Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)


SSS33-01 Room:103 Time:May 19 09:15-09:30

# Estimation of underground structures using microtremors in the southern part of the Osaka Plain

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It is essential to evaluate an underground structure properly or validate previously proposed underground models based on the geological data and/or boring exploration data with observed ground shaking, in order to obtain highly precise estimation of strong ground motions in urban areas.

In this study, we observed microtremors in the southern part of the Osaka Plain in Japan where detailed geological information are comparatively less than the other areas of the Osaka Plain. We calculated H/V spectral ratio of microtremors (HVRM hereafter) from observed data and compared the predominant peak frequencies and amplitudes at these frequencies with theoretical HVRM calculated from our initial model. We searched for the better 1-D structure at each site based on these predominant frequencies and amplitudes.

In our identification approach we used the code that calculates theoretical HVRM for a given underground structure based on a newly proposed theory (Sanchez-Sesma *et al*., 2011). In this theory, HVRM at a site can be expressed in terms of a ratio of the imaginary part of the Green's function components at the site if the site is in the diffuse field.

First we calculated theoretical HVRM from the underground models at three strong motion stations of NIED using the code. By comparing the theoretical HVRMs with the observed HVRMs, we validate the theoretical calculation scheme and our estimation approach for an underground structure. As a result, we found that both theoretical and observed HVRMs show fairly good agreement, except for a site in a hilly zone with highly irregular topography. Therefore it is shown that if an observation point is on an alluvial plain with soft sediments, we are able to identify an underground structure close to the real structure at the point by fitting the theoretical HVRM to the observed HVRM.

Next, we identified both thicknesses and S-wave velocities of underground layers together. We used the grid-search method to identify the best underground structure that yields minimum residual between theoretical and observed HVRMs. As a result, theoretical HVRMs of the proposed models are a better match to those of observed HVRMs in both the predominant frequencies and the amplitudes at these frequencies than theoretical HVRMs of the initial models at all the observation stations.

After finishing our identification, we compared our results to previously proposed studies such as microtremor array observation conducted by the Headquarters for Earthquake Research Promotion, and H/V spectral ratio obtained from Rayleigh-wave ellipticity (HVRR hereafter), in order to validate the appropriateness of the newly proposed theoretical HVRM based on the diffuse field theory.

Finally we further studied a way to apply our identification results for estimation of strong ground motions. Considering the results of our modified underground models, which have different Vs structures at each site (that is, different-Vs models), we identified again underground models with the common Vs values in each layer at all the sites (that is, same-Vs models). As a result we found that we can use the same-Vs models as models for estimation of strong ground motions instead of the different-Vs models since the differences in 1-D amplification characteristics between them seem insignificant.

In this study, following the newly proposed theoretical HVRM based on the diffuse field theory, we could precisely identify the best underground structure by comparing observed HVRM and theoretical HVRM for an assumed underground structure.

We would like to estimate strong ground motions for hypothesized scenarios of earthquakes in future based on the underground structures proposed in this study. We also would like to extend our approach of microtremors for estimation of complex underground structures around faults with much dense sampling in space.

Keywords: microtremors, H/V spectral ratio, Osaka Plain, diffuse field theoy

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SSS33-02 Room:103 Time:May 19 09:30-09:45

# Estimation of variation in site amplification due to uncertainty of shallow Vs profile from microtremor exploration

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Many model parameters are involved in strong motion simulations, and some of the parameters are difficult to determine in advance for future major earthquakes. The variations of estimated ground motion have been often discussed from numerical simulations considering effects of fluctuation of the parameters for fault models. Uncertainty in subsurface structural parameters, such as S-wave velocity, also affects the variation of the ground motion characteristics. However, ground motion variation due to uncertainty of subsurface structure has not been deeply discussed. One of the reasons can be caused from a difficulty to estimate an uncertainty for the model parameters of subsurface structural model from geophysical or seismological investigations.

In this study I estimated an uncertainty of shallow S-wave velocity profiles from microtremor array explorations using Markov Chain Monte Carlo method (MCMC method in the following). The estimated uncertainty was used to know the variation of the amplification from the sampled S-wave profiles. The MCMC inversion method does not determine one model unlike to conventional inversions. It can provide models whose parameter distributions are proportional to their probability density functions. Therefore we can estimate the variation of the amplifications for soil model parameters from the sampled models with the MCMC method.

I used the results of the shallow microtremor explorations conducted in Monzen-machi in Ishikawa prefecture after the 2007 Noto Hanto earthquake (Yamanaka et al., 2008). The MCMC method by Yamanaka (2011) was applied to the Rayleigh wave phase velocity data at periods of less than 1 second from the microtremor explorations. The sampled shallow S-wave velocity models over the engineering bedrock were used to obtain an average and a standard deviation of the S-wave velocity and the thickness of the shallow soils at each site. Furthermore, 1D amplifications of S-wave were also calculated from the sampled models. The variations of the amplification factors are almost the same (about 30%) at all the periods including fundamental peak period. The average amplification factors become much smoother at short-periods than those at long-period. Since the sampled models have different peak periods for the higher mode amplifications, such higher-mode peaks and troughs are smoothed in averaging operation. I also calculated amplification for a model derived in conventional inversion of the phase velocity. The S-wave velocity model from the conventional inversion shows peaks and troughs of higher-mode in short period range. However, these peaks and troughs are not so accurate considering the uncertainty of S-wave velocity profiles from the microtremor explorations.

Keywords: amplfication, shallow soil, microtremor exploration, S-wave velocity profile, inversion, Markov chain Monte Carlo method

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SSS33-03 Room:103 Time:May 19 09:45-10:00

# Soil structure inversion and strong motion estimation based on H/V spectral ratio for earthquakes

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During the 2011 Off the Pacific Coast of Tohoku earthquake which occurred on March 11, 2011, the maximum acceleration of 585.7 cm/s$^2$ and JMA seismic intensity 6 upper was observed at the K-NET Furukawa (MYG006) station, in Osaki City, Miyagi Prefecture. Near the K-NET Furukawa several buildings were collapsed or heavily damaged due to strong motion and subsequent ground liquefaction. We investigated underground structures at and near the K-NET site by using aftershock records to delineate site amplification effects on the strong motions during the main shock.

We deployed five temporary aftershock observation sites around MYG006 on June 2011, and measured ground motions continuously for six months. Among the 63 aftershocks triggered at MYG006 the observed earthquake data at the temporary aftershock observation sites were used. Average Fourier spectra were computed for the NS and EW components to determine the HVRs of NS/UD and EW/UD. As for the aftershock HVRs, a peak was observed at around 0.2 Hz at all six observation sites including MYG006, and all of the sites recorded similar HVRs in the frequencies below 1.5 Hz, which is believed to be the effect of the deep soil structure.

The strong motion HVRs for the main shock and the aftershock that occurred at 23:32 on April 7 (M7.1) and weak motion HVRs calculated as the average of other small aftershocks were compared. The HVRs were almost the same between the two major events but they were different from those of weak motions, which shows the effect of nonlinearity on the strong motion HVRs. During the strong motion, due to the effect of nonlinearity, the frequencies that are said to cause severe damages to buildings, namely 0.5-2 Hz, were greatly amplified and this is believed to be one of the causes for the severe building damages in Furukawa. If we focus our attention to the troughs around 8 to 10 Hz, we can see weak frequency shift from the average HVRs of small aftershocks to the two strong motion HVRs by half at most.

Identification of the soil structure immediately below each observation site was attempted based on the HVRs of weak motion data recorded at each site. For the initial model the results of the previous study (Kawase and Matsuo, 2004) with two more layers for better characterization were used. The theoretical HVRs were calculated based on the concept of Kawase et al. (2011), and were identified by changing both shear wave velocities Vs and thicknesses of assumed layers. We used Hybrid heuristic method (Yamanaka 2007) and minimized the misfit between observed and theoretical HVRs. First we identified common deep soil layers for all observation sites to much all the HVRs in the longer period than 1.0 s. Next we determined shallow soil layers to fit observed HVRs at each observation sites for period range from 10 s to 0.05 s. The identified velocity structures reproduced the observed HVRs quite nicely in a wide period range.

One-dimensional deconvolution analysis was applied to derive the incident seismic wave on the seismic bedrock using the equivalent linear analysis, taking the nonlinearity of the soil structure into consideration. We calculated the incident waves for the main shock record in the frequency range from 0.1Hz to 20Hz. The maximum acceleration of NS bedrock wave was found to be 159.5 m/s$^2$ and the maximum acceleration of EW bedrock wave was 454.2 m/s$^2$ . The latter is high because of large amplification in high frequency range over 10Hz.

We computed the seismic motion at the temporary observation site near MYG006 during the main shock by using the above inverted bedrock motions. The maximum acceleration of calculated wave was almost the same as the observed wave at MYG006. The transfer function between the bedrock and the surface shown strong peak shift to longer period due to the effect of soil nonlinearity with the same degree as the shift observed at MYG006.

Keywords: H/V spectral ratio, strong motion, defuse field theory

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SSS33-04 Room:103 Time:May 19 10:00-10:15

# A new development in shallow explorations using microtremors based on a practical use of a CCA method

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We have continued development of a CCA method (Centerless Circular Array) for nearly 10 years as a tool to determine phase velocities of Rayleigh waves by using vertical-component microtermor arrays. The initial development was characterized by the applicability of a CCA method to irregular arrays consisting of three seismometers (Cho et al. 2004). Later, we found the potential of a CCA method to deal with a very long-wavelength range relative to an array size (Cho et al., 2006). Recently, we showed that wavelengths more than 100 m are analyzable using miniature arrays having radius less than 1 m, by adopting a CCA method and a noise-compensated CCA method (Cho et al., 2013). This time, we have examined the practical use of a CCA method and its application.

We replaced the cross spectra that are involved in a fundamental equation of a CCA method with coherence functions (Hereafter, we call it a coherence CCA method). A comparison between the analysis results of coherence-SPAC and CCA methods indicated that the coherence CCA method can produce confidential and robust results. In particular, the noise-compensated CCA method for miniature arrays were significantly stabilized by the use of coherences, producing performances much higher than that of the SPAC method. We expect that the use of the coherence CCA method with miniature arrays ($r < 1$ m), together with small irregular arrays consisting of three seismometers ($r < 10$ m) depending on the necessity, enables shallow subsurface explorations (to the depth of about several tens of meters) more practical than ever before, from view points of the mobility of observations, broadness of the analyzable wavelength ranges, and the reliability and robustness of the analysis results.

Incidentally, the amplitudes of microtremors, as well as the phase data by an array analysis, have information on the subsurface structure. A peak frequency of H/V spectra is related to either the thickness or the elastic-wave velocity of a surface soft soil, while the height of the peak is related to the impedance ratio between the soft-soil and basement layers. However, we cannot constrain the depth scale corresponding to the peak of a H/V spectrum due to the tradeoff between the velocity and thickness.

This problem can be solved by conducting a miniature-array observation adjacent to a single-point observation. Obtaining a relation between frequency and wavelength from an array observation, we can apply it to the H/V spectra to obtain a relation between the wavelength and the HV ratio. By using some conversion equation from a wavelength to a depth, we can have a plot of depth vs. H/V ratio. We call a subsurface structure obtainable in this way a H/V structure.

We propose an integrative interpretation of H/V section, together with a pseudo shear-wave velocity section (Ling et al., 2003; Haraguchi, 2010), obtainable by adopting miniature arrays for phase velocities and single-point observations for H/V spectra. Miniature arrays for the CCA method have high mobility and high horizontal resolution owing to the array size. A combination of the CCA and H/V methods enables to obtain more information from microtermors in a easier way than before.

We are planning to increase application examples and to validate the usefulness of the method proposed above. A seismometer JU-215, which was co-developed by the NIED and Hakusan Co. (Senna et al., 2006), is best suited for our purpose from a view point of the portability, the simple handling, and the capacity of providing with high-quality data. Fig. 1 shows H/V and pseudo shear-wave velocity sections along a measurement line about 10 km. The data were obtained by a single researcher, who conducted a two-day observation, including a preliminary inspection, using JU215 seismometers. In the presentation, showing analysis results of the data obtained using JU215 (at Tsukuba, Kashiwa, Urayasu, Itako, ... etc), we will discuss the usefulness and problems of the proposed method.

Keywords: microtremor, velocity structure, surface waves, phase velocity, expolation method, array

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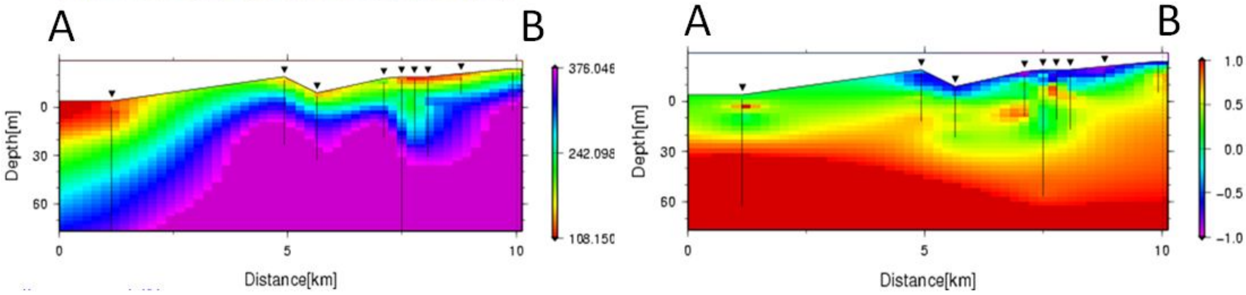
Figure 1
Upper : A measurement line at Kashiwa (about 10 km)
Lower : a pseudo shear-wave velocity section (Left)
and a H/V section (Right)



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# Statistical properties of strong ground motions based on the spectral inversion method

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Studies to separate strong motion properties (source, path, and site properties) from Fourier spectra of observed strong motions by the generalized spectral inversion method have been attempted for several decades (e.g., Iwata and Irikura, 1986; Kawase and Matsuo; 2004). However, there is barely any research to separate strong motion properties using response spectra because the physical meaning of these properties in the separated response spectra is not clear. However, similarities are identified between acceleration Fourier spectra and the velocity response spectra, and so investigation using response spectra seems worth attempting. In addition the data used in Kawase and Matsuo (2004) was those observed from 1996 to 2002 for three nation-wide strong motion networks, namely, K-NET, KiK-net, and Japan Meteorological Agency's seismic intensity-meter network. Since then more than ten years have passed, and vast amount of data has been accumulated. Thus we separated and analyzed strong motion properties for both the Fourier and response spectra of strong motion data between 1996 and 2011 (with Mj 4.5 and over) and summarizes findings on newly obtained strong motion properties.

Strong motion properties separated from acceleration Fourier spectra agreed well with those by Kawase and Matsuo (2004) regardless of earthquake types and regions. The Q values tend to be more linear and stable than their results. The Q values of crustal earthquakes in Hokkaido were obtained for the first time. Site amplification properties show a good match with Kawase and Matsuo (2004). The source properties represented by the so-called Brune's stress drop were also not so significantly different.

The Q values from acceleration response spectra agreed very well above 1 Hz with those from the Fourier spectra. In contrast, different trends were observed below 1 Hz, where the Q values from response spectra showed linear frequency dependence. The site amplification properties matched well with those from Fourier spectra; however, many sites below 1 Hz tend to show a flat trend with high amplitude. As for the source properties, we compared source terms of the pseudo-velocity spectra with those from acceleration Fourier spectra. Basically levels were similar for frequencies higher than 1 Hz, but again data separated from response spectra again maintained a high value below 1 Hz. The differences below 1 Hz would be due to higher response spectral values by prominent peak amplitudes in Fourier spectra in the higher frequency range.

Source properties separated from acceleration Fourier spectra were statistically analyzed. We applied t tests to the Brune's stress drop estimates before and after the Off the Pacific Coast of Tohoku Earthquake of March 11, 2011, to realize that they were not significant for all earthquake scales and types. This means that there are barely any effects of the Off the Pacific Coast of Tohoku Earthquake on the stress drops of small earthquakes including aftershocks in the source region in Tohoku.

We also compared the short-period level A, which is one of the important indicators that determine the area of asperities in the so-called empirical Green's function method, with the generally used scaling relationships by Dan et al. (2001) and Satoh (2003). The obtained data was not considered to be the same as those by Dan et al. (2001), although the regression line for subduction-zone earthquakes is close to their work. The obtained distribution of the short-period level A was also tested against those by Satoh (2003) to find that the distribution for subduction-zone earthquakes and intraslab earthquakes can be considered as the same data; however, the data was not the same for crustal earthquakes because the standard deviation in our study was larger than that by Satoh (2003). On the other hand direct comparison of short-period level A with Sato (2003)'s results showed correlation coefficients higher than 0.8 for all earthquake types.

Keywords: response spectrum, strong motion properties, Q value, stress drop, short-period level A

SSS33-06 Room:103 Time:May 19 10:30-10:45

# TOWARD BETTER ESTIMATIONS OF GROUND-MOTION VARIABILITY

Fabrice Cotton[1*], Rodriguez-Marek Adrian[2], Archuleta Ralph[3], Causse Mathieu[4]

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The random ground-motion-prediction variability strongly influences the seismic hazard curve computation, in particular for long return periods. One of the key challenges of seismology is to be able to calibrate and analyze the physical factors that control the ground-motion variability. The exponential growth of seismological near-field records provides the opportunity to separate the source, propagation, and site factors controlling the ground-motion variability (Al-Atik et al., 2010; Rodriguez et al., 2011). Ground-motion variability is usually divided into between-events variability and within-event variability. We describe and discuss some recent results and analysis performed on these two variability components. In a recent study (Rodriguez-Marek et al., 2013) we estimate the within-event variability for five databases from different regions worldwide (California, Switzerland, Taiwan, Turkey, and Japan). We investigate the potential dependency of the within-event variability on region, Vs30, distance and magnitude. The results show that the variability of the within-event variability across the different regions is small when compared with the within-event standard deviation. In other words, the event-corrected single-station standard deviation is remarkably stable across tectonic regions. Our results also suggest that moderate earthquakes are more variable for a given magnitude than large ones and that some stations are also showing larger variability of ground motions than others. Our analysis of the between-event variability shows (Cotton et al., 2013) that the between-event ground-motion variability gives an upper boundary to the earthquake stress-drop variability. This quantification of stress-drop variability offers a new way to calibrate future earthquakes ground-motion simulations.

Keywords: strong-ground motion, seismic hazard, stress drop, variability

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SSS33-07 Room:103 Time:May 19 11:15-11:30

# Source model of the 2011 Ibaraki-oki earthquake by the empirical Green's function method using strong-motion data

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The 2011 Ibaraki-oki ($M_w$ 7.9) earthquake occurred off the east coast of the Kanto region, the south-eastern part of Japan at 15:15 on 11 March 2011 (JST). It is the largest aftershock of the 2011 Tohoku earthquake ($M_w$ 9.1) which occurred approximately thirty minutes before this event. Kubo *et al.* (2012) estimated the kinematic source-rupture process of the 2011 Ibaraki-oki earthquake by jointly analyzing strong-motion data (0.2-0.02 Hz) and static displacements obtained from GPS data. In this study, we estimate the source model composed of strong motion generation area (SMGA, Miyake *et al.*, 2003) for the 2011 Ibaraki-oki earthquake based on modeling of broadband strong-motion data (0.1-10 Hz) using the empirical Green's function (EGF) method, and compare it with the source model of Kubo *et al.* (2012)

The strong-motion records of the 2011 Ibaraki-oki earthquake shows that several seconds of small amplitude arrival followed by the main rupture phase. This indicates that there was an initial rupture during the 2011 Ibaraki-oki earthquake. Therefore we assume a source model that the rupture of SMGA occurred as main rupture several seconds after the initial rupture started at hypocenter.

The location of the rupture starting point of SMGA and the delay time of SMGA are estimated after the procedure of Takenaka *et al.* (2006) and Suzuki and Iwata (2007) using the arrival-time differences between the initial and main rupture phase. The source parameters of SMGA (spatial dimensions, rise time, rupture starting subfault, and rupture propagation velocity) are estimated based on broadband strong ground motion simulations using the empirical Green's function method (Irikura, 1986). The best set of the parameters is estimated by minimizing the sum of the residuals of the acceleration envelope and displacement waveform fitting (Miyake *et al.*, 1999, 2003) through a grid search. For this analysis, the records at six KiK-net stations are used. The ratios of the source dimension and the stress drop between the large and small events are obtained by the source spectral ratio fitting method (Miyake *et al.*, 1999, 2003) using observed source spectral ratios. The seismic moment ratio between the large and small events is estimated from the source spectral ratio at two F-net stations. As EGF, we adopt the records of an $M_w$ 6.3 event, which occurred at 20:44, on October 10 2005.

The estimated location of the rupture starting point and the delay time are approximately 10 km southeast of the hypocenter and 9s, respectively. The estimated SMGA is located at the deep side of the large slip area obtained from source inversion (Kubo *et al.*, 2012) and partly overlaps with the large slip area. The spatial dimension of SMGA is 28 km$*$28 km and it is smaller than the spatial dimension of the large slip area (60 km$*$60 km). The rise time, seismic moment, and stress drop of SMGA is 2.8s, $3.4*10^{20}$ Nm ($M_w$ 7.6), and 42 MPa, respectively. The rupture within SMGA mostly expands towards the southwest direction at 4.0 km/s. This differs from the result of Kubo *et al.* (2012) where the rupture propagates towards the southeast direction.

Based on the results of this study and Kubo *et al.* (2012), we conclude that the entire source process of the 2011 Ibaraki-oki earthquake was as follows: Approximately 10s after the initial rupture started, the main rupture started at the deeper side of the initial rupture point. At the early stage of the main rupture, short-period seismic waves are mainly radiated. The whole main rupture with a large slip extends toward the southeast direction.

Acknowledgement: The strong-motion data recorded by KiK-net and F-net of NIED was used for this analysis.

Keywords: The 2011 Ibaraki-oki earthquake, Source process, Strong motion generation area, The empirical Green's function method

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# Source Modeling of Sanriku-oki 2011(Mw7.6) Outer Rise Earthquakes Using the Empirical Green's Function Method

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1. Introduction

Just after the Tohoku Pacific ocean earthquake, at 15:26JST outer-rise earthquake (Mw 7.6) occurred in Sanriku?oki area. Outer-rise earthquakes frequently occurred in this area after this. The largest outer-rise earthquake is the 1933 Sanriku-oki earthquake in this area. It was difficult to recognize the character of strong ground motion of outer-rise earthquakes before this earthquake. However after this earthquake, we can study with rich strong ground motion data. It is important to grasp the seismic source characteristics of this earthquake not only for understanding the 1933 Sanriku-oki earthquake but also for next large outer-rise earthquake. In this study, we make the source model of this earthquake using the Empirical Greens Function (EGF) method and compare the parameters with empirical formulas.

2. Data

We use an outer-rise earthquake (05 May 2011 23:58JST Mw6.1) as element earthquake of EGF. Reason of this selection is this earthquake occurred near from target and it has similar source mechanism. Strong motion data which we use is delivered from KiK-net and Institute of Seismology and Volcanology, Faculty of Science, Hokkaido University.

3. Source modeling of EGF

We assume a rectangle strong ground motion generation area with a constant slip and stress drop to simulate wide-band strong-motion with simple fault model. In this case, seismic waves are generated only from strong motion generation area (SMGA) not from background area. The fault plane is determined based on focal mechanism of the target event and aftershocks distribution (Obana et al., 2012). The number to divide the SMGA into subfaults (=N) and the ratio of the stress drop of the target event to the element one (=C) are estimated with Yokoi and Irikura (1991). Under these setting we carry out grid-search analysis to get the size of SMGA, epicenter, rise time and rupture velocity. The epicenter is determined in south part of fault plane. This fact is related to directivity effects owing to the northward propagation of rupture understanding from observed wave forms. The model explains the envelope of acceleration, velocity and displacement records.

4. Combined SMGA and Stress Drop

We compare the SMGA parameters between this outer-rise earthquake and the shallow intraplate earthquakes in the Pacific Plate. The relationship between the combined SMGA and the total seismic moment is similar to the intraslab earthquakes (Sasatani et al., 2006). The stress drops for this earthquake are also similar to those for the intraslab earthquakes. Therefore the SMGA parameters of the outer-rise earthquake are similar to those of the intraslab earthquakes despite the shallow focal depths of the former events.

Acknowledgement

We use strong motion data from NIED (National Research Institute for Earth Science and Disaster Prevention) and Institute of Seismology and Volcanology of Hokkaido University. And we use the focal mechanism from GCMT.

Keywords: Outer-rise Earthquake, Source Characteristics, Empirical Green's function method

SSS33-09 Room:103 Time:May 19 11:45-12:00

# Development of a new ground motion prediction equation applicable up to Mw9 (2)

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We examine a new ground motion prediction equation (GMPE) of instrumental seismic intensity in JMA scale, peak acceleration, peak velocity, and acceleration response spectrum for the purpose of application to seismic hazard assessments. In the last year, we develop a new GMPE which is directly applicable upto Mw9 using the strong-motion records of the 2011 Tohoku-oki earthquake in the last year. However, the new GMPE have a tendency that overestimates the amplitude at near source region. Therefore, we perform the examination towards improvement.

The improving point from the last examination is as follows.
(1) Add the strong-motion records by the earthquake which occurred in 2011 and 2011 to our database.
(2) Introduce the magnitude saturation of the amplitude to the model with a quadratic magnitude term.
(3) Give a larger weight to the data from near source region.
(4) Distinguish the interplate and the intraplate earthquakes for subduction eathquakes.

We confirm that the predicted ground motion amplitudes near the source region becomes small according to the above point (3) compared with the last result. However, the uncertainty of the prediction at near source region for large earthquakes (distance$<$30km, Mw$>$7) still remains. The examination using overseas records may be required.

Acknowledgement: The strong-motion records were operated and provided by a large number of organizations in Japan, especially NIED, JMA and PARI.

Keywords: ground motion prediction equation, strong ground motion, seismic hazard assessment

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# How to construct a recipe for predicting strong ground motions from great subduction earthquakes

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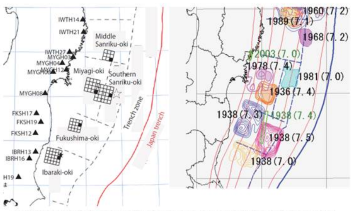
Source models related to strong ground motions have been integrated in the waveform inversion analysis to better characterize rupture processes of inland crustal earthquakes and subducting mega-thrust earthquakes. Generation of strong ground motion is related to slip heterogeneity inside source areas, i.e. strong motion generation areas (SMGAs). High frequency motions are generated from SMGAs which are almost coincident with large slip area for inland crustal earthquakes. On the other hand, ground motions from subduction earthquakes clearly show differences in wave radiation at various frequencies. The short-period generations obtained from the backprojection method using short-period teleseismic arrays from subduction earthquakes are located on deeper down-dip areas. Most of slip distribution inverted from long-period records such as geodetic and tsunami data are placed at shallower depths near the trench. We estimate a source model for generating strong ground motions from the 2011 Tohoku earthquake by comparing the observed records from the mainshock with synthesized motions based on a characterized source model and the empirical Green's function method. We obtained a short-period source model consisting of five SMGAs with large slip velocity or high stress drop. The SMGSs distributed in dip direction west of the hypocenter and in strike direction north and south of the hypocenter, along the down-dip portion of the source fault of this earthquake. These results indicate that great earthquakes on inland active faults and on subduction earthquakes have different source characteristics, especially in the short-period range related to strong ground motions. We developed a recipe for predicting strong ground motions for inland crustal earthquakes (Irikura and Miyake, 2010). Earthquake scenarios based on the recipe successfully estimate ground motions. Then, we propose an improved idea for recipe of predicting strong ground motions for subduction earthquakes.

Keywords: great subduction earthquakes, strong ground motions, short-period source model, strong motion prediction recipe




(Left) The short-period source model and source segments used for the long-period forecast by the ERC. (Right) Source segments for the long-period forecast and the slip distributions of past earthquakes (Earthquake Research Committee 2009).

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SSS33-11 Room:103 Time:May 19 12:15-12:30

# Study on a recipe for strong ground motion prediction for large inland earthquakes along long strike-slip faults

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It has been pointed out that an application of 'the recipe' for predicting strong ground motion to the case of faults with great length leads to negative amount of slips on the background area of the fault model (Headquarters for Earthquake Research Promotion (HERP), 2005). In order to solve the problem, Dan et al. (2011) proposed the new idea of asperity model that can set the fault parameters without having negative slip on the background area for the strike-slip crustal earthquakes even with great length.

In this study, fault models for a scenario earthquake along the Median Tectonic Line faults with overall length of 360 km are established based on the methods by Dan et al. (2011) and the ones by HERP (2005). The spatial strong ground motions are simulated based on the fault models by the stochastic Green's function method. The results of the simulations are examined discussing the adequacy and the problem for each method to establish fault models.

In the cases with reference to the examinations by HERP (that is, the asperity area on the fault plane is calculated by the empirical regression related to the short-period spectral level), it was confirmed that the fault models could not be set due to the negative slip on the background area. For this problem, two fault models ('reference case A') were developed based on the improved method by HERP (2005) in order to set the fault parameters successfully. The ratios of the asperity area to the whole fault area were assumed to be 22 % (Somerville *et al*., 1999). The averaged stress drop of 'reference case B' was calculated by the equation derived from a circular crack model, and that of 'case C' was set to be 3.1 MPa (Fujii and Matsu'ura, 2000). Another fault model ('case D') based on the method by Dan et al. (2011) was also developed.

In order to discuss the simulation results, the peak ground velocities of simulated ground motions are compared to the ones calculated by using the attenuation relationship by Si and Midorikawa (1999). In the 'reference case B', the simulated peak ground velocities reached about 300 cm/s near the source fault and became much greater than the ones by the attenuation relationship since the short-period spectral level was about three times of the other two models. In the 'case C', while most of the results of the simulated ground motions are in the range of the dispersion of the attenuation relations, in the near-field of the source fault, the simulated peak ground velocities reached about 150 cm/s and became a little greater than the ones by the average attenuation relationship. In the 'case D', the simulated peak ground velocities reached about 100 cm/s near the source fault and corresponded well to the attenuation relationship. Therefore, it is concluded that the method by Dan et al. (2011) is the most appropriate to evaluate strong ground motions of a large earthquake along a very long strike-slip fault.

Keywords: very long fault, fault model, strong motion prediction

SSS33-12 Room:103 Time:May 19 12:30-12:45

# Short-period radiation properties of intra-slab earthquakes in the subducting Pacific plate from seismic intensity data

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Intra-slab earthquakes occurring in the subducting oceanic plate radiate more short-period seismic energy than shallow inland and interplate earthquakes and often cause a wide area of strong ground motion. Three damage intra-slab earthquakes in Miyagiken-oki and Kishiro-oki in the Pacific plate are analyzed. Their properties of short-period energy radiation are revealed from JMA seismic intensity data. Seismic intensity inversion analysis is carried out to obtain high-frequency radiation area on their fault planes.

Recently, two damage intra-slab earthquakes occurred in Miyagiken-oki, the 2003/5/26(MJ7.1, D=72km) and 2011/4/7(MJ7.2, D=66km). 6 minus of JMA intensity was observed in Miyagi and the south of Iwate with 174 of the injured and 2 collapsed houses during the 2003 event. Meanwhile, 6 plus of JMA intensity was observed in Miyagi with 4 casualties and 296 of the injured during the 2011 event. The attenuation relationship and site correction factors of seismic intensity are estimated based on recent seismic intensity data. The relationship between focal depth and residual term of attenuation equation for each earthquake shows depth-dependency of short-period radiation. We also find the discrepancy of short-period radiation between the 2003 and 2011 events. It may be due to the Q-value structure in the mantle wedge above a subducting ocean plate. The short-period radiation area of fault plane almost corresponds to a large slip area from waveform inversion analysis.

The 1993/1/15 Kushiro-oki earthquake (M7.5, D=101km) occurred with 6 of JMA intensity at Kushiro-city and caused 966 of the injured and 53 collapsed houses. The Seismic intensity data of intro-slab earthquakes in the vicinity of Kushiro-city are analyzed in the same way as the Miyagiken-oki events. The short-period radiation properties is similar to those of the Miyagiken-oki events and depend on focal depth. The short-period radiation area of the 1993 Kushiro-oki earthquake spread in the rupture direction from the hypocenter.

Keywords: seismic intensity inversion, short-period energy radiation, the 1993 Kushiro-oki Earthquake, off Miyagi Prefecture, intra-slab earthquake, focal depth

SSS33-13 Room:103 Time:May 19 14:30-14:45

# Strong ground motion prediction of the Uemachi fault zone using dynamic rupture scenarios

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Strong ground motion prediction needs realistic earthquake scenarios with characteristics of earthquakes occurring on source faults. We have proposed that physically reasonable dynamic rupture models under a fault geometry and stress fields based on geological or geomorphological data are used as earthquake scenarios for strong ground motion prediction. We apply our method to possible sources of earthquake occurring on the Uemachi fault zone using 3-D geometry of the fault plane and average uplift rate distribution along the fault trace based on the Comprehensive Research on the Uemachi Fault Zone, and calculate ground motion distributions.

The Uemachi fault zone runs just underneath the central part of Osaka plain, extends about 48 km, and the fault plane dips about 60 degrees to the east in the seismogenic zone. The stress conditions for dynamic rupture simulations are presumed based on a large-scale slip distribution on the fault and small-scale heterogeneities of static stress drop. First, a spatially varied cumulative slip distribution along the strike of the Uemachi fault zone was estimated from reflection surveys, borehole data, the subsurface structure model of the Osaka sedimentary basin (Horikawa et al., 2003), and the detailed topography around the fault trace. The borehole data at a site along the fault showed that the vertical slip on the earth's surface due to the last event was about 1.3 m (Kondo et al., in this meeting). Combining these data, we presume a prototype of the slip distribution along strike. A slip distribution along dip is modeled through simulations of spontaneous ruptures under vertically depth-dependent stress conditions to realize spontaneously stopping rupture near the bottom of the seismogenic zone. The large-scale heterogeneous slip distribution is composed of the slip distributions along strike and dip. Second, a stress change caused by the large-scale heterogeneous slip on a 3-D geometry of the fault plane (Kimura et al., 2012), which is a large-scale heterogeneous distribution of static stress drop, is calculated by the formulation of Okada (1992). Onto the large-scale static stress drop model, we add fractal heterogeneities in small-scale created from different random numbers. Finally, the strike and dip components of stress drop are converted to shear and normal stresses, assuming that the heterogeneity of stress drop is caused by a local geometry of the fault plane. We calculate dynamic rupture processes by the finite-difference method (Kase, 2010), assuming the slip-weakening friction law. We run the rupture simulations, changing hypocenter locations within relatively high stress drop area on the fault. The ruptures propagate not smoothly, and some regions remain locking. The rupture area and rupture time on each point depend on the stress model and the hypocenter location. The calculated earthquake scenarios are slightly smaller (Mw6.5-7.0) than an earthquake (Mw 7.1) presumed from the fault length based on "Recipe" of HERP. Predicted ground motion due to one of the largest scenarios is large especially in the northern part of the fault system where slip is relatively larger. The ground motion level along the fault in the northern area exceeds 100 cm/s.

Acknowledgment: This research was funded by the Ministry of Education, Science, Sports and Culture, Grant-in-Aid for Scientific Research (C) 21510190 and the Comprehensive Research on the Uemachi Fault Zone (in FY2012) by MEXT.

Keywords: dynamic rupture, the Uemachi fault zone, ground motion prediction, geomorphology, geology

SSS33-14 Room:103 Time:May 19 14:45-15:00

# Diffracted P and S Waves Excited by Shallow Inland Earthquakes

Michiko Shigefuji[1*], Tsutomu Sasatani[1], Nobuo Takai[1]

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We investigate effects of subsurface structure on diffracted P and S waves excited by shallow inland earthquakes. A shallow earthquake (Mw4.6) occurred on December 2, 2010 beneath the Ishikari plain. The record sections of velocity waveforms along a profile in the NNW direction from the epicenter (NNW profile) show conspicuous later phases at about 2 sec and 4 sec after the direct P and S waves. Both of the direct and later phases have apparent velocities of about 6 km/s and about 3 km/s for P and S waves, respectively; these values are nearly the same as P and S wave velocities of the seismic basement. The amplitudes for the direct and later phases attenuate with $L^{-2}$, where L is the epicentral distance, beyond a certain distance, but the amplitudes of the later phases are larger than those of the direct waves. These conspicuous later phases are also visible on the observed aftershock records along the NNW profile. However these phases are not visible on the records at stations with the different directions.

Ben-Menahem and Singh (1981) obtained approximate solutions for the wave field from a point source in a layered half-space; these solutions were derived from manipulation of integral paths in the complex wavenumber plane. The solution for a point source in the layer is well known as generation of head waves (or conical waves). They also showed the solution for a point source in the half space generates diffracted waves when the source is located very near the interface. The latter case is similar to our observation, because the source is laid beneath the sediment-seismic basement interface as shown below. In this case, the ray of the later phase is reflected 2 times inside the layer before it reaches the observer; the 2 times reflection points are the free surface and the interface. Shigefuji et al. (2012) made theoretical consideration of the wavefield from a point source in the layered half space. They concluded the direct and later phases mentioned above are diffracted waves. Here, to understand the generation mechanism of the conspicuous later phases on the observed records along NNW profile, we make the finite difference method simulation (Aoi and Fujiwara, 1999; Pitarka, 1999) using the 3D velocity structure model of deep sedimentary layers after AIST (Yoshida et al., 2007) and the source parameters after Shigefuji et al. (2012). The seismic basement of the NNW profile is roughly flat and the thickness of the sedimentary layer is about 4 km, and the focal depth is set at a depth of 5 km.

The synthetic waveforms well reproduce the features of the observed waves along the NNW profile. On the basis of the above considerations, we revealed that the direct waves and the conspicuous later phases on the NNW profile are the direct and reflected diffracted P and S waves generated when the source is located near the sediment-seismic basement interface. These also indicate that the AIST velocity structure along this NNW profile is reasonable. The analysis of the diffracted wave is important to verify the structure.

Acknowledgements
We used the strong motion data by NIED, the seismic intensity network of Sapporo city, JMA, Hokkaido Gas Corporation, Ueyama Corporation, and Hokkaido University.

Keywords: Diffracted P and S waves, Shallow Inland Earthquakes, Three dimensional simulation, Deep subsurface structure

SSS33-15 Room:103 Time:May 19 15:00-15:15

# Nonlinear behavior of soft soil deposits in wide area during the 2011 Tohoku earthquake

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In order to understand the effects of strong ground motions on engineering structures, it is important to evaluate the effects of soil nonlinearity on strong ground motions. In this report, based on strong motion records obtained in wide area during the 2011 off the Pacific coast of Tohoku earthquake, degree of soil nonlinearity was evaluated based on the shift of peak frequencies from linear site amplification factors to observed Fourier spectra during the Tohoku earthquake. Then, the relation between the degree of soil nonlinearity and ground motion indices such as PGA, PGV and PSI was investigated. It was found that the degree of soil nonlinearity was best correlated with PGV and the relation can be approximated with a hyperbolic curve. In addition, it was found that the deviation from this empirical formula is correlated with the peak frequencies of linear site amplification factors.

Keywords: nonlinearity, strong motion, the 2011 Tohoku earthquake, empirical equation

SSS33-16 Room:103 Time:May 19 15:15-15:30

# Improvement of Three-Dimensional Velocity Structure Model of the Osaka Sedimentary Basin

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1. Introduction

In the Osaka sedimentary basin, southwest Japan, the three-dimensional velocity structure has been modeled by many studies (e.g., Kagawa et al., 2002; Horikawa et al., 2003; Osaka pref., 2005; Iwata et al., 2008) based on the geophysical and geological surveys and waveform modeling. For reliable and detailed strong motion prediction, precise or reasonable basin velocity structure model is indispensable because of its remarkable effects on the strong ground motions. We improved the basin velocity model by adding new observations and applying newly developed methodology to describe the model (Sekiguchi et al., 2012, 2013) under the Comprehensive Research Project on the Uemachi Fault Zone by MEXT. In this presentation, we report the improvement of the three-dimensional velocity structure model of the Osaka sedimentary basin.

2. Observations and Analyses

We have conducted the microtremor array observation for obtaining phase velocities at 6 sites in southern part of the Osaka basin (Yoshimi et al., 2012), single-station microtremor observation for obtaining H/V spectra at 100 strong motion stations (Asano et al., 2012a), continuous microtremor observation at 15 stations and seismic interferometry (Asano et al., 2012b), and the reflection survey along 2 lines (Iwata et al., 2012, 2013). We also collected strong motion records from seismic intensity observation network by Osaka prefectural government and other strong motion networks (CEORKA, K-NET, KiK-net, etc.), and used them to estimate PS-P travel time by the receiver function analysis (Horikawa, 2012) and to compare with the synthetic waveforms of moderate size events (Sekiguchi et al, 2012). We found that the velocity structure model needed improvement especially in the southeast of the basin, southern part of the Osaka Bay area, and northern edge of the basin.

3. Improvement of Vp and Vs Relationships

The P-wave velocity profile in Horikawa et al. (2003) is estimated by the empirical relationships among age of sediments, burial depth, and P-wave velocity. The age of sediments is estimated by the interpolation of six key layers (Ma10, Ma3, Ma-1, Fukuda tephra, Gauss-Matsuyama reversal, and top of Kobe group) and bedrock depths. We confirmed the empirical relationships proposed by Horikawa et al. (2003) by comparing the P-wave reflection survey data. The S-wave velocity and density profiles are estimated from the porosity and the P-wave velocity with the Gassmann's (1951) equations. The porosity is empirically given by the P-wave velocity and the burial depth following Matsumoto et al. (1998). We reviewed previous studies on the relationship between P-wave and S-wave velocities of the Osaka group, and found that the empirical relationship proposed by Nakagawa et al. (1996) fits well the PS logging data in the Osaka basin. In our final model, the P-wave velocity is given by the empirical relationship of Horikawa et al. (2003), the S-wave velocity profile is given from its P-wave velocity by the empirical relationship of Nakagawa et al. (1996), and the density is given based on Gassmann's equations.

We also include a new correction parameter of burial depth describing the effect of the erosion of the Osaka group. The S-wave velocity profile at near surface is improved especially in the southeast of the basin judging from the observed high frequency phase velocity of the microtremor survey.

4. Revising the Bedrock and Key Layer Model

After reconstructing the initial model following the method proposed by Sekiguchi et al. (2013), we revised the bedrock and key layers depths to fit the observed phase velocities, dominant period of H/V spectral ratios, and PS-P travel times. We will check the improved model based on the three-dimensional ground motions simulations of the moderate size events and the inter-station Green's functions.

Acknowledgements: This study is a part of the Comprehensive Research on the Uemachi Fault funded by the MEXT, Japan.

Keywords: S-wave velocity, strong ground motion prediction, Uemachi fault, H/V spectra, ambient noize survey, receiver function analysis

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SSS33-17 Room:103 Time:May 19 15:30-15:45

# Description of 3D velocity structure: Osaka Basin

Haruko Sekiguchi[1*], Hidetaka Saomoto[2], Masayuki Yoshimi[2], Kimiyuki Asano[1], Haruo Horikawa[2], Takumi Hayashida[2], Tomotaka Iwata[1]

[1]DPRI, Kyoto Univ., [2]AFERC, AIST

1. Introduction

Three dimensional subsurface structure model of the Osaka sedimentary basin is revised with additional survey data conducted under Comprehensive Research on the Uemachi Fault Zone (FY2010-2012) by MEXT. In addition to revision of velocity structure (Yoshimi et al., 2013, this meeting), we explore the way of description of the 3D velocity structure model.

2. Former 3D velocity structure models of Osaka sedimentary basin

3D velocity structure models have been developed for the Osaka sedimentary basin from relatively early time thanks to relatively dense data of underground structure surveys compared to other areas. Former 3D models are classified to two types. One, we call them J-type here, includes Kagawa et al.(1993), Miyakoshi et al.(1997), Miyakoshi et al.(1999), Kagawa et al.(2002), Iwata et al.(2008) and Iwaki and Iwata (2011). Another one, H-type, includes AIST model (Horikawa et al., 2003) and Osaka Prefecture model (Osaka Prefecture, 2004). These two types adopt quite different description of their 3D structure. J-type models divide the sediments into three layers with constant Vp, Vs and densities and adopt spline-function to model the layer boundaries, which make it easy to derive medium properties at arbitrary point. This property of these models has advantage when being applied to numerical computations. H-type models are given in fixed 3D grids to express complex heterogeneity and steep material-boundaries like overhang faults. Medium properties are given by empirical formulas depending on the depth and the depositonal age and the depositonal age is assigned by six key layers modeled in the sediments.

3. Description of our 3D velocity structure

In this study, we aimed to model the layers and medium property structure as faithful as possible to survey data (like H-type models) and to describe the layer boundaries by interpolation functions so that we can get the model in arbitrary mesh (like J-type models). To realize this, we construct our 3D velocity structure model with the following way.

1) Divide the model area by extreme boundaries like faults

2) Describe the layer boundaries by appropriate interpolation functions

3) Prepare the empirical formula for medium properties which depends on depth, depositional age and regionality

4) Prepare dataset and tools to calculate relative location of arbitrary points to layer boundaries and block boundaries and to calculate physical properties for given point or given arbitrary mesh.

We explain more about 2) in the following.

4. Description of layer boundaries by interpolation function

In the Osaka basin, many geophysical explorations such as seismic reflection method, borehole drilling and microtremor survey have been performed to reveal both the three-dimensional depositional structure and the faults configurations. These efforts have also accumulated the data about the depth of sedimentary layers. By virtue of the abundant data, we can construct the sedimentary layer boundaries precisely.

We here tried to construct some representative sedimentary layer boundaries by using the radial basis function (RBF) interpolation. The RBF method has advantages compared to the conventional way based on the spline curve:(1)The RBF method incorporates a parameter concerning the smoothness of the interpolated surface. (2)The RBF method holds robustness in extrapolation operations.

As shown in Figure, we have got the accurate three-dimensional depositional structure.

Keywords: layer boundary, key layer, Radial Basis Function, interpolation

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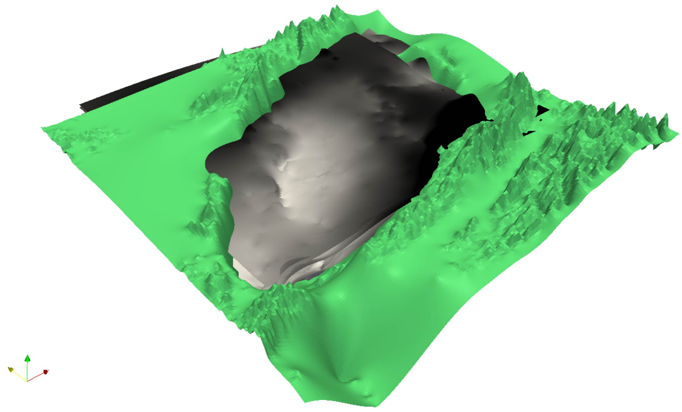

SSS33-18 Room:103 Time:May 19 15:45-16:00

# Overview of the studies on bedrock depth distribution beneath Istanbul, Turkey by microtremor measurements

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On August 17, 1999, a devastating earthquake with a moment magnitude of Mw=7.4 struck the Kocaeli and Sakarya (Adapazari) provinces, and part of suburbs of Istanbul in the northwestern of Turkey, a very densely populated region in the industrial heartland of Turkey. This earthquake is considered to be the largest event to have devastated a modern, industrialized area since the 1923 Great Kanto earthquake. This earthquake caused about 30.000 losses of life and collapsed thousands of buildings. Thus, total loss figure amounted to about $16 Billion. Following the losses during this large earthquake, there has been a broad recognition among Turkey governmental, non-governmental and academic organizations of the need for extensive response planning based on detailed risk analysis of likely seismic hazard, microzonation studies and ground-motion researches in Turkey, in general, and Istanbul particular. In this frame, several studies are performed to map the bedrock depth distribution in the west part of Istanbul. Local S-wave velocity-depth profiles and bedrock depth distribution are key factors in assessing seismic hazard and earthquake ground motion characteristics since they allow determination of the amplification potential of geological formations overlying bedrock. In a project supported by Istanbul University, S-wave velocity structure beneath the European side of Istanbul is determined. One of the aims of the project is to improve the knowledge about the influence of local geology on the expected earthquake ground motion. In this project, both array measurements and single station microtremor measurements at 40 sites are conducted. In another study by Birgoren etal. 2009, an empirical relationship between the thickness of Tertiary?Quaternary sediments overlying Palaeozoic bedrock and their resonance frequencies is calculated for the ?stanbul region and the bedrock depth distribution beneath the city is presented. The bedrock distribution beneath populated areas of ?stanbul is obtained by applying the derived relationship from this study to 86 strong-motion sites, where the resonance frequencies are known. Picozzi etal. 2008, have investigated the site characterization by seismic noise in Istanbul. Single station seismic noise measurements were carried out at 192 sites in the western part of Istanbul, Turkey. This extensive survey allowed the fundamental resonance frequency of the sedimentary cover to be mapped, and identify areas prone to site amplification. There sults obtained by this study are in good agreement with the geological distribution of sedimentary units, indicating a progressive decrease of the fundamental resonance frequencies from the northeastern part, where the bedrock outcrops, towards the southwestern side, where a thickness of some hundreds meters for the sedimentary cover is estimated. From these studies and the other studies, not mentioned here, the conclusion is that the bedrock dips towards SW from NE and S-wave velocity structure shows the presence of strong impedance contrast being responsible of seismic ground motion amplification. On the other hand, the particular distribution of fundamental resonance frequencies indicates that local amplification of the ground motion might play a significant role in explaining the anomalous damage distribution in the west part of Istanbul after the 17 August 1999 Kocaeli Earthquake.

Keywords: Earhquake disaster, Microtremor, Dominant frequency, Istanbul

SSS33-19 Room:103 Time:May 19 16:30-16:45

# The Relationship between Soliton in GPS Wave gage and Seismic Wave of 2011 the Tohoku District Pacific Ocean Earthquake

Masaru Nishizawa[1*]

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Japanese only

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SSS33-20 Room:103 Time:May 19 16:45-17:00

# Severity of Mortality in the 2011 East Japan Earthquake (3) Examination of Age-dependency Part II

Yutaka Ohta[1*]

[1]Ohta, Yutaka

1. Introduction
We started to expand our attention to age-dependency as the third paper of the series studies. It has been known that most probable one is a shape resembling U character in English, as rates are high both at the infant-child ages and the senior ages as 60 or over and low in the middle ages. But we are not yet certain whether such age-dependent characteristics are generally valid or not. So, in this point of view and in comparison with significant past inland and oceanic earthquakes we conducted a study focusing on this age-dependency problem.
2. Surveyed Earthquakes
There is no much available data even now in case when we desire somewhat deeper analysis good for age-dependent characteristics. After careful and in-depth retrievals we obtained 4 domestic earthquakes; the 1933 Sanriku, the 1993 Hokkaido-nansei-oki, the 1995 Kobe and the 2011 East Japan Tsunamigenic earthquakes, and the 3 overseas earthquakes as 2 Turkish earthquakes plus the 2004 Indian Ocean tsunamigenic earthquakes. Especially for the 2004 Indian Ocean earthquake, regarded and significant data were retrieved via papers from US PubMed Database. The dataset of 2 earthquakes in Turkey are based on our own field surveys on due years.
3. Analytical Comparison and Characterization of Age-dependency
After a careful data processing on age-dependent characteristics for each earthquake, we arrived at the conclusion that those are well classified into three principal types.
3.1) U type in English character Typical cases are earthquakes of the 1933 Sanriku-oki, the 1993 Hokkaido-nansei-oki, the 1970 Gediz and the 1976 East Turkey, and northern seaside areas of Indonesia due to the 2004 Indian Ocean Tsunami. In these earthquakes the mortality rate pattern shows typical U shaped type as is high for both of infants-children and senior people of 60 or more. And, this can naturally be accepted as the direct reflection of either humans undeveloped for infants-children or deteriorated for seniors of behavioral performance in case when no assistance by neighbors is expected.
3.2 J type in English character Another pattern we see often is the one expressed as J type in English character. This is somewhat simpler case as increasing age gives increasing rate of mortality; The 1995 Kobe, the 2011 East Japan earthquakes are typical cases. This J type age dependency can be interpreted as a variation when an earthquake occur during day time and then children were outdoors and/or under teachers control and/or they were under care by their parents etc. so, we should be keen to when the event comes. Those above two cases seem typical pattern in somewhat higher mortality rates, but in the initial case as in low mortality rate the pattern might be different and is likely to make age-independent characteristic; Let us call this as Flat type.
4. Results
For the change of age-dependency, we can therefore summarize as in the initial situation of low external force of either seismic shaking or tsunami inundation high, mortality rate seems low and age-independency is as F type and in case when the external force is strong enough the most probable
pattern would be U type, which means higher mortalities for the age-extremities of infants-children and the seniors as of 60 or older, giving a concave as a function of age. So, this pattern can be most probable, if no assistance is available by nearby people, nor recognition for protection is not prevailed.

Keywords: 2011 East Japan Earthquake, Inland and Ocernic Earthquake, Mortality, Age-dependency

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SSS33-21 Room:103 Time:May 19 17:00-17:15

# Development of J-SHIS Web APIs provide seismic hazard information via REST scheme.

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Glossaries are..
J-SHIS : Japan seismic hazard information station.
REST : REpresentational State Trransfer.
API : Application Program Interface.

SSS33-22 Room:103 Time:May 19 17:15-17:30

# Regional Disaster Information System by using IT Kyoshin Seismometer for Buildings : Making the Regional Earthquake Earl

Kiyoshi Takano[1*], Takamori Ito[1]

[1]III & ERI, University of Tokyo

We have developed the IT Kyoshin Seismometer for Buildings(Takano et.al 2005) and installed these sensors for some buildings of the university (Takano et.al 2012, etc).

On the other hand, in order to examine the possibility of utilization as regional disaster prevention information system, we have installed the sensors in several private housings at the local area with the cooperation of the local community.

On the other hand, in order to examine the possibility of utilization as regional disaster prevention information system, we have installed the sensors in several private housings at the local area with the cooperation of the local community in Chigasaki city.

And we have developed the earthquake early information of the housing and regions by e-mail for the users.

In this presentation, we will discuss about the earthquake early information of the housing and regions by e-mail for the regional users.

When an earthquake occurred, the earthquake early information e-mai was sent to the users of the housing installed the sensors.

This information includes the shaking of the ground around the house, first and second floors and ceiling obtained by sensors by using the simple seismic intensity (K-value).

This e-mail may be sent to some mobile phones of the users and their families etc.

As how to take advantage of the this e-mail, we can consider as follows.

1. It will help ease knowing about the shake of the own housing compared to the average of the surrounding housings and help to do the disaster prevention activities.

2. When the major earthquake ocurred, it will help to make rapid response for the status of damage in own house and regions.

And since it can send some mobile phones, we can consider more as follows.

3. By this mail, users can found shaking of the home from office.

4. Can help to watch house of the elderly.

5. Can help the establishment of the regional self-preventing community for disaster prevention organization.

In this report, a presentation on the overview of the system and issues such as this.

Keywords: IT Kyoshin Seismometer, Regional Disaster Information, earthquake early information

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SSS33-23 Room:103 Time:May 19 17:30-17:45

# Relationship between damage ratios and ground motion characteristics during 2011 Tohoku Earthquake

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The relationship between ground motion indices, e.g., PGA, PGV,$I_{JMA}$,SI, and three different building damage ratios, i.e., total collapse ratios(TCRs), collapse ratios(CRs) and damage ratios(DRs), were constructed for the 2011 off the Pacific coast of Tohoku Earthquake. It was found that DRs relate better with ground motion indices than TCRs or CRs. It was also found that PGA was sensitive to predominant period of velocity response spectrum. Large PGA was not related with high DR if the predominant period is shorter than 0.4s or longer than 2.0s. However, the damage ratios are calculated based on an administrative unit, large variability can be seen from the fragility curves. It is necessary to examine the variability of ground motions within a small district, if the ground motions are estimated properly.

As the earthquake motions H/V can be represented theoretically, in proportional to the ratio of transfer funcitons between S- and P-wave, it has been suggested that H/V of earthquake motions can be used to determine the velocity structures. It implies that the microtremor H/V can also be used to estimate the velocity structures at damaged sites, if the consistency of H/V spectral ratios between microtremors and earthquakes can be confirmed there. The ground motions at some damaged sites are estimated by using the underground velocity structures inverted from the microtremor H/V spectra ratios. Then the estimated ground motions are used to be related with damage ratios at the damaged sites.

Keywords: building damage ratio, H/V spectral ratio, velocity structure, estimated ground motions

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SSS33-24 Room:103 Time:May 19 17:45-18:00

# Strong ground motion observation network in Himalaya, India

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It is pointed out that acquisition and analysis of data on the natural hazard and social conditions are fundamental to the disaster mitigation scheme, and that information about disaster impact is essential for the first aid and recovery planning. However, the technical issues and the environment for actual use are not yet established. It is a universal subject. 'Information Network for Natural Disaster Mitigation and Recovery' is a project of 'Science and Technology Research Partnership Sustainable Development (SATREPS) International Collaborative Research Program' supported by JST and JICA. The participants are Keio University, the University of Tokyo, Indian Institute of Technology Hyderabad, CSIR:National Geophysical Research Institute, Indian Institute of Technology Kanpur, Indian Institute of Technology Madras, International Institute of Information Technology Hyderabad, India Meteorological Department Hyderabad, and India Meteorological Department Pune.

In India, heavy rains and floods are causing thousands of casualties and building damages, for example 2001 Gujarat earthquake and 2005 Kashmir earthquake killed thousands of people. In Japan too, heavy rains and floods caused severe damages, and recent inland earthquakes and 2011 Tohoku earthquake caused tremendous damages.

From a view point of disaster mitigation, the infra-structure in India is still in infancy stage. and thus recovery will be hindered in case of such disasters. In Japan, information technology is recognized as useful in case of emergency and has been occasionally utilized. However, 1995 Kobe earthquake, 2004 Hukui and Niigata floods, and 2011 Tohoku earthquake revealed that a lot of issues remain unsolved in handling information.

The objectives of the project are to construct seismic and meteorological observation networks, data acquisition and analysis systems by means of global information network, to develop necessary technology to help effective performance of the first aid and recovery by means of preparing the information infra-structure in case of emergency, and to establish the basis for disaster mitigation and recovery by applying our experiences to Indian conditions.. The project contains studies on earthquake disaster mitigation, basis for meteorological observation, sustainable communication system, and platform of information in case of emergency and for disaster mitigation.

The study on earthquake disaster mitigation aims at observation networks for strong ground motion, crustal movement by GPS, and building performance to understand the seismic hazards and risks, and contribution to earthquake disaster mitigation from future earthquakes in Indo-Gangetic plain near the seismic active region. The present report introduces some achievements on the strong ground motion observation network. India has a warm and humid climate. The equipments are required to operate under such a circumstance. They are also required to be feasible for the infra-structure environment in India. Furthermore, it is desired that the sensor is able to record long period waves as well as short period motions. The velocity type strong motion seismometer was selected according to these conditions. The equipments were deployed at 26 sites in the seismic active region in Himalaya. Networking of the observation sites is on progress. The precise seismic activity, propagation characteristic of seismic waves, and effects of seismic waves to the buildings will be studied in the following years.

Keywords: strong ground motion, observation, network, Himalaya

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SSS33-P01 Room:Convention Hall Time:May 19 18:15-19:30

# Newly developed 3D velocity structure model of the Osaka sedimentary basin

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Three dimensional subsurface structure model of the Osaka sedimentary basin is revised with additional survey data conducted under Comprehensive Research on the Uemachi Fault Zone (FY2010-2012) by MEXT. We improved the three-dimensional basin velocity model by adding new observations and applying newly developed methodology to describe the three-dimensional model under the Comprehensive Research Project on the Uemachi Fault Zone by MEXT.

3D velocity structure models have been developed for the Osaka sedimentary basin from earlier time than in other areas thanks to relatively dense data of underground structure surveys. Former 3D models are classified into two types. One, we call them J-type here, includes Kagawa et al.(1993), Miyakoshi et al.(1997), Miyakoshi et al.(1999), Kagawa et al.(2002), Iwata et al.(2008) and Iwaki and Iwata (2011). Another one, H-type, includes AIST model (Horikawa et al., 2003) and Osaka Prefecture model (Osaka Prefecture, 2004). These two types adopt quite different description of their 3D structure. J-type models divide the sediments into three layers with constant Vp, Vs and densities and adopt spline-function to model the layer boundaries, which make it easy to derive medium properties at arbitrary point. H-type models are given in fixed 3D grids to express complex heterogeneity and steep material-boundaries like overhang faults. Medium properties are given by empirical formulas depending on the depth and the depositional age which were constructed based on geophysical prospection data.

In this study, we aimed to model the layers and medium property structure as faithful as possible to survey data (like H-type models) and to describe the layer boundaries by interpolation functions so that we can get the model in arbitrary mesh (like J-type models). To realize this, we construct our 3D velocity structure model with the following way.

1) Divide the model area by extreme boundaries like faults
2) Describe the layer boundaries by appropriate interpolation functions
3) Prepare the empirical formula for medium properties which depends on depth, depositional age and regionality
4) Prepare dataset and tools to calculate relative location to layer boundaries and block boundaries and to calculate physical properties for given point or given arbitrary mesh

In order to get information to improve the velocity structure, we have conducted the microtremor array observation for obtaining phase velocities at 6 sites in southern part of the Osaka basin, single-station microtremor observation for obtaining H/V spectra at 100 strong motion stations, continuous microtremor observation at 15 stations and seismic interferometry, and the reflection survey along 2 lines. We also collected strong motion records from seismic intensity observation network by Osaka prefectural government and other strong motion networks (CEORKA, K-NET, KiK-net, etc.), and used them to estimate PS-P travel time by the receiver function analysis and to compare with the synthetic waveforms of moderate size events. We found that the velocity structure model needed improvement especially in the southeast of the basin, southern part of the Osaka Bay area, and northern edge of the basin. We made necessary modification to empirical formula for medium properties and depths of layer boundaries.

Keywords: layer boundary, empirical formula for medium properties, physical prospecting, microtremor

SSS33-P02 Room:Convention Hall Time:May 19 18:15-19:30

# Development of estimation method of deep ground structure using long-term microtremor observation and gravity survey

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The purpose of this study is to develop an easy way to estimate deep ground structure. We combine gravity survey and long-term microtremor survey. Seismic interferometry is applied to analyze long-period microtremor, where the influence of deep soil structure appears. Our method is applied to the case in Hsinchu, Taiwan and structure model is modified.

Keywords: long-term microtremor observation, gravity survay, seismic interferometry, deep ground structure

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SSS33-P03 Room:Convention Hall Time:May 19 18:15-19:30

# Estimation of vibration mode of Mt. Fuji from microtremor measurements

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Natural frequency is one of the important characteristics which are determined with physical properties and geometry in subsurface structure including mountains. In particular Monitoring of natural frequency for active volcanic mountain can facilitate our understanding of its dynamic change, such as the intrusion of magma for prediction of the eruption.

In this study, we verify if we can estimate the frequency characteristics of Mt Fuji, the highest mountain in Japan, with microtremor observation. The microtremor observation was conducted from 6 to 9 August 2012. 7 locations are prepared in the observation at the 2nd and from the 5th to the 10th stations of Mt.Fuji. We temporarily installed a three-component accelerometer and a data logger at each station.

In the analysis, we made a spectral analysis of the observed records, and we found the predominant frequency around 0.2 Hz in the NS component. Amplitude distribution at this frequency is similar to fundamental mode shape of vibration. However, the vibration at the 6th station at the predominant frequency shows slight different features. We confirm from a cross-correlation function in the vicinity of the predominant frequency that delay time between the 6th and 10th stations is greater than others. The result suggests the vibration mode changes near the boundary of the 6th station of Mt.Fuji. This feature of the vibration may be related with the subsurface structural changes around there, because it is located near the boundary of Older Fuji and Younger Fuji or it is close to the volcano Hoei. We need to discuss this from long-term observation data.

We also conducted eigen value analysis with FEM using a simple cone model; 20km in diameter and 3km height. The first natural frequency of the model is about 0.2 Hz, and this is almost the same as the results with the observations. This shows that it is possible to estimate the frequency characteristics of Mt.Fuji with microtremor observation. However, the used model was a very simple model, and it is necessary to consider a model closer to the actual model for detailed investigation. Moreover, we need to verify how the natural frequency changes with changing the properties.

We thank participants of the observation in this study. We are also indebted to the people in the mountain hut. We would like to sincerely thank them.

Keywords: Mt.Fuji, frequency charateristics, volcano

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SSS33-P04 Room:Convention Hall Time:May 19 18:15-19:30

# A method to construct subsurface structure model using microtremor, gravity and magnetic data in the Tottori plain.

Yusuke Ishida[1*], Tatsuya Noguchi[1], Takao Kagawa[1], Hitoshi Morikawa[2]

[1]Tottori University Graduate School of Engineering, [2]Built Environment, Tokyo Institute of Technology

In this study, we propose a method to construct a subsurface structure model using microtremor, gravity and magnetic data in the Tottori plain. Recently, different types of physical exploration data are analyzed simultaneously to improve uniqueness and accuracy of subsurface structure model (e.g. Sakai and Morikawa, 2005).

In the target area, granite or sedimentary rock is found for seismic basement (Geological survey of Japan, 2003). The difference of densities is about 0.2t/m3 between the two rocks. Therefore we cannot perform gravity analysis with simple homogeneous two layers model, sediment layer 2.0t/m3 and seismic basement 2.4t/m3 (Noguchi et al., 2003). To overcome this problem, we employed magnetic data with the gravity data, and performed gravity analysis assuming several types of basement rocks with different densities. We applied the MWP (moving window Poisson analysis) method (Chandler et al., 1951) to get boundaries where densities change, and estimated depth distribution of seismic basement from gravity anomaly data. Based on the result, we estimated S-wave velocity structure model through inversion analysis of phase velocities of microtremor array observation data (Noguchi et al., 2003). As the result, we constructed a 3D subsurface structure model with three sedimentary layers and bedrock layer in the target area.

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Keywords: subsurface structure model, microtremor survey, gravity survey, magnetic data, MWP (moving window Poisson analysis) method, Tottori plain

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# Modeling of a subsurface structure from a seismic bedrock to the ground surface for a broadband strong motion evaluation

Shigeki Senna[1*], Takahiro Maeda[1], Yoshiaki Inagaki[2], Hisanori Matsuyama[2], Hiroyuki Fujiwara[1]

[1]NIED, [2]OYO corp

We have built the structure model which can evaluate the strong ground motion characteristic of a broadband for the purpose of the advancement of strong motion evaluation. The built contents are the structure models which unify the subsurface part structure model and the deep structure model, and can reproduce seismic observation record.

In this report, the contents of examination of the structure model construction in a south Kanto area(5 prefectures except Tochigi and Gunma) and a concentrated deformation zone (Niigata, Yamagata, and Akita) area are introduced.

The final contents of examination adjusted the flow of structure model creation, and the valuation method of the periodic characteristic and the amplifying characteristic of the structure model. The result is improved for the period about 1 second in all the investigated areas.

Keywords: Velocity structure model, Microtremor survey, Strong motion evaluation, Borehole data

SSS33-P06 Room:Convention Hall Time:May 19 18:15-19:30

# Determination of underground structure of Palu City, Sulawesi, Indonesia by microtremor observations

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[1]Tottori University, [2]Kyoto University

Palu City is located in the northern part of island of Sulawesi, Indonesia and there is active fault in the western part of city area. In this study, underground structures were estimated by array and single 3-componet microtremor observations. S-wave velocity structure models with 3 to 5 layers at the 10-sites were determined from array observation records. Predominant periods of H/V at 126 sites were obtained from 3-componet observation records. The S-wave velocities of alluvial layers were form 140 to 300m/s. The predominant period was about 1 second that H/V spectral ratio has clear single peak models near the coast line area. Therefore soft alluvial layer was distributed coast line area. Depth to bedrock (S-wave velocity is 600m/s layer) was about 90m maximum in the area.

Keywords: Microtremor observation, S-wave velocity structure

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# Development of Numerical Code for Simultaneous Estimation of Subsurface Structure with Gravity and Magnetic Data

Yusuke Imaeda[1*], Hitoshi Morikawa[1]

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We present the test calculation of simultaneous estimation of subsurface structure with gravity and magnetic data. The simultaneous estimation is performed by the construction of sensitivity matrix and its inversion. For this purpose, we developed a new numerical code for solving the singular value decomposition based on I-SVD scheme. Usually, the sensitivity matrix is ill-conditioned when the number of the observation data and the model points is large. We need some regularization to solve this ill-conditioned inversion. Some technical discussion is also presented.

**Method**

Trial model of subsurface structure is represented by M model points, which has k layers. While each layer has fixed given value, the depth of each model point $z_i$ is variable. We change these depth $z_i$ to account for the gravity and magnetic anomaly at N observation data on the surface.

**Forward Calculation**

We starts the calculation from the plane parallel model as an initial trial model. The prism gravity and magnetic field in arc tangent form is adopted for the gravity and the force calculation. When the depth is changed at each model point, a material in a prism shape volume is replaced from the lower side to the upper side, and vice versa.

The increment of gravity and magnetic field, generated by this replacement, is added to the previous value.

**Inversion Calculation**

Inversion calculation is performed by the construction of sensitivity matrix and its pseudo inverse matrix. The sensitivity matrix is defined by the differentiation of gravity and the magnetic field by each model depth. As the observation data, both the gravity and the magnetic data are used simultaneously. The size of this matrix becomes NxM. We calculate the depth change of each model point to account for the data difference between the model and the observation with the pseudo inverse matrix. However, the depth change sometimes becomes quite different from the adjacent ones, which is physically inappropriate for the successive conversion. Therefore, additional constraint condition is added to the sensitivity matrix, so that $\{\text{Nabla}\}^2$ $\{\text{delta}\}$z = 0. Then, the matrix size becomes (N+M)xM. This additional condition smooths out the adjacent fluctuation.

For this purpose, we developed a new numerical code for solving the singular value decomposition based on I-SVD scheme. Our numerical code is written by Fortran 95 in double precision, except for the lowermost DO loop for singular values calculation. This part is need to be written in quadruple precision.

With this code, we can reproduce the model subsurface structure from the model gravity and the magnetic data set.

We will also present the miscellaneous techniques for matrix regularization in the poster.The inclusion and the unification of microtremor data in this code may also be presented.

Keywords: numerical calcuration, subsurface structure, singular value decomposition

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# Relation between S/N ratio of cross-correlation function and capability of group velocity estimation with seismic noise

Takumi Hayashida[1*], Masayuki Yoshimi[1], Haruo Horikawa[1]

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We have applied seismic interferometry to ambient noise data recorded at Hi-net stations around Chukyo area, central Japan, to estimate velocity structure of the sedimentary basin (Hayashida et al., 2012). The estimated group velocities of surface wave from the stacked cross-correlation functions (CCFs) show variations for each station pair, indicating subsurface velocity structure beneath the area and the estimated group velocities agree with the predicted ones from existing velocity structure models for many station-pairs. However, there is some difficulty in estimating group velocities for some station-pairs and it is important to evaluate its accuracies. In this study we examine the decays of signal and noise amplitudes of CCFs and the growth of signal-to-noise ratio (S/N) of the CCFs with increasing numbers of stacking. We also evaluated the relationships between the shifting patterns and interstation distances (15.2-87.7 km) and azimuths (almost all directions). The results show that the noise tends to decrease with the square root of the stacking number. On the other hand, the S/N ratios tend to increase in the first four months and remain mostly levels after that. For station pairs whose S/N ratios exceed 30, group velocities of surface waves are easily estimated. We also found that the S/N ratios sometimes exceed 100 for station pairs in an almost NNW-SSE direction. Our result indicates that group velocity of surface waves should be estimated considering the S/N patterns in seismic interferometry.

Keywords: seismic interferometry, ambient noise, surface wave, velocity structure model, Chukyo area

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# Estimation of Ground Structure By Microtremor Observation in Penang Island, Malaysia

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Recently, huge earthquakes have been frequently occured off the west coast of sumatra island. The shakes of these earthquakes were felt in many cities of Malay Peninsula and the government of Malaysia has the intended to establish seismic design code. In this research, the microtremor array observation has been carried out around the east coast of Penang island. As a fundamental investigation of the seismic microzonation, the dispersion curve of the phase velocity of the Rayleigh wave has been estimated by applying the SPAC method. Besides, the estimated velocity model was examined by using the H/V spectrum. Since the predominant period on the H/V spectrum was remarkable, the S wave velocity contrast of the subsurface ground and the engineering bedrock is can be analyzed and the depth of the subsurface ground is estimated to be dozens of meters.

Keywords: SPAC method, Microtremor observation, H/V spectrum, Malaysia

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# Determination of subsurface structure in the building damage area of Tohoku earthquake (March, 2011), Tsukuba City using

aiko kawamuki[1*], Tatsuya Noguchi[2], Takao Kagawa[2], Daichi Fukuda[2], Ikuo Cho[3], Shigeki Senna[4], Shinsuke Okada[5]

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Seismic intensity was recorded lower 6 at Tsukuba City, Ibaragi Prefecture when Tohoku earthquake (March, 2011) occurred.
A distribution map of tiled-roof damage ratio in the target area was made by Okada et. al. (2012).
Microtremor array observation at 20-sites and single-site 3-componets observation at 89-points were carried out in the area.
As the result, predominant periods of H/V at single observation points and subsurface structures at array sites were determined. Site amplifications were calculated using subsurface structure models at the array observation points. It is possible that site amplification factor was large and also resonance of house was occurred in the high area of damage ratio.
Therefore, it was considered that such seismic response is a cause of the high tiled-roof damage ratio.

Keywords: microtremor, Determination of subsurface structure, tiled-roof damage, Tsukuba City

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# Determination of subsurface structure in Kurayoshi plain and North part of Daisen, using microtremor and gravity anomaly

Tatsuya Noguchi[1*], Daiki Adachi[1], Shun Okuda[1], Yoshihiro Ito[1], Takao Kagawa[1]

[1]Tottori Univ.

There were earthquake damages by the earthquake that occurred at the Middle West of Tottori in 1983, 2002 and the Western Tottori earthquake in 2000 in this study area. It is supposed that the damage influenced the subsurface structure. In northern part of daisen, many tourists gather on holidays. So it is important that the information of subsurface structures is obtained for prediction of ground motion in these areas. Microtremor and gravity surveys were carried out in the shore part of Kurayoshi plain and northern part of Daisen. S-wave velocity models are obtained at the array observation 9 sites and predominant period distribution at 3-components observation 140 sites newly. The gravity anomalies were obtained by gravity survey data at 122 sites newly.

Keywords: microtremor, gravity anomaly, subsurface structure, Kurayoshi plain, Northern part of Daisen

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# Estimation of ground structure using gravity survey method around Furukawa, Japan, where was severely damaged by the 201

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Estimation of ground structure using gravity survey method around Furukawa, Japan, where was severely damaged by the 2011 off the Pacific coast of Tohoku earthquake

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1Tokyo Institute of Technology, 2Kyoto University, 3Osaki City Goverment, 4aLab Co.Ltd.

The 2011 off the Pacific coast of Tohoku earthquake caused vast damages to Japan, especially in the Northeastern part of country. Most of those damages came from the resulting Tsunami, some came from liquefaction, whereas only a few places were damaged by earthquake ground motions.

Furukawa in Osaki city is one of a few places, where was severely damaged by ground motions. Nevertheless, the level of damage to the structure within this town was totally different even the size of this town is not big, about 2km x 2km. In addition, there are 2 seismometers installed in this town, which are JMA-Furukawa and K-NET-MYG006 stations. Although distance between these 2 stations is about 1 kilometer, the velocity response spectrums of both seismometers were different about two times.

Therefore, investigation of ground structure is necessary. We carried out gravity survey in this town with the observation interval less than a few hundred meters because there was an estimation of depth to the engineering bedrock in this area is less than 50 meters. Moreover, we also carry out another observation using very dense sensors installed in this town to ensure the results of research. Within the area 2km x 2km, 34 sensors have been installed.

The Bouguer anomaly, as a result from gravity survey, has some significant variations in some places, which correspond to the most severely damaged places. Furthermore, residual anomaly as extracted from regional anomaly also states the similar fashion to both Bouguer anomaly and severe damaged places. Moreover, simulated 3-D map showing the altitude of basement, or engineering bedrock with the density of 2.4 g/cm3, presents the variations of the depth in 2km x 2km with the maximum different depth up to 67 meters.

These results from gravity survey are also corresponding to the latest result from very dense sensors project, which measured the arrival time of surface wave at every sensors from earthquake event on December 07, 2012 with epicenter off the Pacific coast.

Because the ground structure beneath this town is quite complicated and generate ground motions non-uniformly, so we will use receiver function analysis technique to supplement our study to better understand the characteristics of ground structure in this area.

Keywords: Furukawa, Osaki, Miyagi, 2011 Tohoku earthquake, gravity survey, ground structure, dense seismic array observation

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# Relation between microtremor amplitudes and largest seismic oscillations observed at TRIES seismographic stations

Torao Tanaka[1*]

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Seismographic stations of Tono Research Institute of Earthquake Science (TRIES) cover the Tono district in Gifu Prefecture since 1999. The station TRIES was the first station, and stations MIZUNAMI, INUYAMA, and others were established one after another. In order to investigate any relevancy between amplitudes of microseisms and maximum seismic spectral amplitudes, we started the data analysis of microtremors and seismographic data. By the discrete Fourier transform we calculated the spectral amplitudes and frequencies from the mainpart of the seismographs in the frequency range from 2.0 to 4.0 Hz. On the other hand we calculated the spectral amplitudes and frequencies of microtremors by the discrete Fourier transform at the intervals of 0.1Hz from 2.0 to 4.0Hz. We consider that the minimum amplitudes of microtremors in the small intervals of 0.1Hz represent the most quietest environment. Dividing the maximum amplitudes and minimum amplitudes at INUYAMA station by those at the referent station TRIES we get the information about the site effect at INUYAMA as normalized by the amplitudes at TRIES. The results indicate that the frequency of the maximm seismic amplitude corresponds to the frequency of rather small microtremor amplitudes. The comparisons of the maximum and minimum amplitudes on the site effects show such a clear tendency that the maximum spectral amplitude clearly relates to the small amplitudes of microtremors. This supports our presumption of the relevancy of the maximum seismic amplitudes to the minimum microtremor amplitudes.

Keywords: microtremor, seismic waves, discrete Fourier transform, ground soil, maximum amplitude, site effect

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# Frequency dependence properties of seismic wave scattering and attenuation at the Kanto basin

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**Introduction**

It is well known that high-frequency seismic wavefield shows complicated propagation features caused by the seismic wave scattering due to small-scale heterogeneities along propagation path. In the shallow low-velocity layer, basin structures, the strength of scattering may be much stronger than it in deeper layers, i.e., crust and mantle.

In this study, to understand propagation characteristics of high-frequency seismic waves in shallow low-velocity basin structures, we estimate the scattering and intrinsic attenuation properties at Kanto basin by using coda envelope analysis.

**Method**

We used the waveform data recorded by K-NET/KiK-net and F-net seismic array in Kanto area, Japan, during earthquakes with Mw 4.5-5.5. We apply a set of band-pass filter with 1-2, 2-4, 4-8 and 8-16 Hz to three-component seismograms. Then we calculate mean square (MS) envelopes of sum of three-component seismograms for each frequency band. By the grid search analysis technique, observed MS envelopes were compared with calculated ME envelopes based on direct-simulation Monte Carole (DSMC) proposed by Yoshimoto (2000) in order to estimate scattering coefficient $g_0$ and intrinsic attenuation $Q_I^{-1}$ in the medium.

To achieve precise estimation of parameters in the basin, first, we estimate the parameters in the crust and mantle using waveform data recorded at F-net. Then, using these parameters in the crust and mantle, we estimate scattering coefficient $g_0$ and intrinsic attenuation $Q_I^{-1}$ in the Kanto basin using K-NET/KiK-net records.

Estimation results of scattering properties at Kanto basin

The values of estimated scattering coefficient and intrinsic attenuation in the crust are $g_0$ = 2.51x10-3, $Q_I^{-1}$ = 5.74x$10^{-3}$ for 1-2 Hz, $g_0$ = 2.93x$10^{-3}$, $Q_I^{-1}$ = 3.35x$10^{-3}$ for 2-4 Hz, $g_0$ = 3.98x$10^{-3}$, $Q_I^{-1}$ = 2.28x$10^{-3}$ for 4-8 Hz and $g_0$ = 5.41x$10^{-3}$, $Q_I^{-1}$ = 1.33x$10^{-3}$ for 8-16 Hz. Estimated scattering coefficients are smaller than these estimated by multi lapse-time window analysis (e.g., Fehler et al., 1992; Yoshimoto and Okada, 2009), while intrinsic attenuation values are comparable with them.

We estimated scattering coefficients and intrinsic attenuation in the Kanto basin derived from K-NET/KiK-net records. The values of estimated scattering coefficient and intrinsic attenuation in the basin are $g_0$ = 0.126, $Q_I^{-1}$ = 6.71x$10^{-3}$ for 1-2 Hz, $g_0$ = 0.0708, $Q_I^{-1}$ = 5.96x$10^{-3}$ for 2-4 Hz, $g_0$ = 0.126, $Q_I^{-1}$ = 6.68x$10^{-3}$ for 4-8 Hz and $g_0$ = 0.0891, $Q_I^{-1}$ = 6.48x$10^{-3}$ for 8-16 Hz. The estimated parameters for all frequency bands in the basin are larger than them in the crust. Estimated scattering coefficients in the basin are intermediate values between volcanic area and lithosphere (e.g., Sato et al., 2012). The values of total attenuation of S wave ($Q_S^{-1}$ = $Q_{Scat}^{-1}$+$Q_I^{-1}$ ) are 2.68x$10^{-2}$ for 1-2 Hz, 1.16x$10^{-2}$ for 2-4 Hz, 1.17x$10^{-2}$ for 4-8 Hz and 6.48x$10^{-3}$ for 8-16 Hz. These results are good corresponding to estimation results by Kinoshita and Ohike (2002).

**Acknowledgement**

We acknowledge the National Research Institute for Earth Science and Disaster Prevention, Japan (NIED) for providing the K-NET/KiK-net and F-net waveform data.

Keywords: Seismic wave scattering, basin structure, intrinsic attenuation

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SSS33-P15 Room:Convention Hall Time:May 19 18:15-19:30

# Estimation of S-wave attenuation in the sedimentary layer beneath southern Kanto by using KiK-net borehole records

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1. Introduction

Seismic wave is amplified greatly at big cities in Japan that are generally located on thick sedimentary layer. In terms of seismic hazard estimation, it is important to evaluate amplification and attenuation characteristics of S-wave in the sedimentary layer. Because nowadays borehole seismic records are available all over Japan, it is possible to estimate $Qs^{-1}$ values at many sites on the thick sedimentary layer. In this study, we estimate $Qs^{-1}$ values by using KiK-net borehole seismograms obtained at three stations in southern Kanto operated by National Research Institute for Earth Science and Disaster Prevention (NIED).

2. Data

Seismograms obtained at Chiba (CHBH10), Yokohama (KNGH10), and Tokorozawa (SITH04) whose depths are 2000m are used. We analyze data recorded for periods from May, 2003 to February, 2011. Epicentral distances of analyzed events are within 150km and peak ground accelerations are less than $100cm/s^2$. The numbers of analyzed events at the three stations are 89, 38, and 20, respectively. We apply a band-pass filter (1-10Hz). Transverse component of velocity waveforms is analyzed.

3. Method

Fukushima et al. (1992) estimated $Qs^{-1}$ values by using incident S waves and surface reflected S waves on seismic records at a 732m-deep borehole at Chikura, southern Kanto region. In this study, we use a method slightly modified from theirs. First, we pick a start time t1[s], an end time t2[s] of an incident phase, and a lag time between the incident and the reflected phase on each observed waveform. Because the lag time is automatically determined for given t1 and t2, we only need to search for the optimal value of t2 with t1 fixed. The optimal value is determined so that correlation of these phases and amplitude of the reflected phase become highest. Finally, we calculate system functions from the incident and the reflected phases, and estimate $Qs^{-1}$ values from the system functions.

4. Results

We fit a power-law model to the estimated $Qs^{-1}$ values in the 1-5 Hz band. $Qs^{-1}$ values at Chiba and Yokohama decrease with frequency with exponents of -0.76 and -0.50 and $Qs^{-1}$ values at 1Hz of 0.020 and 0.032, respectively. On the other hand, $Qs^{-1}$ values at Tokorozawa hardly show frequency dependence. $Qs^{-1}$ values estimated for the stations are smaller than that for Chikura (Fukushima et al., 1992). We speculate that this difference is due to the depth dependence of $Qs^{-1}$ values. Since the variation of $Qs^{-1}$ values is as large as about $\pm$1 order so far, we need to investigate the cause. We plan to conduct similar analysis at many stations in order to understand relationships between $Qs^{-1}$ values and other factors such as geology, S-wave velocity, and depth.

Acknowledgements: We are grateful to NIED for providing us with their digital seismograms of KiK-net.

Keywords: seismic wave attenuation, sedimentary layer

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# Examination of source process for the 2011 off Miyagi earthquake of M 7.2 using strong-motion records

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The 7 April 2011 off Miyagi event of Mj 7.2 was a down-dip compression type earthquake in the Pacific slab, supported from the high dip angle in the moment tensor solution and the focal depth of 66 km. This is the largest event for the intra-slab earthquake occurring after the 2011 Tohoku great earthquake of Mw 9.0. The seismic intensity of 6 upper was recorded at Miyagi prefecture just above the source area, and the region of intensity 5 upper extended from southern Iwate to northern Fukushima prefecture. In this study detailed source rupture process is inferred by the inversion analysis using strong ground motion records in the source region. The source inversion algorithm adopted here is composed of the empirical Green's function method and the very fast simulated annealing developed by Shiba and Irikura (2005). In this inversion procedure we first estimate the spatial and temporal distributions of the slip and the rise time on the assumed fault plane from the relatively low-frequency ground motions. Then the effective stress and slip distributions are determined by using the result of the previous inversion analysis as a prior distribution of the new research with the waveforms in the higher frequency range. The fault plane model is assumed as the east-dipping plane with high dip angle based on the F-net moment tensor solution. For the empirical Green's function, the aftershock on 28 April of Mj 4.8 is employed and the sub-fault size is determined from the corner frequency of its source spectrum. Two horizontal velocity motions numerically integrated from the acceleration records at 21 KiK-net stations with one K-NET are provided for the inversion procedure. The source model derived from the slip and rise-time inversion shows rather simple slip distribution consist of one asperity located west of the hypocenter. The area of the asperity is 15 km long and 10 km wide, which is about 14 % of the whole rupture area. Rise time is relatively short of around 1 second, suggesting larger slip velocity and higher effective stress. Furthermore the source model obtained by the simultaneous inversion of the effective stress (peak slip velocity) and the slip indicates that the area of the high effective-stress is coincide well with the asperity, however the highest effective stress area is concentrated to the west end of the asperity, where the large slip ceases. The peak effective stress reaches about 120 MPa and the average on the asperity is 70 MPa, which is consistent with the stress drop on the strong motion generation area for the characterized source model of this event estimated with forward modeling analysis (Harada and Kamae, 2011; Somei et al., 2012).

Keywords: 2011 off Miyagi earthquake, intra-slab earthquake, source process, inversion analysis, strong motion record, effective stress

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# Estimation of the rupture process of the 2011 Fukushima-ken Hamadori earthquake using strong ground motion data

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1. Introduction

On April 11, 2011 in southeast Fukushima prefecture, the 2011 Fukushima-ken Hamadori earthquake (Mw6.6) occurred and it is thought to be triggered by the 2011 off the Pacific coast of Tohoku earthquake. Tsutsumi and Toda (2012) surveyed this area and found two nearly parallel surface ruptures, the Itozawa and Yunodake faults. The hypocenter determined by JMA is located west of the Itozawa fault so it is thought the Yunodake fault ruptured after the Itozawa fault did. There are few cases that surface ruptures are appeared by a crustal normal-fault-type earthquake in Japan. In this study, the source rupture process was estimated by using strong motion data with two fault models (the Itozawa and Yunodake faults). In addition, we compared the obtained slip distributions with the surface displacement distributions by Tsutsumi and Toda (2012).

2. Data and Method

Three components of time series data from nineteen strong motion stations of the K-NET, KiK-net and JMA are used. These original acceleration data are integrated into velocity, band-pass filtered with 0.1~1.0Hz and resampled at 10Hz. The dataset in the source inversion comprises 35s of the time series from 1s before the S-wave arrival. The Green's functions are calculated with the discrete wave number method (Bouchon,1981) and the reflection and transmission coefficient matrix method (Kennett and Kerry,1979) assuming a one-dimensional velocity structure model for each station which is extracted from the Japan three-dimensional integrated velocity structure model (Koketsu et al.,2012).

Two planar fault models (the Itozawa and Yunodake faults) are assumed. Their strike and dip angles are 156 deg.,73 deg. and 130 deg.,62 deg., respectively, in reference to Fukushima et al.(2013), the size of models is 22km$*$14km, 16km$*$14km in accordance with the aftershock distributions in a day after the mainshock. The rupture starting point of the Itozawa fault is shifted about 1.8km from the hypocenter by JMA. That of the Yunodake fault is assumed at northern end, middle, or southern end at the depth of about 12.3km.

The inversion method is the multiple time window linear source inversion (Hartzell and Heaton,1983). The rake angle variations are limited within the dip angle plus and minus 45 deg. The temporal moment-release history at each subfault is expressed by six smoothed-ramp functions which have the duration of 1.0s and each function is separated by 0.5s. The rupture front propagation velocity is 2.04km/s, which is 60% of the S-wave velocity at the rupture starting point of the Itozawa fault. The time difference between the Itozawa's and Yunodake's rupture starting time has five variations, 4.5, 5.0, 5.5, 6.0, 6.5s.

3. Inversion Result

The difference between observed and synthetic waveform is the smallest when the rupture starting point of the Yunodake fault is located northern end of fault model and the delay time is 4.5s. The total seismic moment was estimated to be $1.0*10^{19}$Nm(Mw6.6). On the Itozawa fault the large slip is found in the north of the rupture starting point in the shallow portion. On the Yunodake fault it is found in the north area of the fault model and south in the slightly deep portion. The obtained maximum slip is 1.6m on the Itozawa fault and 2.2m on the Yunodake fault. The slip distributions in the shallow portion of both faults almost correspond to observed surface displacement distributions.

The observed and synthetic waveform fit well when the rupture front propagation velocity and the time difference between two faults is small. Then we will examine slip distributions with more wide range of parameters. Furthermore it is necessary to consider the depth of rupture starting point of the Yunodake fault.

4. Acknowledgments

We thank the NIED, Japan and JMA for providing data.

Keywords: the 2011 Fukushima-ken Hamadori earthquake, the Itozawa fault, the Yunodake fault, sorce process, strong motion data

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# Relation between stress drops and depths of strong motion generation areas based on previous broadband source models

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Miyake et al.(1999) showed that broadband strong motion records in the near fault regions for the 1997 Kagoshima-ken Hokusei-bu earthquake were simulated using strong motion generation areas (SMGAs) by the empirical Green's function method. After their pioneering work, the broadband source models composed of strong motion generation areas were estimated for many earthquakes by many researchers by the empirical Green's function method. On the other hand, Asano and Iwata (2011) studied on the relations between stress drops and depths of asperities for crustal earthquakes. Here asperities (Somerville et al., 1999) were estimated from long-period heterogeneous source models by waveform inversion method using strong motion records in the period range longer than about 1s. They derived the relation that the stress drop is large, so that asperity is deep. In this study we study on relations between stress drops and depths of strong motion generation areas based on previous broadband source models for crustal earthquakes in Japan.

Total 22 articles for 13 earthquakes with the moment magnitude Mw from 5.7 to 6.7 occurring to April, 2011 are used in this study. The numbers of the strike-slip, reverse, and normal faults are six, six, and one, respectively. We independently treat each source model for the same earthquakes, and so the total 25 source models are examined. We also independently treat each strong motion generation area.

The relations between stress drops stress [MPa] on SMGAs and the center depths h [km]are shown in the attached figure. The equations (1), (2), and (3) are derived from three data-set for strike-slip, reverse, and all-types faults, although the standard deviations of the regression relations are large.

stress=0.63h+7.88 (standard deviation=5.26) strike-slip (1)
stress=1.42h+8.54 (standard deviation=8.39) reverse (2)
stress=1.15h+7.98 (standard deviation=8.05) all (3)

The stress drops for reverse faults are larger than those for strike-slip faults at the same depth.

We also derive the relations between seismic moment M0 [dynecm] and total areas of SMGAs Sa [$km^2$] for strike-slip, reverse, and all-types faults as shown in equations (4), (5), and (6).

$Sa=4.57*10^{-16}M0^{2/3}$ (standard deviation=0.18) strike-slip (4)
$Sa=3.64*10^{-16}M0^{2/3}$ (standard deviation=0.09) reverse (5)
$Sa=4.02*10^{-16}M0^{2/3}$ (standard deviation=0.15) all (6)

Sa for strike-slip, reverse, and all-types faults are 0.9, 0.7, and 0.8 times of total area of asperities by Somerville et al.(1999). The result that total area of SMGAs are smaller than total area of asperities is interpreted by frequency-dependent source radiations (Satoh, 2010).

Short-period spectral level A which means the flat level of acceleration source spectrum (Dan et al., 2001) is represented by equation (7) based on the crack model (Brune, 1970).

$A=4pi(Sa/pi)^{0.5}stress\ Vs^{2}$ (7)

Here Vs is S-wave velocity of source and pi is circle ratio. We calculate A by substituting equation (1) to (6) for (7) assuming Vs=3.4km/s. The resultant A for all faults with depths of deeper than 7 km is larger than A derived from the M0-A relation by Dan et al.(2001). The A for strike-slip faults with depths of deeper than 10 km and reverse faults with depths of deeper than 5 km is larger than A by Dan et al.(2001).

As mentioned above, we derived the empirical relations that the stress drop is large, so that strong motion generation area is deep. In addition we showed that the stress drops for reverse faults were larger than those for strike-slip faults at the same depth. The relations between stress drops and depths would be useful for advancement of strong motion predictions for crustal earthquakes.

Acknowledgements:This study is a result of joint research "Study on improvement of evaluation method of earthquake ground motions taking into consideration the Pacific coast of Tohoku earthquake" by twelve electric power companies.

Keywords: strong motion generation area, stress drop, depth, empirical Green's function method, crustal earthquake

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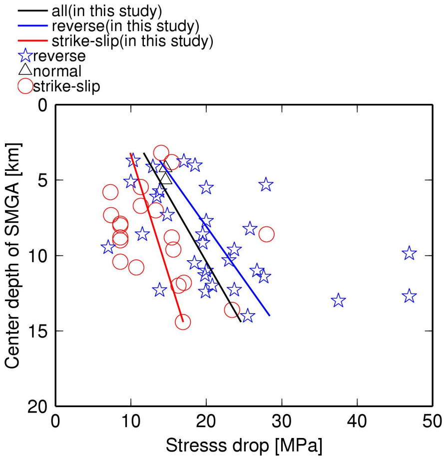

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# Determination of long- and short-period pulse sources of the 2011 Tohoku earthquake using the subduction zone structure

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The Tohoku earthquake on 11 March 2011 is a megathrust event on the subducting plate boundary. Several pulses can be seen in the strong motion records of this earthquake. It is important to determinate their sources using the subduction zone structure.

In our previous study, strong motion records by K-NET and KiK-net were used and integrated to long-period (10 ~ 100 s) and short-period (0.01 ~ 10 s) velocity waveforms using causal filtering, and we identified three main long- and short-period pulses, respectively. We located the pulse sources using arrival times of their initial motions. In our analysis, we used the 3-D velocity structure of the JIVSM model (Koketsu *et al*., 2008). The pulse sources were located by using a nonlinear, probabilistic earthquake location method called NonLinLoc (Lomax *et al*., 2000), in which a solution is represented by probabilistic density function and includes location uncertainties. The result showed that the long-period pulse sources were consistent with the results of the strong motion inversions by Koketsu *et al*. (2011) and Yokota *et al*. (2011), and that short-period pulse sources were consistent with strong motion generation areas by the empirical Green's function method (e.g., Asano and Iwata, 2012). Long- and short-period pulse sources were located to the up-dip and down-dip regions, respectively.

In this study, we picked the arrival times of the maximum amplitude of the second long-period pulse using a zero-phase filter, and located its source by the same method. Combined with the result of the initial motions, this study indicates that the slip related to the second long-period pulse occurred somewhat in the east of the epicenter about 56 s after from the origin time and expanded not seaward but landward. We plan to perform the same analysis of earthquakes of various magnitudes in the mainshock source region in order to check the validity of our analysis, and make detailed discussions.

Acknowledgement:
We would like to thank NIED (K-NET, KiK-net) for strong motion records and JMA for arrival time data of the JMA unified hypocenter catalog.

Keywords: 2011 Tohoku earthquake, strong ground motion, 3-D velocity structure, source process

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# Relationship between asperity and surface earthquake faults for behavioral segments in a long active fault zone

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## Introduction

Taking into account the characteristics of a behavioral segment in a long active fault zone can be the key to establishing a construction methodology of a source model for strong ground motion simulation for a variety of multi-segment rupture scenarios. In this research, we compile the source fault parameters and the geological fault parameters (e.g., surface displacements) for each segment of the source faults of inland crustal earthquakes. Based on the relationships among these extracted parameters, we examine a method to estimate inner fault parameters for each behavioral segment from these geological fault parameters.

## Data and method

We target 7 earthquakes: 1979 Imperial Valley, 1992 Landers, 1995 Hyogo-ken Nanbu, 1999 Duzce, 1999 Hector Mine, 1999 Kocaeli, and 2002 Denali. For each segment of the source fault of these earthquakes, we utilize the source fault model, which was obtained by applying the waveform inversion technique in previous researches (e.g., Hartzell and Heaton, 1983; Wald and Heaton, 1994; Sekiguchi *et al.*, 2000; Birgoren *et al.*, 2004; Ji *et al.*, 2002; Sekiguchi and Iwata, 2002; Asano *et al.*, 2005), and extract the asperity area by following the procedure in Somerville *et al.* (1999). Then, we compile the outer fault parameters (segment length and segment width) and inner fault parameters (average slip on asperity and area of asperity) for each segment. We also obtain the geological fault parameters, such as the maximum value of coseismic surface displacements, and the recurrence interval. Here, we use the value obtained by multiplying the maximum value of surface displacements by the segment length, as a parameter value related to an shape of the distribution of surface displacements. In this presentation, we examine the segments with a segment length of less than 60 km and an aspect ratio (segment length/segment width) of less than 2.5.

## Examination on the average slip on asperity and the area of asperity

The correlation coefficients between the average slip on asperity and, the segment length, the maximum value of surface displacements, and the recurrence interval are 0.49, 0.61, and 0.94, respectively. Here, the recurrence intervals for the segments ruptured in the 1992 Landers earthquake, 1995 Hyogo-ken Nanbu earthquake and the 1999 Hector Mine earthquake are used. The average slip on asperity is found to have a high correlation with the recurrence interval. The average slip on asperity also has a relatively high correlation with the maximum value of surface displacements. If we exclude two segments where the upper edge of asperity area reaches the ground surface and the relatively larger maximum value of surface displacements is observed, the correlation coefficients are improved (0.91). Moreover, the area of asperity correlates with the value obtained by multiplying the maximum value of surface displacements by the segment length (correlation coefficient: 0.62).

From our results, it is found that the maximum value of surface displacements correlates with not only the average slip on asperity, but also the area of asperity if we utilize the segment length together. This means that the maximum value of surface displacements is one of the useful geological fault parameters to estimate the parameters on asperity. We will examine the relationship between the inner fault parameters and both seismological and geological conditions near the source faults.

Acknowledgements

In this research, we use the source fault models compiled in the Finite Source Rupture Model Database (http://equake-rc.info/srcmod/). We sincerely thank Dr. Kimiyuki Asano for providing the information on the source model of 2002 Denali earthquake.

Keywords: long active fault zone, behavioral segment, asperity, surface earthquake fault

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# Updating of source scaling relationships evaluated from the waveform inversion of recent inland crustal earthquakes

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Somerville et al.(1999) compiled slip models for fifteen inland crustal earthquakes (Mw5.7-7.2), and obtained empirical scaling relations for source parameters (total rupture area and asperity area). Irikura and Miyake (2001) proposed a recipe for predicting strong ground motion for future earthquakes based on mainly Somerville's empirical scaling relations.

After 1995 Hyogo-ken Naubu earthquake, a lot of strong ground motion stations (K-NET, KiK-net) have been installed in Japan by NIED (National Research Institute for Earth Science and Disaster Prevention). A large amount of the waveform inversion analyses have been done in recent years for estimating rupture processes using strong ground motion data.

Using the waveform inversion results of resent fifteen crustal earthquakes (Mw5.6-6.9), which happened after the 1995 Hyogo-ken Naubu earthquake, we try to revise the empirical scaling relationships between seismic moment and entire rupture area and between seismic moment and asperity area. According to the criterion of Somerville et al.(1999), we extracted the entire rupture area (S) and the asperity area (Sa) from inverted heterogeneous slip distribution. The combined area of asperities over the entire rupture area is about 0.17 in average for fifteen earthquakes. The averaged ratio (Sa/S) of the combined area of asperities to the entire rupture area is smaller than Somerville's result (0.22). The averaged ratio (Sa/S) varies dependent on fault type (strike slip, reverse slip, and normal slip) as follows.

Strike slip type (seven earthquakes): Sa/S = 0.16
Reverse slip type (seven earthquakes): Sa/S = 0.16
Normal slip type (one earthquakes): Sa/S = 0.22

It should be examined whether the asperity areas (Sa) obtained above are effective for strong motion prediction, comparing them with strong motion generation areas from simulation using the empirical or stochastic Green's function method.

Acknowledgments: We thank Dr. Asano(DPRI), Associate professor Sekiguchi (DPRI), Professor Iwata, Dr. Horikawa(AIST), Dr. Hikima(TEPCO), Dr. Suzuki(NIED), and Dr. Aoi(NIED) for providing waveform inversion results. We also used waveform inversion results from JMA.

Keywords: strong ground motion, a recipe for predicting strong ground motion, empirical scaling relations, waveform inversion

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# Examinations toward establishing procedure of evaluating fault parameters for predicting strong motions from intra-slab

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For precise prediction of strong motions from intra-slab earthquakes, it is necessary to establish a new procedure of evaluating fault parameters based on the characteristics of intra-slab earthquakes. Although such studies have been conducted by Sasatani et al. (2006) and Dan et al. (2006), procedures of evaluating fault parameters that have been proposed have not been fully verified by reproduction of the actual earthquake records. Then, in this study, we simulated the ground motion of the intra-slab earthquake that occurred off the coast of Miyagi Prefecture on April 7, 2011 and we pointed out the problem of existing procedures of evaluating fault parameters and suggested the ideas to overcome the problem.

In the case of the intra-slab earthquake of April 7, 2011, there was a possibility that the result of evaluation of strong ground motion using the equation of short period spectral level proposed by Sasatani et al. (2006) or Dan et al. (2006) became too small. But we found that the fault models could not be set due to negative slip amounts on the background area by only increasing the short period spectral level according to the detailed knowledge of this earthquake obtained by Harada and Kamae(2011). For this problem, we developed three new fault models using a method to reduce the area of the asperities while increasing the short period spectral level and using a crack model.

We set five fault models of the intra-slab earthquake off the coast of Miyagi Prefecture on April 7, 2011, which are models just based on the relationships of intra-slab fault parameters by Sasatani et al. (2006), another one by Dan et al. (2006), and newly proposed three fault models. By using these five fault models, we evaluated strong ground motions at several KiK-net stations by the empirical Green's function method. As a result, ground motion evaluation results using Sasatani et al. (2006) and Dan et al. (2006) are smaller than the actual records especially at the observation stations near the epicenter. On the other hand, ground motion evaluation results using the newly proposed three fault models showed better agreements with the actual records.

Keywords: Intra-slab earthquakes, Strong motion prediction, Fault model

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# Source Process Analysis of the 1995 Kobe Earthquake Using 3-D Velocity Structures

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The Kobe (Hyogo-ken Nanbu) earthquake with a JMA magnitude of 7.3, which occurred on 17 January 1995 near the Akashi Strait located in the southern part of Hyogo Prefecture, caused great disaster. The notable feature of this earthquake is violent ground motions with a JMA intensity of 7 occurred in a narrow zone, called ”damage belt”. Previous studies (e.g., Kawase, 1996; Furumura and Koketsu, 1998) have shown that their occurrence is attributed to the 3-D velocity structure in this zone. This indicates not only that a 3-D velocity structure significantly affects strong ground motions, but also that we should consider its effects in precisely determining the rupture process of this earthquake. However, the previous studies of source process analyses only used 1-D or half-space velocity structure models.

In this study, we calculated 3-D Green’s functions for the strong-motion and geodetic stations located in the Osaka basin using a 3-D velocity structure model. Then, we performed a joint inversion of strong motion data, teleseismic body waves and static displacements for the source model of the earthquake. Before performing the inversion, we validated the 3-D velocity structure model and refined it using the strong motion data of aftershocks.

We compared our source model to that of Yoshida *et al.* (1996), which is one of the previous studies. The seismic moment and largest slip in our source model are slightly larger than those of Yoshida *et al.* (1996). Distinctive differences are seen in between our source model and that of Yoshida *et al.* (1996): a new large-slip zone beneath the city of Kobe and larger slips in the shallow part along the Nojima fault. These differences suggest that our source model is more consistent with the violent ground motions in the ”damage belt” and the surface rupture of the Nojima fault. We also confirmed that our source model realized better fit to the strong motion observations.

Keywords: Source process, Joint inversion, 3-D Green’s function, Velocity structure

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# Main shock-aftershock interval effect on the liquefaction damage in Tohoku Region Pacific Coast Earthquake

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During the Tohoku Region Pacific Coast Earthquake, extensive liquefaction damages were observed over a wide range of reclaimed coastal land. The following two characteristics have been pointed out: (1) Large liquefaction damages occurred even under small ground acceleration. (2) Intermediate soils with large fine fraction content that have been considered to be hard to liquefy also exhibited extensive liquefaction. While long duration of the seismic motion may be one of the main reasons for them, the authors previously focused on the stratum organization. That is, soft alluvial clay located directly under the alluvial sand on the inland side is thin, where liquefaction damage is relatively small. The thickness of this clay layer increases as it approaches to the coastal side, where liquefaction damage becomes severe. Based on the 1D elasto-plastic seismic response analysis, the authors indicated that a thick soft clay layer below the liquefied layer can amplify seismic waves over a range of longer periods, and the resulting large plastic strain may cause severe liquefaction damage even in clayey sand that normally resists liquefaction.

The third characteristic will be (3) large aftershock generated only 29 minutes after the main shock expanded the liquefaction damage, considerably. In this study, authors focused on the influence of main shock-aftershock interval to the liquefaction damage. Before the elasto-plastic seismic response analysis, elasto-plastic soil properties were precisely identified by the various soil tests in laboratory using undisturbed soil samples obtained through boring exploration in the Urayasu city, details for which will be delivered later.

The difference of the thickness of clay layer affects greatly on the liquefaction damage as shown in Fig. 1(a). Fig. 1(b) indicates the time-excess pore water pressure ratio relationships during the aftershock that occurred 29 minutes after the main shock. D foundation with a very thin clay layer does not exhibit any liquefaction during both main shock and aftershock. To the contrary A and B foundations with a thicker clay layer, liquefaction was clearly observed both during the main shock and during the aftershock. The C foundation exhibited interesting behavior. The C foundation is on the relatively thin clay layer, and this foundation does not exhibit liquefaction during main shock. However, 29 minutes after the main shock the foundation reaches liquefied state during aftershock (Fig.1 (b)). This is, of course because 29 minutes is not long enough for the dissipation of excess pore water pressure even for the sand which is covered with reclaimed clayey soil layer of small permeability. Suppose that the aftershock occurred one day after the main shock. Fig. 1(c) shows the time-excess pore water pressure ratio relationships during the aftershock. No foundations from A to D exhibit any liquefaction during the aftershock. One day interval will be long enough for the excess pore pressure dissipation through the top clayey sand layer. Short interval between main shock and aftershock may have enlarged liquefaction damage in Tohoku Region Pacific Coast Earthquake.

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Keywords: Liquefaction, Clay layer thickness, Main shock ? aftershock interval, Elasto-plastic seismic response analysis

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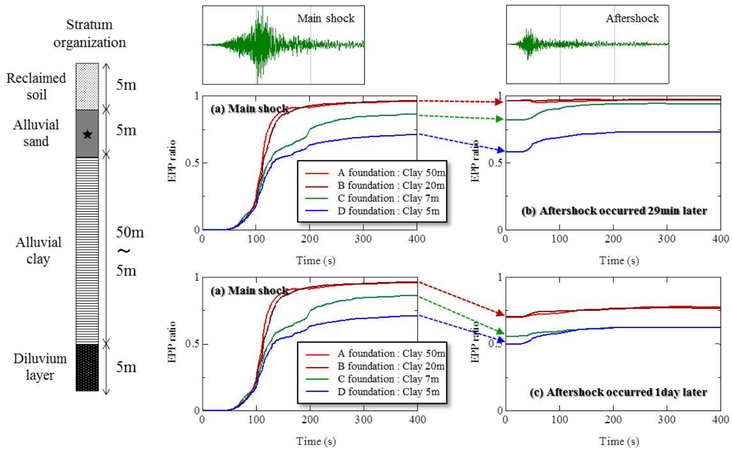

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# Effect of the non-linearity of the ground in synthetic ground motion by using Empirical Green's Function

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In seismic hazard in an engineering problem, it is required to consider the ground motion in a period band of about 10 seconds from 0.1 seconds. Strong ground motion in a period range of less than one second are controlled by generation region called [asperity] on a fault plane. The short-period component, is also strongly influenced by characteristics of the propagation path effect. In order to obtain such effects theoretically it is required a huge amount of calculation and data for underground structure. It is also necessary for more accurate evaluation method of ground motion.

In this, we calculate synthesis ground motion of main shocks for past events by using the empirical Green's function method, and to assess the effects of the non-linearity of soil from the difference between the observed and synthesis waveforms.

We compared the observed waveforms and synthetic waveforms at the observation point K-net during five crustal earthquakes occurred in Japan, using the source model obtained by the inversion in the past. We used characterized source models that has been obtained in previous studies, first, I was examined how much the non-linearity effects of soil are included at the observation point by comparing the observed and synthetic waveforms. When PGAs are more than 200gal, PGVs are greater than or equal to 10kine, the synthetic waveforms tend to be significantly different from the observation waveforms. In order to evaluate quantitatively the nonlinearity of the soil of each observation point, using (which was summed in the frequency domain for each ratio of H / V spectrum at the aftershocks and the main shock) DNL method, we examined the relationship DNL and the PGA. Then, for the PGAs above 200 gal, the DNL has become equal to or greater than 6, and the DNL for PGA of 200gal is about 4. We have found that DNL is one of good parameters to evaluate the nonlinearity of the soil. This is also consistent with the results by Noguchi (2009). Next, we evaluated the effect on PGV and PGA ratios (synthesis/observations) with the difference condition of subsurface structure. We used the difference of each Vs20 which is the S-wave velocity average of up to 20m depth as parameters for the soil condition. In spite of the differences in the Vs20, the relationship between the Vs20 and PGA or PGV ratios is not so clear. One of the reasons for this is that the used characterized source model only asperity source model, was not sufficiently tuned model for all sites.

We try to assess the effects of nonlinear amplification by quantitatively evaluating the difference between the synthesized waveform and the observed waveform and adding to the result of empirical Green's function method. However, the PGA and PGV from observed waveform cannot good parameters for this evaluation, because of including high frequency pulses Different evaluation criteria, such as seismic intensity and spectral integration value will be examined.

We thank National Research Institute for Earth Science and Disaster Prevention for the seismograms of the stations in the K-net and KiK-net.

Keywords: Empirical Green's Function, non-linearity of soil, DNL, strong motion

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# Rough and rapid estimation of rupture area for gigantic earthquakes from seismic intensity distribution

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We are developing some rapid estimation techniques for rupture area roughly. Yokota and Kaida (2011) proposed a method for estimating rupture area for a big earthquake( $Mw > 8.0$) from seismic intensity distribution. In their method, they estimate rupture area on the plate boundary with relationship between the shortest distance from source area and Mw. It is difficult to estimate rupture area especially near trench (far area from land) with this method. And it takes 10min after earthquake occurrence to analyze the source area, because small seismic intensity data are observed late due to travel delay.

In this study, we use only seismic intensity data of large values to estimate rupture area. By using only large intensities, we can analyze 3min after earthquake occurrence in the case of 2011 Tohoku-oki earthquake. Since large seismic intensities are observed at a short epicentral distance, we can estimate the outer rim of the source area.

We will report results for other large earthquakes.

Keywords: Rapid estimation of rupture area, seismic intensity distribution

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# The Surface Distributions of the Durations of the Low Frequency Seismic Waves

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If large earthquakes occured, the 2011 off the Pacific coast of Tohoku Earthquake for instance, low frequency seismic waves with 2 second or longer periods were observed. These sometimes cause damages for high-rise buildings and other large structures. However JMA has no method to announce observed data about low frequency seismic waves. Therefore JMA has considered how to announce them from 2011 and will establish new information.

As for strong ground motion, seismic intensities are used generally. In addition, specialists use PGA and PGV. On the other hand, maximum amplitudes of velocity about various frequencies are important to grasp low frequency waves. Furthermore those time series are also important because those damping rate are smaller than those of strong motion.

In Japan, seismic intensities can be grasped in detail by about 4300 intensity-meters. However there are only about 1500 stations which can observe low frequency waves: that is K-NET, Kik-net, F-net of NIED and JMA strong motion observation network. We must estimate low frequency motion on each place by those limited data. Muto and Katsumata (2012) proposed spatial interpolation of maximum velocities using natural periods which calculated from the subsurface velocity structures. We considered the relation between natural periods of subsurface structures and time series of ground motions in this study.

We investigated 2 parameter: (1) the periods from the P-wave arriving times to the peak amplitudes appearance ones, and (2) the durations that large amplitude waves continued. On the second one, we can give some definiations. In this study, we calculated durations of time series of velocity responce using a method by Izutani and Hirasawa (1987). It was ascertained that the ratios of the durations of S-wave calculated by 0.1-0.5 Hz velocity responces to those of P-wave calculated by 5Hz them were fixed generally regardless of locations. On the other hand, We found that there were correlations between durations whose amplitudes were above certain thresholds and subsurface structures. Using those two knowledges, it may be able to forecast the durations of low frequency seismic waves at any point by the durations of high frequency ones solved by actual records observed at nearby stations.

Acknowledgements.
K-NET, KiK-net and F-net data of NIED were used in this study.

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Keywords: low frequency seismic wave, ground motion duration, deep subsurface structure

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# Ultra high density questionnaire seismic intensity survey and the shallow S-wave velocity structures

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To clarify the vibration characteristics in central Maesawa Town of Oshu City, Iwate Prefecture, the dense survey of seismic intensity was done using questionnaires for the 2011 off the Pacific coast of Tohoku Earthquake and the aftershock occurred at April 7, 2011. This earthquake was the aftershock of the 2011 off the Pacific coast of Tohoku Earthquake. JMA reported that the seismic intensities at the Maesawa Town of Oshu City were 6 weak for the main shock and same for the aftershock. The questionnaire revised by Ohta et al.(1998) was used for calculating seismic intensity. The seismic intensities estimated from questionnaires were averaged for 250 m square meshes to clarify the distribution of seismic intensity in the central area of Maesawa Town. To avoid differences among individuals for questionnaire survey, the effective mesh where the number of the questionnaire was more than three was used for analysis. The mesh that seismic intensity was 6 strong were found for theresult of the aftershock. The results shows that the seismic intensity was large at the area where houses were damaged. Microtremor observations with a single and/or array sencers were also carried out in this area. Results of microtremor H/V shows clear peaks in the damaged area, namely Gojunin-machi area, but do not in other area. Estimated shallow S wave velocities from microtremor array survey are small, e.g. about 100 m/s in the damaged area but not in other area.

Keywords: the 2011 off the Pacific coast of Tohoku Earthquake, aftershock at April 7 in 2011, Questionnaire Seismic Intensity Survey, earthquake damege, Maesawa Town, Oshu City, Iwate Prefecture, microtremor array survey

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# Relationship between liquefaction occurrence ratio and strong ground motion duration

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A report of research that the length of strong ground motion duration time including aftershock of the 2011 Tohoku-oki earthquake enlarged the damage range and scale of liquefaction occurs.

In this research, it aims at examination of the influence of the duration time of the strong ground motion of the 2011 Tohoku-oki earthquake about liquefaction occurrence rate.

First, "the real-time seismic intensity" by Kunugi et al(2008) and instrumental seismic intensity were calculated from strong ground motion waveform record.

Next, the relation with strong ground motion duration time was considered using the technique of calculating a liquefaction occurrence rate of Matsuoka et al(2011).

As a result, the liquefaction occurrence rate of the 2011 Tohoku-oki earthquake are much larger than those of past earthquakes caused liquefaction.

Moreover, it turned out that the size of strong motion duration time also affects a liquefaction occurrence rate of incidence.

Keywords: Liquefaction, Liquefaction occurrence ratio, Strong ground motion duration, Realtime intensity, Geomorphologic classification

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# On-site experiment of seismic monitoring network by utilization inside sensors of mobile terminal

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Mobile terminal devices have a small, lightweight, and cheap accerelation sensor called MEMS, and also have a bettery and wireless communication adaptor inside it. If we use such MEMS sensor for observation of earthquake and then upload to cloud computing system, we would know detailed information of shaking. And If we share information observed by MEMS sensor using the cloud computing system, we could raise awareness about disaster prevention. For example, Yoshida et al.(2011) developed an experimental earthquake observation system using the iPhone/iPad/iPod touch named ”i-Jishin”, and released in August, 2010.

Furthermore Naito et al. (2011) installed ”i-Jishin” on the base and observed in parallel with K-NET02 seismometer. They compared same seismic waves, then concluded as regarding JMA intensity, over 3 it is within the margin of 0.1, but up to 2 it becomes overestimate.

In this research, we report about the performance of MEMS acceleration sensors and on-site experiment of seismic monitoring network by utilization inside sensors of mobile terminal.

In order to examine the possibility of application about strong motion observation of the building using ”i-Jishin”, we installed it on two different floors in the low-rise 5 RC buildings, and started monitoring from January 2012. After installation, we were able to get a large number of earthquake records corresponding up to an intensity 4. By analyzing these data, one building showed significantly high velosity response value. This building was significantly damaged in the non-sutructual component after the Tohoku-Pacific Ocean Earthquake. After that, we tried the microtremor observation using JU-310(Hakusan Corp.), we found the largest gain compared to others in this building looking at the H / V spectral ratio, and it was consistent with the result as previously mentioned.

In addition, for the purpose extracting social issues, we installed ”i-Jishin” on the floors of more than 30 different buildings which have different types of structure and network environment around the city of Nagaoka, Niigata Prefecture and Fujisawa, Kanagawa Prefecture since January 2012.(Azuma et.al, 2012) In that case, the staff of NPO installed terminals and they are considered favorable, so well understood about the effect of sensing. However, many problem was found such as, diversity of networking enviroment, no easily understandable benefits of the installation, requirement to ensure the stability of the measurement, and the human resources for maintenance.

To solve these promblems, we will develop a more reliable and accurate system or a sytem that is easily understanble for general person. Besides we are going to enhance the cooperation with ”i-Bidou” which is the system of the cloud type microtremor observation system(Senna et al.2012). We will keep developing the system to visualize the harzard information of regional soil and building conditions, and keep performing experiments of the sensor network system so that everyone can measure and share information of the buildings.

Keywords: MEMS, Cloud, Sensor Network, On-site experiment

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# Attenuation measurements by laboratory tests using rock core samples for earthquake ground-motion estimation

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An applicability of attenuation measurements by laboratory tests using rock core samples (5 cm-diameter and 10 cm-long) is described. The pulse rise-time technique [Gladwin and Stacey,1974] and the spectral ratio technique [Toksoz et al, 1978] were applied to measure an attenuation of four granite core samples by ultrasonic wave measurements using S-wave transducer of 100 kHz. As a result, the damping factors ranged from 0.009 to 0.014 (Qs=37~54) were obtained from the pulse rise-time technique. Additionally, from the spectral ratio technique, the damping factors ranged from 0.009 to 0.014 (Qs=37~54) were obtained by using aluminum with Qs=150000 [Zamanek and Rundnik, 1961] as a reference sample. These results indicate that almost equal damping factors are estimated by two different techniques used ultrasonic wave measurements. Further, the cyclic uni-axial compression tests using cyclic loading wave of 0.1 Hz were also performed to get stress-strain curves with ten stress-levels for same samples used in ultrasonic wave measurements. From the stress-strain curves, we found that the curves with the strain levels lower than about 2.x$10^{-5}$ were difficult to provide reliable damping factors because of an unstable and distorted shape of hysteresis loops. Meanwhile, the damping factors with the four strain levels ranged from 2.6x$10^{-5}$ to 2x$10^{-4}$ were obtained from the stress-strain curves and showed strain-dependent characteristics. The damping factors of minimum strain level of 2.6x$10^{-5}$ were obtained from 0.008 to 0.01 (Qs=50~63). From the comparison with the results from ultrasonic wave measurements, we showed that almost the same damping factors of small-strain level were estimated by the two different methods.

Keywords: rock core sample, attenuation measurement, ultrasonic wave measurement, cyclic uni-axial compression test, near surface rock, earthquake ground-motion estimation