Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

SCG65-01 Room:A04 Time:May 26 09:00-09:25

A perspective on the 20-year active fault survey

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Overview of the 20-year survey of active faults

110 major active faults had been surveyed within ten years after the 1995 Great Hanshin-Awaji Earthquake by the national survey project. In the second ten years from 2005 to 2014, intensive surveys have been conducted on designated active faults, either having a possibility of a huge earthquake in the near future, or causing serious damage in case of the occurrence of an earthquake. Taking account of successive occurrence of three damaging earthquakes in coastal areas in 2005 and 2007, the government started a nearshore active fault survey project in 2009. For onshore active faults without sufficient data, additional or supplementary surveys have been carried out. The author will pick out several major active faults, and will highlight valuable results and important unsolved problems.

Challenges in active fault research

The author points out the following three issues to challenge, on the basis of the 20-year national survey of active faults as well as surveys on surface faults that appeared in association with damaging earthquakes after the 1995 Great Hanshin-Awaji Earthquake. The author is looking forward to discussing how we should approach and solve these issues with all the participants

1. Unveiling the mechanism of diversity in fault reactivation.

1-1: Diversity in lateral extent of rupturing (single, multiple or chained fault rupturing with various combination of faults) in and around an active fault system.

1-2: Diversity in co-seismic displacement of active faults (more than tenfold variation in some cases) even at the same points of the same active faults.

2. Clarifying the relationship between the ”shallow part” (active fault) and the ”deep part” (source fault), being not strongly constrained by geophysical exploration or geological modelling even now.

3. Survey and evaluation of ”unknown” active faults (faults with unclear fault-related geomorphic features).

Keywords: active fault, inland earthquake

Japan Geoscience Union Meeting 2015
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SCG65-02 Room:A04 Time:May 26 09:25-09:40

Relation between the 1995 Hyogoken-Nanbu Earthquake and the great Keicho Earthquke

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The 1995 Hyogoken-nanbu Earthquake occurred only about 400 years after the previous event, the 1596 great Keicho earthquake. The average recurrence interval of the active fault system from the Rokko Mountain to the east coast of the Awaji Island is estimated to be about 900 ? 2800 years. The interval of about 400 years is much smaller than the average interval of the active fault system, and it can be explained by a break of the region that was not broken by the 1596 earthquake.

Keywords: Kobe Earthquake, Nojima Fault, intraplate earthquake, Median Tectonic Line, stress change, recurrence interval

Japan Geoscience Union Meeting 2015
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SCG65-03 Room:A04 Time:May 26 09:40-09:55

Complexity of source fault of inland earthquakes revealed by SAR interferometry

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Since the Landers earthquakes of 1992, SAR interferometry (InSAR) has been utilized to detect coseismic deformations and estimate configuration of source fault and slip distribution. In Japan, studies of conseismic deformation and fault model have been conducted using mainly L-band SAR sensors (JERS-1 SAR and ALOS/PALSAR) since the Kobe earthquake of 1995. Especially, ALOS/PALSAR observed coseismic deformations of earthquakes all over the world since 2006 and had successful results. Among of all, the complexity of source fault is the most important. In this report, I review some of important results and discuss their significance in earth and disaster sciences.

For example, Hashimoto et al. (2010) and other group revealed slip on parallel faults, heterogeneous slip distribution and variation of configuration of faults along strike for the Wenchuan earthquake of 2008. Takada et al. (2010) clarified the existence of an eastward dipping sub-fault in addition to the westward dipping main fault for the Iwate-Miyagi earthquake of 2009. Anti-correlation of coseismic deformation to the topography was detected during the Haiti earthquake in 2010. Hashimoto et al.(2011) concluded that the source fault is not a vertical left lateral sinistral fault, the Enriquillo fault, but a buried one in the crust. In the same year, more than 5 small segments ruptured during the Darfield, NZ, earthquake (Hashimoto, 2012). Obliquely crossing faults ruptured during the Iwaki earthquake of 2011 (Fukushima et al., 2013). Of course, there are earthquakes with a simple plane fault such as L'aquila, Italy, in 2009 and Yushu, China in 2010, but they are minority during the 5 year operation of ALOS/PALSAR.

The present long-term forecast by the Headquater for Earthquake Research Promotion is mainly based on so-called characteristic earthquake model that assumes repetition of unit slip on the same fault plane. However, the above results contradict this simple model. Propagation of rupture between segments such as the Darfield and Iwaki earthquakes makes it difficult to estimate final moment release. Modeling research of such complicated fault behaviors should be hastened including the effect of subsurface structure. We cannot deny that faulting contribute to the formation of topography, but it is a big issue in Earth science how faulting occurs that is uncorrelated to the topography such as Haiti earthquake. It is also important to take this kind of earthquakes into hazard evaluation from the viewpoint of disaster mitigation.

Keywords: InSAR, ALOS/PALSAR, inland earthquake, active fault, crustal deformation

Japan Geoscience Union Meeting 2015
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SCG65-04 Room:A04 Time:May 26 09:55-10:10

Problems of long-term earthquake forecast in Japan: Do we learn from the Kobe earthquake properly?

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When the 1995 Kobe earthquake occurred, existence of seismic potential was not recognized by the local people at all and almost no countermeasures had been taken against strong shaking. After this experience, the Japanese government started to produce a seismic hazard map based on long-term earthquake forecasts as well as strong ground motion prediction. According to the latest release of the Japanese national seismic hazard map, the southern coast of the mainland and the Shikoku island are characterized by the highest probability (>26% in next 30 years) for seismic intensity 6-.

However, this hazard map is based on various assumptions that may heavily bias the evaluation. 30-year probability of earthquakes along the Nankai Trough is estimated as 70% based on the time-predictable model. The Nankai Trough is the only place the time-predictable model was applied. The probability becomes as low as 20-30% if we do not apply this model. As a result, seismic potential along the Nankai Trough may be over-emphasized. Therefore it is not appropriate to use the current seismic hazard map for comparing seismic potentials of different areas. This point is critical if we use seismic hazard map for allocating limited budget for earthquake hazard mitigation, or determining premium for earthquake insurance for each locality. Moreover, by putting too much emphasis on the Nankai Trough, people tend to disregard seismic hazard in other areas. Origin of difficulties in mitigating earthquake disaster is its low probability. Artificially raising earthquake probability may conceal such difficulty and can be misleading. This situation is similar to one before 1995, when the government conducted earthquake prediction program focused on the Tokai earthquake. Considering that preparation for big disaster with very low frequency is the main challenge of disaster mitigation, current long-term forecast contains serious problems. It is more important to let people understand that seismic hazard is pervasive throughout Japan, and current science is insufficient to provide reliable forecasts, which are important lessons from the Kobe earthquake.

Keywords: long-term earthquake forecast, seismic hazard map, Nancy Trough earthquakes, time-predictable model, Kobe earthquake

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SCG65-05 Room:A04 Time:May 26 10:10-10:25

Ultra-fine amorphous particles preserved in the primary slip zone within the Arima-Takatsuki Tectonic Line

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Friction causes comminution and wearing of minerals in the fault, forming a fine powder that can act as a lubricant (powder lubrication). Such particles are suggested as a potential proxy for identifying the slip zone of the most recent earthquake along a fault, because they were observed only in the latest slip zone within the Taiwan Chelungpu fault that slipped at the 1999 Chi-Chi earthquake. However, the occurrence in the active faults was not fully reported, so we investigate the latest slip zone within the Arima-Takatsuki Tectonic Line.

By applying the quantitative estimation of amorphous component using halo peak area on XRD patterns, we confirmed approximately 20 weight % of the component. We also observed ultrafine particles probably attributed to the amorphous component. Therefore, such particle could be universally observed in the latest slip zone within the active fault.

Keywords: active fault, amorphization, quantitive method of amorphous

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SCG65-06 Room:A04 Time:May 26 10:25-10:40

Characteristics of radiated short-period seismic energy from moderate-to-large inland earthquakes

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It is in 1990s that envelope inversion methods have been developed to study earthquake source processes in shorter period ranges than about 1s (e.g. Gusev et al., 1991; Zeng et al., 1993; Kakehi and Irikura, 1996). Motivated by the occurrence of the 1995 Hyogo-ken Nanbu earthquake, the authors developed an envelope inversion method (Nakahara et al., 1998) to estimate the spatial distribution of short-period seismic energy radiation on earthquake source faults. So far, we have applied the inversion method to more than 10 moderate-to-large earthquakes. Compiling the results, we consider statistical characteristics of short-period seismic energy radiation from the earthquakes especially focusing on inland earthquakes.

We have so far analyzed 6 inland earthquakes: the 1995 Hyogo-ken Nanbu (Kobe) earthquake (Mw6.9), the 1998 Northern Iwate Prefecture earthquake (5.8), the 1999 Chi-Chi, Taiwan, earthquake (7.6), the 2000 Tottori-ken Seibu earthquake (6.6), the 2004 Niigata-ken Chuetsu earthquake (6.6), and the 2008 Iwate-Miyagi Inland earthquake (6.6). We compile the results in terms of 3 items:

1. Scaling law of short-period seismic energy

The logarithm of seismic energy in short period bands (1-2, 2-4, 4-8, and 8-16Hz) is found to be proportional to the moment magnitude. In other words, the short-period seismic energy is proportional to the fault area. The absolute values for 6 inland earthquakes are explained well by the omega-squared model with the short-period spectral level A obtained by Dan et al. (2001). On the contrary, the absolute values for the other plate-boundary type and intra-slab type earthquakes are about 10 times larger than those for the inland earthquakes.

2. Spatial relationship between asperities and short-period sources

We compare relations between locations of asperities estimated by waveform inversions in longer periods and locations of short-period energy radiation obtained by the envelope inversion in shorter periods. The relation is found to be complimentary for 3 earthquakes of the 1998 Iwate, the 1999 Chichi, and the 2000 Tottori. But the relation is complex for the other 3 earthquakes.

3. Statistics of short-period seismic energy radiation

Seismic energy radiation is estimated for each subfault and each period band by the envelope inversion method. Plotting energies from all the subfaults in a descending order, we find that the logarithms of the energies are linearly decrease against the order. This is explained by the two-parameter Weibull distribution. The slope is characterized by the shape-parameter which ranges from 0 and 2 depending on earthquakes and period bands. The shape parameter of 1 corresponds to the exponential distribution and that of smaller than 1 means more heavy-tailed distributions.

Given these results, we need to physically understand the statistical characteristics of short-period seismic energy radiations and to take them into account in predicting strong-ground motions.

Keywords: inland earthquakes, short-period seismic energy, envelope inversion

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SCG65-07 Room:A04 Time:May 26 11:00-11:25

Progress in ground motion prediction

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Methodologies of ground motion prediction have developed rapidly during the last few decades incorporating the knowledge obtained through analysis of destructive earthquakes and taking advantage of progress in computers. The progress was highly accelerated thanks to the dens strong motion observation networks installed after the 1995 Hyogo-ken Nanbu earthquake.

In the modeling of source processes for anticipated earthquakes, as the patch asperities successfully explained the directivity pulses in downtown Kobe for the Hyogo-ken Nanbu earthquake (Kamae and Irikura, 1998), the asperity-based model has been the mainstream in Japan. The way to decide properties of asperities has been pursued by developing scaling relations for asperities estimated for observed earthquakes. The way to adequately locate asperities has been sought for in the relation between slip at depth and displacement along the fault traces or in the relation between asperity and fault geometry. In addition to asperities, realistic smaller-scale heterogeneity in the distribution of source parameters is considered to fill the deficiency of the wave excitation of asperity model and to moderate the forward directivity effect.

Underground velocity structure model with 3-dimensional variation like the Osaka basin model by Kagawa et al. (1993) was very rare before the Hyogo-ken Nanbu earthquake. Hyogo-ken Nanbu earthquake made us realize not only the difference in medium physical property but also the topography of the soft-hard boundary of the sedimentary-basin floor had great effect on the ground motion. This fact promoted the surveys and modeling of the velocity structure of large basins. Moreover, we have seen at every destructive earthquake that various aspects of the underground structure can cause locally large ground motions.

I am going to review how the methodology developed with our experience of destructive earthquakes and discuss whether we have successfully solved each problems.

Keywords: ground motion prediction, source model, velocity structure, asperity

SCG65-08 Room:A04 Time:May 26 11:25-11:40

Various Topics on Engineering Applications of Strong Ground Motion Prediction near Active Fault

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We report three topics on the engineering applications of the strong ground notion prediction near active faults. First, although the recipe for predicting strong ground motions is a very useful tool for engineering applications, it is important to know its limitations, especially for simulating ground motions near faults. This is because the recipe is based on a very simplified source model. Second, we need to develop a new recipe for predicting ground motions including the effects from the surface faulting (e.g., the fling step and the inclined ground level), which is excluded in the current recipe. Third, we need to understand the differences between the sumulated strong ground motions for aseismic design and risk management. The former must be stable for several decades under the consensus among experts and society. On the other hands, the latter is simulated considering the newest information and methodology (the source, structures, and so on), and may be exceed the former results for aseismic design, which is useful for the risk and crisis management of the target facility.

Keywords: Active Fault, Recipe for Predicting Strong Ground Motions, Forward Directivity Pulse, Fling Step, Strong Ground Motions for Aseismic Design, Strong Ground Motions for Risk Management

SCG65-09 Room:A04 Time:May 26 11:40-11:55

Strong Ground Motion Generation for the 2014 Northern Nagano Earthquake

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The 2014 Northern Nagano earthquake (JMA Magnitude 6.7, Mw 6.2) on 22 November caused strong ground motions in Hakuba of the Nagano prefecture. Damaged wooden houses are reported at the Horinouchi region in Hakuba, Active fault surveys, InSAR analyses, and aftershock observations suggest the relation of source fault and the Itoigawa-Shizuoka Tectonic Line. Near-source strong ground motions are observed by K-NET/KiK-net of NIED and seismic intensity sensors of local governments.

Observed ground motions generally agreed with ground motion prediction equations. Long-period ground motions in the Kanto and Nobi basins are not significant, but we confirmed surface waves in the Matsumoto and Suwa basins at the southern part of the Itoigawa-Shizuoka Tectonic Line.

Hi-net Hakuba-Kamishiro station is located at the Mikka-Ichiba region, where is the south of the Horinouchi region. However, the borehole velocity sensor at the depth of 50 m can measure up to around 4 cm/s, the mainshock records are saturated. We have installed a temporary strong motion station at the Hakuba cross country field (Snow Harp) since 12 November 2014. The portable measurement consist of JAP-6A3-10 and LS-7000XT. The continuous ground motions are transmitted every second as WIN packets. Most aftershock records have dominant periods of around 1 s.

One of concerns is that both K-NET/KiK-net Hakuba stations observed larger NS velocity component rather than EW velocity component. This is hard to explain by a simple reverse faulting. This feature is only seen in the mainshock records, not for the foreshock and aftershock ones, suggesting complex mainshock rupture. Based on the source inversion by Kobayashi et al. (2015, this meeting), we estimate strong motion generation areas by the empirical Green's function simulation for broadband ground motions. We also simulate the mainshock ground motion at the temporary station from the strong motion generation area.

Keywords: 2014 Northern Nagano earthquake, strong ground motion, continuous strong motion observation, ground motion prediction equation, empirical Green's function method

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SCG65-10 Room:A04 Time:May 26 11:55-12:10

Long-period Ground Motion in Tokyo Bay Area Observed from the M7 Class Events in the North of Nagano Prefecture, Japan

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The earthquake of Mj6.7 occurred in the north of Nagano prefecture on November 22, 2014 (the 2014 event) and seismic intensity 6- in Japan Meteorological Agency (JMA) scale was observed in the northern part of Nagano prefecture. Around the north of Nagano prefecture, the earthquake of Mj6.7 occurred at Niigata - Nagano border on March 12, 2011 (the 2011 event). These shallow events have the same magnitude in JMA scale, similar source mechanism, and the geometric relation between the epicenters and the Tokyo bay area are similar. It was expected that the ground motion observed in Tokyo bay area during these events showed similar characteristic. This article reports the ground motion characteristics of both events in the Tokyo bay area.

The records of the broadband velocity type seismometers (VSE-355G3) installed in the thermal power stations on Tokyo Bay shore, K-NET and KiK-net in Kanto district were used for the analysis of ground motion characteristics. The 2011 event occurred at Niigata - Nagano border was estimated as magnitude 6.7 event with focal depth of 8 km by JMA. According to the analysis result of F-net, the source mechanism of the event is reverse fault with the northeast - southwest strike direction, Mw is 6.2 and focal depth is 5 km. The 2014 event occurred in the vicinity of Kamishiro fault was estimated as magnitude 6.7 event with focal depth of 5 km by JMA. According to the F-net result, the source mechanism is similar to that of the 2011 event, Mw is 6.3 and focal depth is 5 km. The epicenter distance and back azimuth of the 2011 event from the Shinagawa observation station are 184 km and 325 degree, respectively. Those of the 2014 event are 206 km and 305 degree, respectively. It seems that the seismic wave from these events were propagated from the approximately same direction.

In the velocity seismograms of the 2011 event, remarkable later arrivals with predominant period of five seconds were recognized in both of horizontal components and vertical component except Yokosuka observatory. In addition, the appearance time of this phases in the seismograms of the Chiba station on the ease side of the Tokyo bay was later than that of Shinagawa station on the west side of the bay. We can confirm that this wave packets propagates from the Western mountainous to the Kanto basin by making paste up figures using K-NET and KiK-net records. For all stations on the Tokyo bay shore except Yokosuka station, the remarkable peak was recognized at 5 seconds in horizontal and vertical components of the velocity response spectra with 5 % damping. The remarkable later arrivals like in the records of the 2011 event was not recognized in the records of the 2014 event, but consecutive later arrivals with predominant period of 8-10 seconds were recognized. These later phases also propagate from the west to the east in the basin. There was no station where the significant peak of five seconds was recognized in the velocity response spectra with 5 % damping. But the peak in velocity response spectra was recognized at period of 7 to 8 seconds in horizontal component for Ooi and Shinagawa stations on the west side of the Tokyo bay and between Anesaki and Chiba on east side of the bay.

The ground motions in Kanto Mountains were studied to examine the property of the incident wave to the Kanto basin. Remarkable later pulses were confirmed in the velocity seismograms of the 2011 event. In velocity response spectrum with 5 % damping, the significant peak was recognized at period of five seconds. Because the horizontal motion was different 90 degrees in phase with vertical motion in this later arrivals, it was estimated that this later arrivals were Rayleigh waves. On the other hand, no special later arrival was recognized in the velocity seismograms of the 2014 event. It is thought that the difference of incident wave to the basin between the 2011 event and the 2014 event caused the difference of ground motion in the Tokyo bay area.

Keywords: Long-period Ground Motion, Surface Waves, Later-phases, Tokyo Bay area, Velocity Response Spectrum

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SCG65-11 Room:A04 Time:May 26 12:10-12:25

Rupture process of the 2014 Northern Nagano earthquake as deduced from near-source strong motion records

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The 2014 Northern Nagano, central Japan, earthquake (M_{JMA} 6.7) is a moderate-size crustal event with prominent surface rupture along the southern part of Kamishiro fault (e.g., Katsube et al., 2015 this meeting). I inferred the rupture process of this earthquake, inverting near-source (epicentral distance of less than 30 km) strong motion records. The original accelerograms were band-pass filtered between 0.1-1.0 Hz, and then numerically integrated into displacement. The inversion methodology adopted in this study is the same as that of Horikawa (2001, BSSA). I conducted preliminary inversion analysis to choose a focal mechanism among those of (centroid) moment tensors of the Global CMT, the National Research Institute for the Earth Science and Disaster Prevention (NIED), and the Japan Meteorological Agency (JMA). I then adopted the focal mechanism of the JMA centroid moment tensor (strike of 18 degrees, dip of 58 degrees, and rake of 59 degrees), assuming a fault plane with length of 23 km and width of 21 km. The inversion analysis revealed that the overall rupture finished within 10 s. After subtle moment release of the first 1 s, a large amount of moment release abruptly occurred with duration of 4 s. This large moment release comes from two patches of large slip: one is just beneath the hypocenter and with the maximum slip of more than 1 m, the other is located to the northeast of the hypocenter. The seismic moment of this earthquake was estimated to be 2.0 x 10^{18} Nm (M_w 6.1), and smaller than those of (centroid) moment tensor analysis (e.g., 3.0 x 10^{18} Nm from the global CMT). The two patches of large slip are deeper than the hypocenter (5.4 km below the ground surface around the source region), and little slip was found at the shallow part of the fault, which does not agree with the distinct surface rupture. A speculative interpretation of this discrepancy is that the moment release at the shallow part proceeded with long (maybe tens of seconds) duration that does not heavily affect the frequency components analyzed in this study. However, further analysis is required for validation of this interpretation.

Acknowledgements: Strong motion data were provided by NIED (K-NET and KiK-net) and the Earthquake Research Institute, the University of Tokyo (SK-net). As for the moment tensor solutions, I referred to the web sites of the Global CMT Project, NIED (F-net), and JMA. The unified earthquake catalog of JMA was used in this study.

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Strong motion simulation for the 2014 Northern Nagano Prefecture earthquake based on the pseudo point-source m

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In our country, the characterized source model, which is composed of rectangular subevents generating strong ground motions, have extensively been used for the purpose of predicting strong ground motions (e.g., Kamae and Irikura, 1997). On the other hand, the author (Nozu, 2012) proposed a new source model, namely, the pseudo point-source model, which could be regarded as a simplified version of the conventional characterized source model. In the pseudo point-source model, the spaciotemporal distribution of slip within a subevent is not modelled. Instead, the source spectrum associated with the rupture of a subevent is modelled and it is assumed to follow the omega-square model (Aki, 1967). The source model consists of only six parameters for each subevent, namely, the longitude, latitude, depth, rupture time, seismic moment and corner frequency of the subevent. The model involves much less model parameters than the conventional characterized source model. Once the model parameters are given, by multiplying the source spectrum with the path effect and the site amplification factor, the Fourier amplitude at the site of interest can be obtained. Then, combining it with the Fourier phase of a smaller event, the time history of strong ground motions from the subevent can be calculated. Finally, by summing up contributions from the subevents, strong ground motions from the entire rupture can be obtained.

If such a simplified source model can explain strong ground motions with certain accuracy, it would be helpful in reducing costs for strong motion prediction especially a large number of scenarios are considered. Moreover, according to the results of past studies, the model can explain strong ground motions from a mega-thrust earthquake (Nozu, 2012) and an intraslub earthquake (Nagasaka et al., 2014), sometimes better than the conventional characterized source models.

Its applicability to short distances, however, could be restricted, because it is expressing the subevent with a point. Therefore, its applicability to shallow crustal earthquakes should carefully be examined by using observed records.

The examination of the applicability of the model to shallow crustal earthquakes has already been started (e.g., Hata and Nozu, 2012). In this study, a pseudo point-source model was developed for the 2014 Northern Nagano Prefecture earthquake and strong ground motions were simulated based on the model. The selected parameters are as follows: number of subevents=1, longitude=137.901, latitude=36.722, depth=4.6 km, seismic moment=2.0E+18 Nm, corner frequency=0.25 Hz. A medium density of 2.7×10^3 kg/m^3 and a shear wave velocity of 3.5 km/s were assumed. The mean value of 0.63 was used for the radiation coefficient. Another mean value of 0.71 was used for *PRTITN* (Boore, 1983), which is a coefficient indicating the partition of energy into two horizontal components. The Q value estimated in a past study (Satoh and Tatsumi, 2002) was used to represent the path effects. Records of the November 23, 12:46 aftershock were used to evaluate the Fourier phase. According to the results, the pseudo point-source model generally can explain strong ground motions around the source region fairly well, although there is still a room for future improvement (The figure shows the results for the velocity waveforms and the Fourier spectra at NGN002, NGN005 and NGN007).

Acknowledgement: Strong motion data used in this study were kindly provided by the NIED.

Keywords: the pseudo point-source model, the 2014 Northern Nagano Prefecture earthquake, strong ground motion, omega-square model, Fourier phase

SCG65-12 Room:A04 Time:May 26 12:25-12:40