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Dynamic Characteristics of R/C Building on Niigata University Campus based on Earthquake Observation Records

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Abstract

Strong motion observation of a five-story reinforced concrete (R/C) building on Niigata University campus has been conducted since 2001. Each seismograph is located at the roof floor, ground floor, and free field beside the building. Acceleration was measured records have been 120 earthquakes, including the 2004 Niigata-ken Chuetsu earthquake (maximum acceleration at roof level is 325 gal), the 2007 Niigata-ken Chuetsu-oki earthquake (maximum acceleration at roof level is 360 gal), the 2011 off the Pacific coast of Tohoku Earthquake (maximum acceleration at roof level is 67 gal; duration more than 700 seconds), and. The 2019 Yamagata-ken oki earthquake (maximum acceleration at roof level is 226 gal). The building was not damaged, even though the natural frequency of the building changes during an earthquake. During the main earthquake motion, the natural frequency of the building is lower. After the main part of ground motion, the frequency returned to the original position. Although the natural frequency and earthquake intensity correlate, the variation is significant. Microtremor observation in the same building was conducted in 2010. The changes in the natural frequency associated with temperatures: the natural frequency increased in the summer season and decreased in the winter season. The relational expression between the frequency and Niigata Local Meteorological Observatory measured temperature was obtained. When the natural frequency of the soil-structure system for building estimated from strong motions were corrected using the temperature at the time of the earthquake, a higher correlation with the seismic intensity of earthquake records was observed.

Keywords: reinforced concrete building, strong motion observation, natural frequency

1. Introduction

Strong motion observation of a five-story reinforced concrete (R/C) building on Niigata University campus has been conducted since 2001 [1]. Microtremor observations were also conducted in this building from 2010 to 2011 [2]. We have reported a correlation between the natural period by microtremor observation and Niigata Local Meteorological Observatory measured temperature, and the natural period of the soil-structure system for building also changes during main part of the 2011 off the Pacific coast of Tohoku Earthquake motion. During the main earthquake motion, the natural period of the building became longer. After the main part of ground motion, the period returned to the original position [3]. Several researchers also reported correlation of the natural frequency of reinforced concrete building with temperature. [for example] [4].

During 18 years, the acceleration records have been measured 120 earthquakes, including the 2004 Niigata-ken Chuetsu earthquake (maximum acceleration at roof level is 325 gal), the 2007 Niigata-ken Chuetsu-oki earthquake (maximum acceleration at roof level is 360 gal), the 2011 off the Pacific coast of Tohoku Earthquake (maximum acceleration at roof level is 67 gal; duration more than 700 seconds), and the 2019 Yamagata-ken oki earthquake (maximum acceleration at roof level is 226 gal). In this report, the changes in natural frequency is analyzed based on these observation records.

2. Building outline

A building on Niigata University campus located in Niigata city, Japan, is studied. The building is a 5-story reinforced concrete structure with piles that was built in 1982 (Ultimate state design was introduced in 1981 to seismic design code in Japan). The structure is a moment resisting frame with shear walls. Fig 1. shows first-floor plan and overview of the building. The installed seismographs are the GPL-6A3P model manufactured by the former Akashi Co., Ltd. The seismographs were installed at the first floor and roof floor. The seismograph was installed at free field near the building in 2008. In Fig 1, a circle indicates the place of first-floor observation point, and a triangle indicates the roof floor observation point. The direction of strong motion observation is not magnetic north-south and east-west but the longitudinal and the span direction of this building. (These directions term NS and EW for descriptive purposes in this paper)

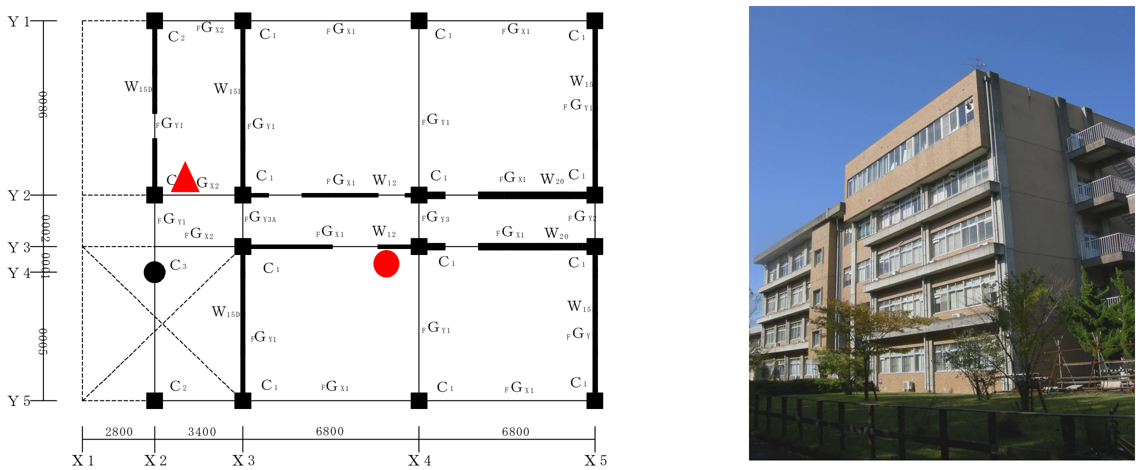
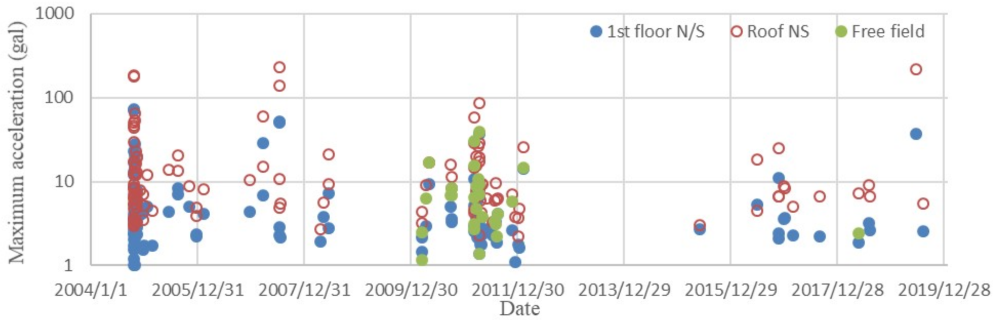


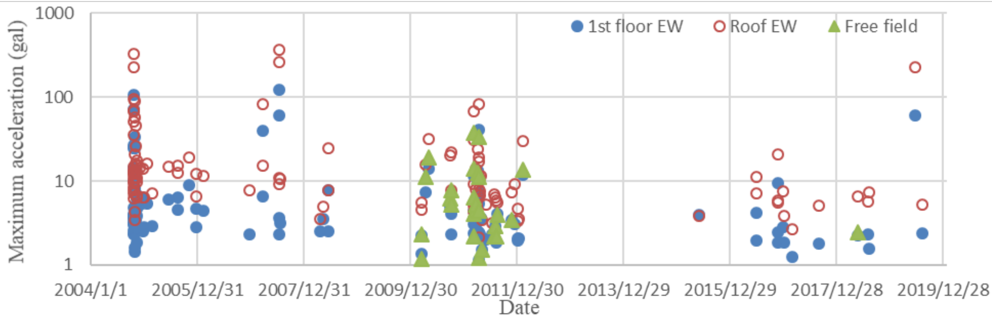
Fig. 1 – First floor plan and overview of the building

3. Observation records

In this paper, observed acceleration records from 120 earthquakes are analyzed. Fig. 2 shows maximum accelerations and observed date. A large number of earthquakes happened in 2004 and 2011 are due to aftershock of the 2004 Niigata-ken Chuetsu earthquake and the 2011 off the Pacific coast of Tohoku Earthquake. There was a period during which observation was not possible due to malfunction. The maximum of the Japan Meteorological Agency seismic intensity scale in Niigata city in 18 years is intensity 4. We had records of five earthquakes of them. The details of five earthquakes and the epicentral distance to the building are listed in Table 1, and the maximum acceleration of each record is listed in Table 2. The relationship between maximum acceleration at first floor/free field and roof level are shown in Fig. 3. A proportional relationship is observed in Fig. 3. Therefore, the building behaved within the elastic range and was not damaged by each earthquake.



a) N/S direction



b) E/W direction

Fig. 2 – Maximum acceleration for 18 years

Table 1 – Details of five earthquakes

Name	M	Date	Max. I_{JMA}	I_{JMA} in Niigata-city	temperature (°C)
Niigataken chuetsu	6.8	2004/10/23	7	4	14.6
Niigataken chuetsu-oki	6.8	2007/7/16	6+	4	23.9
Sanrikuoki	9	2011/3/11	7	4	3.3
Fukushimaken hamadori	7	2011/4/11	6-	4	5.1
Yamagakaken oki	6.7	2019/6/18	6+	4	19.4

Table 2 – Maximum acceleration of each record

	Maximum acceleration (cm/sec^2)					
Eq name	First floor		Roof level		Free field	
	N/S	E/W	N/S	E/W	N/S	E/W
Niigataken chuetsu	71.5	106.8	178.1	326.0	-	-
Niigataken chuetsu-oki	51.0	61.0	138.9	260.7	-	-
Sanrikuoki	-	-	58.3	67.3	30.5	37.8
Fukushimaken hamadori	36.6	41.0	84.9	82.6	39.1	33.1
Yamagakaken oki	36.8	61.0	218.2	226.9	-	-

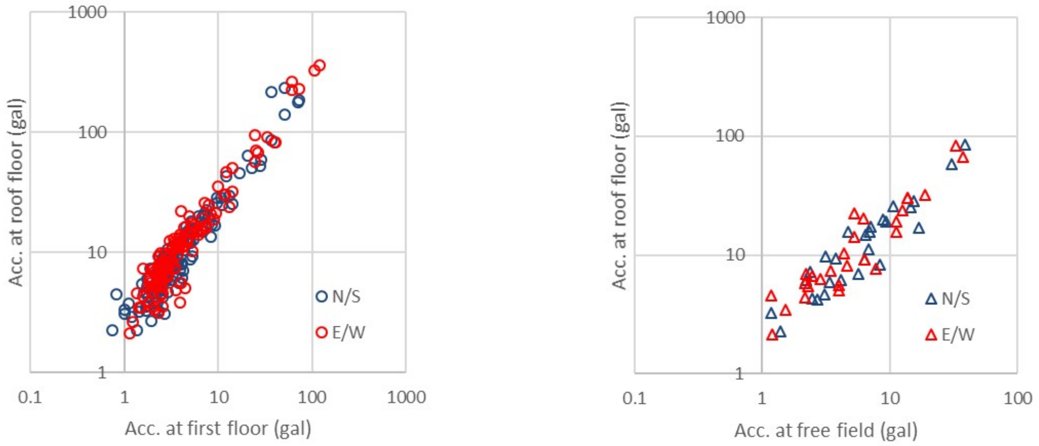
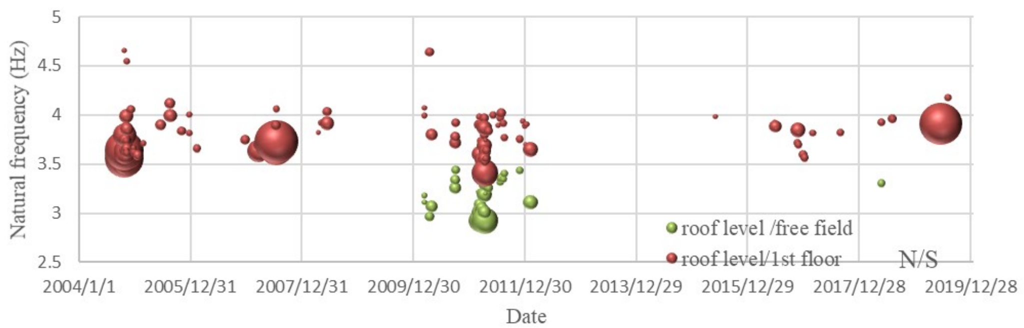


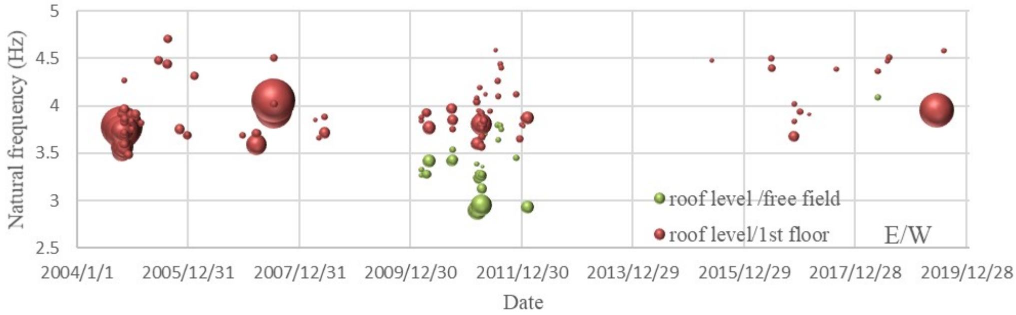
Fig. 3 – Roof level and first floor / free field maximum acceleration

4. Natural frequency

To estimate natural frequency, peak frequency was extracted by Fourier spectrum ratio of roof floor to first floor / free field. The Fourier spectra were calculated using the observed acceleration records. The observation records are 32768 time-history acceleration data at 100 Hz for 327.68 s. To use Fast Fourier transform was performed, the record length is set to 32768 data with trailing zero in the case of the data length is shorter than 327.68 s. The Fourier spectra were applied 0.4 Hz Parzen window. Fig. 4 shows the estimated natural frequency for 18 years. The size of the bubble in Fig. 4 indicates each of the maximum acceleration records. Although the natural frequency varies, there is no change over the years.



a) N/S direction



b) E/W direction

Fig. 4 – Natural frequency for 18 years

4.1 Correlation between acceleration and modified natural frequency

The correlation of the natural frequency during earthquake motion with maximum acceleration and Niigata Local Meteorological Observatory measured temperature [5]. In the previous study, a high correlation between the natural frequency of E/W direction and temperature was demonstorated [3]. On the other hand, the natural frequency changes depending on the building response supplied by earthquake was investigated. Fig. 5 shows the relation of natural frequency to temperature by microtremor measurement, and the regression line is added in Fig. 5. The regression equation is as follows:

Natural frequency for the building: $F=0.035t+3.7466$ (1a)

Natural frequency of the soil-structure system for building: $F=0.0251t+3.2986$ (1b)

Where F is Natural frequency, t is temperature

Correlation of modified natural frequency using the regression equation (1) and maximum acceleration at the roof level was examined. The relation of natural frequency / modified natural frequency to maximum acceleration are shown in Fig. 6. Correcting the natural frequency depending on the temperature became clear the correlation of modified natural frequency with the maximum acceleration.

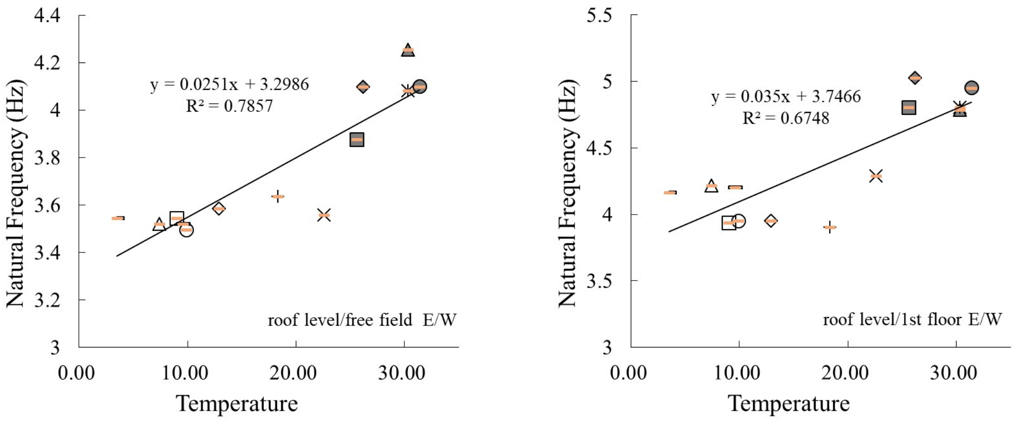
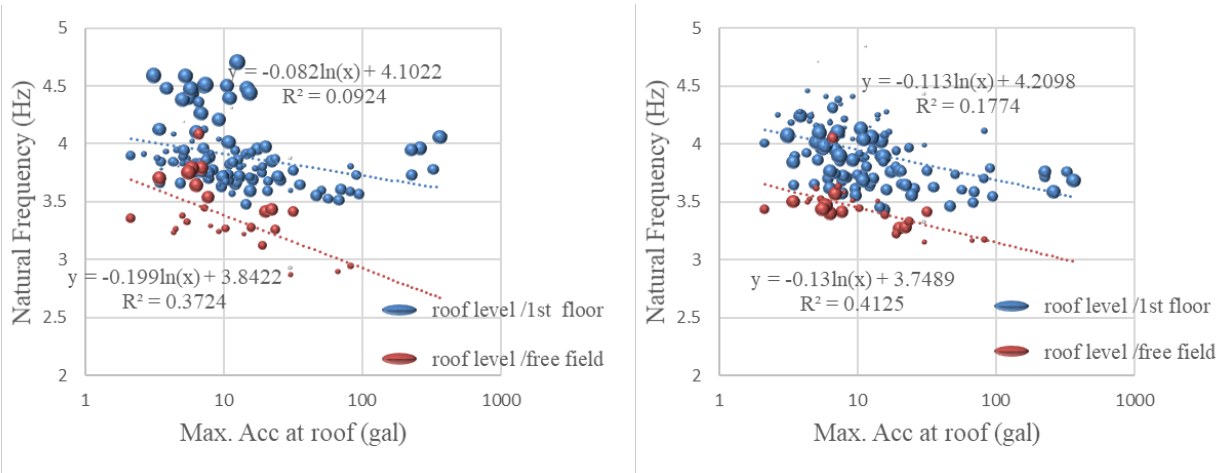


Fig. 5 – Relation of natural frequency of E/W direction to temperature by microtremor measurement [3]



(a) Natural frequency (b) Modified natural frequency

Fig. 6 – Relation of natural frequency to maximum acceleration

4.2 Natural frequency during strong motion

In this section, the change of natural frequency depending on the building response is examined. To clarify the change, running spectra were calculated using acceleration data of the five earthquakes shown in Table 1. To calculate running spectra, the start time was shifted by 20.24 seconds, records that length was 40.98 seconds was made. Fourier spectrum of each 40.96 seconds record is calculated. The peak frequency of the spectrum ratio of roof level to first floor / free field is obtained as the natural frequency of building / natural frequency of the soil-structure system for building. Fig. 7 shows the maximum acceleration of each 40.96 seconds record and the natural frequency during each record. The dotted line indicates the natural frequency of the soil-structure system for the building determined using records at free field and roof level, and the solid line indicates the natural frequency of the building determined using records at first floor and roof level.

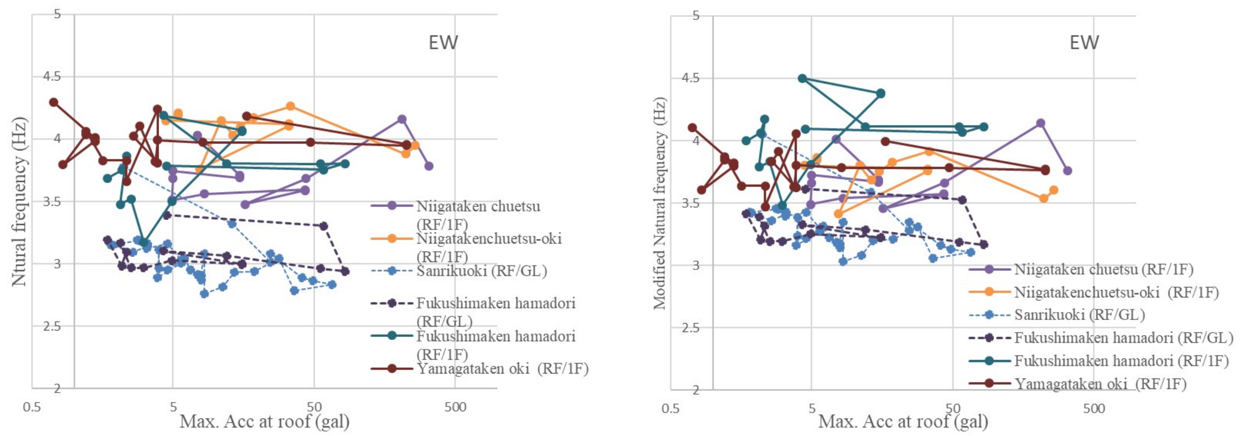
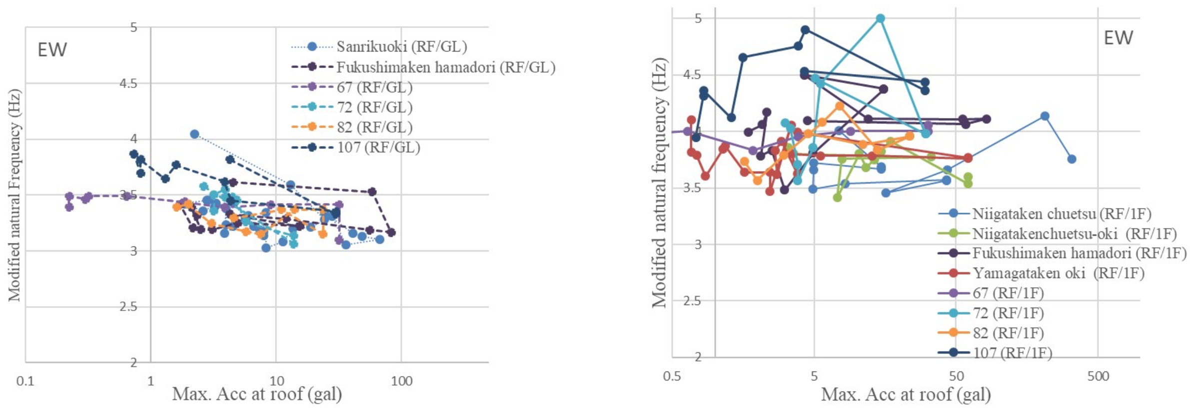


Fig. 7 – Relation of natural frequency to maximum acceleration using running spectra

The natural frequency of the soil-structure system for building declines during large acceleration in comparison with the natural frequency of the building. Further, the frequency changes are examined with four additional earthquakes. These four earthquakes are with a maximum acceleration of 10 gal or more and recorded both on the free field and first floor. The relation of natural frequency to the maximum acceleration of these earthquakes are shown in Fig. 8. The correlation between the natural frequency of the soil-structure system for buildings and maximum acceleration was clearly shown.

Table 3 – Details of four earthquakes

No. of eq	Epicenter	M	Date	I_{JMA} in Niigata-city	temperature (°C)
67	Niigataken huetsu	4.9	2010/5/1	2	14.1
72	Naganoken hokubu	6.7	2011/3/12	3	2.8
82	Miyagiken oki	7.2	2011/4/7	3	11.1
107	Sado	5.7	2012/2/8	2	-1.9



(a) Roof level / free field (b) Roof level / first foor

Fig. 8 – Relation of natural frequency to maximum acceleration based on running spectra

5. Conclusions

The conclusions of this study are as follows:

1. 18 years of strong motion records in a five-story reinforced concrete structure were summarized.

2. The natural frequency modified by the correction equation based on the microtremor observation results, the correlation between the natural frequency and the acceleration increased.

3. The running spectra were obtained from the records of five earthquakes with JMA seismic intensity four or higher, and the relationship between the maximum acceleration and the natural frequency of each was examined. The frequency of the soil-structure system for the building decreased when the acceleration was high, and then returned slowly. The frequency of building determined using records on the first floor and roof level as the superstructure varied.

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