20 Years of K-NET

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Strong motion observation in Japan has been operated since 1950’s together with the development of the SMAC strong motion sensors, which succeeded in recording the ground motions of the 1968 Tokachi-oki and 1978 Miyagi-oki earthquakes. Near-fault ground motions were observed during the 1995 Hyogoken-nanbu (Kobe) earthquake, however, several problems were posed regarding initial response. After the 1995 Kobe earthquake, the Japanese strong motion observation was drastically stimulated. Many Japanese organizations such as the National Research Institute for Earth Science and Disaster Prevention (NIED) have made a lot of efforts to improve the quality and quantity of the seismic observations in Japan. Since 1996, NIED has been in charge of the operation of two strong motion networks: K-NET and KiK-net. K-NET consists of about 1000 stations with 3-component acceleration strong-motion seismographs on the ground surface. KiK-net consists of about 700 stations with 3-component acceleration strong-motion seismographs both on the ground surface and at the bottom of the boreholes. NIED is a pioneer institution in Japan to releasing all digital data for free through the Internet immediately after an earthquake, and nowadays this open-data policy is becoming a common practice among the seismological field. NIED also developed new instruments of K-NET and KiK-net for upgrade with new technology. The first, second, and third generations of NIED accelerometers are capable of measuring up to 2000, 4000, and 8000 gals, respectively. The first generation, K-NET95 (Kinoshita, 1998) and SMAC-MDK (Aoi et al., 2004), adopted a dial-up system in which the Data Management Center (DMC) of NIED called to stations and collected data via telephone line after earthquakes. The second generation, K-NET02/K-NET02A (Fujiwara et al., 2007) and KiK-net06 (Aoi et al., 2011), adopted a dial-out system in which stations automatically sent data to DMC after triggered. Real time seismic intensity (Kunugi et al., 2008, 2013) is also calculated at stations. The third generation is K-NET11/K-NET11A and KiK-net11/KiK-net11A (Kunugi et al., 2014). K-NET02/K-NET02A has been officially approved as a seismic intensity meter by the Japan Meteorological Agency (JMA). Step-wise noise was improve by using the JA40GA sensor with quarts hinge, which can measure the long-period components. In the third generation, 4-component sensors are installed to ensure the accuracy of the acceleration measurement based on lessons from severe situation in the 2011 Tohoku earthquake. K-NET and KiK-net have recorded the JMA seismic intensity of 7 four times, intensity 6+ and 6- 188 times, and over 1000 gals 42 times including 4022 gals during the 2008 Iwate-Miyagi earthquake. Because of the low-frequency occurrence of large earthquakes, strong motion has been commonly observed by event triggering system, which requires connection of the telephone-line only during the data collection. To advance the rapidity and reliability, continuous observation is one of the most likely options. Data recorded by an event triggering system provides important information of past earthquake and helps to assess the seismic hazard and risk of a future earthquake. With a continuous observation system, owning to the rapid progress of information technologies, we would soon be able to fully monitor ground motions in real time and thus directly contribute to mitigate seismic disasters. Strong motion observation has been operated over years due to selfless efforts of our frontrunners. Even though recent trend regards the short-range research progress as important, it is also quite important to incorporate with new technology to ensure recording of less frequent but very important events occurring once per years or decades, such as the 1995 Kobe or 2011 Tohoku earthquakes.

Keywords: K-NET, KiK-net, Strong motion observation

Utilization of K-NET data in Central Disaster Management Council

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Central Disaster Management Council is making master plan for disaster prevention and deliberating important part about disaster prevention. And Central Disaster Management Council establishes committees for technical investigation to investigate a technicality. We are able to find mentioning about use of K-NET in the reports which the committees for technical investigation on earthquake disaster issued. For example, the records which acquired by K-NET are compared with synthesized waveforms on the report issued by the “Committees for Technical Investigation on Countermeasures Against Tokyo Inland Earthquake”.Observed data by K-NET are useful to evaluate the subsurface structures. Yokota et al. (2011) evaluated the amplification of long-period component of seismic records, and confirmed that the natural period which calculated from velocity structures related to the amplitude of long-period component of ground motion. The relation was that the longer the natural period at the observation station was, the larger the amplification of long-period component of observed record was.We introduce the trend of use of the above-mentioned K-NET data.

Keywords: K-NET, disaster mitigation, strong motion

Application of K-NET records to development of design long-period ground motions

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Long-period ground motions in the period range from 2 to 10 s are influential to super high-rise buildings and base-isolated buildings. In order to develop design long-period ground motions for these buildings we studied long-period ground motions from 2008 to 2012 with Building Research Institute in the "Promotional project for upgrading the building standards" under the auspices of the Ministry of Land, Infrastructure, Transport and Tourism (MLIT). Based on these studies MLIT called for public comments on "Countermeasure plan for super high-rise buildings against long-period ground motions caused by mega-thrust earthquakes along the Nankai Trough" on December, 2015. In this paper we mainly show technical and academic results on empirical long-period ground motion predictions using K-NET and the other strong motion records.

Firstly we develop ground motion prediction equations (GMPEs) of response spectra and Fourier phase spectra in the period range from 0.1 to 10 s using many K-NET, KiK-net, JMA-87 and JMA-95 records. About 10000 earthquake-station pairs of hypocentral distance X < 400 km for 51 subduction-zone earthquakes with M_J6.5-M_J8.2 and depth < 60 km and 6000 earthquake-station pairs of X < 350 km for 26 crustal earthquakes with M_J6.0-M_J7.3 are used. The GMPE of response spectra is modeled by rupture distance, Mw^2 and Mw considering with saturation effects on distance. The GMPEs for average and variance of group delay time which is the differential of Fourier phase spectra within narrow frequency bands is modeled by X and seismic moment. The GMPEs for average and variance of group delay time enable us to empirically generate time history. For subduction-zone earthquakes, we get different site factors in the Kanto basin for the earthquakes of the Pacific plate and the Philippine Sea plate, respectively. The site factors for earthquakes of the Philippine Sea plate are larger than those for those the Pacific plate due to 3D effects of the Kanto basin.

The site factors are obtained at strong motion stations with about 10-20 km intervals. Since the site factors in the period range from 1 to 10 s are found to be different from 1D amplification factors for S waves, we develop a regression model of site factors to predict them at any construction sites in three major urban regions. The regression model is developed using Tz, which is 1/4 of the natural period from seismic bedrock to engineering bedrock calculated from the deep substructure model with about 1 km grid space by HERP. The site factors are empirically represented by a bi-linear function of Tz well. We show that the bi-linear function can be interpreted from medium responses of surface waves. However Tz is not enough to represent the site factors in the area where the deep subsurface structure abruptly changes such as Kobe area. In that case we correct Tz so as to empirically consider 3D effects on site factors.

Time history of ground motions in the period range from 0.1 to 10 s can be predicted by the developed method using outerfault parameters. For large earthquakes whose faults are composed of several segments, time history is generated by summing up the time history for each segment considering each rupture starting time. This method is verified by simulating strong motion records of K-NET and KiK-net stations for the 2011 Tohoku earthquake. We also confirm that long-period ground motions predicted by this method are consistent with those predicted by 3D-FDM by HERP for the Tokai earthquake, the Tonankai earthquake, and the Nankai earthquake.

Acknowledgments : The strong motion records observed at K-NET and KiK-net stations by NIED, JMA-87 and JMA-95 stations by JMA and a station at Kogakuin University are used in this study. The seismic moments determined in the F-net by NIED and Global CMT project and hypocenter information by JMA are used.

Keywords: K-NET strong motion records, Long-period ground motions, Ground motion prediction equation , Mega-thrust earthquakes along the Nankai Trough, Phase spectra, Super high-rise buildings

Long-Period Ground Motion of Tokyo Metropolitan Area during the Deep Event occurred off West of Ogasawara Islands

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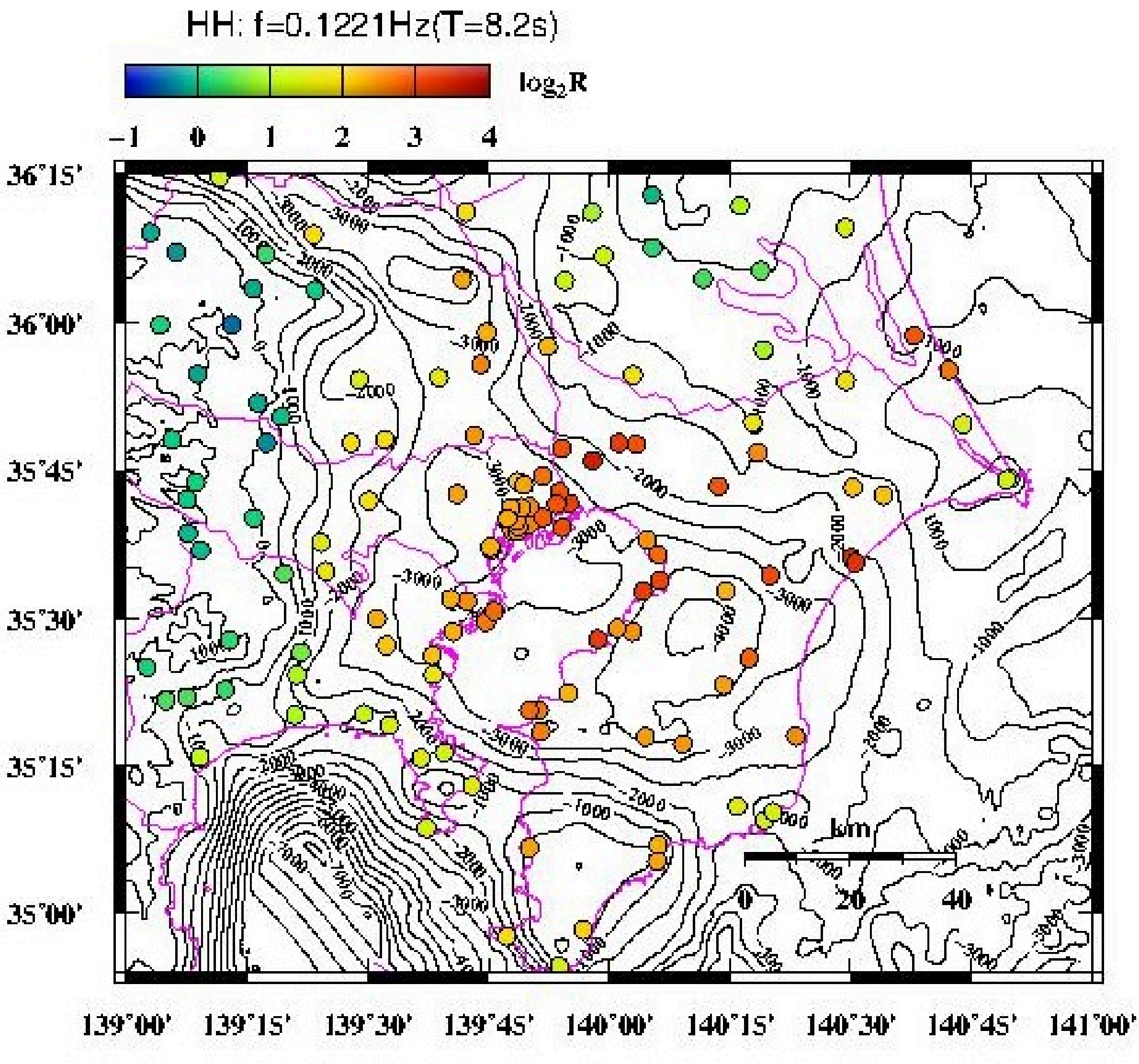
1. Introduction
The large earthquake with M8.1 has occurred in the west off Ogasawara Island at 628 km in depth on May 30, 2015. This event data give several merits for empirical site factor study of Tokyo Metropolitan area. Large magnitude means the high-SN ratio in long-period band. Deep epicenter means the incident wave was body wave with high incident angle. Long distance makes the radiation pattern effect small in the observation network area. In this study, the empirical amplification factor in long-period band of 2 to 10 s using the data observed in the Tokyo metropolitan area.
2. Data
The acceleration data observed by K-NET and KiK-net located in Kanagawa, Tokyo, Chiba, Saitama and Ibaraki prefecture were used in this study. The velocity data observed at the thermal power stations of TEPCO around Tokyo bay area were used, too. Almost K-net seismometers were triggered at S-wave and P-wave portion of the data was lost. It was not problem because the analysis target in this study was S-wave portion.
3. Propagation in sediment layers
The propagation characteristics of S-wave portion were checked by comparison of the wave forms between ground surface and the bore hole at KiK-net stations. Significant phase propagated from deep underground and reflected at ground surface. The time lag between the input phase and the reflected phase was coincident with the time calculated from subsurface velocity model.
The F-K spectral analysis of S-wave portion were performed using dense K-NET stations located in the east part of Tokyo. The result shows that the low-frequency wave propagation velocity was over 6km/s in horizontal direction. It means that the S-wave propagate from bedrock with high incident angle.
4. Spectral ratio to the rock site
First, the Fourier spectra were made from the S-wave portion of acceleration records with the time window of 81.92 s by FFT methods. The spectra were smoothed by Parzen window of 0.05 Hz width. Next, the Fourier spectral ratios were made by division of the ground surface data at each station by the ground surface data at TKYH13. TKYH13 is located in the Kanto Mountain in west of Kanto plain. At TKYH13, there are almost no amplification in lower frequency band than 1Hz from the bedrock with Vs=2500m/s at 100 m depth to ground surface. We can consider the record of TKYH13 the outcrop bedrock data in low frequency band.
The value of spectral ratio becomes bigger from the west station to the east station. The spatial distribution of spectral ratios at about 8 s and the distribution of the bedrock depth are almost conformable except for the southern part and northern part of Chiba prefecture. If a period becomes shorter, the correlation of spatial distribution of spectral ratio with the seismic bedrock depth is worse. This means that the short period ground motions was affected by the more shallow subsurface structure.
5. Discussion and conclusions
We compared the spectral ratios to TKYH13 in this study and the site amplification factors from the bedrock calculated from the subsurface structure models made from the past investigations. The results show that the spectral ratios were higher than the theoretical amplification factor in the Kanto basin. However, the spectral ratios between ground surface to the bedrock at each station

accorded with the theoretical ratio calculated from subsurface structure model. These results mean that the incident wave from the seismic bedrock at deep sediment stations were bigger than incident wave at TKYH13. This spacial change in the Tokyo metropolitan area may be given under the influence of the plate structure like the abnormality seismic intensity area.

Acknowledgments
We used the data of K-NET and KiK-net strong motion observation network of the National Research Institute for Earthquake Science and Disaster Prevention.

Keywords: Deep Event, Long-Period, Metropolitan Area, Body Wave, Spectral Ratio



Development of real-time earthquake damage information system using K-NET

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We develop a real-time earthquake damage information system that provides information by combining amplification characteristic data for subsurface ground accumulated in the course of the development of the Japan Seismic Hazard Information Station (J-SHIS), basic information on population and buildings, methods for predicting ground motion, methods for assessing building damage, and strong motion data observed by K-NET, KiK-net, local governments, and the Japan Meteorological Agency (JMA) in real-time. This system estimates spatial ground motion distribution in 250m-mesh from seismic intensity information sent at different timing for observation stations, estimates population exposure to seismic intensity and building damage using estimated ground motion as input, and provides information as “J-RISQ earthquake quick report” to users via Web (http://www.j-risq.bosai.go.jp/report/en/). The system estimation is based on intensity data obtained at different timing to ensure recency by updating results when it receives new data and updates results when it receives estimation results. We will improve the system for not only estimating damage situations but also confirming them by various type of information. In this study, we report on system outline and progress in developing building and population models covering the entire country of Japan, along with the development of methodologies related to damage estimation and situation assessment which are core components in the research and development of a real-time earthquake damage information system.
Acknowledgements
This work was supported by the Council for Science, Technology and Innovation (CSTI) through the Cross-ministerial Strategic Innovation Promotion Program (SIP), titled ``Enhancement of societal resiliency against natural disasters'' (Funding agency: JST). The seismic intensity data from local governments and JMA that were used in the real-time system were provided by JMA.

Keywords: real-time, earthquake damage, K-NET

Improvement of Earthquake Disaster Response in Central City Area in Megacity using the Real-Time K-NET Data

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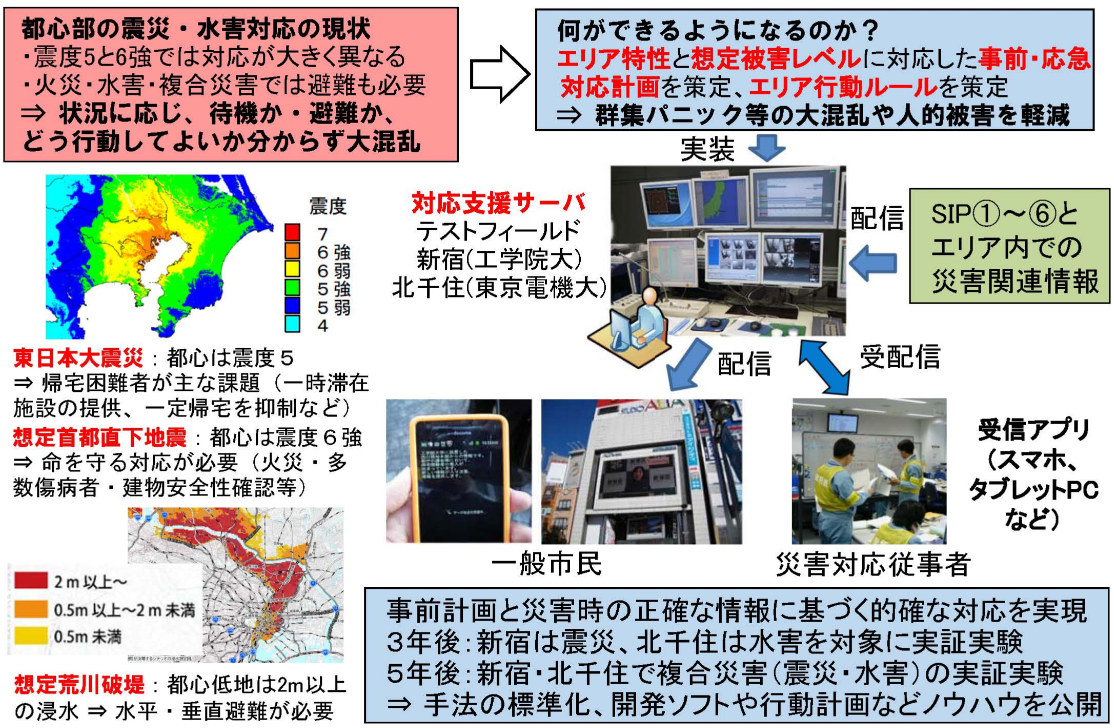
Although the JMA seismic intensities were 5 without major damage in Tokyo, its central city areas were thrown into confusion, because of the traffic jams and the huge number of commuters unable to get home. In order to prepare against larger-scale earthquake disasters in the central city area in Megacity, such as the Shinjuku Station area in Tokyo, we have been developing a series of the application systems, which consists of the pre-action area plan and rule based on the level of disasters, the information server and application software for portable PC and cellular phone, and earthquake disaster drill. We developed the prototype of the systems using the real-time K-Net data, and tested its effectiveness by a map exercise in the Shinjuku station area in 2015. We have been improving them, and test again by a drill in 2016.

Keywords: K-NET, Central City , Improvement of Earthquake Disaster Response, Complex Disater, Prior Action Plan and Rule



Current status of K-NET

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1.National Research Institute for Earth Science and Disaster Prevention

National Research Institute for Earth Science and Disaster Prevention (NIED) has installed K-NET95, K-NET02/02A, K-NET11/11A strong motion seismographs to observatories of K-NET. These seismographs were developed by NIED, employing state-of-the-art technologies. One of the features of K-NET02 and later models is their operating systems (Linux). Due to the OS, these seismographs are able to perform multi-functional operations. The operations are easily re-programmable. K-NET02/02A and K-NET11/11A share almost all of their programs.
NIED started a feasibility study for continuous monitoring of strong motion. As a part of this study, NIED had added new functions for continuous calculations and transmissions of strong motion to seismographs at observatories in Kanto and Tokai areas. Continuous monitoring of strong motion is useful for research and development of "Earthquake area alarm" (Nakamura et al, 2014). Also continuous transmissions are useful for robust recording of strong motion data.
In this presentation we will introduce current status of K-NET, focusing on K-NET11/11A seismographs and new observation system.
Acknowledgements
This work was supported by the Council for Science, Technology and Innovation (CSTI) through the Cross-ministerial Strategic Innovation Promotion Program (SIP), titled "Enhancement of societal resiliency against natural disasters" (Funding agency:JST).

Keywords: K-NET, Strong motion seismographs, Continuous monitoring of strong motion, Earthquake damage estimation, Earthquake early warning

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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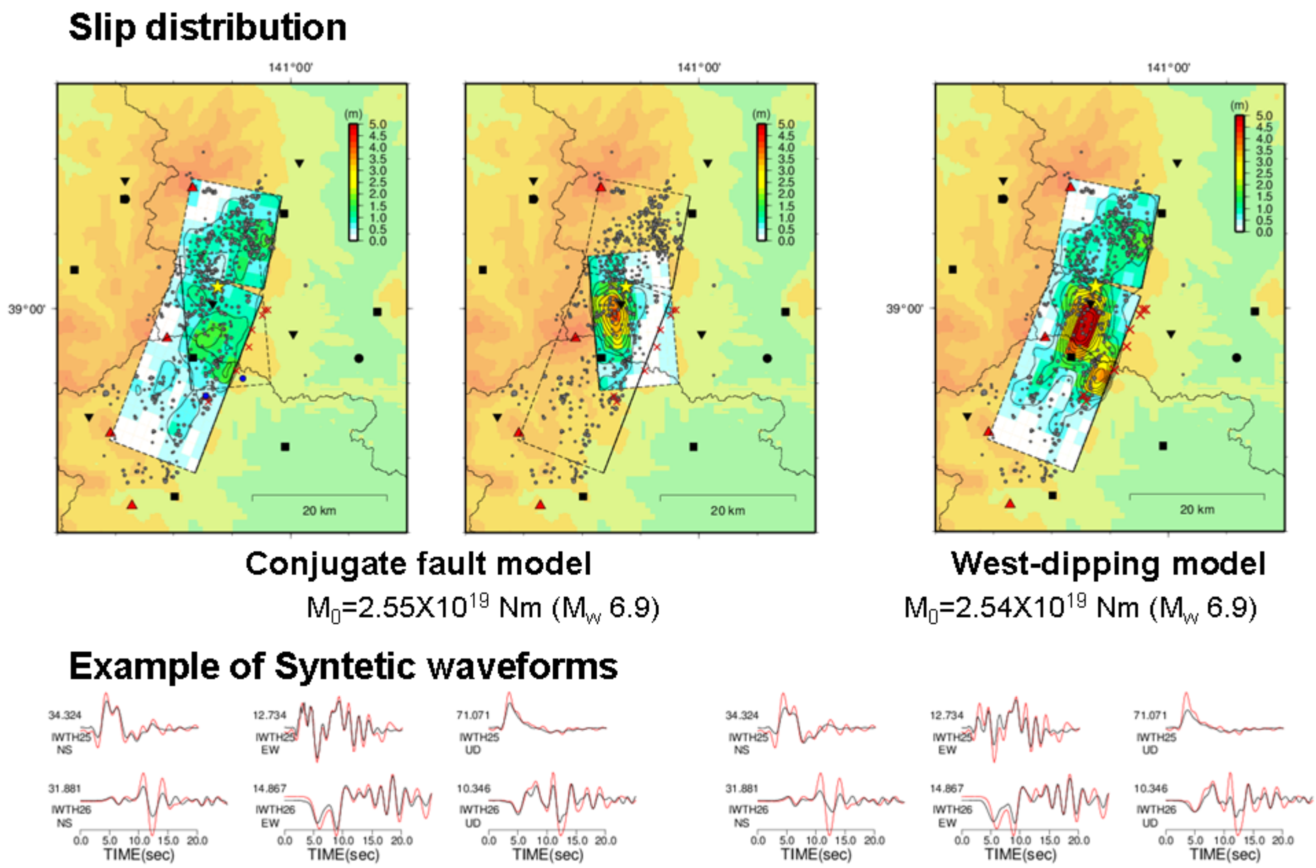
INTRODUCTION
Since K-NET was constructed, multiple strong motion records are often observed in the source region of large crustal earthquakes. Those data have revealed not only detailed rupture process on a fault, but also complex fault system in itself. The 2008 Iwate-Miyagi Nairiku Earthquake is an 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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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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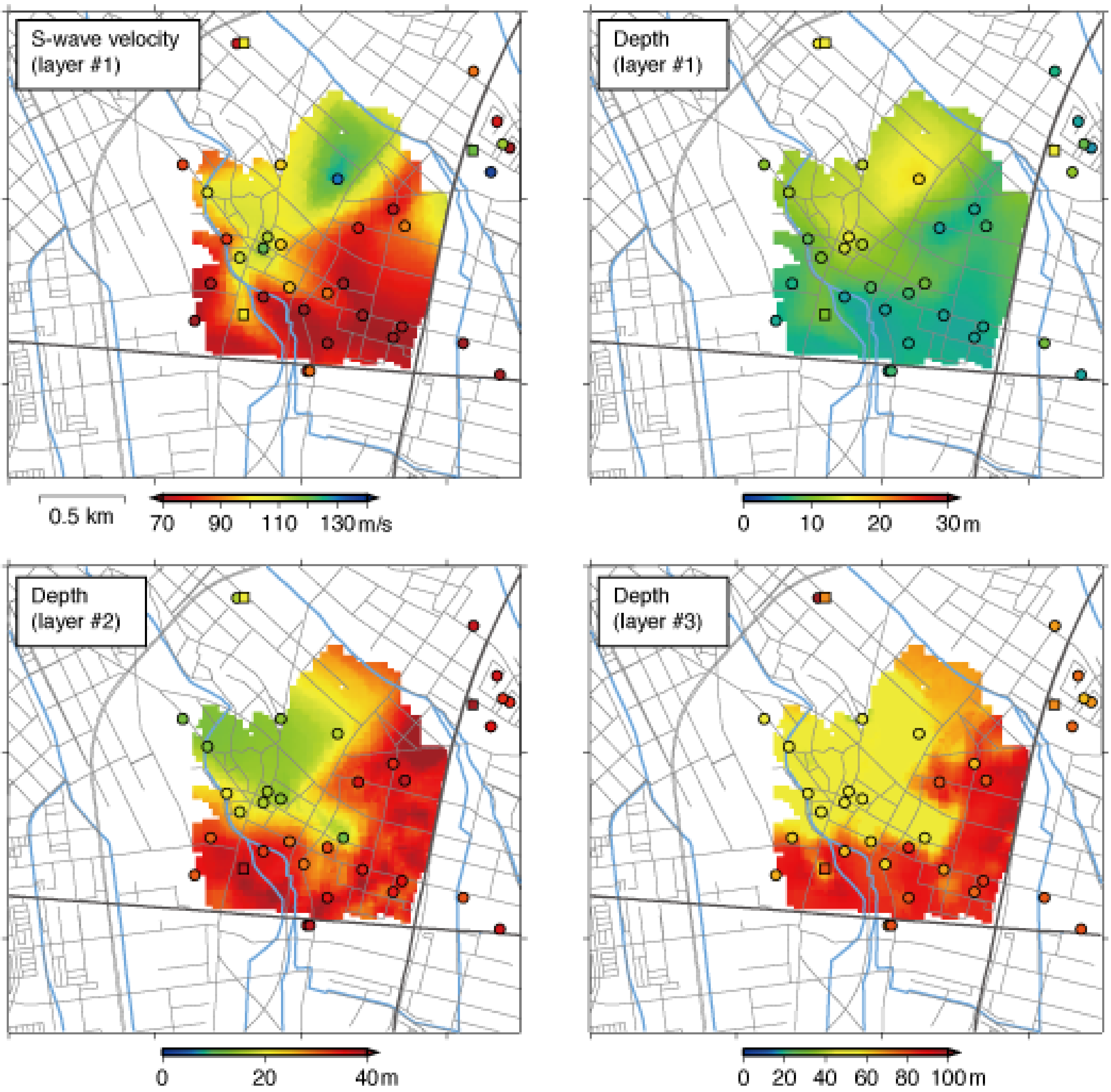
Keywords: dense aftershock records, microtremor observation, shallow subsurface structure



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.

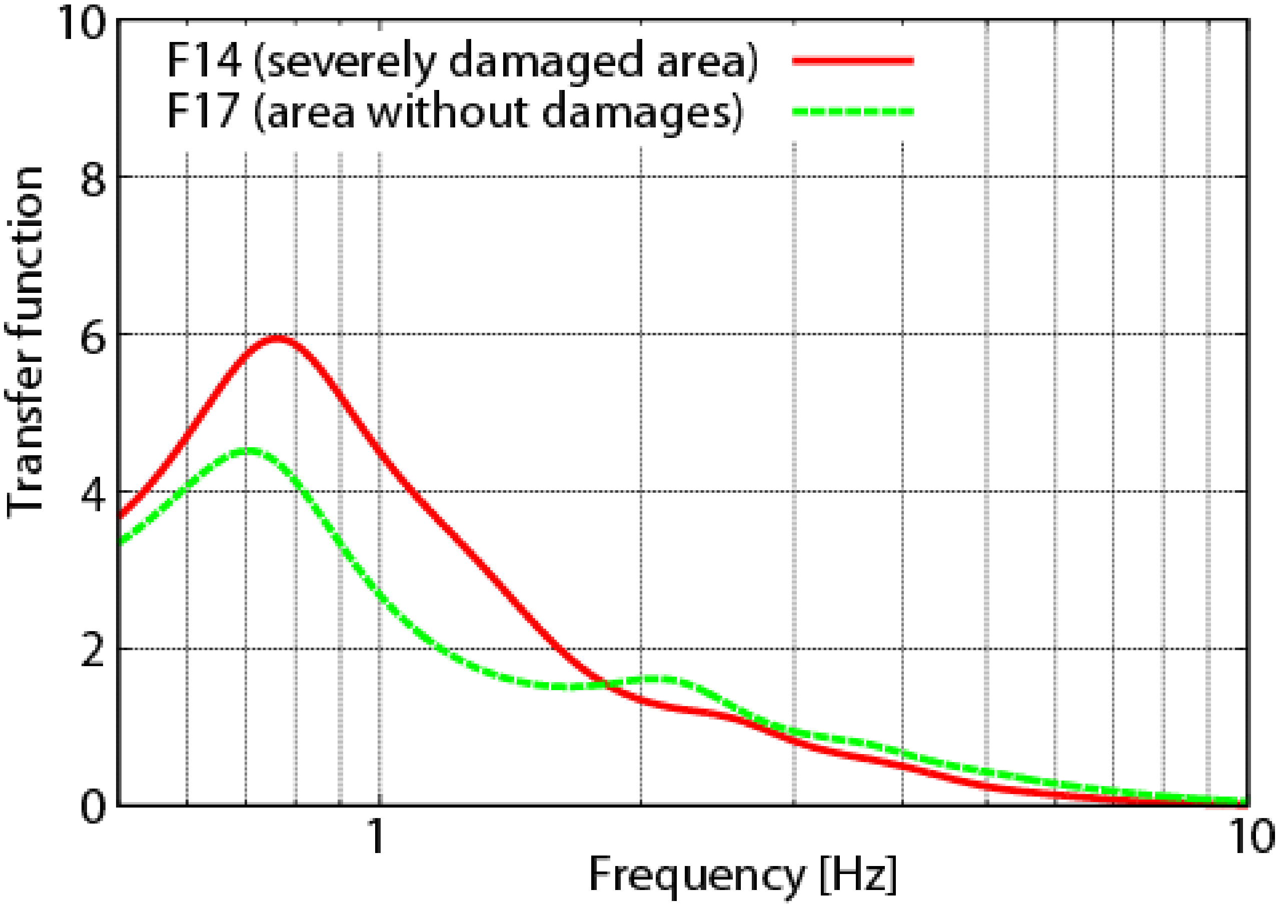
We have applied the model of velocity structure and calculated numerically the dynamic responses by the soft soil sediments, which are shallower layers than engineering-base layer. Although the target area is only about 1.5 x 1.5 km, the responses in the frequency range between 1 to 2 Hz differ according 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

