Preliminary report on strong motion estimation at damaged and non-damaged clusters in Kamishiro District, Hakuba Village during a large earthquake (M_{JMA}=6.7) in northern Nagano Prefecture, central Japan

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Key Facts
- Hazard Type: earthquake
- Date of the disaster: November 22, 2014
- Location of the survey: Kamishiro District, Hakuba Village, Nagano Prefecture, Japan
- Date of the field survey: November 24, December 12-14 & 26-28, 2014
- Survey tools: seismographs, digital cameras and so on
- Key findings
  - [1] In-situ investigations were carried out at damage and non-damage cluster sites.
  - [2] Strong ground motions were estimated based on the site-effect substitution method.
  - [3] Site-specific nature of ground motions was one of main causes of the collapsed houses.

Key Words : *seimic waveform, aftershock observation, site effect, wooden house*

1. INTRODUCTION

At 22:08 on November 22, 2014 (JST), a large earthquake of M_{JMA}= 6.7 occurred at northern part of Nagano Prefecture (see Fig. 1). This earthquake, rupturing on NNE-WWS trending Kamishiro active fault, officially named “the 2014 Kamishiro Fault Nagano Prefecture Earthquake” by the Nagano Prefecture, will hereafter be referred to as “the 2014 main shock”, caused collapse of wooden houses at some locations along the source fault[1),2)].

We observed severe damage known by total collapse of many wooden houses are concentrated in Kamishiro Area (see Figs. 2 and 3). Kamishiro Area includes Iida residential cluster, Horinouchi, Tagashira and Mikkaichiba residential clusters (see Fig. 4), whose epicentral distance is approximately 5.4 km (see Fig. 2). On the other hand, the epicentral distance of K-NET Hakuba (inside of the Hakuba Village Office site[3)]) which was non-damage of wooden houses is 2.7 km. It is very important to evaluate strong ground motions in Kamishiro Area to understand the collapse mechanism.

In this report, we show our aftershock observations and preliminary results of strong ground motion estimation in Kamishiro Area.

Fig.1 Location of target site in Japan.

2. OBSERVED GROUND MOTIONS AROUND THE EPICENTRAL AREA

In Nagano Prefecture, besides nationwide strong motion networks operated by such organizations as NIED (K-NET and KiK-net[3]) and JMA[5], a dense strong motion network is also operated by the local government, which is now a part of SK-net[6]. Thus, a large number of strong motion records were obtained during the 2014 main shock[7]. The locations of strong motion stations around the target site are shown in Fig. 2, with observed peak ground accelerations (PGAs), observed peak ground velocities (PGVs) and JMA seismic intensities[5]. In Fig. 2, however, in order that the permanent strong motion observation station is not installed in Kamishiro Area, strong motion due to the 2014 main shock is not recorded.

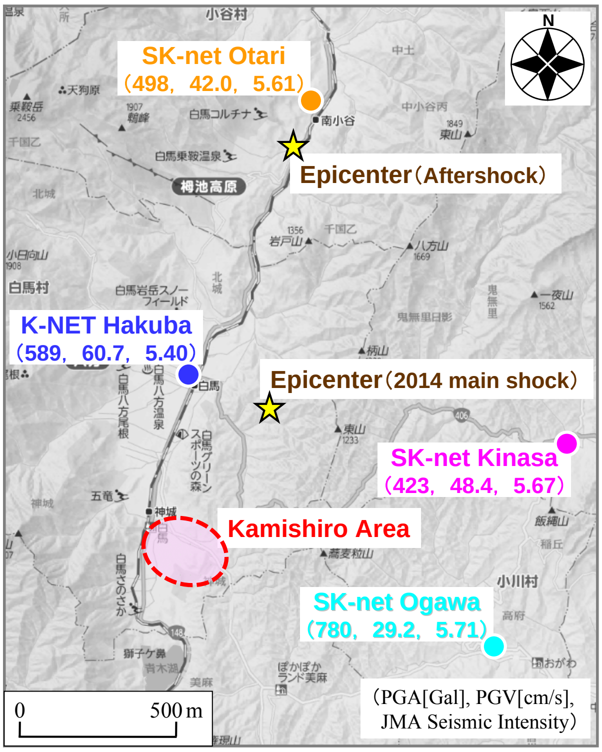

Fig.2 Distribution of permanent strong motion stations.

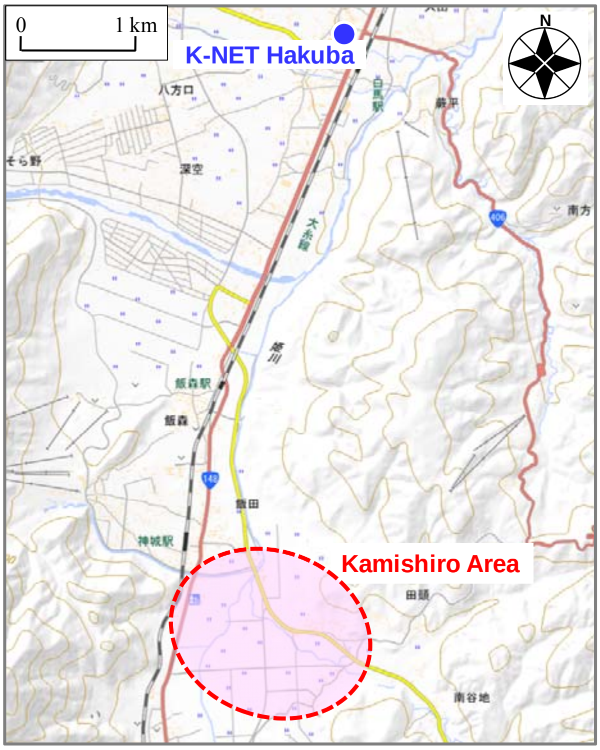

Fig.3 Relationship between K-NET Hakuba and Kamishiro Area.

3. IN-SITU GEOTECHNICAL INVESTIGATIONS INCLUDING TEMPORARY AFTERSHOCK OBSERVATION

First, we performed theoretical study with respect to the ground characteristics in/around the target site. In particular, bedrock geological map, subsurface geological map, geomorphological land classification map and soil map based on National Institute of Advanced Industrial Science and Technology (AIST)[8] and Ministry of Land, Infrastructure, Transport and Tourism (MLIT)[9] are shown in Figs. 5, 6, 7 and 8. In Figs. 5, 6, 7 and 8, we can understand that the difference of ground condition between the damaged clusters (Horinouchi, Tagashira and Mikkaichiba residential clusters) and the non-damaged cluster (Iida residential cluster).

The microtremor H/V spectra are shown in Fig. 9. For details of the calculation of the microtremor H/V spectra, refer to Hata et al.[12]. For P-1~8 (P-1, P-2, P-3: Horinouchi sites, P-4, P-5, P-6: Tagashira sites, and P-7, P-8: Mikkaichiba sites), the features of the H/V spectra almost coincide, which indicates the homogeneity of the site characteristics at the damage site in Horinouchi, Tagashira and Mikkaichiba residential clusters. On the other hand, we can also understand that the features of the H/V spectrum at the both aftershock observation sites between the damaged cluster (Tagashira residential cluster) and the non-damaged cluster

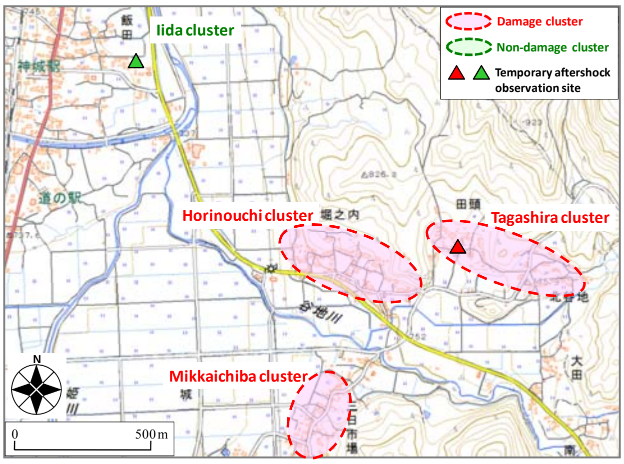

Fig.4 Damage and non-damage cluster in Kamishiro Area.

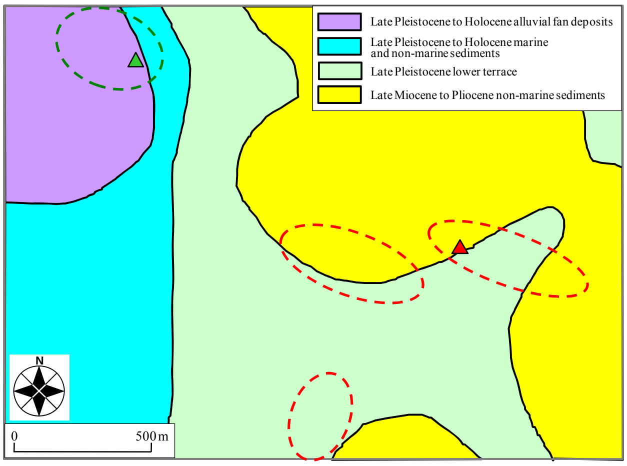

Fig.5 Bedrock geological map.

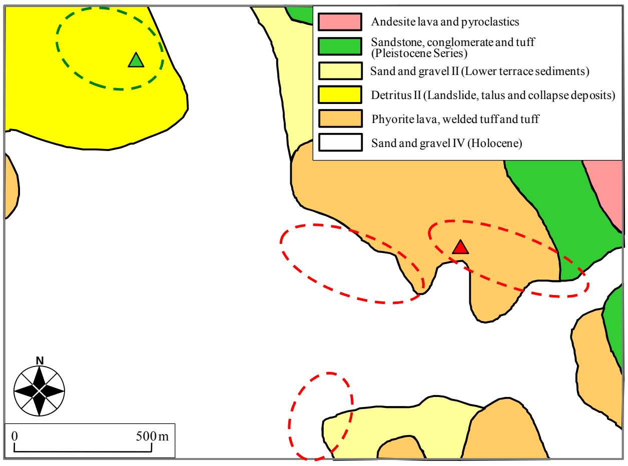

Fig.6 Subsurface geological map.

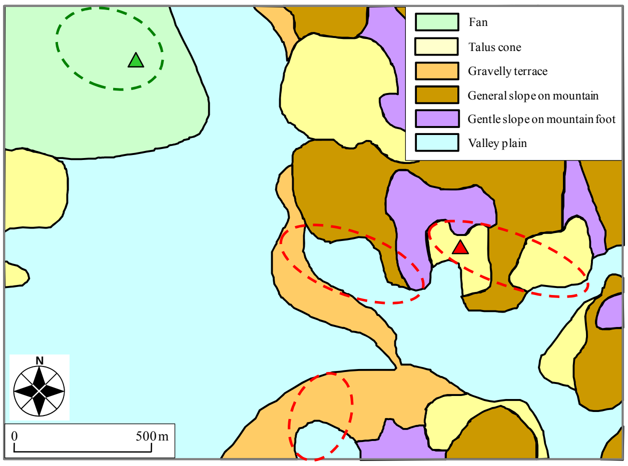

Fig.7 Geomorphological land classification map.

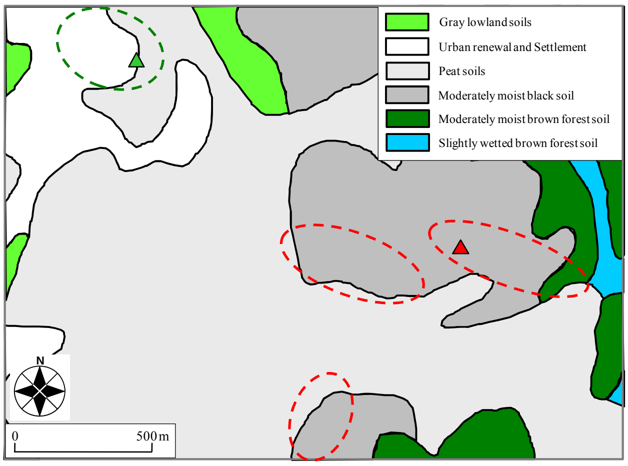

Fig.8 Soil map.

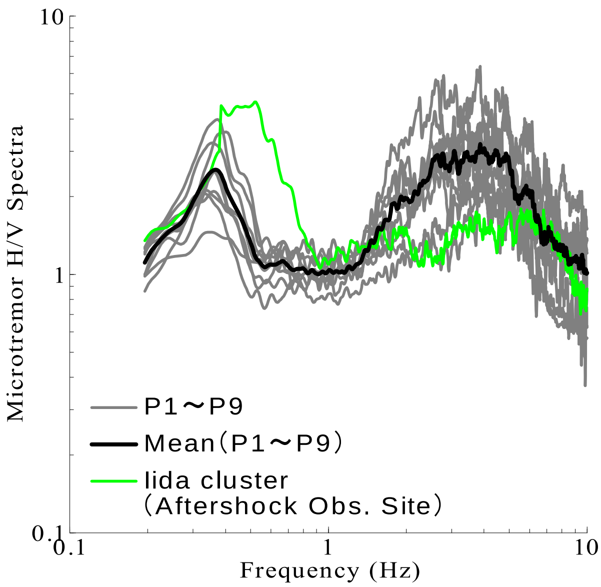

Fig.9 Comparison of microtremor H/V spectra.

(Iida residential cluster) have a significant difference.

Finally, temporary aftershock observation was conducted at Tagashira residential cluster site (P-5 site) and Iida residential cluster site (see Fig. 4). The observation was done for 20 days from November 24, 2014 to December 13, 2014 in order to investigate the ground motion characteristics in detail. A stationary type seismograph was installed at the ground surface in Iida and Tagashira residential clusters (see Fig. 4). We used JU-210 (Hakusan Corporation: 3 components accelerometer JA-40GA and 24 bit data acquisition system) as an observation system[13]. The observation was conducted for 3 components (NS, EW and UD), and the sampling frequency was 100 Hz.

4. SITE AMPLIFICATION FACTOR

The horizontal site amplification factors for K-NET Hakuba site has already been evaluated by Nozu et al.[14] based on spectral inversion. However, those for SK-net station sites, as well as Tagashira and Iida sites have not been reported yet.

The method is based on moderate earthquake records obtained at the reference station and the target sites simultaneously. The target sites include SK-net Otari, SK-net Kinasa, SK-net Ogawa, Tagashira residential cluster site and Iida residential cluster site. K-NET Hakuba is selected as the reference station in this study.

For each combination of the target sites and the reference station, the spectral ratio of the Fourier amplitude of the records at the reference station and the target site is calculated. Here, the moderate earthquake records before the 2014 main shock are used for SK-net station sites. For Tagashira and Iida sites, the recorded aftershocks are used. The effects of geometrical spreading and anelastic attenuation are considered as the path effect[16),17)] to correct the Fourier spectra. The mean of the corrected spectral ratios (the target site / the reference station) are calculated. Fourier amplitude spectrum are always smoothed with a Parzen window of 0.05 Hz, without consideration of filters.

Concretely, in principle, Fourier amplitude spectrum of an observed ground motion is the product of the source, path and site effects. In the situation under consideration, because the source effect is assumed to be the same for these two sites (the target site and the reference station), the ratio of the Fourier spectra between the sites represents the difference of the path and site effects for the two sites. If the effects of geometrical spreading and anelastic attenuation are considered as the path effect $P(f)$ using the following equation[16)].

$$P(f)= 1/r \exp(-\pi f r / Q V_S) \tag{1}$$

Here, r is hypocentral distance, f is frequency of ground motion, V_S is shear wave velocity on the seismic bedrock and Q is the empirical Q value of inland-zone earthquake in eastern Japan[17)]. Thus, the ratio of the Fourier spectra is corrected for the path effect, and then the corrected ratio represents the ratio of the site amplification factors between the two sites. When records of more than two moderate earthquakes are available at both sites, the spectral ratio is averaged for all the records. The site amplification factor at the target site can be obtained as the product of the site amplification factor at the reference station and the spectral ratio. Here, the frequency range for the evaluation of the site amplification factor is from 0.2 Hz to 10 Hz, because the site amplification factor at the reference station is reliable in this frequency range[14)].

Fig. 10 shows the comparison of site amplification factors (Note that K-NET Hakuba is reference). As shown in Fig. 10, the site amplification factors at Tagashira site and Iida site are not similar to those at the other sites. The site amplification factors differ also between Tagashira site and Iida site. In particular, in the frequency range from 0.2Hz to 10Hz, the site amplification factor of Tagashira site overall exceeds those of Iida site. In other words, the results shown in Fig. 10 suggest that input ground motions to wooden houses at Tagashira site must to be more intense than those at not only other stations but also Iida site.

5. GROUND MOTION ESTIMATION

(1) Estimation method

Fig. 11 shows the framework of strong motion estimation at the sites of interest (SK-net station sites, Tagashira residential cluster site and Iida residential cluster site) using the site-effect substitution method[4)]. Note, Fig. 11 is based on an assumption by which the records during the 2014 main shock are not observed at SK-net station sites, Tagashira residential cluster site and Iida residential cluster site other than K-NET Hakuba site in order to confirm the application of the site-effect substitution method based on comparison of observed ground motion and synthetic ground motion. The method is simply composed of 3 steps.

First, the Fourier amplitude at the sites of interest for the 2014 main shock is evaluated by correcting the observed Fourier amplitude at K-NET Hakuba site for the difference of the path effects[16),17)] and the site amplification factors (see Fig. 10) between the sites of interest and K-NET Hakuba site with consideration of “Reference Point” in fault model due to the 2014 main shock by Headquarters for Earthquake Research Promotion (HERP) (see Figs. 12 and 13)[18)]. Here, “Reference Point” is almost located at the center of the area whose final slip was large based on measurement results of a diastrophism using synthetic aperture radar

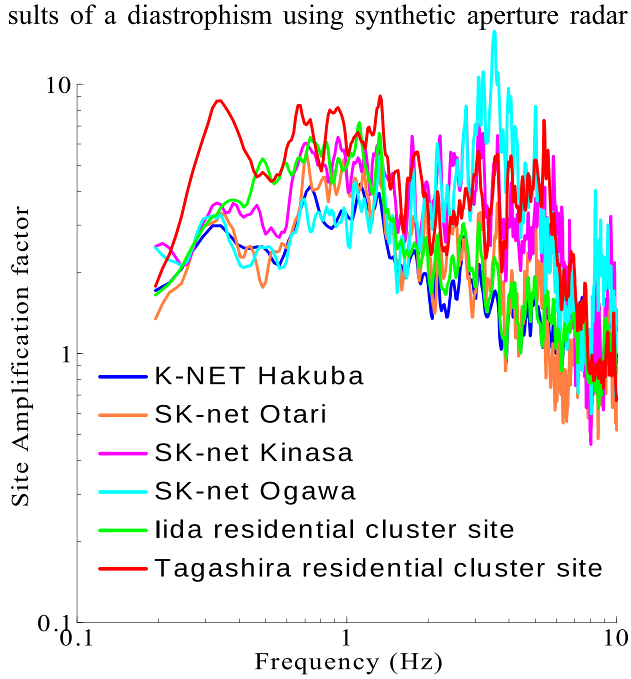

Fig.10 Comparison of site amplification factors.

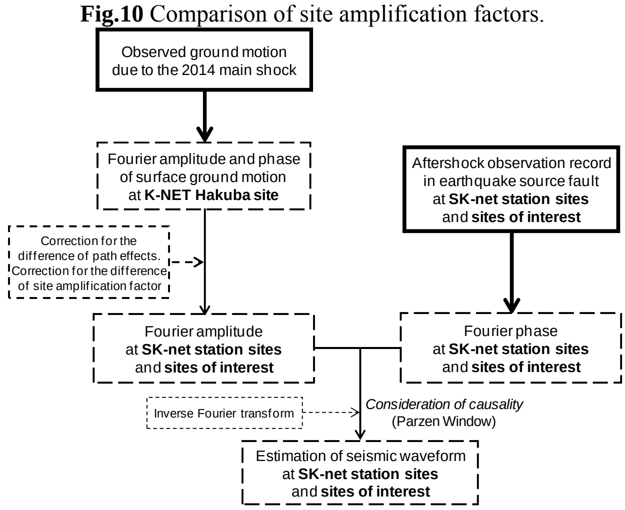

Fig.11 Framework of site-effect substitution method.

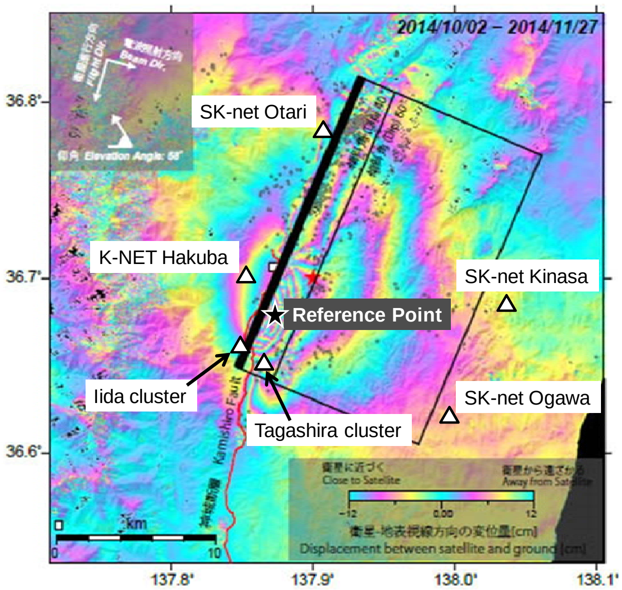

Fig.12 Location of "Reference Point" (1)[18].

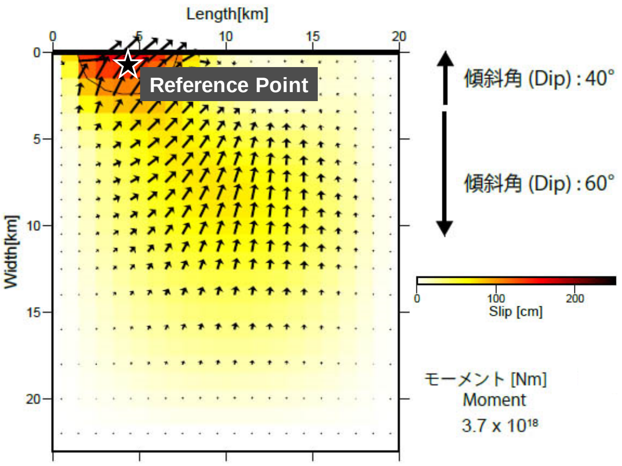

Fig.13 Location of "Reference Point" (2)[18].

"2nd DAICHI". Thus, about the acceptance of "Reference Point", a future study based on results of the waveform inversion using empirical Green's function is left behind. As reason for the selection of K-NET Hakuba site, K-NET Hakuba site is an observation station nearest to not only Tagashira residential cluster site but also Iida residential cluster site, at present, a lot of ground motions are recorded by National Research Institute for Earth Science and Disaster Prevention (NIED)[3]. Then, the Fourier phase at the sites of interest during the 2014 main shock is approximated by the Fourier phase at the same site for a small earthquake (2011/11/ 25 06:26 M_J3.9) occurred close to the 2014 main shock (see Aftershock in Fig. 2). The Fourier phase of an aftershock is often a good approximation of the Fourier phase of the main shock, as long as the location of the aftershock is close to the main rupture area of the 2014 main shock[19),20)].

Finally, inverse Fourier transform is conducted to obtain causal time history[21)] of strong ground motions at the sites of interest during the 2014 main shock. In order to confirm the validity of the estimation method, the observed velocity waveforms (the black traces) and the synthetic velocity waveforms (the red traces) at SK-net Otari site, SK-net Kisana site and SK-net Ogawa site are compared in Fig. 14. Here, both traces are not band pass filtered. Figs. 15 and 16, respectively, are comparison of response spectra for observation (black) and estimation (red). Here, damping ratios of the response spectrum are common to 5%. In Figs.14, 15 and 16, the similarity of all traces is confirmed, indicating the applicability of the estimation method.

(2) Estimation results

First, Fig. 17 and Fig. 18 show the estimated velocity and acceleration waveforms at Tagashira residential cluster site and Iida residential cluster site with the observed velocity and acceleration waveforms at K-NET Hakuba site. In comparison between Fig. 14 and Fig. 17, a striking feature of the estimated waveforms at Tagashira site (serious damage) is that the waveforms include a much larger strong motion pulses compared to the records at the permanent observation stations around the target site, although there is no significant difference in the values of peak ground velocity with comparation of K-NET Hakuba site. In Fig. 18, the value of peak ground acceleration is approximately 1G at Tagashira residential cluster site, although the value of peak ground acceleration is approximately 0.4G at Iida residential cluster site. These features agree well with the degree and difference of seismic damage of wooden houses between Tagashira and Iida residential clusters. Then, JMA seismic intensities[5)] with 2 horizontal components are 6.05 at Tagashira residential cluster site and 5.30 at Iida residential cluster site. Furthermore, the modified JMA seismic intensities focused on seismic damages of wooden house[22)] are 5.71 at Tagashira residential cluster site and 5.31 at Iida residential cluster site.

Finally, Fig. 19 is the comparison of the observed and estimated response spectra (Damping: 5%) at 3 sites of interest in Hakuba Village. In Fig. 19, in natural period range from 0.1 s to 10 s, the estimated velocity and acceleration response spectra at Tagashira site envelopes not only the observed velocity and acceleration response spectra at K-NET Hakuba site but also the estimated velocity and acceleration response spectra at Iida residential cluster site. Fig. 20 is the comparison of the response spectra (Damping: 5%) between the 2014 main shock and the previous large scale earthquakes in Japan. Here, as a target for the comparison, we adopted JR Takatori Station site due to the 1995 Kobe Earthquake, KiK-net Hino site due to the 2000 Western Tottori Earthquake, Kawaguchi Town Office site due to the 2004 Mid Niigata Prefecture Earthquake and the Yokokura cluster site due to the 2011 Nagano-Niigata Border Earthquake. Note, only the Yokokura cluster site is based on the estimated strong motions instead of

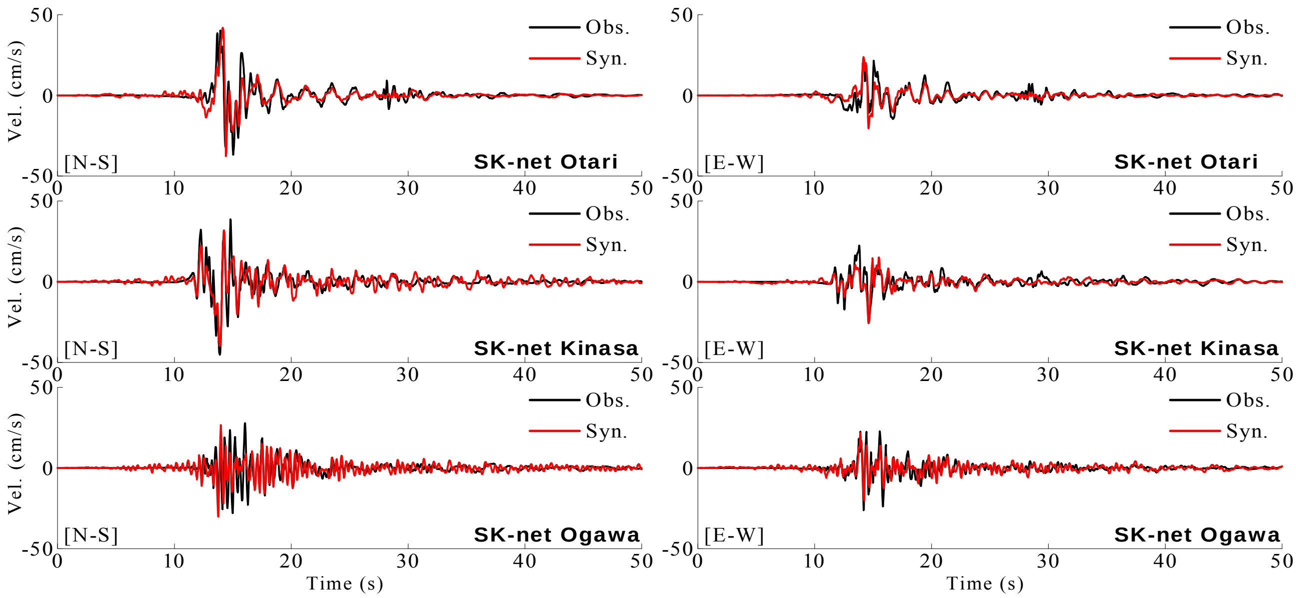

Fig.14 Confirmation of the the site-effect substitution method using the observed seismic waveforms.

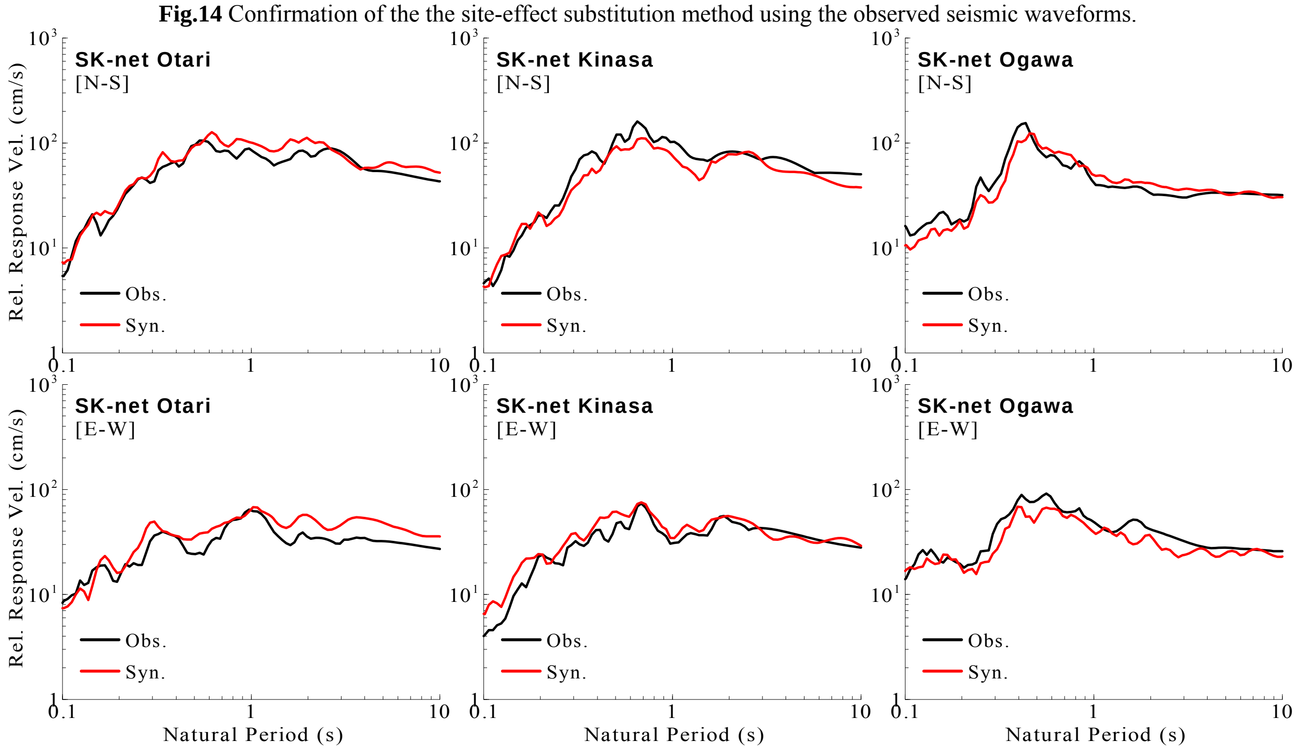

Fig.15 Confirmation of the the site-effect substitution method using the observed velocity response spectra.

the observed strong motions[23]. In Fig. 20, in close to 1.0s on the natural period which has influence against the seismic damage of a wooden house[22], the estimated velocity and acceleration responses at Tagashira site due to the 2014 main shock are less than those responses at the damage sites of wooden house due to the previous large scale earthquakes.

6. SUMMARY AND CONCLUSIONS

During the 2014 Kamishiro Fault Nagano Prefecture Earthquake (M_J6.7), damage of wooden houses due to strong motion was reported in Kamishiro Area, where epicentral distance is approximately 5 km. In this study, to understand the cause of seismic damage at such a restrictive site, in-situ geotechnical investigations including aftershock observations were carried out at target sites. Then, we applied the site-effect substitution method to estimate strong ground motions at the target site. The results of the study can be summarized as follows.

(1) The site amplification factors at the target site are not similar to those at permanent strong motion observation stations around the target site. It suggests that the 2014 main shock ground motions at the target site were different from those observed at the permanent observation stations.

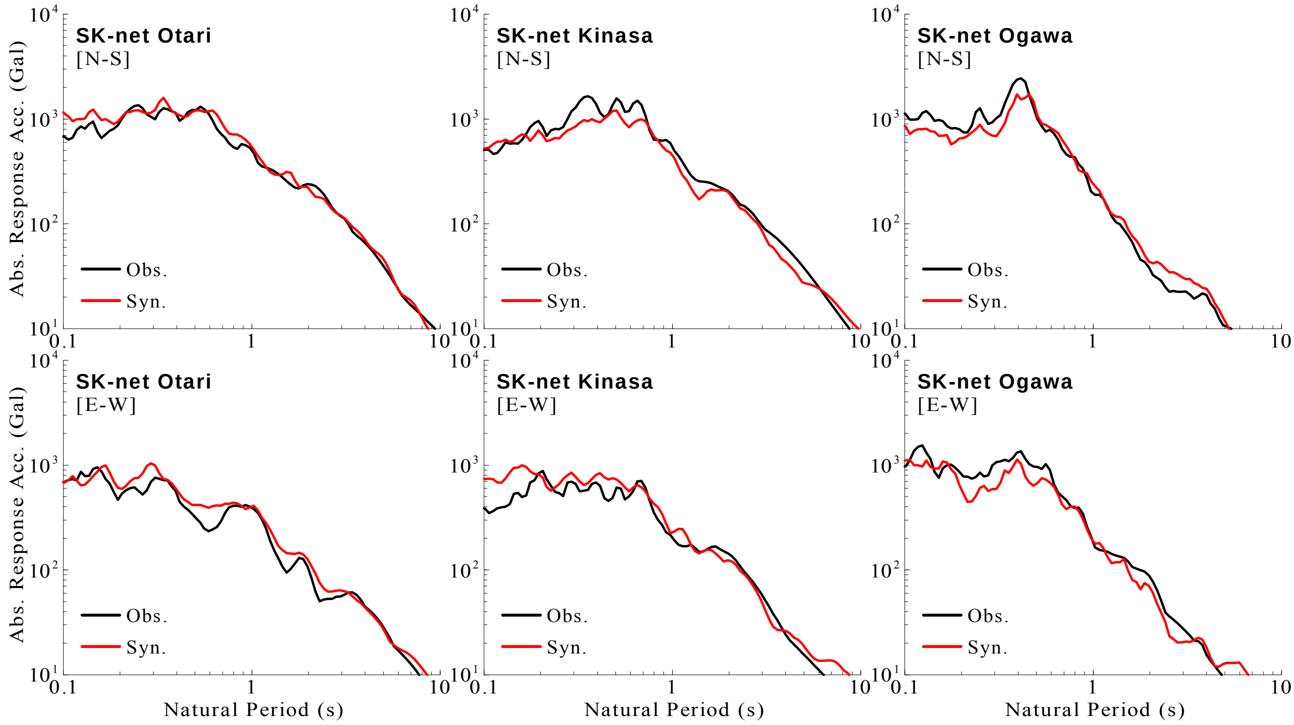

Fig.16 Confirmation of the the site-effect substitution method using the observed acceleration response spectra.

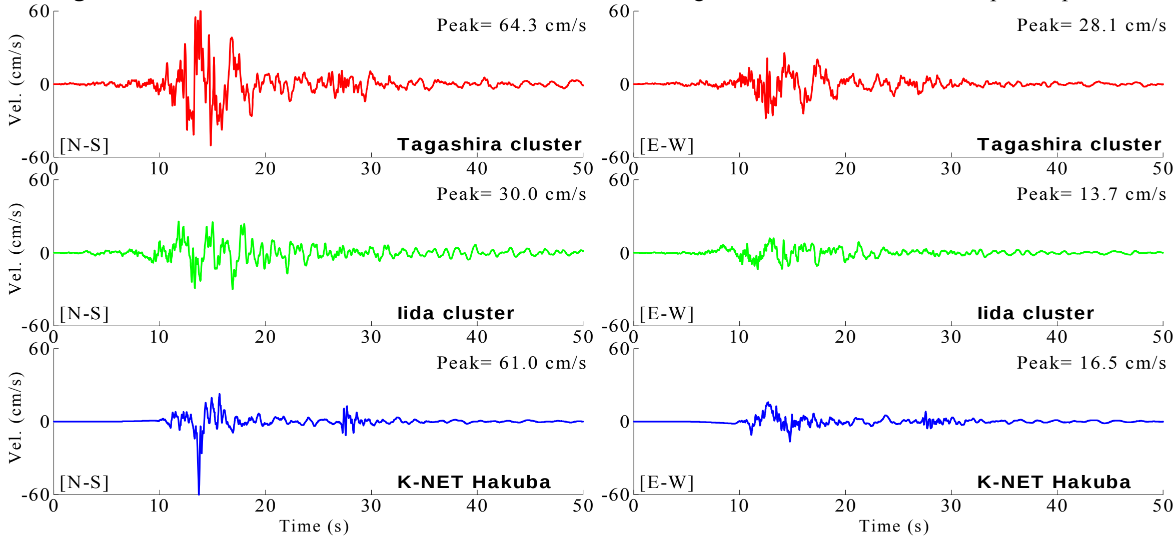

Fig.17 The estimated velocity waveforms at the sites of interest with the observed velocity waveforms at K-NET Hakuba site.

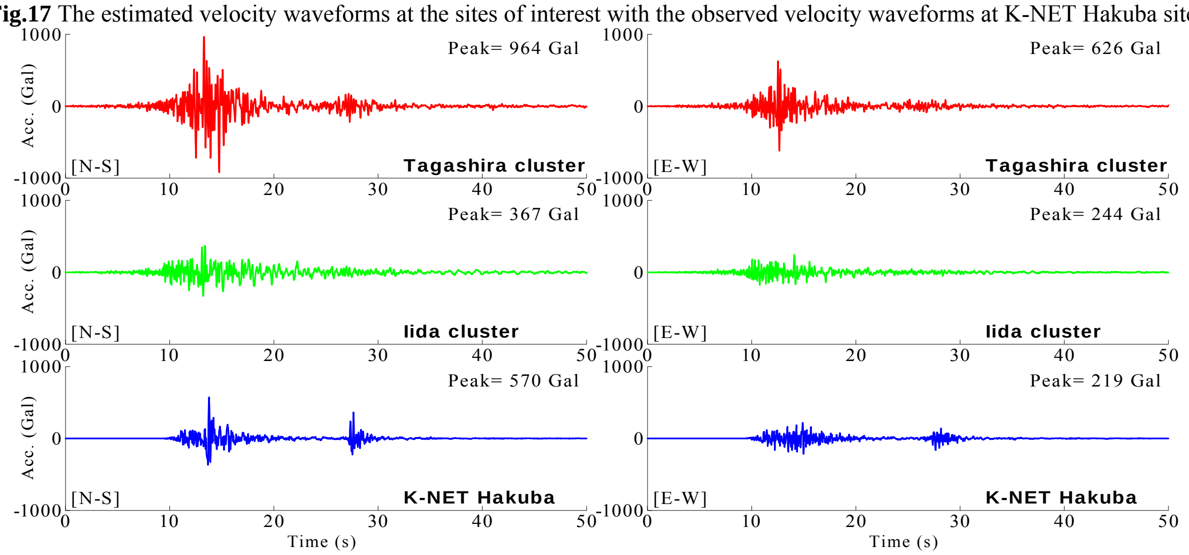

Fig.18 The estimated acceleration waveforms at the sites of interest with the observed acceleration waveforms at K-NET Hakuba site.

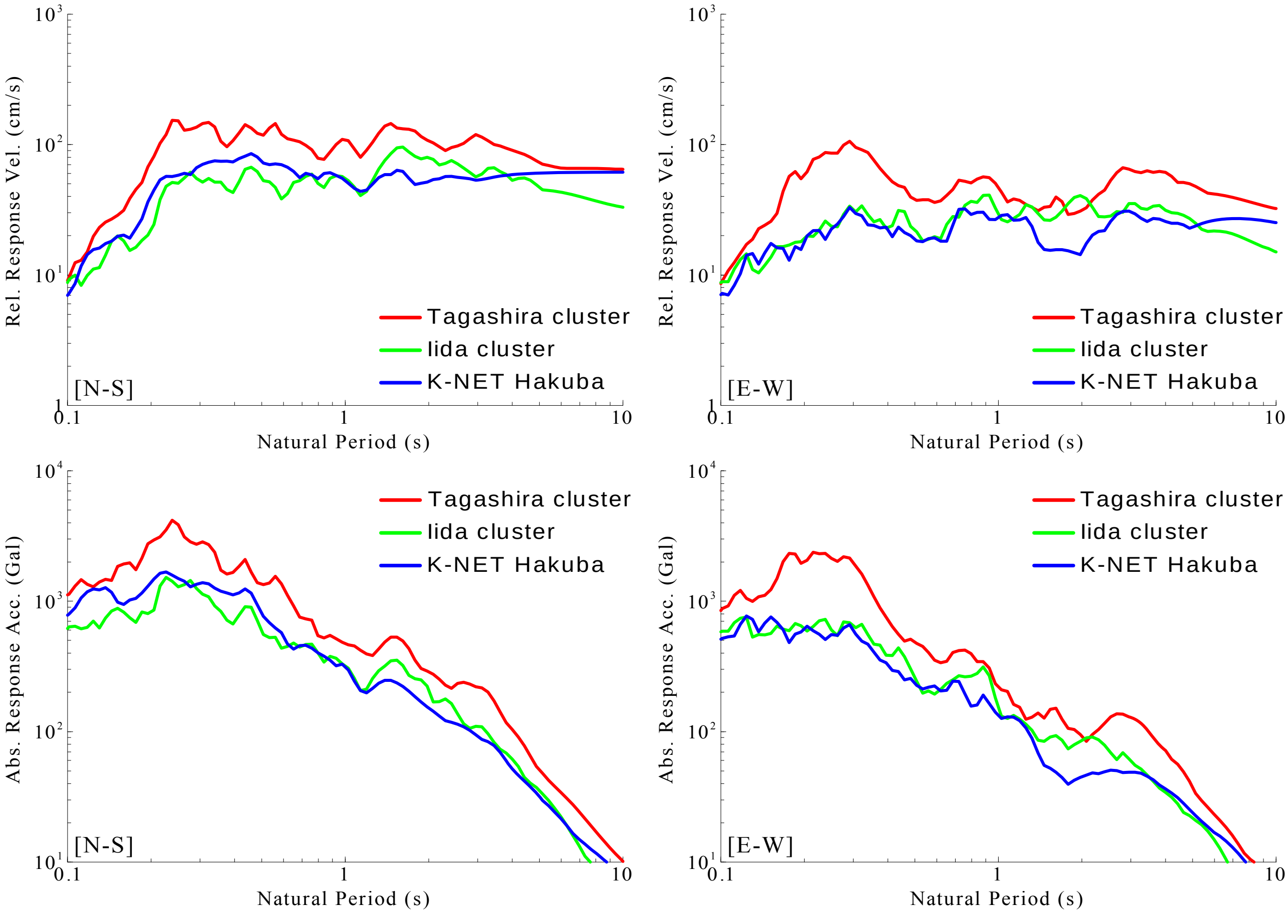

Fig.19 The estimated response spectra at the sites of interest with the observed response spectra at K-NET Hakuba site.

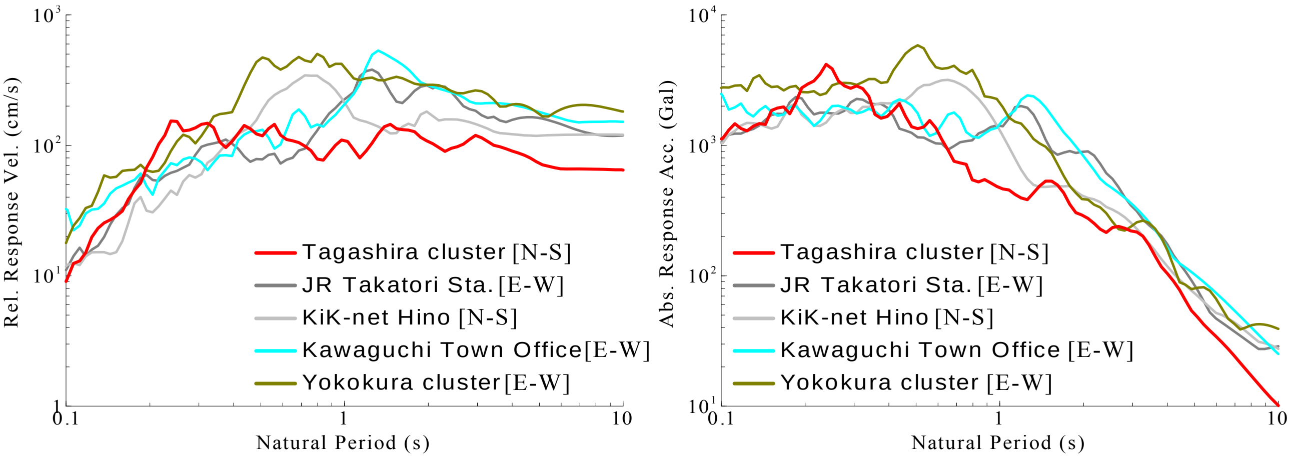

Fig.20 The estimated response spectra at Tagashira residential cluster site with the response spectra due to the large scale earthquakes.

(2) The estimated waveforms of the target sites in Kamishiro Area include a much larger strong motion pulses compared to the records at the permanent observation stations around the sites.

As a future study, using estimated waveforms at the target site, seismic response analyses of the wooden house will be carried out.

DATA AND RESOURCES: Strong motion data of K-NET can be obtained from National Institute for Earth Science and Disaster Prevention at www.kyoshin.bosai.go.jp (last accessed January 2015). Strong motion data of SK-net can be obtained from Earthquake Research Institute, University of Tokyo at www.sknet.eri.u-tokyo.ac.jp/ (last accessed January 2015).

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ern Part of Nagano Prefecture Earthquake" organized by the Earthquake Engineering Committee, JSCE.

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