Estimation of Empirical Green's Tensor Spatial Derivative Elements: A Preliminary Study using Strong Ground Motion Records in Southern Fukui Prefecture, Japan

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To demonstrate the applicability of the empirical Green’s tensor spatial derivative (EGTD) method, proposed by Plicka and Zahradnik (1998), for simulation of near-field strong ground motion records, I estimated the EGTD from velocity waveforms between 0.2 and 1 Hz. I used data from seven events (M_J3.7–4.2) in the southern part of Fukui Prefecture, Japan, observed at FKI007 and several neaby stations of the K-NET and KiK-net operated by the National Research Institute for Earth Science and Disaster Prevention (NIED). The agreement between the observed and simulated waveforms for the all events is satisfactory over a long duration and there is a good match for the amplitude. The EGTD estimated in this report should be confirmed when future earthquakes occur around the same source area. To enhance the applicability of the EGTD method, further data accumulation and investigation is required.

Keywords: empirical Green’s tensor spatial derivative, focal mechanisms, moment moment tensorwaveform , strong ground motion, waveform inversion

Source process of the 2008 Iwate-Miyagi Nairiku Earthquake considering the conjugate faults and its relation to strong motion

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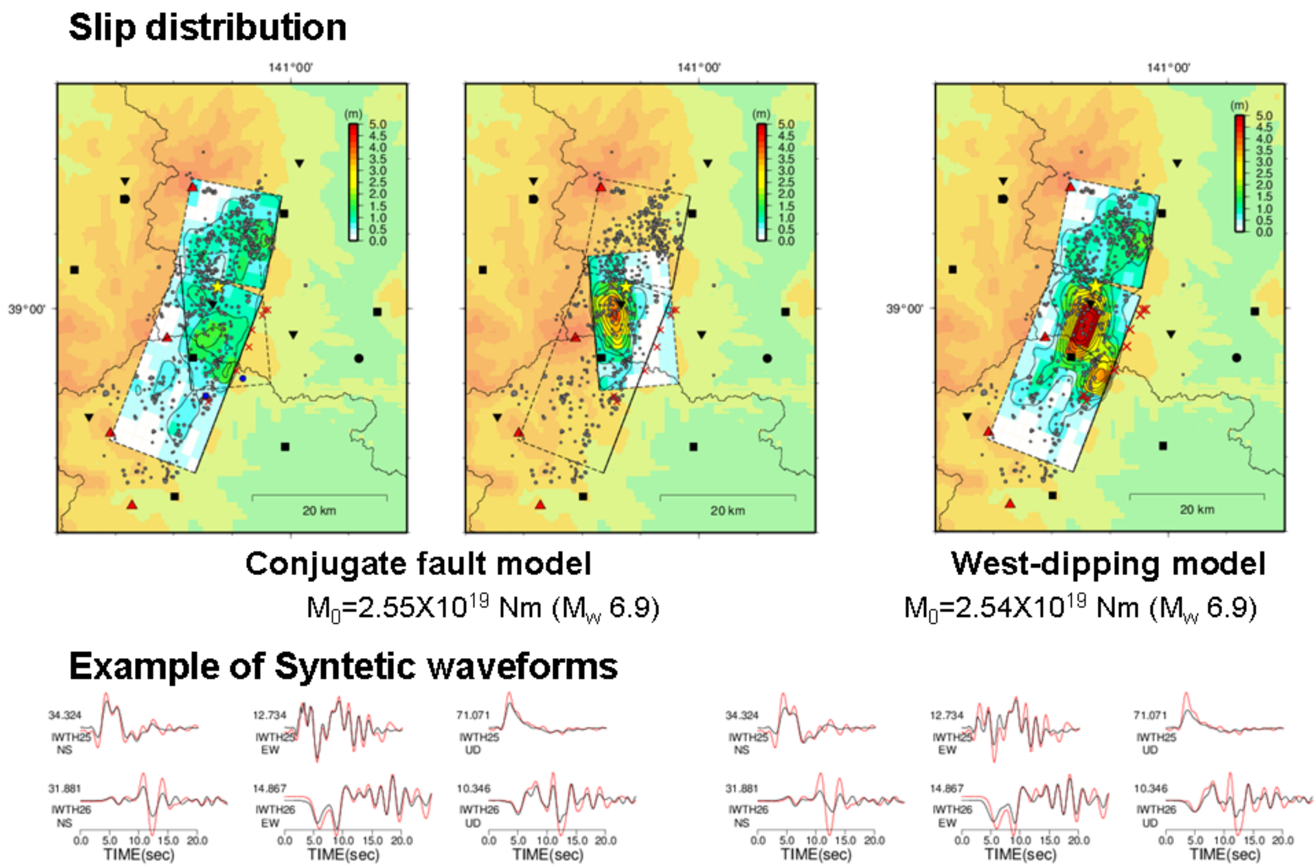
INTRODUCTION
Since K-NET was constructed, multiple strong motion records are often observed in the source region of large crustal earthquakes. Those data have revealed not only detailed rupture process on a fault, but also complex fault system in itself. The 2008 Iwate-Miyagi Nairiku Earthquake is an example of such faults. Hikima and Koketsu (2013) revealed that fault displacements occurred on the complex source composed by conjugate faults, namely west-dipping faults and east-dipping fault. In this study, we revalidate the source model and discuss the strong ground motions caused by those complex faults.
OUTLINE of ANALYSES
We get the idea of the conjugate faults by referring the results of Abe et al. (2013), which were determined using InSAR deformation data. The total length of the west-dipping fault is 42 km, and the fault is composed in two planes. Abe et al.’s curved east-dipping fault is modified to one plane of 20 km length. We determined those planes by considering aftershock distribution those were relocated using DD method (Hikima et al., 2008).
The source process was inverted by the multi time window analysis (Yoshida et al., 1996, Hikima, 2012). The velocity waveforms obtained by K-NET and KiK-net, filtered between 0.03 and 0.5Hz, were used. The Green’s functions were calculated using 1-D velocity models, which were estimated by the waveform inversion method (Hikima and Koketsu, 2005). We used the geodetic data by the GPS stations simultaneously.
RESULT and DISCUSSION
A large slip area (asperity) is recovered on the east-dipping fault as same as the result of Hikima and Koketsu (2013). To examine the reality of the conjugate faults, we performed inversion analysis assuming only the west-dipping fault, additionally.
/ Reproducibility of waveforms
The agreement between the synthetic and observed waveforms is better for the conjugate fault model, in general. The synthetic waveforms of IWTH25, which is located just above the conjugate faults, are significantly better than the west-dipping fault model.
/ Crustal deformation
At Kurikoma-2 of GPS station, which was used in inversion analyses, its large deformation is reproduced better by the conjugate faults. In addition, the acceleration waveforms were integrated to produce displacements, and those were compared to calculated waveforms. Although it can't deny the possibility that the displacements contain a few errors, the uplift at IWTH25, which is over 1.5 m, was reproduced by the conjugate faults sufficiently.
/ Aftershock distribution
Our fault models were determined as following the relocated aftershocks, so the fault planes are generally shallower than the other analyses. Moreover, the relocated aftershocks by Yoshida et al. (2014) are roughly consistent with the conjugate faults.
/ Stress drop on the faults
The maximum slip of the west-dipping fault is larger than that of the conjugate faults, and the average stress drop at the asperity is about 25 MPa. On the one hand, the stress drop of the conjugate faults is about 15 MPa, which is typical value for asperities of crustal earthquakes.

As shown above, the conjugate fault model is more consistent with a number of observed data. It is, therefore, highly likely that the east-dipping fault exists.
STRONG MOTION
Although it is an easy-to-use calculation, we computed equivalent fault distances (Ohno et al., 1993) for the conjugate faults and the west-dipping fault, respectively. Those distances are almost same at distant points from the fault area, and even in near fault area the differences are 1 to 2 km at the most. Therefore, it is thought that the difference of the expected strong motions from these two fault models is not so large. Of course, more quantitative analyses, e.g. strong motion simulation, are needed for detailed discussion. However, those are future studies.

Keywords: 2008 Iwate-Miyagi nairiku earthquake, Source process, Crustal earthquake, Near fault, Strong motion



Velocity waveforms at IWTH25 and IWTH26 (Red: obs., Black: syn.)

Difference in Ground Motion Characteristics Between the Surface and Buried Rupture Crustal Earthquake in Japan

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Existence of surface fault rupture in inland crustal earthquake significantly affects on ground motion characteristics. Somerville (2003) has indicated that the ground motion by buried rupture is larger than ground motion by surface rupture earthquake in the period range around 1 second.
Inland crustal earthquakes in Japan have occurred frequently after the 1995 Kobe earthquake, and some of them have surface fault ruptures (e.g., 2008 Iwate-Miyagi earthquake, 2011 Fukushima-Hamadori earthquake, 2014 Nagano-North earthquake).
The ground motion characteristics were compared from the deviation of the observed response spectrum with average response spectrum calculated from spectrum attenuation relationship by Chiou and Youngs(2006). The result basically agrees well with the difference between the two types of earthquakes proposed by Somerville (2003).
The source parameters were obtained through detecting fault rupture area and asperity areas from slip distribution, applying the method by Somerville et al. (1999), and the source characteristics were compared from the source parameters between the two types of earthquakes.
Finally, we created the characteristic source models from the source parameters, and calculated waveforms using Stochastic Green’s function method. The result agrees well with the characteristics from observed ground motion.
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Somerville, P. G.(2003): Physics of the Earth and Planetary Interiors, 137, pp. 201-212.
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Keywords: Inland crustal earthquake, Surface fault rupture, Ground motion Characteristics, Source Characteristics

A study on spatial variations of Qs-value caused by differences of propagation pass.

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Strong motions are expressed simply as products of source, pass, and site factors in the frequency domain. Researchers have been developing the prediction methods by evaluating these factors. The property of S-wave attenuation (Qs) is one of the most important factors for strong motions, because the amplitudes of strong motions change depended on Qs dramatically.

Iwata & Irikura (1986) introduced spectral inversion method which was able to estimate the source, pass, and site factor from strong motion records (e.g., K-NET or KiK-net managed by National Research Institute for Earthquake Science and Disaster Prevention (NIED)). This method gives us important knowledge about mechanisms and properties of strong motions. Nakano et al. (2015) performed spectral inversion methods to 6 regions of Japan, and obtained the source, pass, and site factors at each region by using the enormous amount of data (from 1996 to 2011). Please note that the values estimated by this method are just average values of target regions and assumed parameters.

On the other hand, we know the way to investigate Qs-value directly in the any area. That is called twofold spectral ratio method (TSRM) is provided by Matsuzawa et al. (1989). Kato (1999) assumed geometric spreading factor n was 1.04 (=constant) in the same manner as Ibanez et al. (1993), and applied TSRM to southern Kyushu region to evaluate Qs by crustal earthquakes. Izutani (2000), Izutani & Ikegaya (2002) and Maeda & Sasatani (2006) shows that Qs would be change in the space of regions. Noda et al., (2010) reports the probability of differences of Qs based on epicentral distance in the Kashiwazaki and adjacent region. Their studies suggest that we have to pay attention to select the appropriate propagation pass (in brief, it is earthquake-site pairs).

From the above, we investigate the effect of the difference of propagation pass has on evaluations of Qs. We performed TSRM to southern Kyushu and Hokkaido region in Japan. We were interested in the changes of Qs in the space of regions, so we needed comparison our results to previous studies. We used the strong motion records of K-NET and KiK-net provided by NIED. The Fourier spectra were calculated from the acceleration of strong motion records (0.1-20 Hz in frequency domain). We used taper window (0.4Hz) to smoothen Fourier spectra.

We obtain Qs-values depended on frequencies are comparable to ones estimated by spectral inversion methods (e.g., Kato, 1999; Nakano et al., 2015) at Kyushu and Hokkaido region. However those are different by each propagation pass. It would be supported previous studies. The results bring about the useful knowledge to configure Qs-value for strong motion predictions.

Such studies are depended on density of observation points and amount of data. We would continue to study about spatial variations of Qs-values, by increasing the amount of data and dividing the area (or depth) finely.

Acknowledgements: We used the strong motion records provided by National Research Institute for Earthquake Science and Disaster Prevention (NIED) in this study. We gratefully appreciated it.

Keywords: Qs, Propagation pass, twofold spectral ratio method

Shallow subsurface structure estimated from dense aftershock records and microtremor observations in Furukawa district, Miyagi, Japan

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Severe structural damages due to ground motions were occurred in some limited areas of Tohoku and Kanto regions, northeast Japan, during the 2011 off the Pacific coast of Tohoku earthquake. Furukawa district in Miyagi prefecture was one of the most significant damaged areas (Goto and Morikawa, 2012). Frequency contents of ground motion records at K-NET MYG006 and JMA Furukawa stations, where are located in Furukawa district, are similar to ones of JMA Kobe and JR Takatori records during the 1995 Kobe earthquakes. It indicates that ground motions in Furukawa district were effective against the structures (Goto and Morikawa, 2012). Significant damages were locally observed within about 1.0 x 0.5 km^2 areas, which is center of the downtown.

In order to investigate the reason why the damage was concentrated into very limited area, Goto et al.(2012) established a temporal network of seismometers in the downtown area, namely Furukawa Seismometer Network (FuSeN). FuSeN consists of more than 30 accelerometers with a spatial interval of about 100m, which is one of the densest seismometer networks in the world. The observed peak ground acceleration (PGA) and velocity (PGV) indicate that ground motions are greatly amplified in the significantly damaged area (Goto et al., 2012). It is considered that difference of the amplification is mainly caused by difference of the shallow subsurface structures. Inatani et al.(2013) estimated the shallow ground structure based on the ground motion records obtained by FuSeN. Thicker surface soil is estimated at the sites with the larger amplifications. It suggests that the subsurface structure in the local region was very important factor to cause the structural damage by ground motions.

Inatani et al.(2013) used relative transfer functions obtained from the ground motion records, whereas it constrained only the relative differences of velocity structures. In addition, the resolution is limited in the scale of spatial intervals among the sensors in FuSeN. For this purpose, single-site observations and array observations of microtremor may be helpful to improve the subsurface structure in Furukawa district. We carry out extreme dense single-site observations of microtremor in order to obtain the densely distributed dataset, and array observations of microtremor to identify the S-wave profile. Both results are merged to model the subsurface structure. We, then, update the subsurface structure in Furukawa district, and discuss contribution to the site amplification. The array observations estimated phase velocity of Rayleigh wave at three sites, and S-wave velocity models were established. The single-site observations estimated the peak period distribution of surface layer on the basis of H/V spectral ratio. We then revised the shallow subsurface structure on the basis of the microtremor results and ground motion records of FuSeN. The model implies that slower S-wave velocity and deeper surface layer to the basement are estimated around the southern area. Distribution of averaged value of the transfer functions in 2-4Hz agrees well with the damage area.

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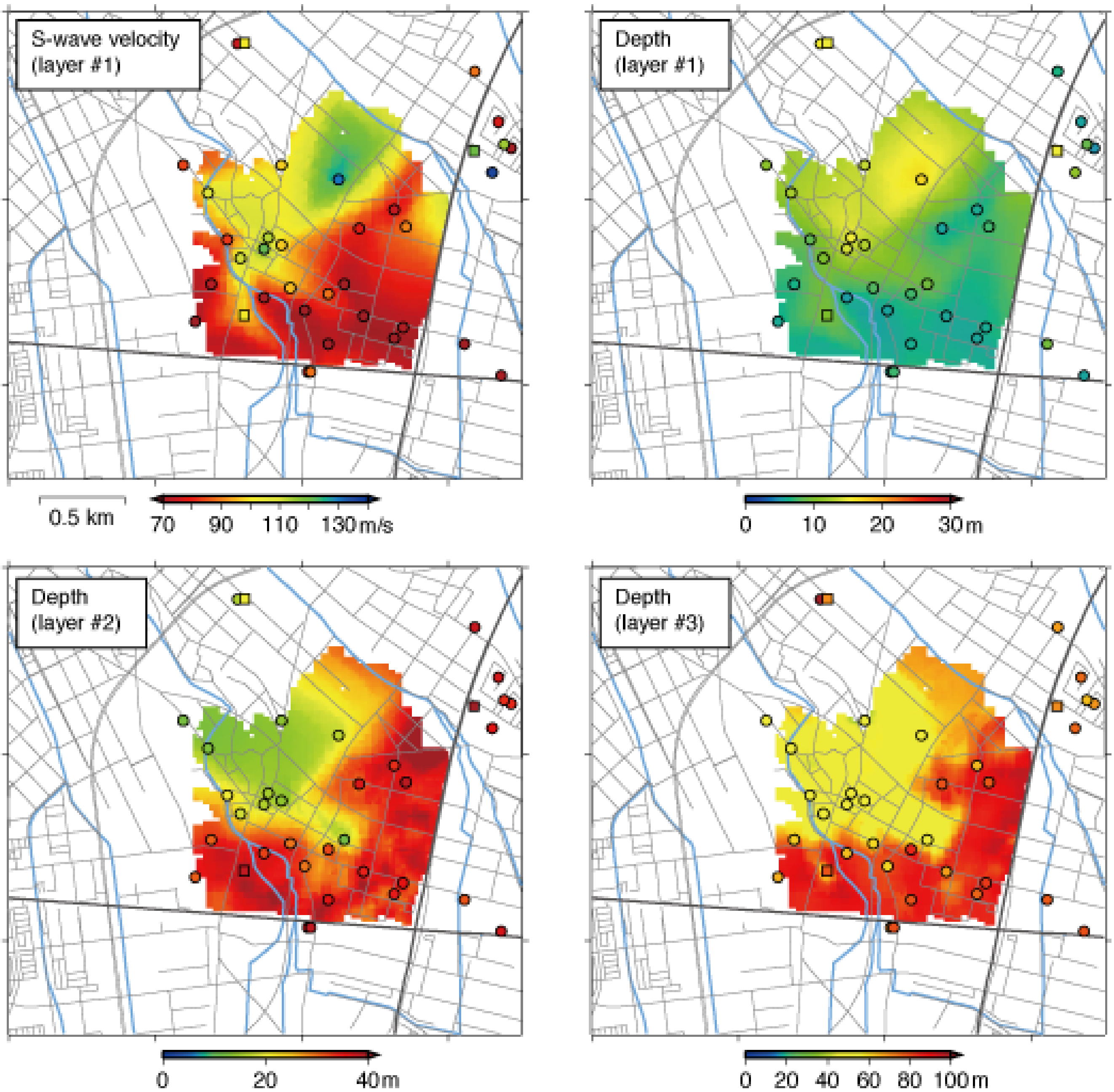
Keywords: dense aftershock records, microtremor observation, shallow subsurface structure



Estimation on spatial distribution of dynamic response by shallow sedimens in Furukawa, Japan

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It is very important to know the causes of anomaly of damage distribution by an earthquake. This may be occurred by the differences of structural strengths, ground motions, and so on. After the 2011 off the Pacific coast of Tohoku earthquake, we have found the typical examples on this problem at Furukawa district, Miyagi, Japan. To make clear this, we have installed very dense seismic observation network into Furukawa, which is named Furukawa Seismic Network (FuSeN) (Goto et al. 2012), and carried out microtremor survey around the area. Goto et al. (2016) proposed a detailed model of velocity structure for Furukawa using the observed data of earthquakes and microtremors.

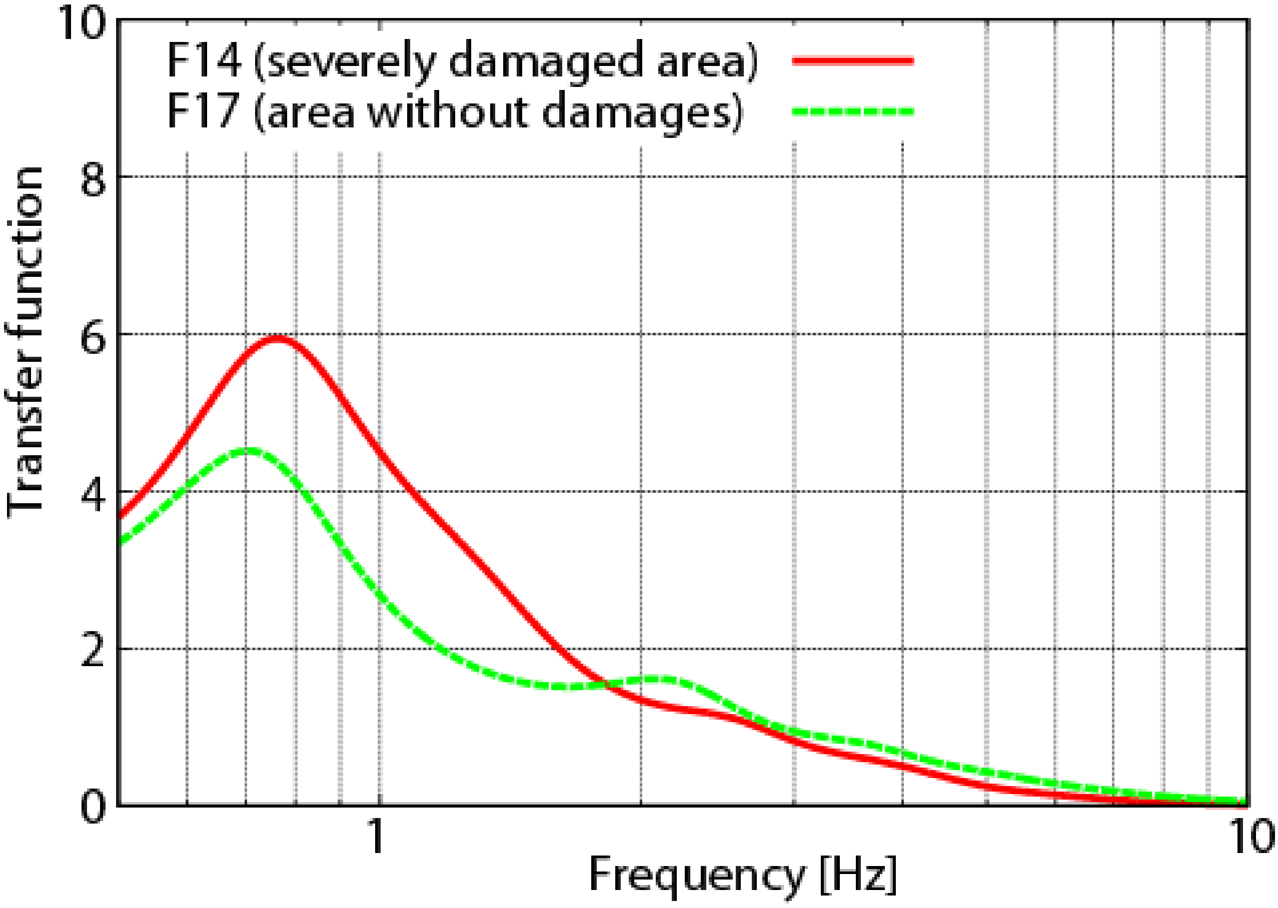
We have applied the model of velocity structure and calculated numerically the dynamic responses by the soft soil sediments, which are shallower layers than engineering-base layer. Although the target area is only about 1.5 x 1.5 km, the responses in the frequency range between 1 to 2 Hz differ according to location in the area. The transfer functions from engineering base to surface for linear response at typical two sites, where F14 and F17 are located in severely damaged and in the area without any damages, respectively. In this case, F17 is about 1.1 times larger than F14. On the other hand, the amplitudes of transfer function at F14 is about 1.5 times larger than F17 in average for non-linear responses, in the frequency range between 1 to 2 Hz. Figure shows the transfer function for non-linear response at sites F14 and F17.

Generally speaking, the predominant frequencies are around 1 to 2 Hz for typical wooden structures in Japan. This suggests that the small differences of velocity structures of ground cause the large differences of structural damage and the non-linear responses of soft soils play very important roles at the target area.

References:

Goto et al., Very dense seismic array observations in Furukawa district, Japan, Seism. Res. Lett., 83, 765-774.

Keywords: seismic response of soft soil, transfer function, non-linear response


F14 (severely damaged area)
F17 (area without damages)
Transfer function
Frequency [Hz]
0
2
4
6
8
10
1
10

Detecting temporal changes in shallow subsurface structures by using K-NET data

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The Kyoshin network (K-NET) of the National Research Institute for Earth Science and Disaster Prevention (NIED) has been recording strong ground motions for about 20 years since its construction in June 1996. K-NET data have been used to understand many subjects such as physics of earthquakes, seismic hazard caused by strong ground motion, and resultant earthquake disasters. In this presentation, I will show that K-NET data can be used to detect seismic velocity changes in shallow subsurface structures. Borehole data such as KiK-net are more suitable for the purpose, but the number of data is still limited. Hence, I proposed a method to use auto-correlation function of coda waves from local earthquakes recorded at K-NET (Nakahara, 2015). I applied this method to the 2011 Tohoku-Oki earthquake.

I used K-NET stations in the Pacific side of Northern Honshu (from Aomori to Chiba). At each station, two horizontal component records from earthquakes of M smaller than 7.0 which occurred at depths of 20-60km off Pacific region in 2010 and 2011 were used. In the frequency range of 1-20Hz, normalized auto correlation function of the record was calculated for a 10.24 s-long coda waves starting from the 1.5 times the direct S-wave travel time. I repeated such calculations 20 times by sliding time windows by 1 s. Normalized auto correlation functions were stacked with respect to different time windows. Aligning the stacked normalized auto correlation functions along time, I found changes in arrival times of phases in the auto correlation functions. Focusing on shallow depths, I dealt with phases in lag times of less than 1s. The results show that temporal variations occurred at some stations. Especially, clear phase delays were found at stations along the coast in Iwate and Ibaraki. And this change was associated with the mainshock. These delays recovered in a few month at some stations. However, these delays continued for a few years at other stations. This result may have an important implication for earthquake hazard estimation for large earthquakes that take place consecutively in a short time. Amounts of phase delays were in the order of 10% on average with the maximum of 30-50%. This method has an accuracy of about a few percent, which is much larger than methods using earthquake doublets. Hence this method might be applicable to detect larger changes. In spite of these disadvantages, this method is still attractive because it can be applied to records on the surface without boreholes.

Acknowledgments

I thank NIED for making K-NET strong-motion data available.

Keywords: K-NET, subsurface structure, temporal change

Seismic Intensity Measurement by IT Kyoshin Seismometer and Strong Motion Accelerometer at Campus Buildings

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Campus seismic observation of ground motions and building vibration is a useful tool to develop and explorer the frontier research issues. At the University of Tokyo, a campus building observation system of IT Kyoshin seismometers installed by Takano et al. (2004). The observed data are online via campus intranet, and monitoring for building response and simplified seismic intensity measurement are performed in real-time. At the Earthquake Research Institute of the University of Tokyo, strong motion observation system at the three different types of buildings as well as ground surface was deployed in 2005. The strong motion accelerometers are operated as a triggered system and measurement capability is up to 2097 cm/s/s. The three types of buildings of the Earthquake Research Institute composed a 7-story base-isolated RC building with a basement, a 6-story retrofitted RC building with 2-story basement, and a 4-story steel framed building. For each building, both the IT Kyoshin seismometers and strong motion accelerometers are installed at the lowest and top floors. To estimate prompt seismic intensity just after the earthquake is quite effective for evacuation and preparedness for the following disasters. We compare seismic intensity measure by two different seismometers. Generally the intensity show the good agreement within a difference of 0.3 in the Japan Meteorological Agency instrumental seismic intensity scale. However, the lowest and top floors tend to larger and smaller seismic intensity for strong motion accelerometers rather than IT Kyoshin seismometers, respectively. Takano and Ito (2010) already confirmed the JMA instrumental seismic intensity observed at campus is a function of 1.029 x -0.0092, where x is the simplified seismic intensity used in this study. We further investigate the difference of azimuth and period dependency using ground and building motion time histories, and design maximum and minimum ground motion levels of ground motion agreement.

Keywords: Campus seismic observation, IT Kyoshin seismometer, Strong motion accelerometer

