On the dynamic characteristics of subsurface structure at a university campus located at a seaside area

Y. Nakajima, T. Mori & N. Maeda
Kanto Gakuin University, Japan

SUMMARY:
The 2011 off the Pacific coast of Tohoku Earthquake with M9.0, which occurred on March 11, 2011, attacked Tohoku and Kanto areas and brought severe damages. Strong motion records were obtained at many points. In Kanazawa Hakkei Campus of Kanto Gakuin University in Yokohama City, authors also recorded the ground motions caused by the main shock and aftershocks. The seismograms observed at one of the stations with thick alluvial deposits usually shows predominant periods of 0.8s, which correspond to the predominant period obtained from the microtremor observation. As a result of the analysis using response spectra, we found that the predominant period of the main shock becomes longer, or about 1.0s, and that the predominant periods of the aftershocks are correlated with the magnitudes of the input seismic motions. We think this result is caused by nonlinear characteristics of the subsurface layers.

Keywords: Seismic observation, Predominant period, Nonlinear effect

1. INTRODUCTION

Kanazawa Hakkei Campus of Kanto Gakuin University in Yokohama City, Japan is located in a seaside area, whose size is about 250m by 750m. The greater part of the campus, whose size is about 250m by 500m, is reclaimed land and flat. We have many geological borehole logs for building construction in the campus, for the discussion of the details of the subsurface structure. Compiling the materials of borehole logs, we found that the campus has a complicated relief of basement (Takahasi and Kawa, 2000, Nokubo and Saito, 2006). We think the campus as a good experimental field for studying seismic ground motion characteristics, and we carried out seismic observations, microtremor observations, and elastic wave surveys.

As the result of the seismic observation, the differences of JMA (Japan Meteorological Agency) instrumental seismic intensity among the observation points are about 1 at most (Maeda et al., 2006). The differences of seismic intensities correspond to the depth of the top surface of the basement at the observation site, and the seismograms observed at the sites with the large intensity show long predominant periods of 0.8s, which correspond to those obtained from the microtremor observation (Nakajima et al., 2000) and estimation from velocity model of the campus (Kamata, 2005).

The 2011 off the Pacific coast of Tohoku Earthquake with M9.0, which occurred on March 11, 2011, attacked Tohoku and Kanto areas and brought severe damages. In Kanazawa Hakkei Campus of Kanto Gakuin University, authors recorded the ground motions caused by the main shock and aftershocks. The amplitudes of ground motions caused by the main shock are the largest ones since we started the seismic observation in 1996. At one of the stations with thick alluvial deposits, we observed a longer predominant period for the main shock than weak earthquakes. We think that this elongation of the predominant period caused by nonlinear characteristics of the subsurface layers. In this study, we investigated variation of the predominant periods for the seismograms in order to clarify the characteristics of nonlinear effect at the campus.

2. SEISMIC OBSERVATION SITE

2.1. Kanazawa Hakkei Campus of Kanto Gakuin University

Figure 1 shows elevation of the top surface of the basement with seismic observation points. The western part, whose size is about 250m by 500m, is reclaimed land and flat, and the eastern part is higher place with elevation of 6m to 8m, which consists of sedimentary rocks of the early Pleistocene. The basement of the western part also consists of the sedimentary rocks of the early Pleistocene. There is a hill area composed of rocks of the early Pleistocene to the south of the campus. The ridges are extended to the underground of the campus, and we can find the several underground ridges. A large valley runs from SSW to NNE. The lowest elevation of the top surface of the basement is about 30 m below the sea.

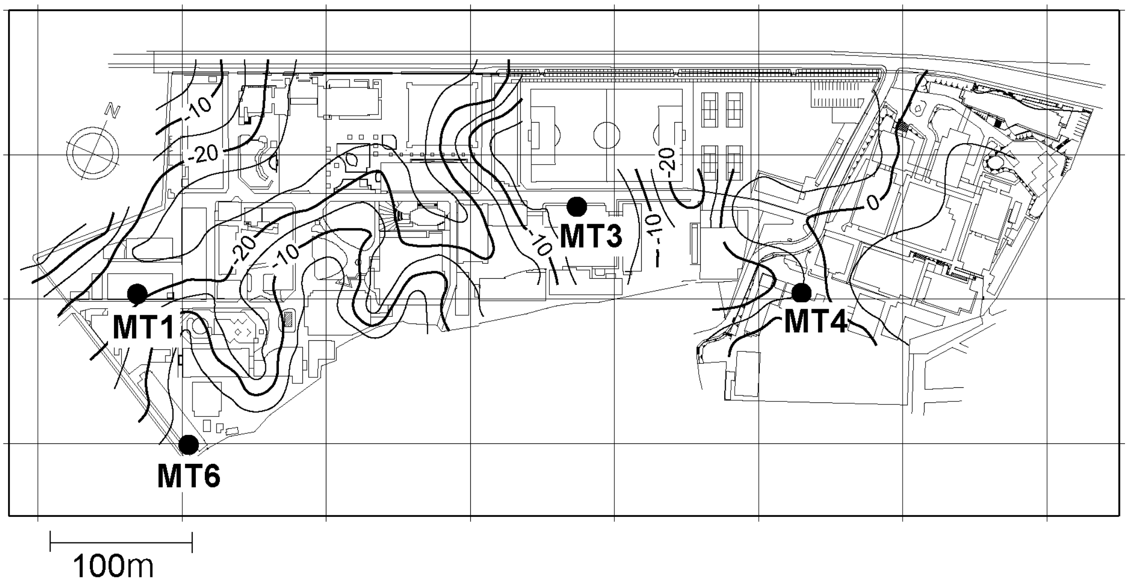

Figure 1. Elevation of top surface of basement with seismic observation points (Maeda et al., 2006)

2.2. Seismic Observation

Figure 1 shows four seismic observation points. Seismographs are set on first floor or basement floor of building except MT6. The seismograph has nine channels, consisting of three components of low gain velocity, high gain velocity, and acceleration. Those recordable ranges are up to 100cm/s, 5cm/s, and 1000cm/s^2, respectively. The frequency characteristic of the seismograph is flat from 0.025Hz to 70Hz. Seismograms are acquired with event trigger recording with a sampling frequency of 100Hz. The setting conditions of the seismographs are summarized in Table 1.

Table 1. Setting condition of seismographs

observation point	setting condition
MT1	1st floor of 5 story building
MT3	1st floor of 2 story building
MT4	basement floor of 2 story building
MT6	2nd floor of 2 story building

2.3. Characteristics of Seismograms

Maeda et al. (2006) found that the predominant period of horizontal components of seismograms observed at MT1 is about 0.8s. Figure 2 and Figure 3 show the seismograms observed at MT1 and

MT3, respectively, for the earthquake with magnitude 5.1 whose epicenter is located in the E off Izu Peninsula Region. The amplitudes of horizontal components of the seismograms at MT1 are larger than those at MT3 by a factor of about 4, and the predominant period at MT1 looks longer than that at MT3. Figure 4 shows the velocity response spectra for the horizontal components shown in Figures 2 and 3. The predominant period of horizontal components at MT1 is about 0.8s, while that at MT3 is about 0.4s. These values of the predominant period correspond to those obtained from the microtremor observation (Nakajima et al., 2000).

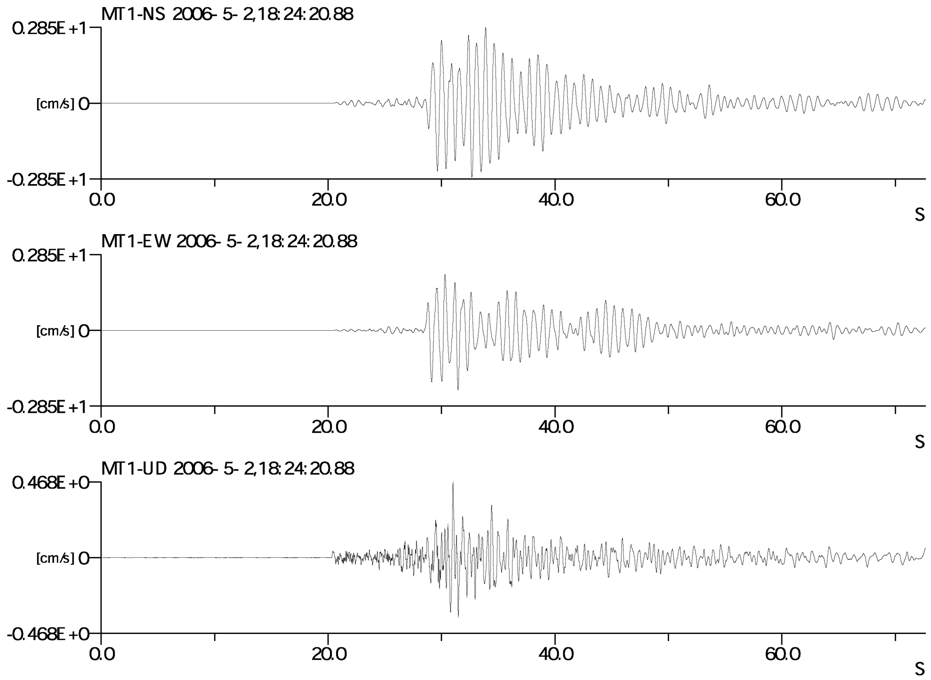

Figure 2. Velocity seismogram observed at MT1 for the earthquake in E off Izu Peninsula Region (Maeda et al., 2006)

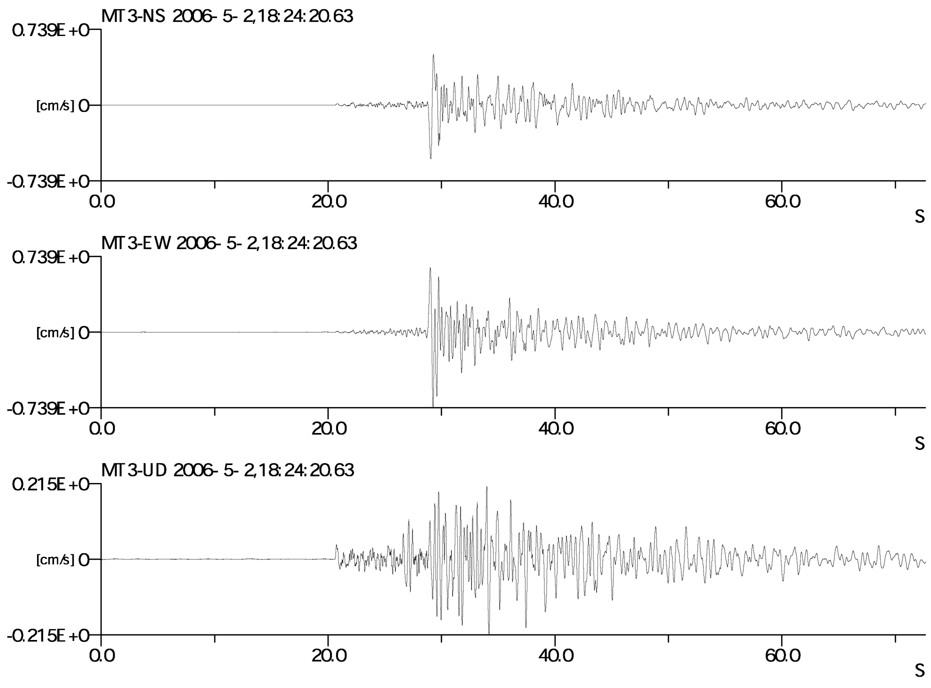

Figure 3. Velocity seismogram observed at MT3 for the earthquake in E off Izu Peninsula Region (Maeda et al., 2006)

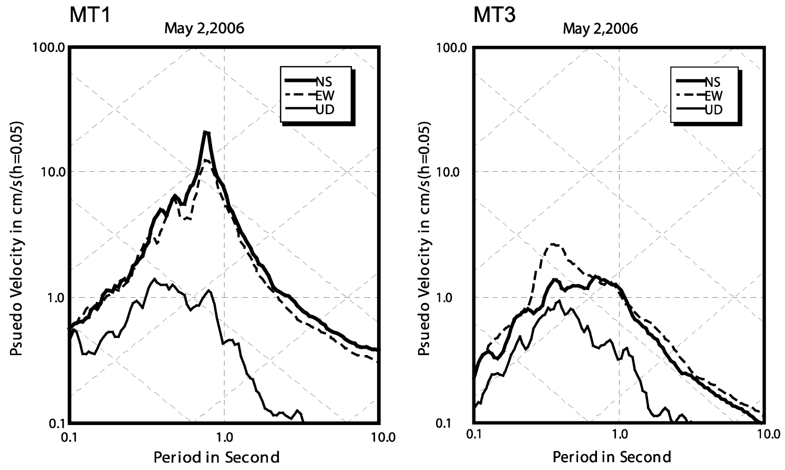

Figure 4. Response spectra for seismograms shown in Figures 2 and 3 (Maeda et al., 2006)

Kamata (2005) constructed a one-dimensional velocity model at point, where the depth of top surface of basement is 26.4m, by using empirical formulae for the borehole logs, and estimated predominant period and seismic amplification at 0.78s and 4.8, respectively. The value of 0.78s of predominant period corresponds to the predominant period of 0.8s at MT1, where the depth of top surface of basement is 21m.

3. SEISMOGRAMS THE 2011 OFF THE PACIFIC COAST OF TOHOKU EARTHQUAKE

3.1. Seismograms of the main shock

Figure 5 shows the epicenters of the aftershocks with magnitude of 6.0 or more in March and April 2011 and the location of Kanazawa Hakkei Campus of Kanto Gakuin University. The length of focal area was estimated at about 500km. Kanazawa Hakkei Campus is located about 420km away from the epicenter.

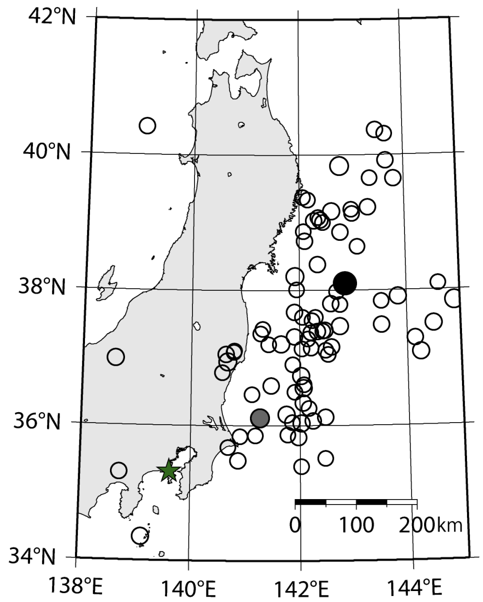

Figure 5. Epicenters of aftershocks with M6.0 or more in March and April 2011. A solid circle represents the epicenter of the main shock. A star symbol shows the location of Kanazawa Hakkei Campus of Kanto Gakuin Universiy. Epicenters are determined by JMA.

We obtained the seismograms of the main shock except the first motions for four stations. Figures 6 and 7 show the velocity seismograms of MT1 and MT3, respectively.

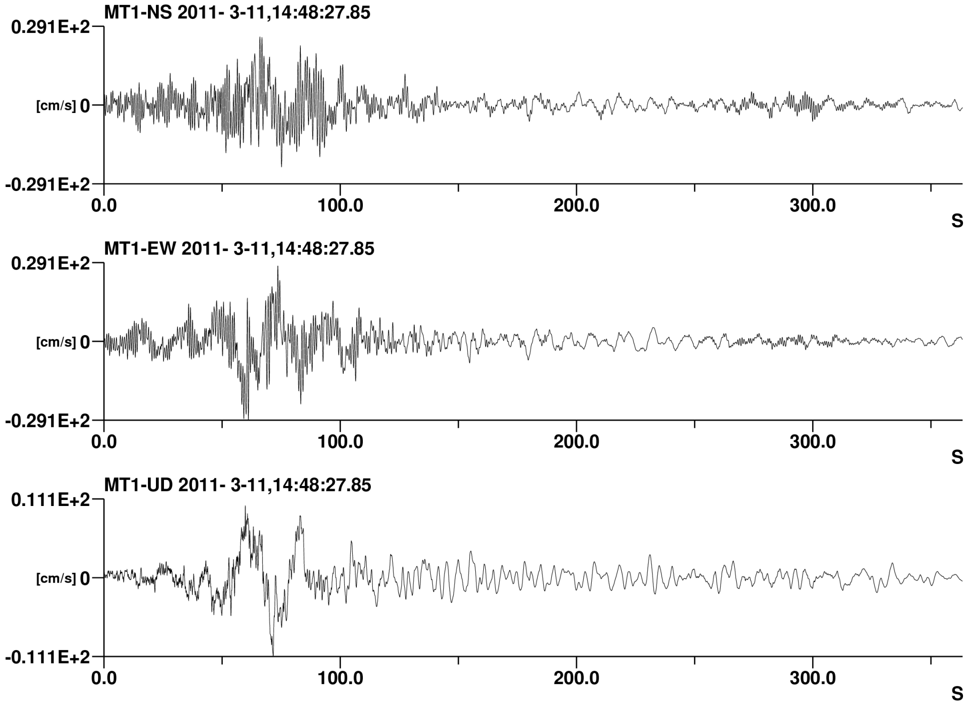

Figure 6. Velocity seismograms of the main shock at MT1

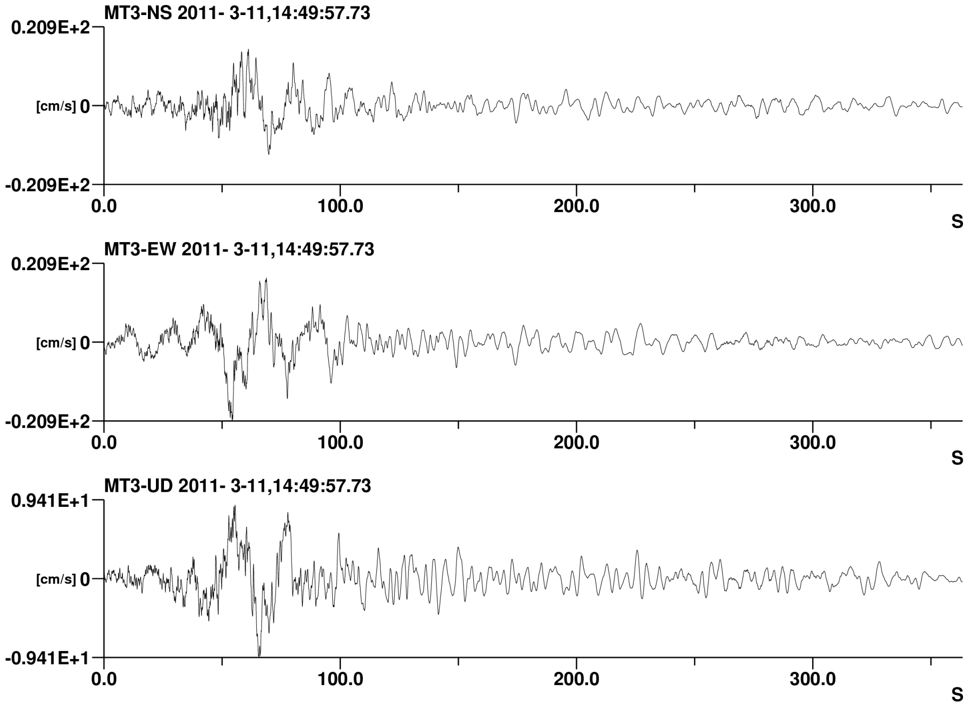

Figure 7. Velocity seismograms of the main shock at MT3

The waveforms of the seismograms are quite different in short period range. Table 2 shows JMA instrumental seismic intensity for each station. The difference of intensities between MT1 and MT3 are 1.1 because of difference of soil conditions. The difference corresponds with the result of Maeda et al. (2006).

Table 2. Instrumental seismic intensities for the main shock

observation point	instrumental seismic intensity
MT1	5.2
MT3	4.1
MT4	4.4
MT6	4.5

3.2. Response spectra for the main shock and aftershocks

Figure 8 shows velocity response spectra for the main shock at MT1. For the main shock the predominant periods of horizontal components are around 1.0s, while the predominant periods for horizontal are shows 0.8s in the previous work (Maeda et al., 2006), as shown in Figure 4.

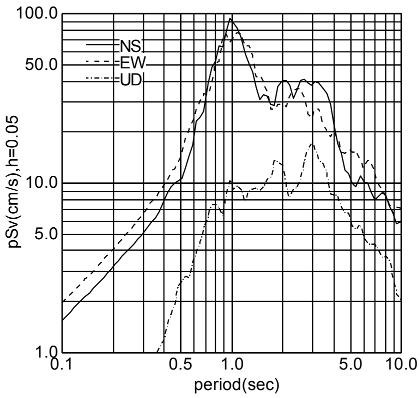

Figure 8. Velocity response spectra of the main shock at MT1

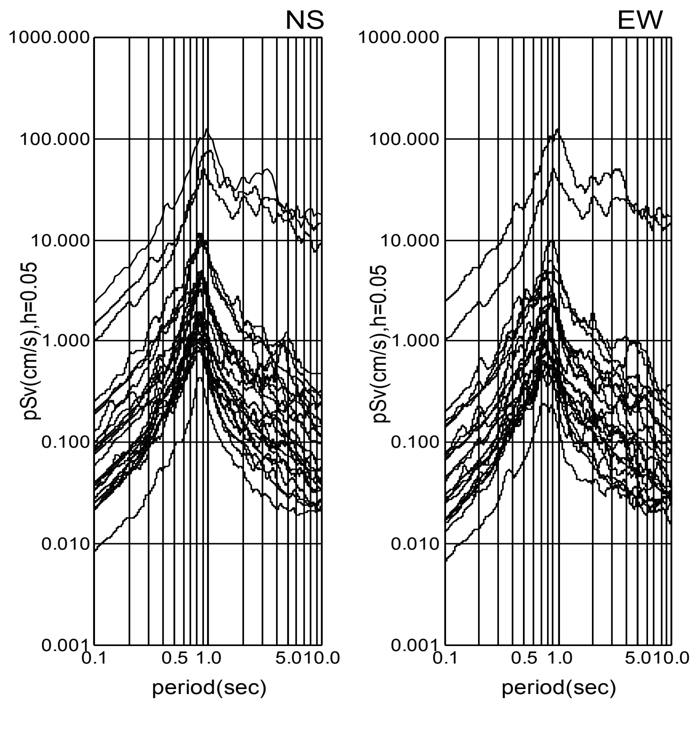

Figure 9. Velocity response spectra of the main shock and aftershocks at MT1

Figure 9 shows velocity response spectra of horizontal components for the main shock and the aftershocks. As shown in Figure 9, the predominant frequencies are scattered in the range between 0.7s and 1.0s according to the magnitude of the velocity spectra. Figure 10 shows the predominant periods versus magnitude of earthquakes. As shown in Figure 10, predominant period becomes longer according to magnitude of earthquakes. These results show that shear modulus decreased by large magnitude of ground motions.

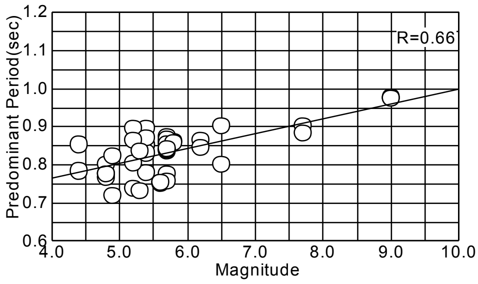

Figure 10. Predominant period versus magnitude of earthquake

4. DISCUSSION

Predominant period is roughly estimated by means of law of quarter wavelength for the case of two-layer model. The predominant period T is expressed as

$$T = \frac{4H}{V_S} \quad , \tag{1}$$

where H and V_S represent thickness and S wave velocity of upper layer. Shear modulus G is written as

$$G = \rho {V_S}^2 \quad , \tag{2}$$

where ρ represents density of upper layer. Consequently, elongation of predominant period is attributed to decrease of S wave velocity or shear modulus of the upper layer.

Let G_0 and T_0 be shear modulus and predominant period for weak ground motion, respectively, the ratio of G/G_0 is written as

$$\frac{G}{G_0} = \left(\frac{T_0}{T}\right)^2 \quad . \tag{2}$$

Putting 0.8s and 1.0s at T_0 and T, respectively, the ratio of G/G_0 is estimated at 0.64. We are able to explain the elongation of predominant period of the main shock by decrease of shear modulus of about 36%. This amount of decrease of shear modulus corresponds to strain from 0.05% to 0.1 % for clay or sand.

5. CONCLUDING REMARKS

We observed seismograms of the main shock of the 2011 off the Pacific coast of Tohoku Earthquake and its aftershocks. In Kawazawa Hakkei Campus of Kanto Gakuin University, we found the predominant periods of 0.8s for weak earthquakes. For the main shock, we found that the predominant period of the main shock becomes longer, or about 1.0s, and that the predominant periods of the aftershocks are correlated with the magnitudes of the input seismic motions. We think this elongation is caused by nonlinear characteristics of the subsurface layers.

In this study, we did not obtain the relationship between predominant period and magnitude of the incident seismic motion at bedrock. We will re-analysis the seismograms used in the past study, and clarify the relationship.

AKCNOWLEDGEMENT

We used hypocenter data of Japan Meteorological Agency. Some figures are made using the GMT (Wessel and Smith, 1995).

REFERENCES

Kamata, Y. (2005). A generation of simulated earthquake ground motion by an empirical method. **Graduation thesis, Dept. Architecture, Faculty of Engineering, Kanto Gakuin University**.

Maeda, N., Nakajima, Y., Matsuda, I., and Abeki, N. (2006). Evaluation of the seismic amplification characteristics at a university campus with complicated relief of basement. **Proceedings of Third ESG Symposium**, 443-451.

Nakajima, Y., Abeki, N., and Watanabe, D. (2000). Study on the stability of H/V spectral ratio of microtremor in short period range for the estimation of dynamic characteristics of surface geology. **12WCEE**, 2094.

Nokubo, Y. and Saito, N. (2006). Surface geology in Kanazawa Hakkei Campus of Kanto Gakuin University. **Graduation thesis, Dept. Civil Engineering, Faculty of Engineering, Kanto Gakuin University**.

Takahashi, M. and Kawa, H. (2000). Microtremor observation in the Mutsu’ura Campus of Kanto Gakuin University -- Correspondence to the surface geology --. **Graduation thesis, Dept. Architecture, Faculty of Engineering, Kanto Gakuin University**.

Wessel, P. and Smith, W. H. F. (1995). Free software helps map and display data, **EOS, 72-441**, 445-446.