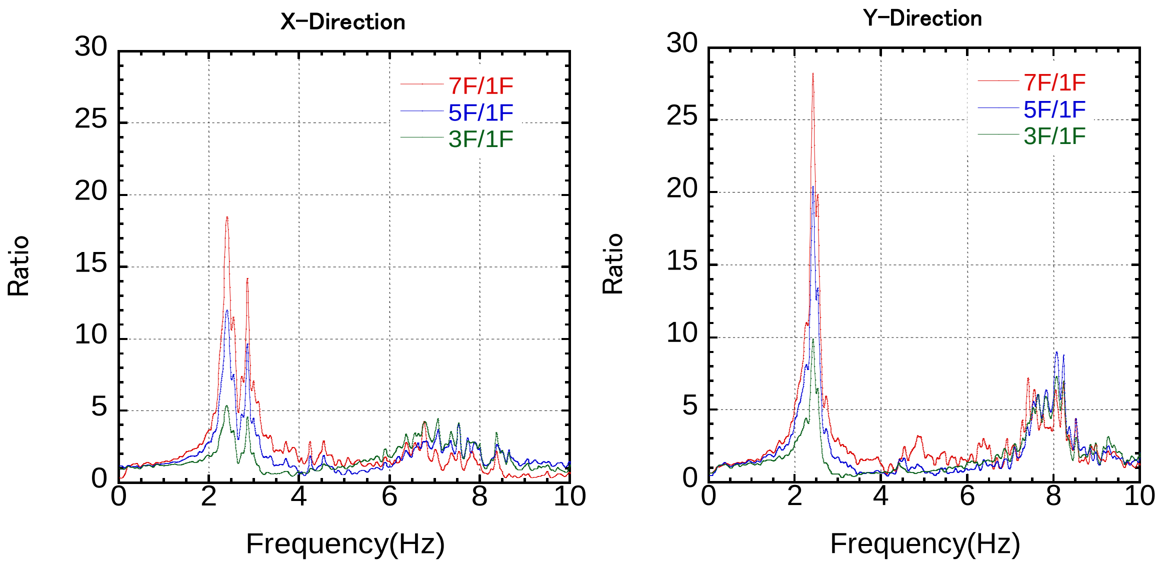

Fig. 4 Spectral ratios of microtoremor (left: X-direction right: Y-direction)

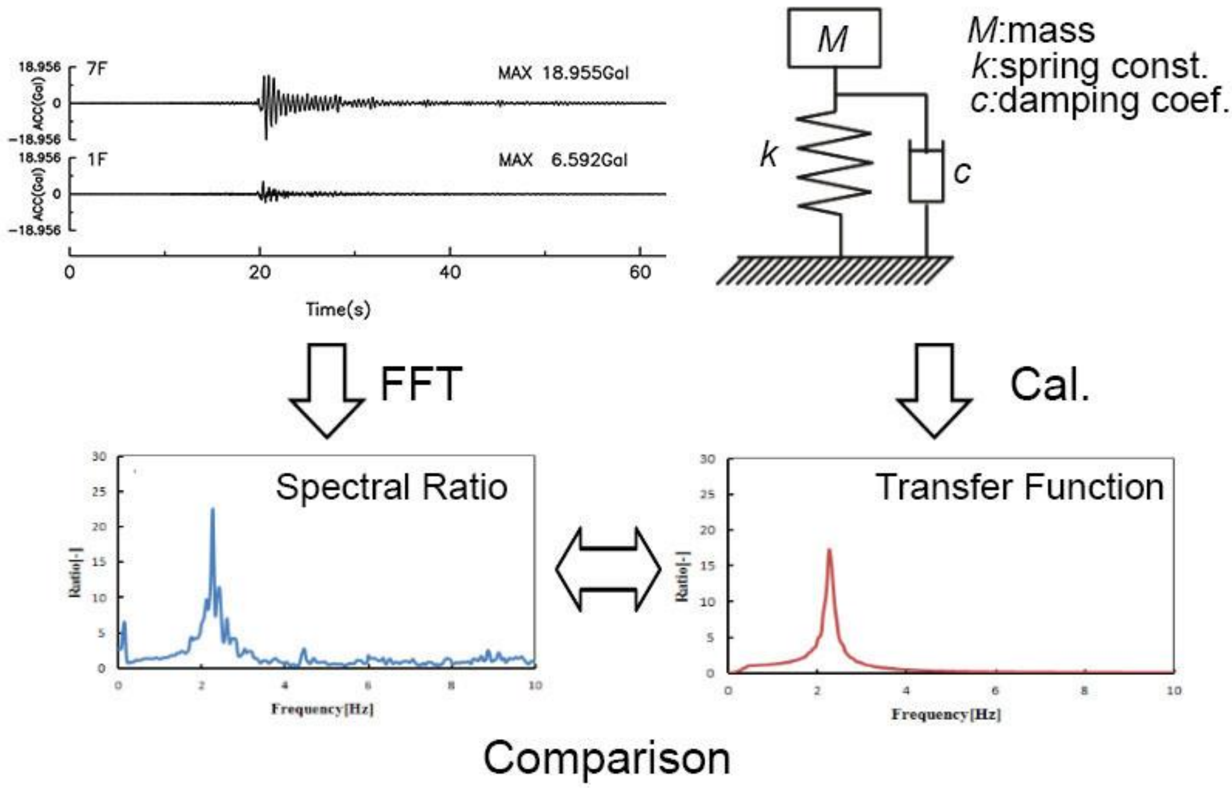

Fig. 5 A flow chart of natural frequency estimation using strong motion data

IV. Variation of Natural Frequency Based on Strong Motion Data

4.1 Strong motion observation inside the building

Strong motion observation inside the building is started from March 2011. The seismometers were installed on the 1F and the 7F shown in Fig. 1. The seismometer on the 1F and on the 7F is Akashi GPL 6A3P and Akashi SMAC-MD, respectively. The sampling rate of this observation is 0.01 sec/point. The internal clock of GPL 6A3P and SMAC-MD is calibrated by GPS and radio wave signal, respectively.

4.2 Estimation of the natural frequency

To estimate a variation of the natural frequency of the target building, a method of spectral ratio was used. An estimation flow of analysis is shown in Fig. 5. First, Fourier spectrum of a strong motion data with an analysis time window of 60 sec was calculated by FFT. The spectral ratio of 7F to 1F was calculated. Second, fitting a transfer function with an assumption of the damping ratio ζ=0.05 using SDOF model to the spectral ratio, the natural frequency was estimated. The Y direction that consists of simple mode vibration was used for this analysis.

The variation of the natural frequency is shown in Fig. 6. The average of the natural frequency is 2.28Hz, it seems almost constant from a macro point of view. However it is smaller than the one estimated by microtremor, and there are some dispersion. The amplitude of strong motion is bigger than that of microtremor. Since a distribution of response amplitude of strong motion on 7F is wide, a relation between the natural frequency and the response amplitude is shown in Fig. 7. In case that the peak response amplitude is under 10Gal, the distribution of the natural frequency indicates the frequency band between 2.10Hz and 2.60Hz. Otherwise, in case that the peak response amplitude is over 20Gal, it is lower than the average of the natural frequency. It indicates that the natural frequency depends on the peak response amplitude.

To know the variation of the natural frequency, the relation between the natural frequency and the peak response amplitude from April to June, 2012 is shown in Fig. 8. The natural frequency indicates around 2.30Hz in case that the peak response amplitude is under 10Gal. Increasing the peak response amplitude, the natural frequency decreases. For example, an earthquake occurred on May 29 2012, the peak response amplitude is 55.3Gal, was estimated 2.02Hz as a natural frequency. In case that the earthquake with the peak response amplitude of 3.1Gal that is occurred after 2 hours of previous one, it indicates 2.35Hz. It means that the natural frequency depends on the peak response amplitude.

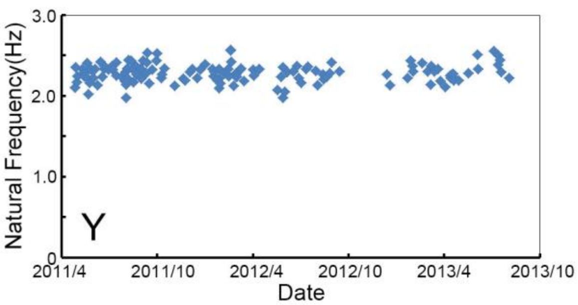

Fig. 6 Secular change of natural frequency on the target building

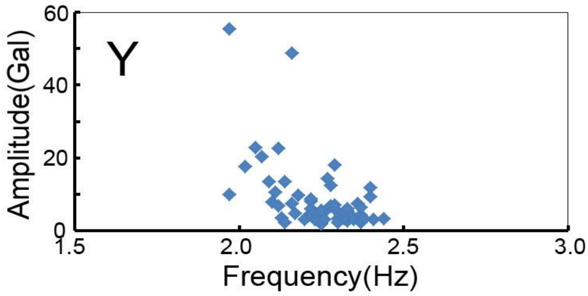

Fig. 7 Comparison between natural frequency and response amplitude

V. TEMPORAL CHANGE IN THE NATURAL FREQUENCY ON STRONG MOTION

As a result estimated by strong motion records, the natural frequency depends on the peak response amplitude. Next, temporal change in the natural frequency was investigated to understand vibration characteristics of the building during earthquakes.

An estimation method is following Kashima and Kitagawa (2005) [8]. First, a relative displacement waveform of 7F to 1F is calculated using strong motion records on 1F and 7F. Second, response waveform using a strong motion record as an input wave was calculated by SDOF model. To minimalize the sum of squared residuals between relative displacement and response waveform, the natural frequency was estimated. In this time, moving a time window that is 10sec for this analysis, it was done. And the damping ratio is assumed as ζ=0.05.

An example of results is shown in Fig. 9. It indicates acceleration waveforms on 7F, 1F, relative displacement and estimated natural frequency, respectively. In a part of small acceleration amplitude before a principal motion on 7F, the natural frequency indicates 2.2Hz. However in the peak amplitude part, it decreases to 2.0Hz. As the amplitude is decreased gradually, a trend of the natural frequency indicates to get back. The natural frequency on the building structure changes depending on the response acceleration amplitude during an earthquake.

VI. DISCUSSION

Since the natural frequency of structures is one of important parameters to indicate vibration characters, change of it is used for some application. One of them is structural health monitoring system. An example of health monitoring study using microtremor is Tanaka and Motosaka (2009)[9]. They found a discontinuous change of the natural frequency between before and after a big earthquake from monitoring data on the target building. It indicates a part of damage on the building.

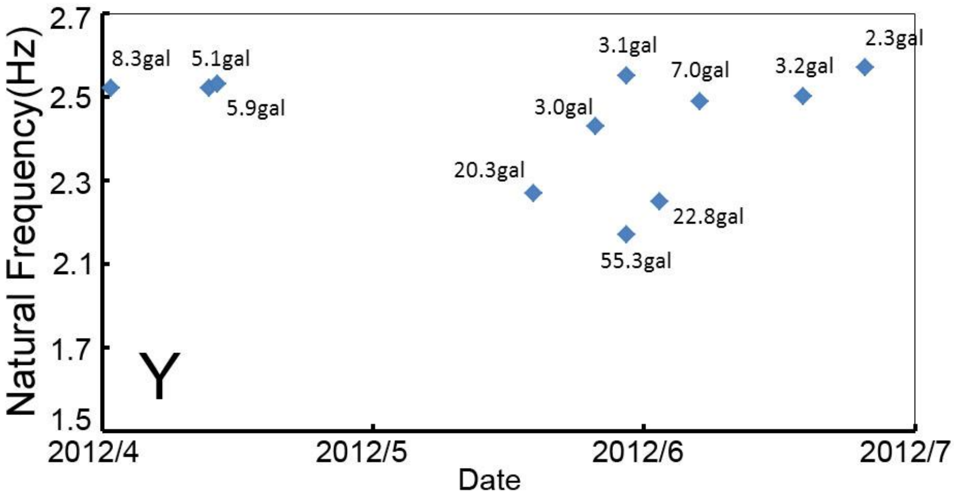

Fig. 8 Secular change of natural frequency from 2012/4 to 2012/7

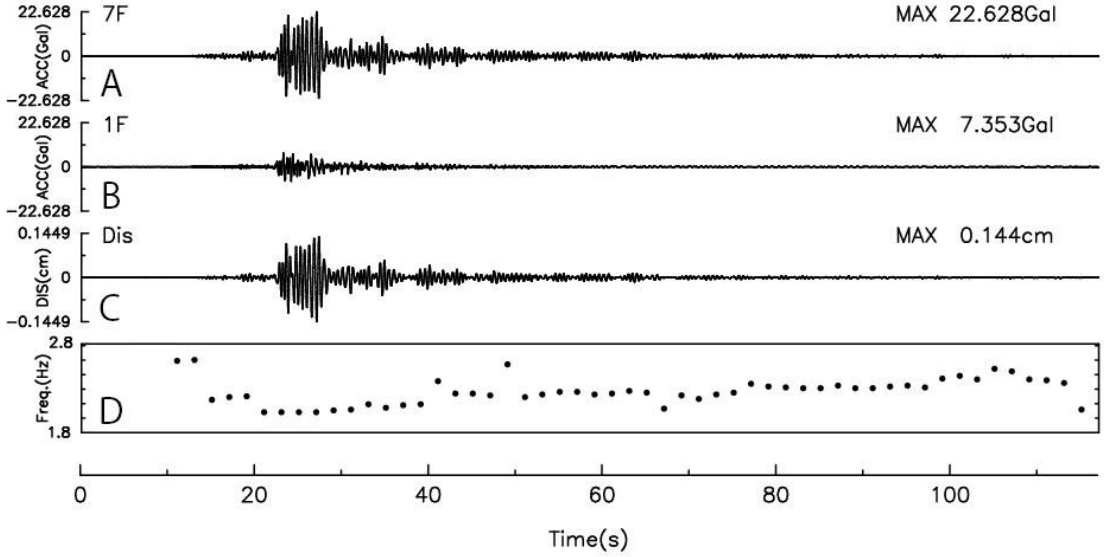

Fig. 9 Waveforms and temporal change of natural frequency on the target building A: Acceleration waveform on 7F B: Acceleration waveform on 1F C: Relative displacement waveform between 1F and 7F D: Natural frequency with the time windows of 10sec.

The amplitude dependence of the natural frequency on structures is not so severely. However it is difficult to do the structural health monitoring by change of the natural frequency only using strong motion records, because of response amplitude dependency. It needs to do it with the other information.

Hence, a relation between the natural frequency and the story drift investigated by relative displacement is shown in Fig. 10. It is possible to explain a relation between them by a regression expression. As a damage of the structure cause a stiffness degradation of it, the natural frequency does not fit into the regression expression between the story drift and the natural frequency. Because of this reason, it needs to combine the natural frequency with another parameter such as response amplitude, when the natural frequency estimated by seismic ground motion will be used as a parameter for health motoring.

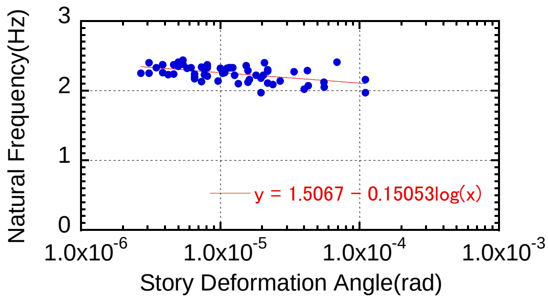

Fig.10 Relation between story deformation angle and natural frequency

VII. CONCLUSION

In this study, vibration characteristics of the building from the natural frequency point of view were investigated using microtoremor and strong motion.

First, the natural frequency of the target building was estimated using microtoremor. It was 2.40Hz in the minor axis of the building.

Second, the average natural frequency was estimated using strong motion data. It was 2.28Hz that is lower than that of microtremor. In case estimated using strong motion data with the peak acceleration amplitude under 10Gal, the natural frequency was distributed between 2.10Hz and 2.60Hz. However, in case of over 20Gal, it was under the average value. It means that the natural frequency of the structure depends on the peak acceleration amplitude.

From a time series analysis on strong motion data, the natural frequency indicates high value before the part of principal motion, it drops to a lower on the part of principal motion. And it goes back with the decreasing acceleration amplitude of motion.

It means that it is difficult to evaluate a health index only using the change of the natural frequency estimated by strong motion data and it needs to use another parameter together.

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