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PRELIMINARY STUDY OF GROUND MOTION CHARACTERISTICS IN FURUKAWA DISTRICT, JAPAN, BASED ON VERY DENSE SEISMIC-ARRAY-OBSERVATION

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ABSTRACT: We perform very dense seismic-array-observation in Furukawa district, Japan, where severe damages occurred due to ground motions during the 2011 off the Pacific coast of Tohoku earthquake. Low-cost sensors form a seismic array with an interval of less than 500m, and data is sent to a remote server through the Internet connection in real time. Ground motion records exhibit non-uniform distribution of PGA and PGV in Furukawa district.

Key Words: Great East Japan earthquake, Ground motion, Furukawa, Seismic array observation

INTRODUCTION

On March 11, 2011, off the Pacific coast of Tohoku Earthquake (Mw9.0) hit eastern part of the main land, Japan, and killed more than ten thousand of persons mainly due to great Tsunami. On the other hand, strong ground motions during the earthquake were observed in almost the whole region in Japan by K-NET, KiK-net organized by NIED, and the other seismometer networks. At least 17 of K-NET and KiK-net stations observed over 980 cm/s^2 of PGA in horizontal components, and two stations observed over 6.5 of seismic intensity on JMA scale. However, damaged areas due to the ground motion do not correspond to either the large PGA or seismic intensity sites (e.g., Goto and Morikawa, 2012).

We focus on Furukawa district of Osaki city, where severe residential damages occurred at the downtown. Ground motion records in the downtown area are available at two stations, MYG006 (K-NET) and JMA Furukawa (JMA). The damage level was different between the areas within several hundred meters from MYG006 and JMA Furukawa stations, which are about 1 km away from each other. The severe damages were concentrated within the area about 1x1 km^2 including the JMA station. This implies that the ground motion characteristics were not uniform in sub-kilometer scale, and the existing two stations are not enough to clarify the distribution.

We scattered dozens of low-cost seismometers, namely ITK sensor, around the area about 2x2 km^2 in Furukawa district. The observed data are sent to the remote server through the Internet connection in real time. The seismometers were installed beside the volunteer's houses introduced by Osaki city office. The volunteers can access the interactive information service, namely on-line viewer system.

In this study, we analyze the ground motion data of minor earthquakes, and show the differences of ground motion characteristics as preliminary results.

GROUND MOTIONS DURING 2011 EARTHQUAKE

During off the Pacific coast of Tohoku Earthquake, severe structure damages occurred in Furukawa district of Osaki city, where is located at about 35km north from Sendai city (Fig.1). Furukawa station of JR Tohoku Shinkansen and JR Riku-u-tosen in located at the center of the district. There are four seismic stations, K-NET MYG006, JMA Furukawa, Furukawa Gas, and NILIM Furukawa. However, record during the main shock at Furukawa Gas was unfortunately missed (Goto *et al.*, 2011). K-NET MYG006, JMA Furukawa and NILIM Furukawa observed PGAs of 583cm/s^2, 568cm/s^2, and 483cm/s^2, and the seismic intensities on Japan Meteorological Agency (JMA) scale of 6.1, 6.2 and 6.1, respectively.

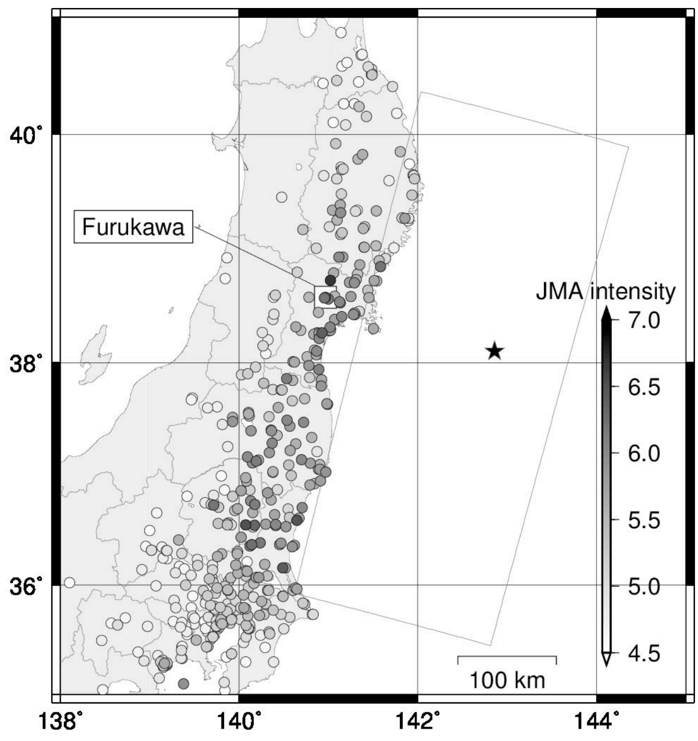


Fig. 1 Location of Furukawa district and distribution of seismic intensity on JMA scale

Damage distribution based on the reconnaissance immediately after the main shock is reported in Goto and Morikawa (2012). Figure 2 shows the details of damage distribution and the location of seismic stations, K-NET MYG006 and JMA Furukawa. Furukawa Gas is located at about 1 km west away from the area, and NILIM Furukawa is located at about 2 km east away from the area. Damages due to the liquefaction were observed in the western area of JR Furukawa station, and ones due to the ground motion were observed in the area neighbor to the liquefaction area.

The damage level was different between the areas within several hundred meters from K-NET MYG006 and JMA Furukawa stations, which are about 1 km away from each other. The severe damages were concentrated within the area about 1x1 km^2 including the JMA station. We have no clear reasons, e.g., difference of structure types, difference of ground motions, etc. Goto and Morikawa (2012) pointed out the difference of ground motions recorded at K-NET MYG006 and JMA Furukawa. This implies that ground motions are not spatially uniform in the area.f

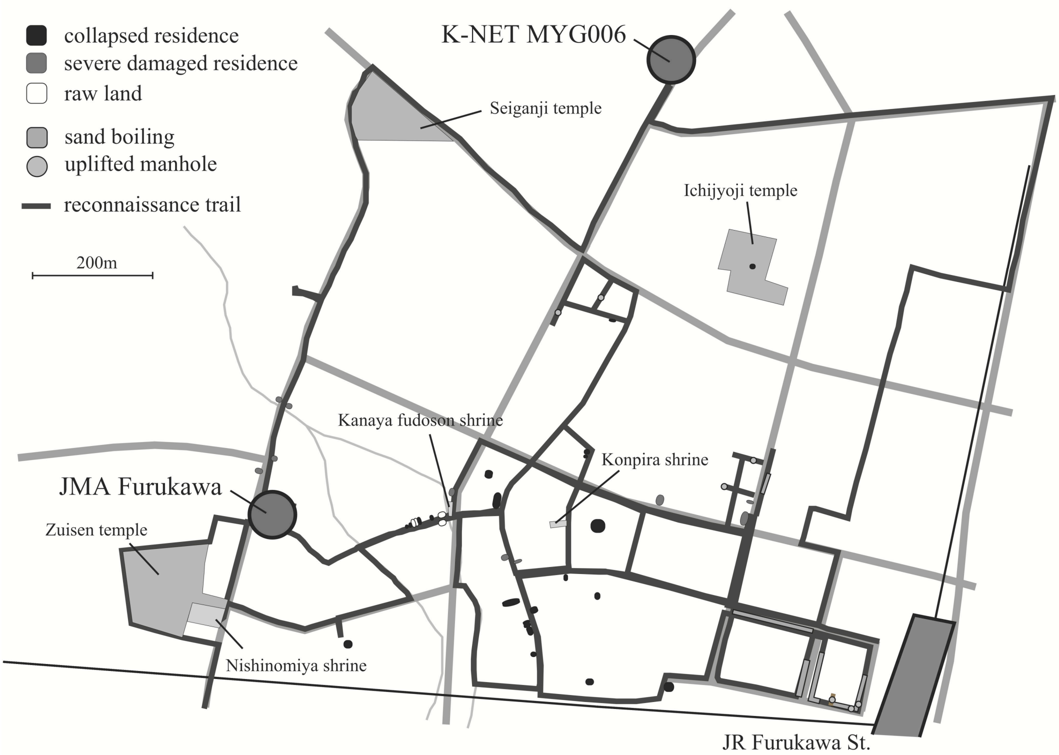


Fig. 2 Location of seismic stations, K-NET MYG006 and JMA Furukawa, and significant damages in Furukawa district

VERY DENSE SEISMIC-ARRAY-OBSERVATION

We cannot give more detailed discussion without the actual records of ground motions. In order to quantify the spatial variation of the ground motion characteristics, we develop very dense seismic-array-observation in the Furukawa district.

We adopt low-cost seismometers, namely ITK sensor, to form the array observation. The sensor requires AC power supply and Internet connection for data streaming. The original system of ITK sensor uses the NTP (network time protocol) to synchronize the inner clock. NTP supports enough accuracy in a closed network system, however, it is not enough in a case where the packets of NTP pass through gateway or router. To insure the time accuracy, we modified the ITK system to adjust to the clock signal from GPS (global positioning system).

We asked for cooperation of citizens living in Furukawa district through Osaki city office. We offered the volunteers two terms in order to participate the project: 1) appropriate spaces with AC power supply and 2) Internet connection. A number of volunteers gradually increase in setting up the sensors. As a result, we have installed 19 sensors during Sep. to Dec., 2011. Most of sensors are located inside of 2x2 km^2 in Furukawa district, as shown in Fig.3. The interval of sensors is less than about 500 m. The dense array is really unique as an application of the seismic sensor network. Some of the sensors are set very closely such as Site F06 and F07. They are located inside of one resident premise; one is set on the original ground and the other is set on the improved ground.

The sensors are fixed on a concrete slab using gypsum. The sensor and a few components of the system are packed into one box, as shown in Fig.4. All of the sensors are oriented to north, however, the accuracy of the bearings is not guaranteed. After the installation, we corrected the bearings using the observed data under an assumption that the seismic waves have very few spatial variations in low frequency components.

The observed data is sent to remote sever successionally through the Internet connection. The data are stored as one-minute binary files. Therefore, we can access the real-time data without picking up the storage data at the actual places.

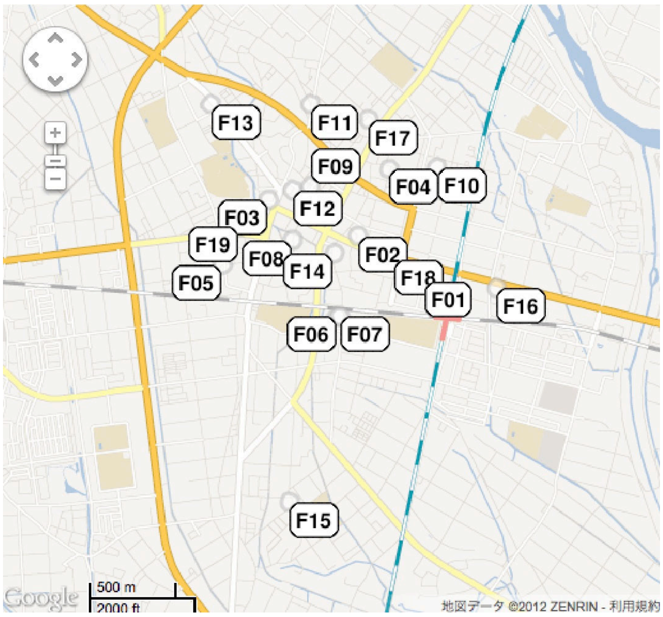


Fig. 3 Sensor locations in Furukawa district.

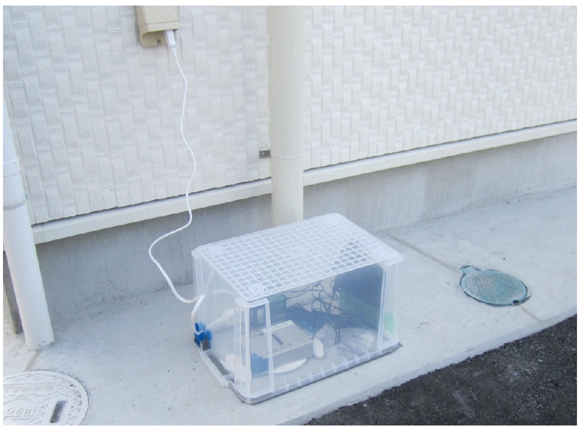


Fig. 4 Appearance of sensor and system components.

IMPLEMENTATION OF ON-LINE VIEWER SYSTEM

In compensation for the volunteer, we provide pseudo real-time information of seismic intensity through an on-line viewer system, which is developed using the real-time data sent from the local ITK sensors.

The real-time data is stored as one-minute binary files, as mentioned above. Seismic intensities on JMA scale corresponding to the one-minute data are calculated in every one-minute. The process is registered on job scheduler in a main server. If more than half of sensors observe the intensity over 0.0, the process turns on a flag of event trigger. At the same time, another process start to capture the data from one-minute ahead of the trigger minutes until one-minutes behind of the time when more than half of sensors observes less than 0.0. The process adds the detected event to file, namely event list file, and also the intensities of each sensor to another file, namely intensity list file, generated in JSON (JavaScript Object Notation) format.

On-line viewer system displays the distribution of seismic intensities on the Google Maps (Fig.5). Initially, it displays the distribution corresponding to the last event, and users can rewind at most 100 events. The system asynchronously controls the display depending on user actions by using Google Maps API and the technique of Ajax.

The system is available to access from Web browsers. Volunteers can view the intensity distribution as the same with the usual Web site. When the sensors observe the event, the display is automatically updated within one-minute.

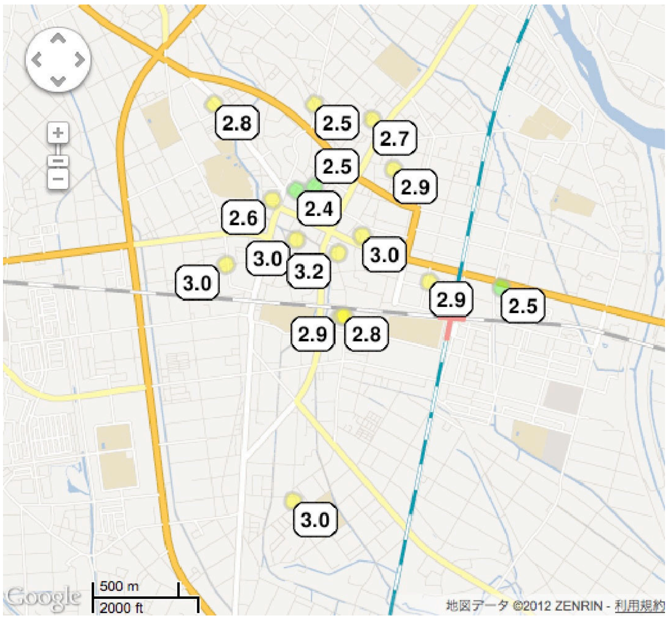


Fig. 5 On-line viewer system displaying the distribution of seismic intensities.

OBSERVED DATA

A number of events detected by the above system are over 100 until the end of Jan. 2012, whereas records at K-NET MYG006 for all of the events are not available. After selecting efficient S/N data from the records at MYG006, only 22 of them are available.

We compare PGA and PGV observed at each sensor and K-NET MYG006. Figure 6 show PGA and PGV ratios relative to MYG006 in horizontal components. Points correspond to each event, and the error bars indicate the range in standard deviations of log(PGA ratio) and log(PGV ratio), respectively. Amplifications of PGA and PGV depend on the sensor locations. Especially, F03, F09, and F12 indicate less, whereas F02, F04, F05, F08, and F14 indicate larger PGA and PGV relative to those at MYG006.

We focus on two significant events observed in the array: #E1 on Dec. 10th, 2011 and #E2 on Jan. 1st, 2012. Figure 7 show accelerograms in East-West component of the two events. #E1 (Mj4.7) is the largest aftershock of the Tohoku earthquake after installation of the array, and #E2 (Mj7.0) is deep-focus earthquake with the depth of 400km. The durations and envelopes are similar independent of the sensors, whereas the phases are different. Figure 8 shows Fourier amplitudes of the accelerograms in EW component during #E2. This clearly shows the difference of sensor performance in low frequency component. This implies that ITK sensors do not guarantee the performance lower than 0.3Hz.

Figure 9 show the spectrum ratio in horizontal components of F01-F19 sites relative to F17 site. The records at F17 are assumed to be almost same with the records at K-NET MYG006 because F17 is located close to MYG006 in a distance of about 65m. Spectrum ratios for both events are similar to each other. It implies that the spectrum ratio almost corresponds to the relative site amplification because the site amplification is independent of the hypocenter location. Peak frequencies of the spectrum also vary depending on the sensor locations. Significant peaks around 3Hz are recognized at F01, F02, F04, F05, F06, F07, F08 and F14.

The differences of the spectrum ratios reflect the differences of shallow subsurface structures. We have just started to construct the model to satisfy the spectrum ratios.

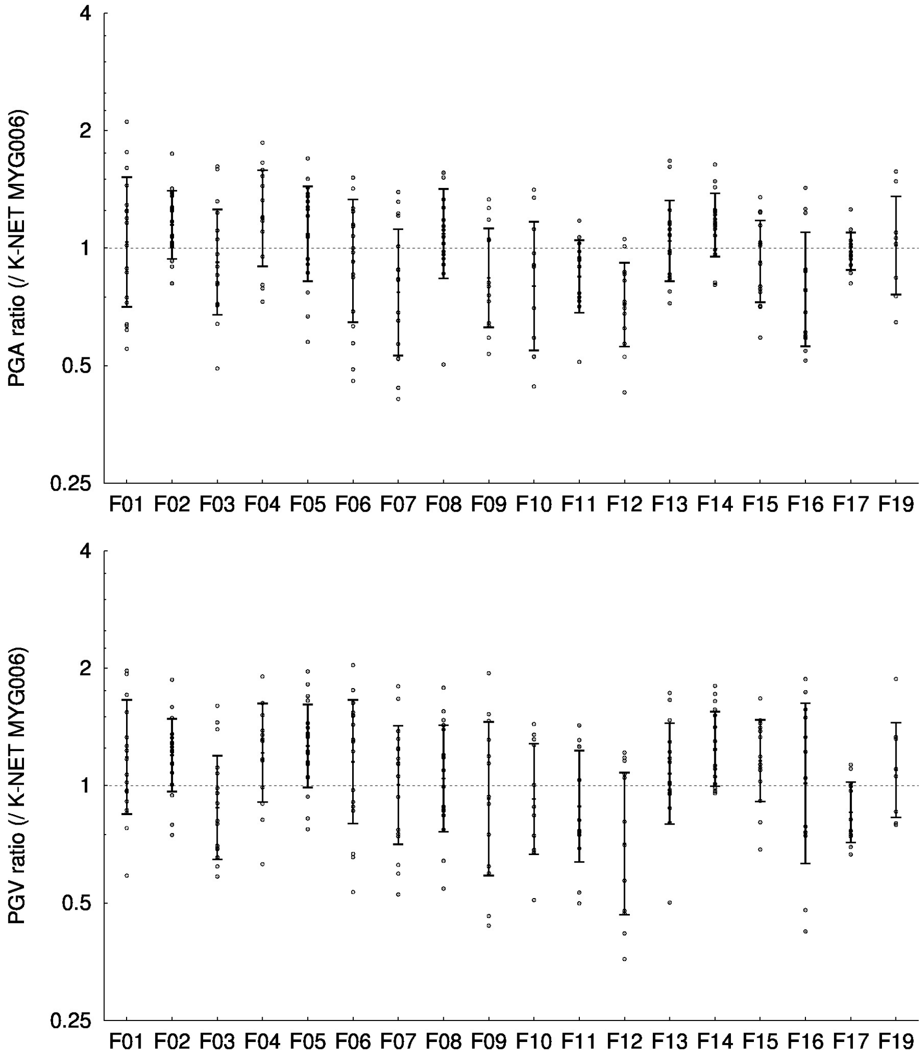


Fig. 6 PGA and PGV ratios to K-NET MYG006.

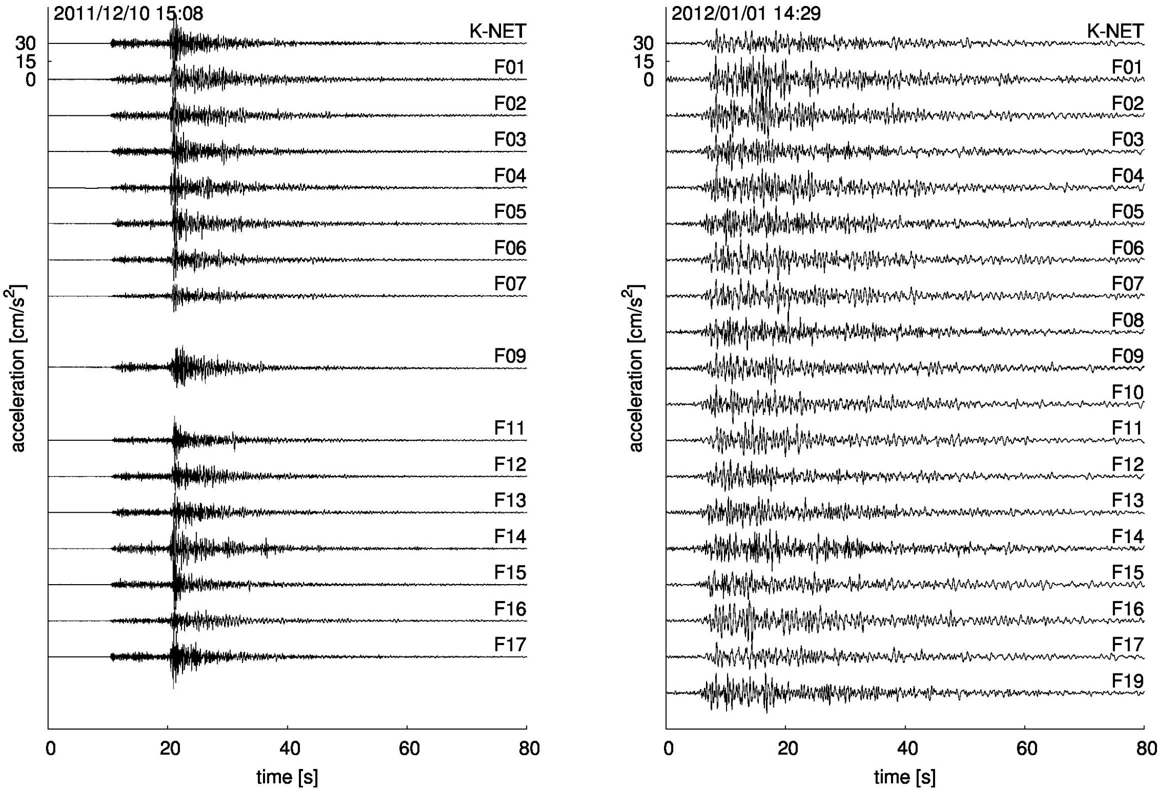


Fig. 7 Accelerograms in East-West component of #E1 and #E2.

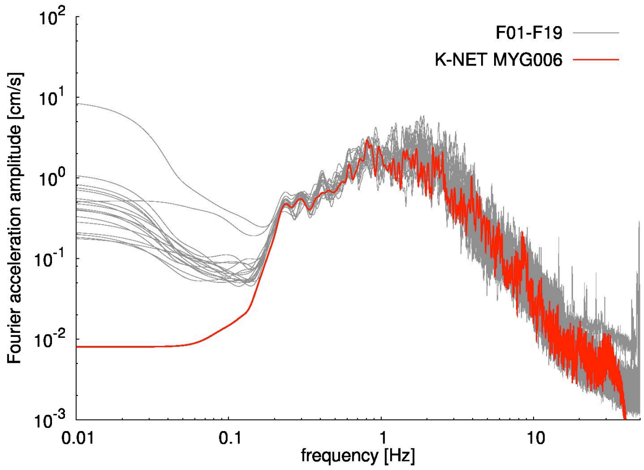
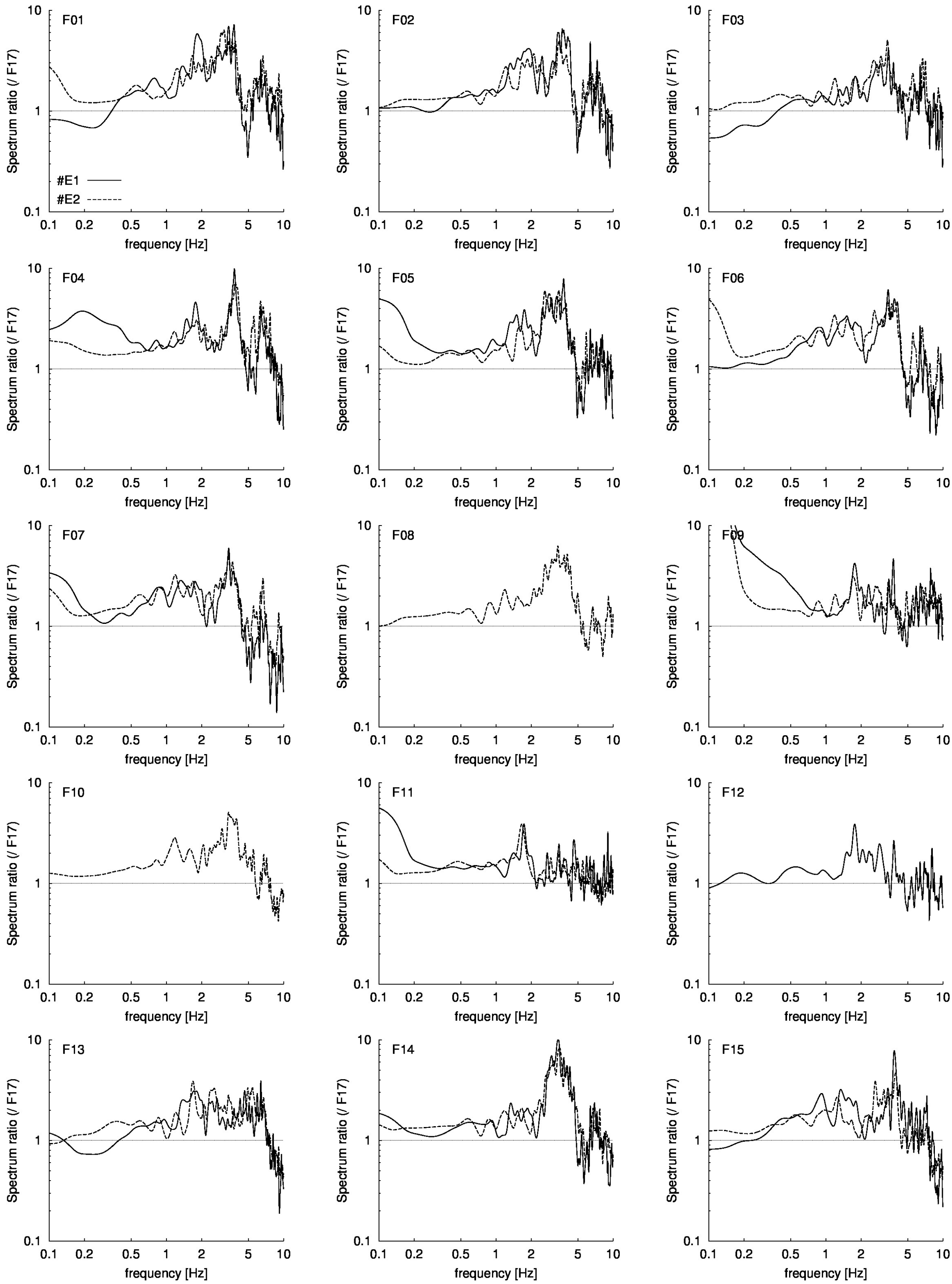


Fig.8 Fourier amplitudes of accelerograms in EW components during #E2.


F01
F02
F03
F04
F05
F06
F07
F08
F09
F10
F11
F12
F13
F14
F15
#E1
#E2
Spectrum ratio (/ F17)
frequency [Hz]
0.1
1
10
0.1 0.2 0.5 1 2 5 10

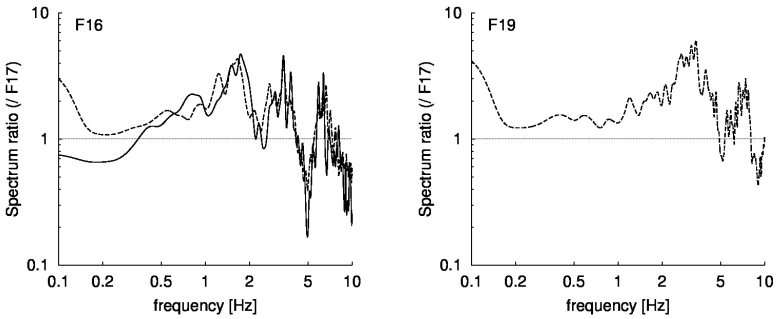


Fig.9 H/H spectrum ratios of F01-F19 sites relative to F17 site.

CONCLUSION

We developed very dense seismic-array-observation in Furukawa district, where severe residential damages occurred at the downtown. Sensors were distributed with an interval of less than 500m. Observed PGA and PGV have a spatial variation, and differ from those at K-NET MYG006.

We start to analyze the observed data to estimate the spatial variation of subsurface structure, and perform geophysical surveys, e.g., microtremor observations and gravity surveys. The results will be presented in near future.

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