Study on dynamic behavior of building which has rather long and slender configuration

S. Koyama & M. Iiba
Building Research Institute, Tsukuba, Japan

SUMMARY:
Building Research Institute (BRI) of Japan is operating a nationwide strong-motion network on building in order to accumulate records of response during earthquake. As the types of building installed seismometer are various, the vibration characteristics are also various and complicated. For these 6 years, the temporally observation on rather simple, long & slender configuration building has been conducted for farther understanding. There are 6 seismometers installed on and around the building to get detailed seismic response. The records of the 2011 off the Pacific coast of Tohoku Earthquake Japan were also caught and they showed changes of predominant periods during intense shaking. The variation of predominant period depending on maximum acceleration, before and after the 2011 off the Pacific coast of Tohoku Earthquake Japan, was examined.

Keywords: the 2011 off the Pacific coast of Tohoku Earthquake, strong motion, variation of predominant period

1. INTRODUCTION

The BRI, one of national institute, is operating a nationwide strong-motion network on building since 1957 in order to accumulate earthquake records that will be used for rationalization of design seismic motion for building. Through this network, a great number of significant strong motion records have been accumulated from repeated big earthquakes. The numbers of buildings installed seismometer are 79. They are various about year of completion, construction types, height, the uses of building and equipped with or without base-isolation devices. As the result, the vibration characteristics of buildings are also various and rather complicated to evaluate dynamic behaviour of buildings through observed earthquake record. In order to break through this situation, the temporally observation on rather simple, long & slender configuration building has been conducted for 6 years. The number of records accumulated exceed 400. The records of the 2011 off the Pacific coast of Tohoku Earthquake Japan, hereinafter referred to as the East Japan Earthquake, are successfully included. The paper reports the feature of the records of the East Japan Earthquake and the variation of predominant period of the building through the earthquake.

2. THE OULINE OF TARGET BUILDING

The target building stands next to BRI at Tsukuba city, Ibaraki prefecture, Japan, is 7 stories reinforced concrete with pile foundation, used as dormitory. The building, hereinafter referred to as KKC, completed in 1976, designed following former seismic code of Japan. In 2002, it was renovated following current regulation and strengthened walls. As the size of building is 20m heights, 9.6m× 54.7m flat plan, it's expected that the building will be affected by torsion and rocking type vibration. As shown in Figure 1, the seismometers simultaneously installed on building are five, two are on penthouse and three are bottom (1st floor). On the ground near by, one or two seismometers were installed as the reference. The positions of seismometers were subjected to change on occasion. Each of seismometers is operated independently.

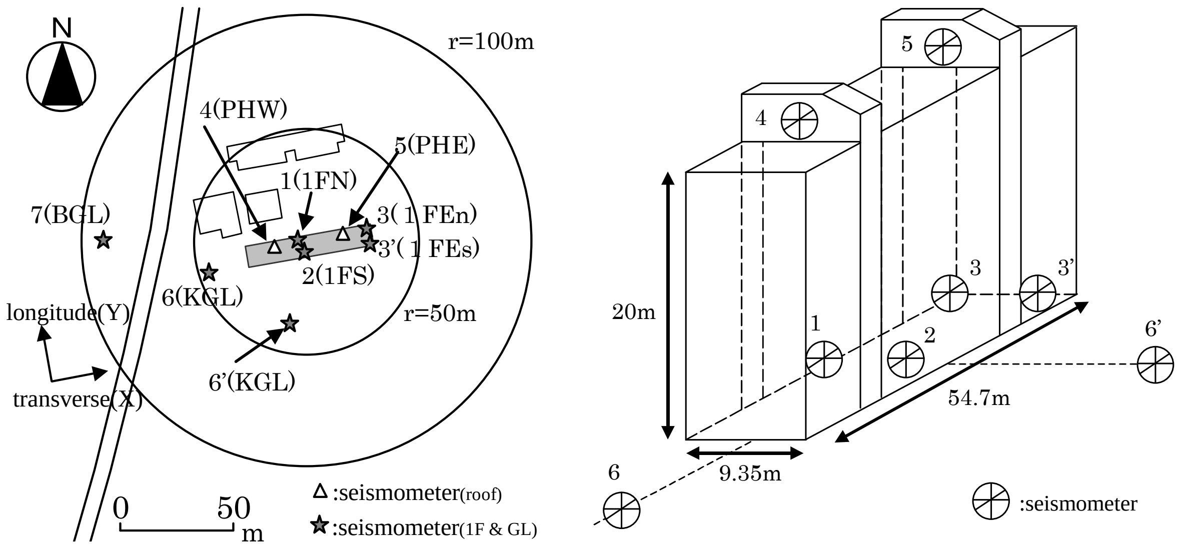

Figure1. Position of seismometer at KKC site

3. STRONG MOTION DATA OF THE 2011 EAST JAPAN EARTHQUAKE

On March 11, 2011, the East Japan Earthquake, a moment magnitude (Mw) of which is 9.0, occurred off the Pacific coast of the north-eastern Japan. It brought us disastrous damages mainly to the eastern Japan. Besides, the distinctive strong motion records for seismic engineering were provided.

At KKC of which the epicentral distance is 330 kilometers, the records caught by 6 seismometers showed strongest shaking as ever. According to damage inspection report, the damages of 1.5 mm wide crack were found on concrete walls, mainly on 1st and 2nd floor. The acceleration waveforms and its Fourier spectra in the longitudinal and transverse component on penthouse (PHW), the 1st floor (1FEn) and ground (KGL) are shown in Figure 2. The maximum value of acceleration, velocity and JMA (Japan Meteorological Agency) calculated seismic intensity are listed in Table 1.

Table 1. Strong motion data at KKC site

Position of seismometer	PHW	PHE	1FS	1FEn	1FEs	KGL
JMA Intensity	6.3	6.2	5.6	5.7	5.6	5.4
Max. Acc (m/s/s)	8.3	8.2	3.7	4.3	3.9	4.7
Max. Vel (m/s)	0.86	0.80	0.47	0.48	0.48	0.33

The maximum acceleration at penthouse exceeded 8 m/s/s, was more than 2 times bigger than 1st floor. On Fourier spectra of longitudinal direction, the period of 0.65 second predominate as predominant period of structure at PHW. Beside, the predominance periods of 0.21, 1.2 and 2.59 seconds were commonly recognized on all waves, could be considered to be originated by source and ground conditions.

As KKC building has rather long & slender configuration, it's expected the seismic records contain torsion and rocking type vibration. To separate these motions from recorded seismic motions, absolute time of records was adjusted considering arrival time of typical phase appear on each record. Then, the translational and torsional motions are reproduced by taking average and difference of two longitudinal horizontal component at the top of building, i.e., PHW and PHE. The torsional motion is converted into the value at the end of building considering distance of two seismometers and width of building. The rocking motions is reproduced and converted into the value at penthouse by rocking angle derived from two Up-down component, i.e., 1FEn and 1FEs, at 1st floor and vertical difference of height between penthouse and 1st floor.

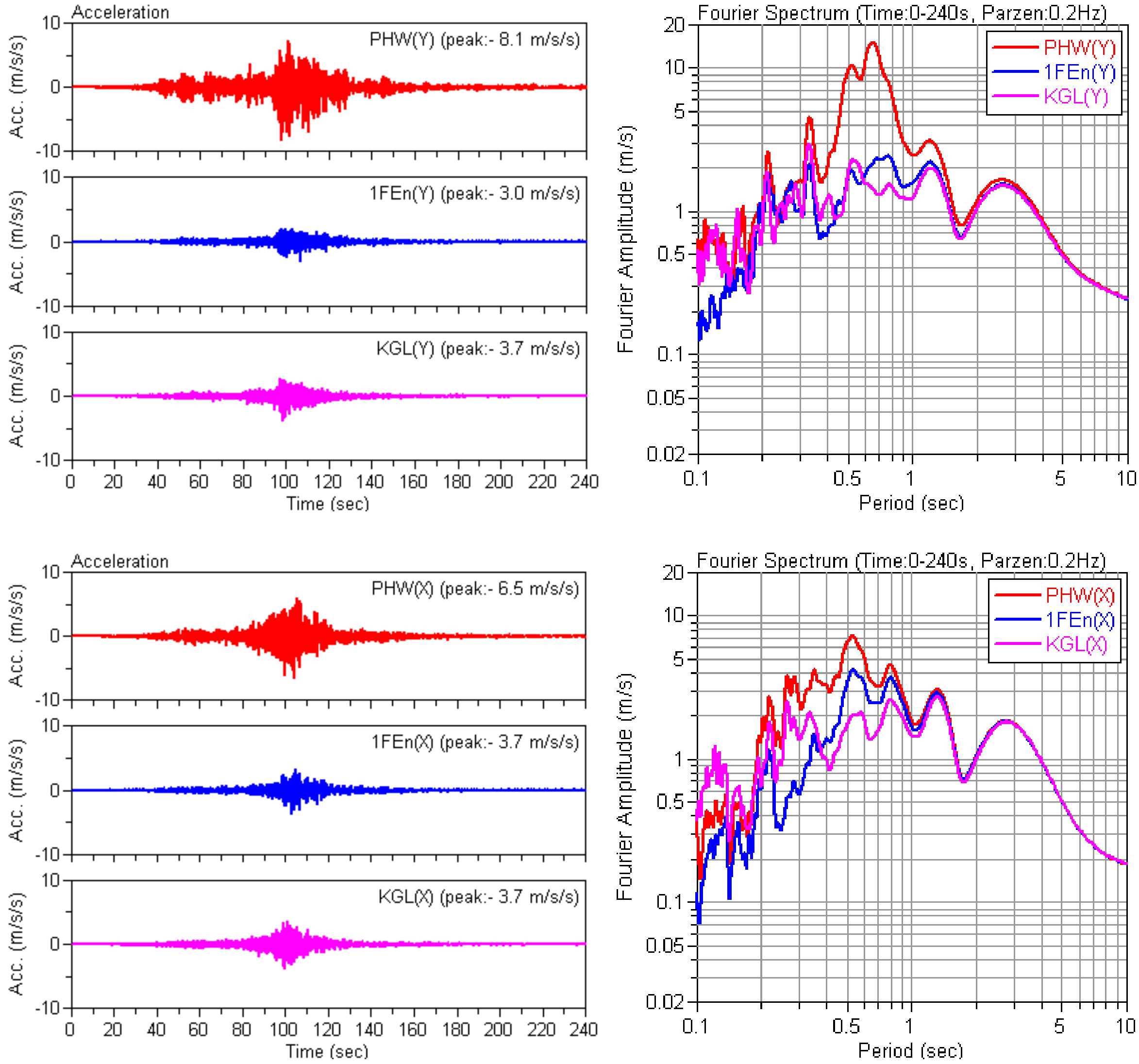

Figure 2. Acceleration waveforms on PHW, 1FEn and KGL and their Fourier spectra (Upper : longitudinal, Lower: transverse)

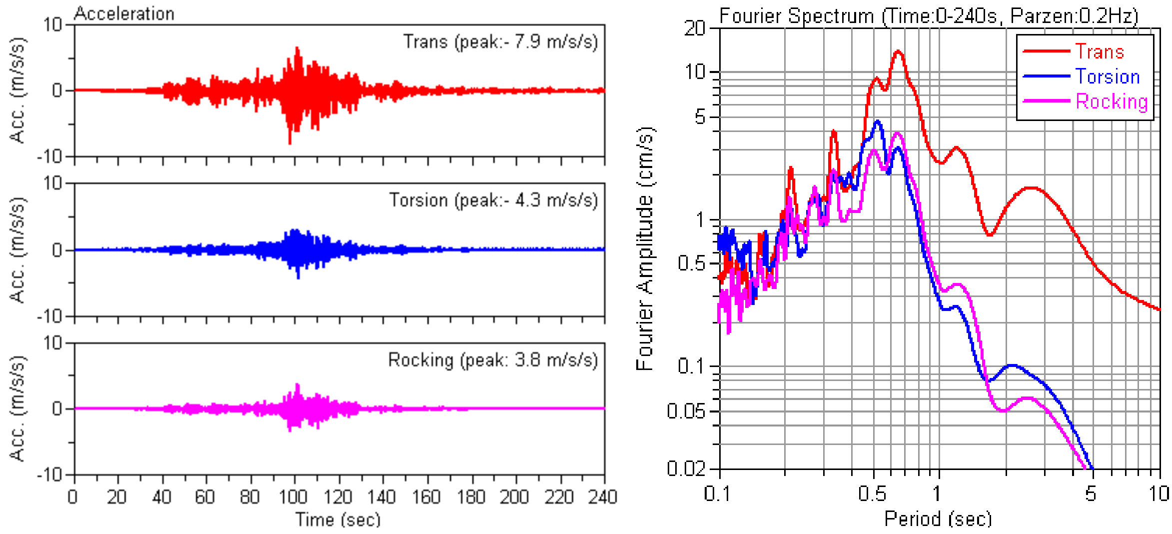

Figure 3. Reproduced Acceleration waveforms for the translational, torsional and rocking motions at penthouse and their Fourier spectra

Figure 3 shows separated translational, torsional and rocking motion at penthouse level and its Fourier spectra. The maximum acceleration of translational, torsional and rocking motion are 7.9, 4.3 and 3.8 m/s/s, respectively. The coupled predominant period of translational and rocking motion is 0.65 sec, and 0.53 sec in torsional motion. The longitudinal motion was mainly composed by translational motion.

It is reported that some building in which seismic observation is conducted by BRI showed variation of predominant period during the East Japan Earthquake (Kashima et al., 2012). KKC building is also expected to show similarity and non-stationary spectra of translational, torsional and rocking motion are examined. Figure 4 shows non-stationary spectrum with its waveform. The contour of spectrum is normalized by maximum amplitude of each of them in logarithmic scale and thick portion implies high amplitude. In case of translational motion, it shows approximately 0.5 to 0.6 sec predominant period while maximum acceleration is up to 2 m/s/s, before arrival of big phase on 90 sec. During big phase on 90 to 140 sec, the predominant period increases gradually till 0.7 to 0.8 sec and keeps 0.6 to 0.7 sec for a while, and then recovered 0.6 sec at 240 sec, end of the waveform. The similar variation is also recognized on rocking motion. In case of torsional motion, the pattern of variation is similar but predominant period is rather short. The predominant period of before and after the main phase were differ and became long, it is guessed that nonlinearity deformation on structure was generated during big phase.

4. VALIATION OF PREDOMINANT PERIOD THROUGH THE EAST JAPAN EARTHQUAKE

The records with rather high maximum acceleration at PHW till March 31, 2010 were examined and all of the vibration types show variation of predominant period depending on the maximum acceleration (Koyama et al., 2010), i.e., when the maximum acceleration is big, predominant periods become long. In order to examine the influence of the 2011 East Japan Earthquake on variation of predominant period, the earthquake records simultaneously observed at all stations are used. Those are 23 records, whose maximum accelerations at PHW are 0.38 to 8.13 m/s/s.

Figure 5 shows variation of predominant period defined from spectral ratio that divided Fourier spectrum at PHW by that at 1Fs or 1FEn. The horizontal axis of a graph shows Maximum acceleration at PHW and the vertical axis shows examined predominant period. The symbols are classified into 3, i.e., before "3.11" ("Before"), "3.11" and after "3.11" ("After") by the recorded period, where "3.11" implies the 2011 East Japan Earthquake. The approximations for "Before" and "After" are entered. It's clear that predominant periods before "3.11" show linear relation especially longitudinal direction. In the case of PHW/1F, longitudinal direction, it seems that the approximation for before "3.11" can explain the predominant period of the East Japan Earthquake (3.11). That is because there are three predominant period, 0.47, 0.53 and 0.63sec, were appeared on Fourier spectrum ratio and shortest one with highest amplitude was recognized as the predominant period. These three predominant periods were resulted from variation of predominant period during main phase. After "3.11", predominant periods get longer and linearity is decreased. Comparing intercept of approximation, predominant periods during "After" are 1.23 times longer that those of "Before" in longitudinal.

5. CONCLUSIONS

BRI is conducting earthquake observation on rather simple, long & slender configuration building, KKC. The records of the East Japan Earthquake showed changes of predominant periods during intense shaking. Comparing predominant periods, the variation of them before and after the Earthquake predominant period is recognized. It is expected that KKC building suffered damage to some extent. The relation of damage level with variation of vibration characteristics should be examined in the next step.

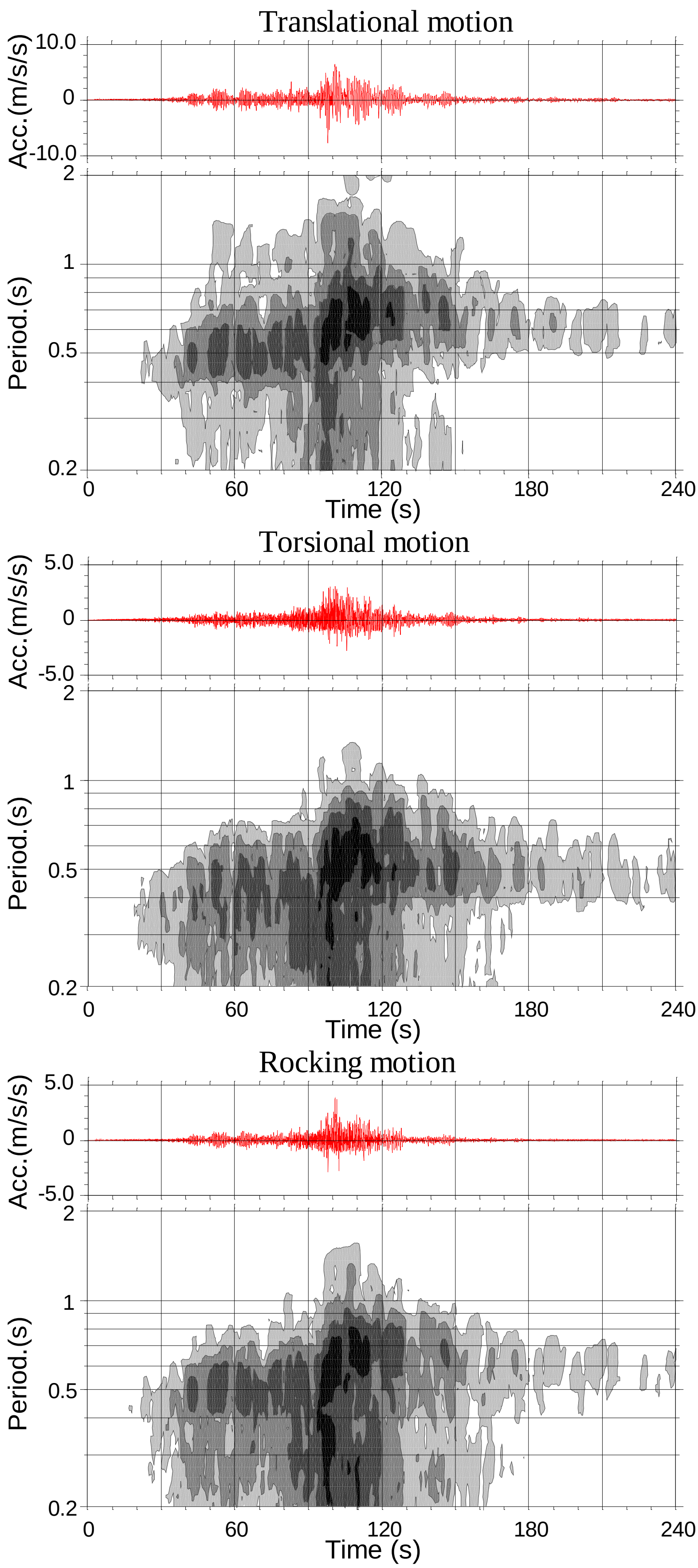

Figure 4. Non--stationary spectrum of translational, torsional and rocking motion

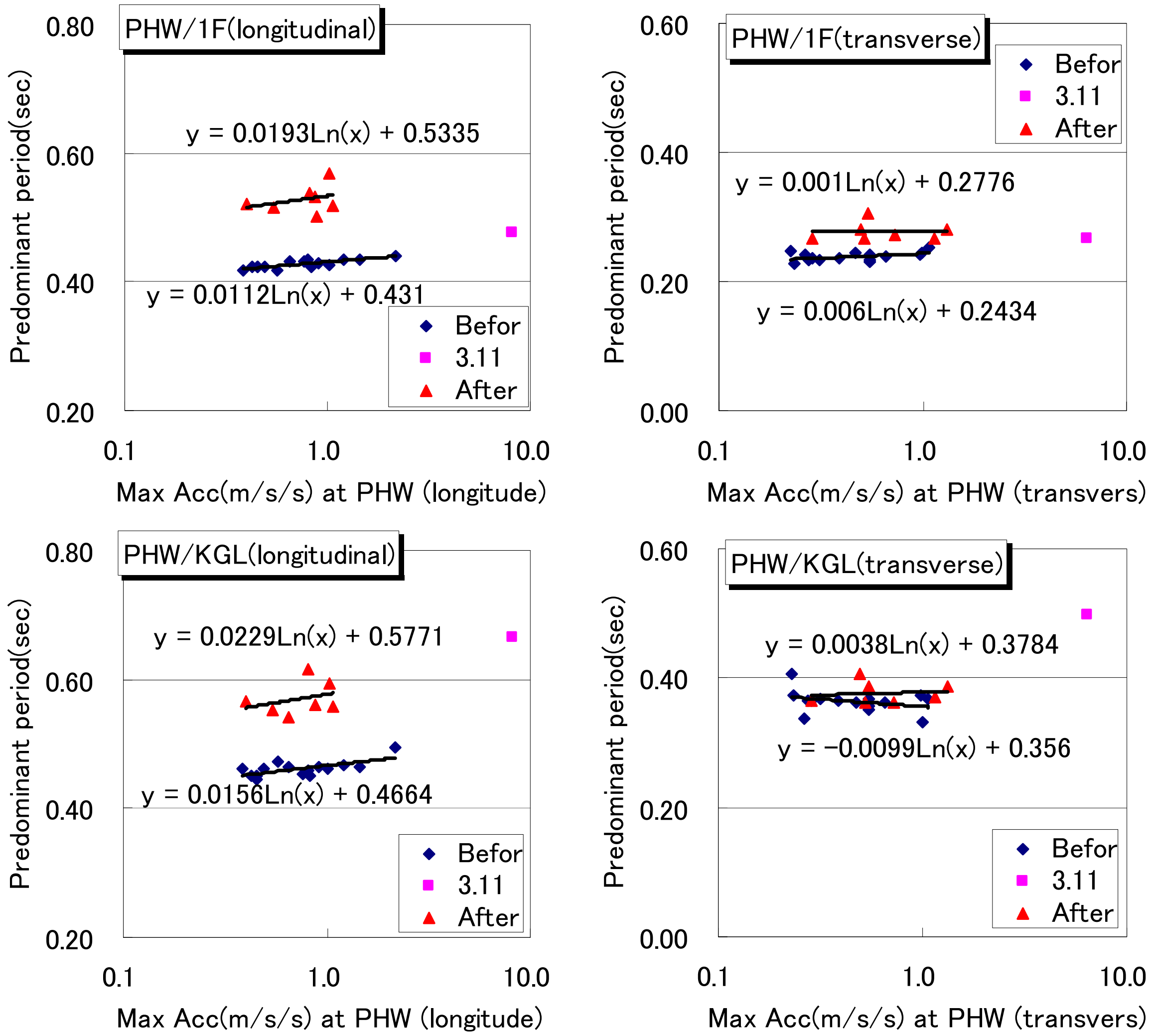

Figure 5. Variation of predominant period defined by spectral ratio

ACKNOWLEDGEMENTS
The author expresses his gratitude to the owners, administrators and users of the target buildings for their deep understanding and considerable cooperation. Some figures are plotted using Generic Mapping Tools (GMT) developed by Wessel and Smith (1998)

REFERENCES

Kashima, T., Koyama, S. Okawa, I. and Iiba, M. (2012). Strong Motion Data Recorded in Buildings damaged by the 2011 Great East Japan Earthquake. Proceedings of the International Symposium on Engineering Lessons Learned from the 2011 Great East Japan Earthquake, 1169-1179.

Koyama, S., Iiba, M. and Yasui, M. (2010). Study on Dynamic Behavior of Building which has Long and Slender Configuration, -Part1- Vibration Characteristics of Earthquake Records. Proceedings of the 13th Japan Earthquake Engineering Symposium (in Japanese)

Wessel, P. and Smith, W. H. F. (1998). New, improved version of Generic Mapping Tools released. EOS Trans. Amer. Geophys. U., vol. 79 (47), 579.