EVALUATION OF PREDOMINANT FREQUENCY OF 8 STORIES RC BUILDING USING OBSERVATION RECORDS

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ABSTRACT: Monitoring the structural health of buildings is crucial to ensure their safety and reliability, especially for aging structures that are susceptible to corrosion and wear. This study focuses on monitoring the changes in the predominant frequency of an 8-story reinforced concrete building located in Nagaoka, Japan, under the influence of external factors. Vibration records obtained from velocity sensors are used to measure the vibrations induced by daily activities and environmental factors. Signal processing techniques are employed to analyze the data and determine the predominant frequencies of the building's structure. The research findings reveal that the predominant frequencies of the building exhibit cyclic variations over time, closely associated with the impact of external factors, particularly temperature changes in the environment. These temperature changes contribute to fluctuations in the stiffness of the reinforced concrete structure at different surface temperatures.

KEYWORDS: natural frequency, predominant frequency, vibration, SHM.

1. INTRODUCTION

Buildings serve as vital infrastructure for human societies, providing shelter, workspaces, and various essential functions. However, their safety and reliability can be compromised by natural disasters or human activities, emphasizing the importance of monitoring their structural health. This is particularly critical for older buildings that may experience deterioration due to corrosion and wear over time [1]. One key aspect of structural health monitoring is the assessment of a building's dynamic behavior, as it provides valuable insights into its structural integrity. Vibration-based monitoring techniques have proven to be effective in capturing the dynamic response of structures. By analyzing the vibration characteristics, it is possible to identify any changes in the structural properties and detect potential issues at an early stage [2].

In this study, we focus on an 8-story reinforced concrete building situated in Nagaoka, Japan. The objective is to monitor the changes in the predominant frequency of the building over time, taking into account the influence of external factors. Vibration data is acquired using velocity sensors, which capture the vibrations induced by both daily activities and environmental factors. Signal processing techniques are employed to analyze the collected vibration data and extract meaningful information regarding the predominant frequencies of the building's structure. The predominant frequency represents the frequency at which the structure exhibits its maximum response, and monitoring its variations can provide insights into the building's condition [3].

The research findings indicate that the predominant frequencies of the 8-story reinforced concrete building undergo cyclic variations over time. These variations are closely linked to the impact of external factors, with changes in environmental temperature playing a significant role. Fluctuations in temperature result in corresponding changes in the stiffness of the reinforced concrete structure at different surface temperatures, thus affecting the building's dynamic characteristics.

By understanding the relationship between external factors and the variations in the predominant frequency, this study contributes to the field of structural health monitoring. The findings can aid in developing effective strategies for the maintenance and safety assessment of buildings, especially older structures that are more vulnerable to deterioration. Additionally, this research highlights the importance of considering environmental influences when analyzing the dynamic behavior of buildings.

2. EXPERIMENTAL STUDY

2.1. Building target

Target building is an 8-story reinforced concrete building, built in 1976 in Nagaoka city, Niigata prefecture, Japan. The building has a normal rectangular shape with a length of 61.2 m and a width of 14.4 m. The height of each floor is 3.5 m. The building was constructed for educational and research purposes, with most of the rooms serving as classrooms or offices for university staff and faculty. As the building was constructed in Japan, which regularly experiences earthquakes.

2.2. Data Collection

2.2.1. Vibration data

In this study, sensors were installed on the first and eighth floors of the building to record the vibration data of the building and the ground during the building's use. Vibration data recording started on March 11, 2022. Vibration data is continuously recorded until August 31, 2022.

2.2.2. Whether data

The collected weather data includes information on temperature, rainfall, wind speed, wind direction, and relative humidity. The observation station is located at 37 degrees 27 minutes north latitude, 138 degrees 49.4 minutes east longitude, and has an elevation of 23 meters above sea level. The distance from the building location is approximately 2 km.

Weather data is collected by recording data through the website https://www.data.jma.go.jp/gmd/risk/obsdl/

3. DATA ANLYSIS

The collected vibration data is processed and analyzed to extract the natural frequencies of the building. Signal processing techniques such as Fast Fourier Transform (FFT), Transfer function and linear regression are employed to analyze the vibration signals and determine the predominant frequencies.

Analysis sequence:

Figure 1. The overview of the 8-story RC building and its location

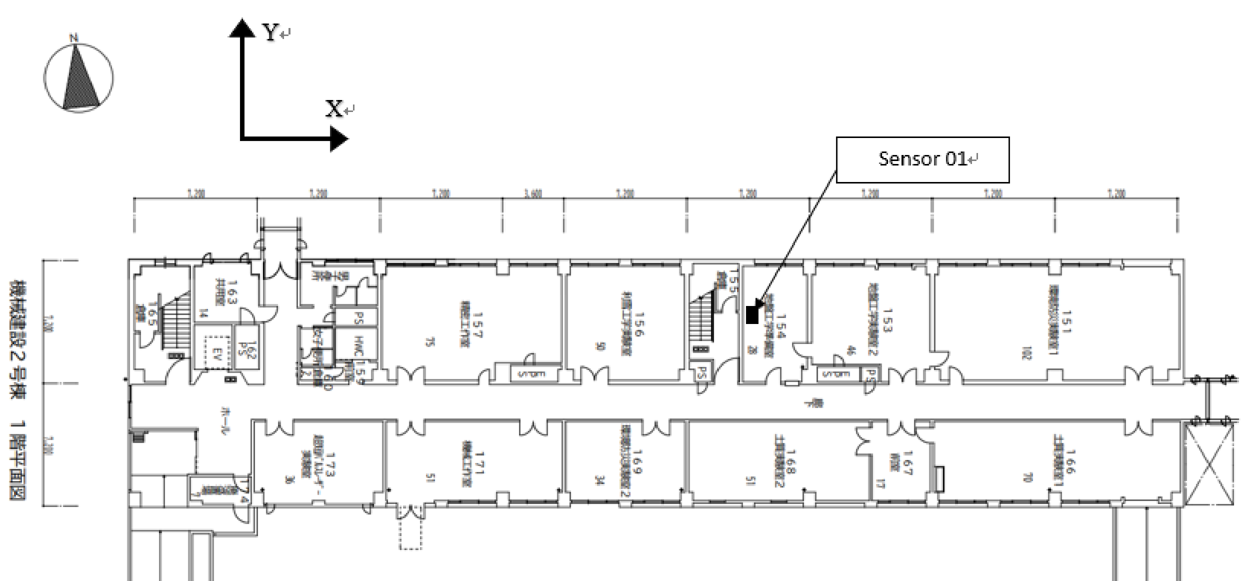

Figure 3. Location of sensor 01 installation on the first floor of the RC building

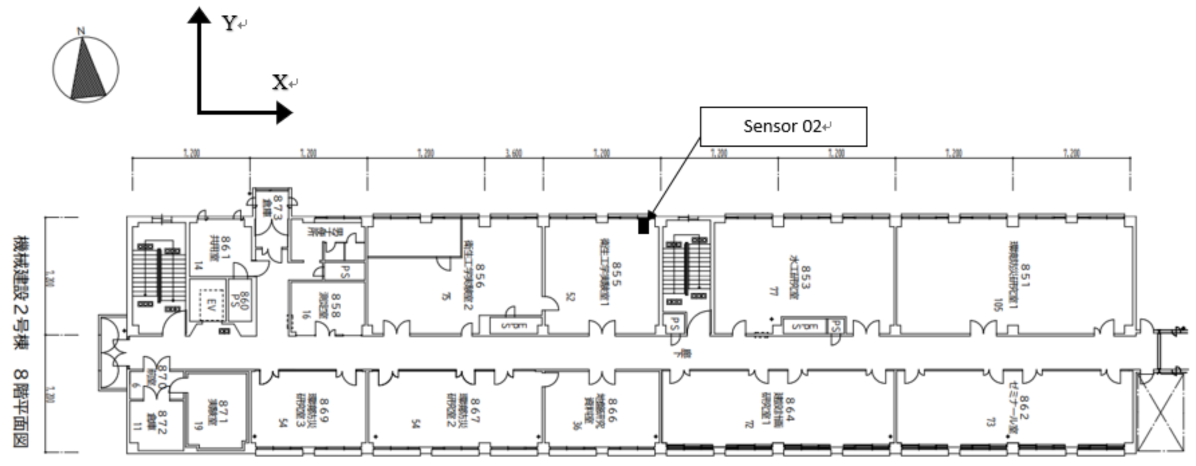

Figure 4. Location of sensor 02 installation on the 8th floor of the RC building

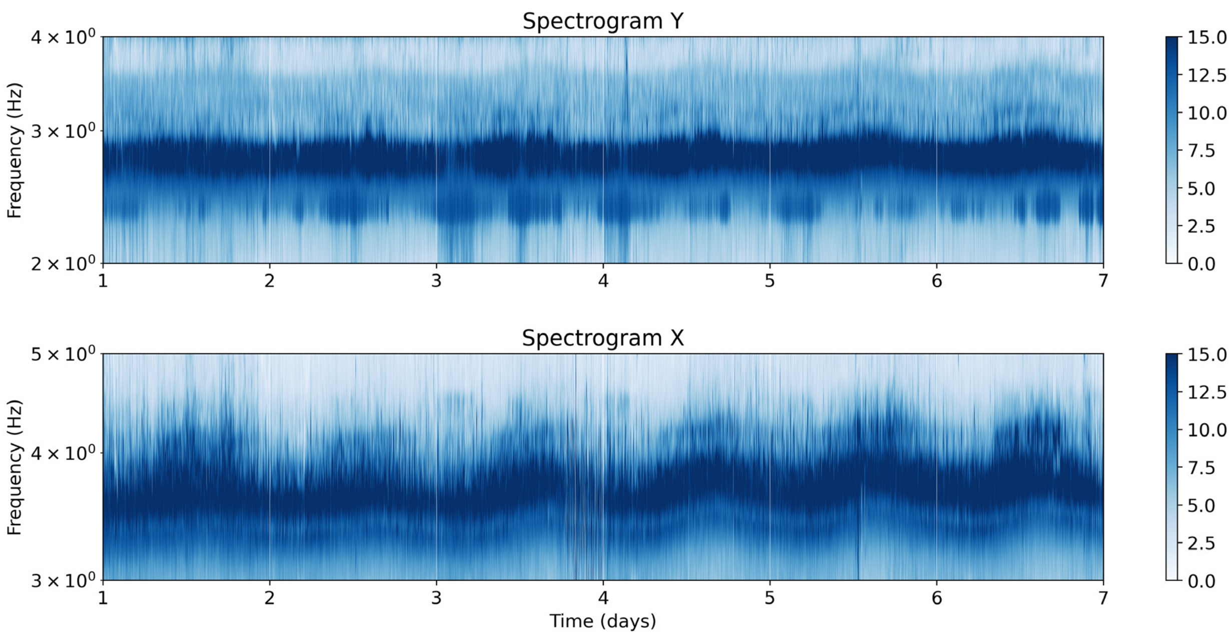

Figure 6. Changes in predominant frequency in May 1 to 7/2022

Step 1: Select observation data.

Step 2: Convert vibration data from the time domain to the frequency domain by using the FFT method.

Step 3: Calculate the transfer function of the building by equation:

$$TF = \frac{FA_R}{FA_B}$$

In which: FA_R is the Frequency Amplitude of Roof floor.

FA_B is the Frequency Amplitude of Base floor.

Step 4: Determine predominant frequency of building based on the Transfer function ratio.

Step 5: Monitoring the change of predominant frequency by using spectrogram.

Step 6: Evaluation the change in predominant frequency of building.

4. RESULTS

4.1. Predominant frequency

By analyzing the transfer function, we can obtain valuable insights into the behavior of the project. It is possible to identify the peak of the graph, which corresponds to the natural frequency of the system.

Figure 6 displays the predominant frequency results of the building on July 10, 2022, with values of 3.68 Hz and 2.74 Hz for the x and y directions, respectively. It can be concluded that the predominant frequency value of the building at each time point varies, which may be due to external factors. To ensure safety, further research is necessary to provide a more specific assessment.

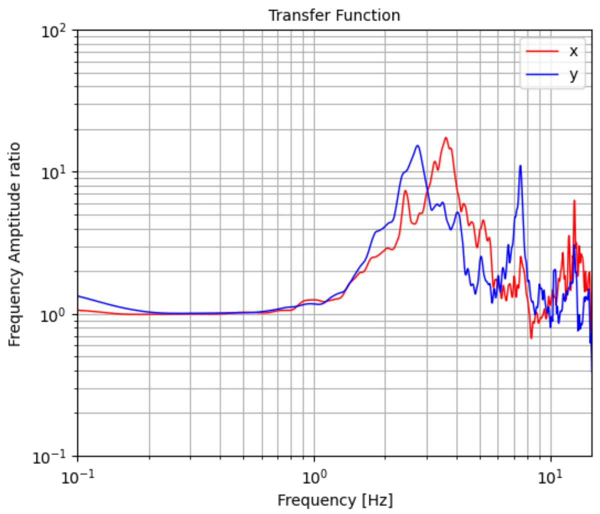

Figure 5: Transfer function of the building

4.2. Spectrogram

To monitor predominant frequency changes automatically, we use a spectrogram with two axes: frequency and time. This provides data that shows the predominant frequency changes of the construction during the observation period. Each window in the spectrogram contains vibration data for 163.84 seconds and repeats every 81.92 seconds. To further elaborate, the spectrogram can be seen as a visual representation of the vibration data that is obtained during the observation period. By utilizing the data from the spectrogram, we can easily detect even the slightest changes in the predominant frequency over time, which can be crucial in identifying potential issues with the construction.

Although these changes are small and do not affect the operation of the structure, it is necessary to evaluate the changes in the predomiannt frequency and investigate their causes to ensure the safety of the structure during use.

4.3. Evaluation the change of predominant frequency

The natural frequency of a structure, which refers to the rate at which it vibrates when disturbed, is determined by its stiffness and mass. Generally, the more massive the structure, the lower its natural frequency. However, since the mass of the structure is constant, any change in natural frequency must come from a change in the structure's stiffness. This means that if we want to change the predominant frequency of a structure, we need to adjust its stiffness.

There are several external factors that may affect the stiffness of a structure. For instance, changes in environmental temperature may cause the structure's materials to expand or contract, which can alter its stiffness. Similarly, changes in wind velocity and direction can produce vibrations that affect the structure's stiffness, as can human activity such as walking or jumping. Even humidity levels can play a role in affecting the stiffness of certain types of structures, such as wood or paper products.

In summary, factors that may affect the natural frequency of a structure include temperature, wind speed, humidity, and human activities. Investigating the relationship between these external factors and the natural frequency of a structure can help us understand the causes of small changes and cycles in the structure's natural frequency.

Based on long-term environmental vibration records from March to August 2022, we have extracted the natural frequency of the building system, including the interaction between the ground and structure. This enables us to study the relationship between natural frequency and external factors.

To estimate the predominant frequency, we used a Fourier analysis technique that involves dividing each hourly vibration record into twenty 163.84-second-long windows. We then took the average Fourier spectra from these windows and applied a smoothing window of a Parzen window 0.2 Hz. By analyzing the datasets throughout the observation period using the same method, we were able to determine the predominant frequency of the building system with a high degree of accuracy.

During research on the correlation between external factors and predominant frequency (Figure 7), it became clear that temperature has the strongest correlation. The predominant frequency primarily increases when the temperature increases, and decreases when the temperature decreases [4, 5]. Furthermore, a broader analysis shows that the predominant frequency changes in sync with environmental temperature variations.

Linear regression is a method used to evaluate the relationship between the dominant frequency and external factors. Figures 8, 9, and 10 illustrate the relationship between humidity, wind speed, and temperature versus the dominant frequency.

Comparing the R^2 coefficients, it is clear that temperature has the strongest relationship with the change in the dominant frequency, with r2 values of 11% and 44%, respectively. In contrast, the R^2 coefficient for wind speed is only 1% and 2%, and for humidity, it is 3% and 4%.

In addition, we also observed that the specific types of human activity within the building can also affect the predominant frequency. For example,

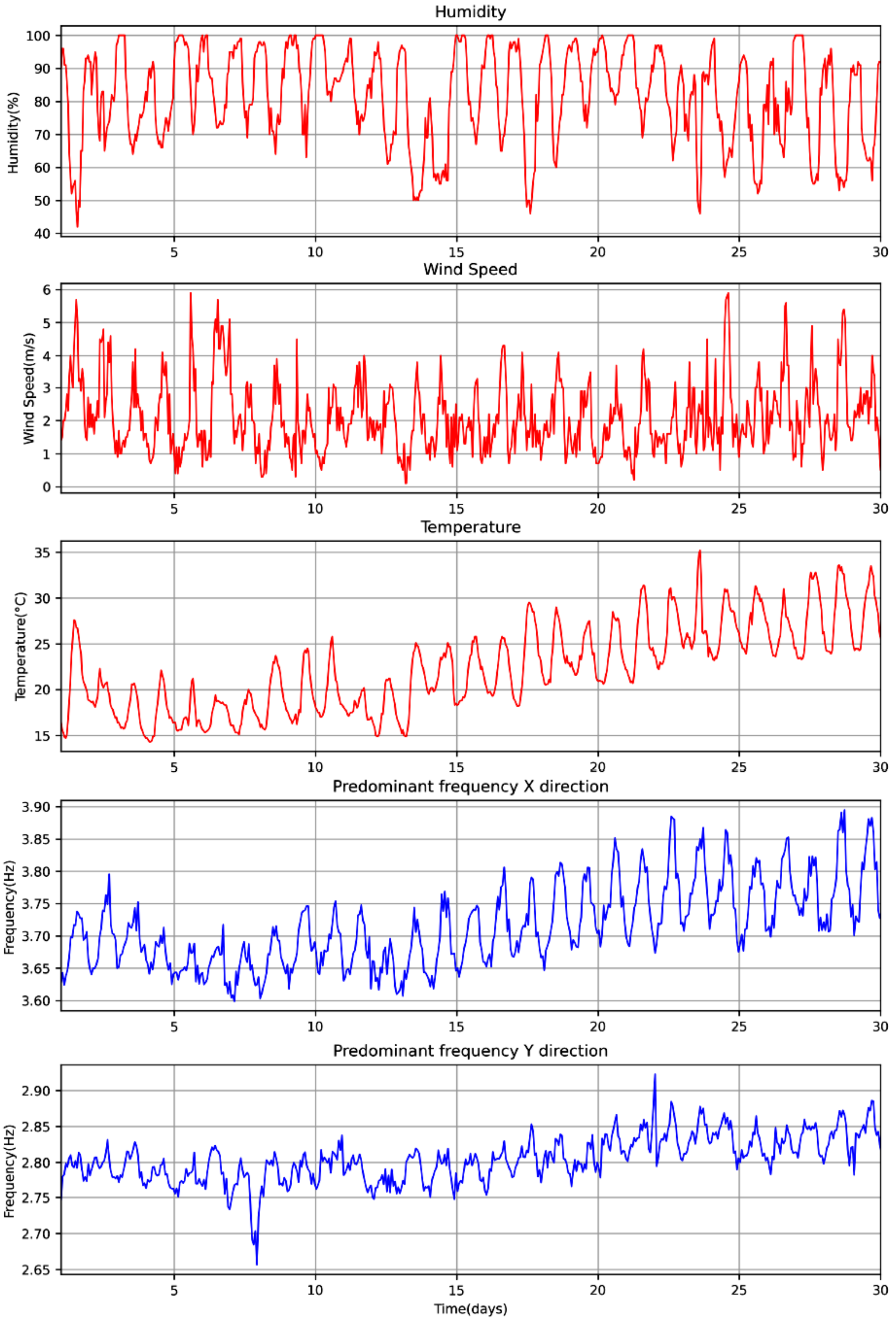

Figure 7. Change in predominant frequency and external factors of 8-story RC building From June 1 to 30,2022

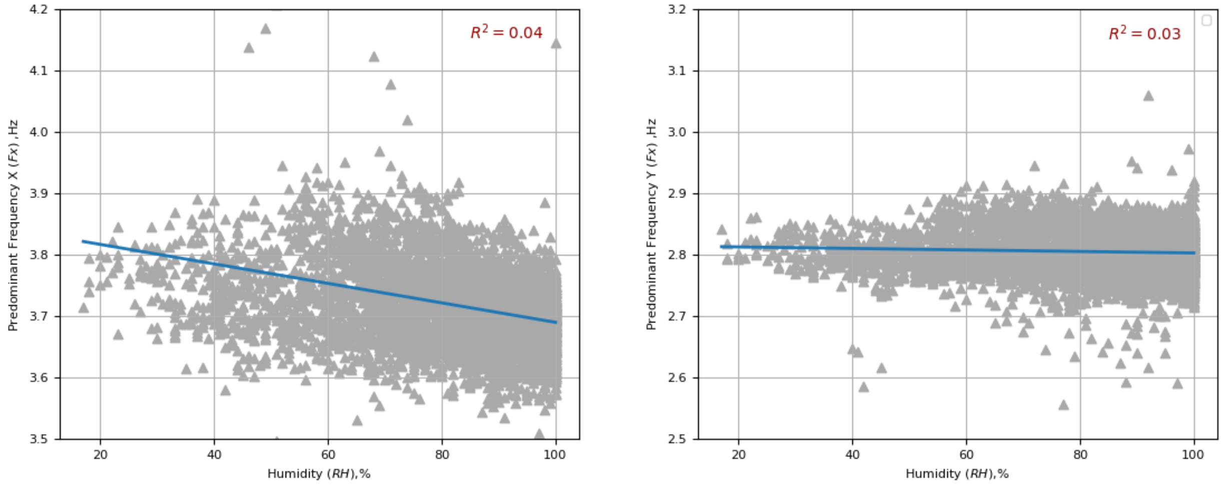

Figure 8: Relationship between frequency and Humidity

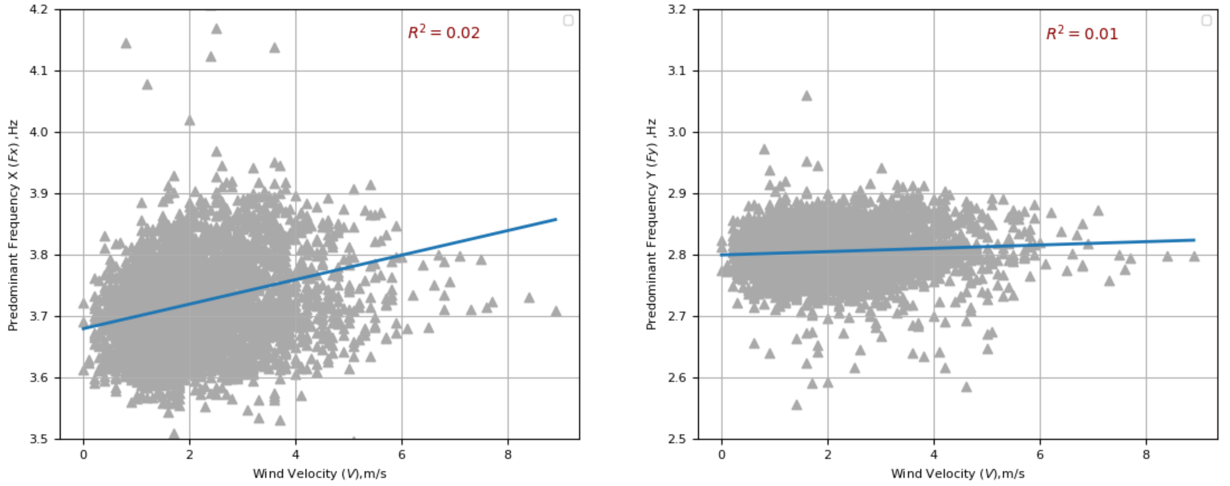

Figure 9: Relationship between frequency and Wind velocity

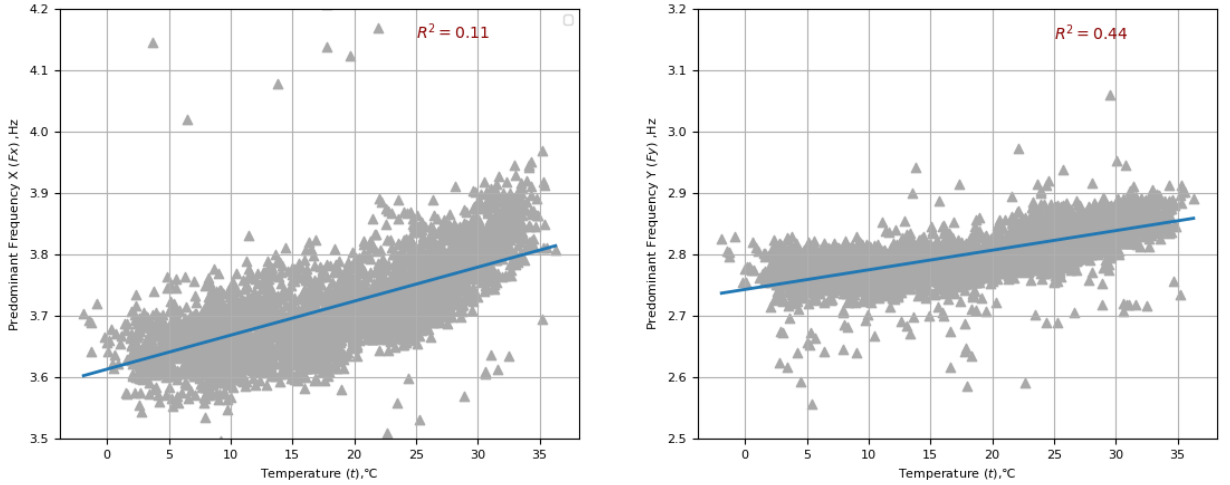

Figure 10: Relationship between frequency and Temperature

during certain times of the day, we noticed that the predominant frequency tends to increase when there are more people using the elevators or walking on the floors. Overall, our research supports the idea that human activity does have a significant impact on the predominant frequency of the building, with various factors contributing to this effect.

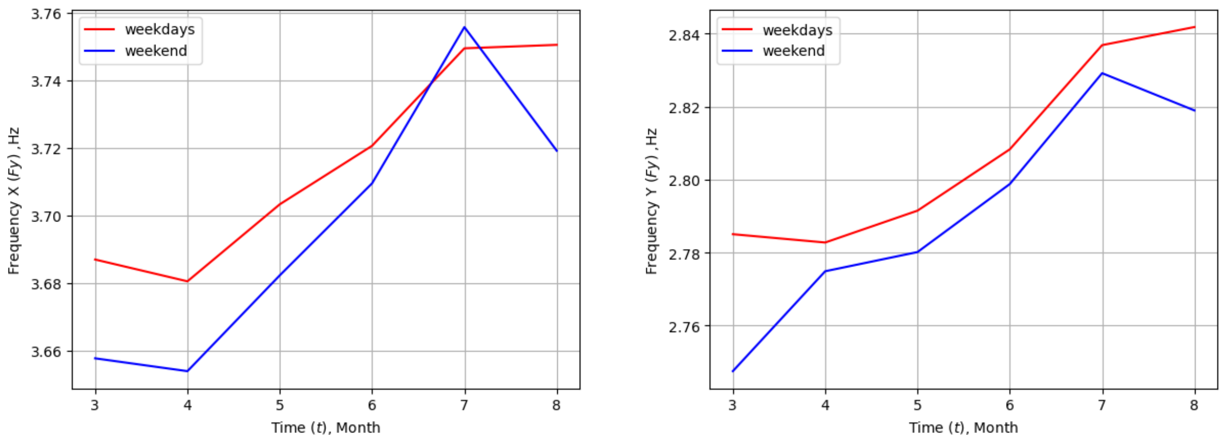

Figure 11. Relationship between frequency and human activity

5. CONCLUSION

The use of vibration records has aided in determining the predominant frequency range of the building and identifying small changes in the predominant frequency.

Temperature is the factor most strongly related to frequency changes, as an increase in temperature leads to an increase in the predominant frequency and a decrease in temperature leads to a decrease in the predominant frequency.

The predominant frequency is also influenced by human activity, with an increase on weekdays and decrease on weekends.

The study's results demonstrate the potential for establishing high-precision structural monitoring technology by using vibration records.

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