Japan Geoscience Union Meeting 2015
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Waveform inversion converged towards the grand minimum: A Wiener-filter approach

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Not only in seismology but also in many research fields of earth and planetary sciences, waveform inversions are widely used. Some on-going data analyses even adopt automated inversion procedures with huge amounts of data. Their basic concept is the minimization of the difference between each observed time-domain waveform and its synthetic waveform in the least squares sense. Since waveforms are characterized by a series of peaks and troughs, there are many local minimums around the true or grand minimum so that we may obtain our final inverted model for one of local minimums rather than the desired grand one particularly if our initial model for inversion is not close to the true model. In a mathematical point of view, this problem is related to the ambiguity of 2π in phase. The general process to overcome the above problem is called 'phase unwrapping', but this process is rather empirical, very subjective and different from a problem to another.

We propose a new inversion approach in order to make waveform inversions objective and stable. This consists of two stages. At first, the difference between each observed waveform $d(t)$ and synthetic one $p(t)$ (here we shall assume that all the waveforms are expressed by discrete time series) by a Wiener filter $w(t)$. The Wiener filter is defined by the filter that minimize the sum of squares of $p(t)*w(t)$-$d(t)$, where $*$ represents the convolution. Coefficient of w(t) can be obtained efficiently by a recursive algorithm (Levinson, 1949). If $p(t)$ and $d(t)$ were same, the Wiener filter $w(t)$ would be a unit filter, that is, 1 for t=0 and zero otherwise (corresponding to a delta function in a continuous case). In the second step, therefore, we introduce a new criterion to minimize the sum of squares of $w(t)$ multiplied by a time lag for all the records together: $t \bullet w(t)$. In practice, we need to normalize the above criterion divided by the square of $w(t)$.

With this new criterion, the time lag of $w(t)$ is only weighted without its sign (i.e., positive peak versus negative trough), there are no ambiguities in phase, unlike any conventional waveform inversions. If we iterate the above inversion procedure by modifying a given model in each step, our model will be converged towards a optimal one without falling into any local minimums.

For large-scale inversion problems, one uses an adjoint matrix or operator rather than the formal inverse matrix of a given forward problem. The modification of a model in each iteration step is obtained by the data residual, $p(t)$ – $d(t)$, multiplied by the adjoint matrix. The adjoint matrix is derived by the partial derivative of by the minimizing criterion (the sum of squares of $t \bullet w(t)$ in this case) partially differentiated by the synthetic $p(t)$. Its result is expressed by - $t^2 \bullet w(t)^2 * p(t)^{-1}$. That is , we only need to deconvolve the sum of squares of $t \bullet w(t)$ by $p(t)$. Other procedures are similar to those of conventional waveform inversions.

We conducted numerical tests in order to confirm the efficiency of our new inversion approach, using a medium with velocity fluctuations. Even without a dense coverage of paths connecting sources and receivers, our inversion leads to a final model close to the true model. In contrast, an initial model very close to the true one is required if we obtain a satisfactory model with conventional least-squares criteria in inversion. That is, the present inversion approach can lead our model search into the true or grand minimum without falling into or being stuck by local minimums around it.

Keywords: inverse problem, seismic waveform, Wiener filter, grand minimum, phase unwrapping

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Seismic wave propagation in the heterogeneous structure associated with the subducting Philippine Sea Plate

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Introduction

In the southwestern Japan, where the Philippine Sea Plate (PHS) is subducting from Nankai Trough, several distinct later phases were observed during intraslab earthquakes (e.g., Ohkura, 200; Miyoshi and Ishibashi, 2007; Hayashida et al., 2010). Since such later phases propagate through wider area compared with direct body waves, we examine the characteristics of distinct later phases in the southwestern Japan derived from dense Hi-net observations and three-dimensional (3D) numerical simulations in order to reveal heterogeneous structure around the subducting PHS.

Observed characteristics of high-frequency seismic waves

We used observed waveforms from dense Hi-net network during earthquake (Mw 4.2) that occurred at southern Hiroshima, southwestern Japan, on 2004 September 21. In fore-arc side of southwestern Japan (Shikoku region), distinct later phases were not observed and spindle-shape S waves with strong peak delay were dominant at stations, where the PHS exists at shallower depths. On the other hand, in back-arc side of southwestern Japan (Chugoku region), several distinct later phases were observed and effectively propagated at distance over 300 km. Especially, amplitudes of sSmS (Moho reflection of S waves) were lager than those of direct S waves and provided the peak ground velocities (PGV) at stations with distance larger than 150 km.

Simulation of seismic wave propagation

To clarify causes of such observations, we conducted finite-difference-method (FDM) simulation of seismic wave propagation in 3D layered structure JIVSM (Koketsu et al., 2008). The 3D model covered a region of 512 km$\times$320 km$\times$80 km, including Chugoku and Shikoku region of southwestern Japan. Since the model was discretized by grid intervals of 0.25 km in horizontal directions and 0.2 km in vertical direction, the FDM simulations can examine seismic wave propagation for frequency less than 1.5 Hz.

Although distinct later phases were also found in simulation results of JIVSM, simulation results did not perfectly reproduced the observed features, such as large amplitude sSmS and spindle-shape S waves in fore-arc side.

By travel-time tomography, the low-velocity anomaly (LVA) with high VP/VS ratio was detected just above the PHS at depths of 30-50 km (Hirose et al., 2008). Thus, according to this observation, we introduced the LVA in the simulation model, where the seismic S-wave velocities were reduced by 10% compared with the original JIVSM. By introducing LVA, impedance contrast between oceanic crust and mantle became smaller and consequently maximum amplitudes were found in sSmS rather than direct S waves. The LVA associated with subducting PHS affect the distribution of PGV of intraslab earthquakes in southwestern Japan.

Acknowledgement

We acknowledge the National Research Institute for Earth Science and Disaster Prevention, Japan (NIED) for providing the Hi-net waveform data and F-net CMT solutions. The computations were conducted on the computer system of the Earthquake and Volcano Information Center of the Earthquake Research Institute, the University of Tokyo.

Keywords: Seismic wave propagation, intraslab earthquake, Philippine Sea Plate, crustal structure, numerical simulation

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Temporal velocity changes after the 2014 northern Nagano earthquake, central Japan

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Since 2003, we have calculated daily fluctuation of seismic velocity for all over Japan by applying interferometry method to Hi-net continuous ambient noise records using vertical component. Several stations showed reduction of velocity after large earthquakes such as the 2004 Chuetsu earthquake, the 2008 Iwate-Miyagi earthquake and the 2011 Tohoku-Oki earthquake, and after magma intrusions like the seismic swarms at the eastern Izu peninsula. However, we still need to investigate velocity changes associated with the seismic or volcanic event, since we still have no idea why velocity reduction after these events occurs and whether the velocity reduction is generally observed or not. On 22 November 2014, a large earthquake of Mj6.7 occurred at the northern Nagano prefecture, which is located near the northern part of the Itoigawa-Shizuoka Tectonic Line (ISTL). In this study, we investigated the earthquake effect on the velocity structure by way of the interferometry method using Hi-net data.

Around the source area of the northern Nagano earthquake, there are typical six Hi-net stations and six easy Hi-net stations which are composed of only a three-component high-sensitivity and short-period velocity seismograph. Three of them, N.HBAH, N.HKKH, and N.OTNH are on the source region. Using ambient seismic noise of 1-3 Hz bandwidth, we calculated auto-correlation functions (ACFs) of vertical component applying a one-bit normalization correction. Since the relative delay of the ACFs for each lag time corresponds to the relative change of the velocity, the velocity fluctuation for each Hi-net station could be estimated by applying a stretching method to waveforms obtained before and after the earthquake.

The three stations on the source area showed 1 % to 3 % velocity reduction during the earthquake. In addition, N.IGWH at northward and N.MKGH at northeastward from the source area also decreased approximately 0.5 % and 1.5 %, respectively. We could not find clear correlation between the velocity reduction and values such as peak ground acceleration, peak ground velocity, site amplification effect, tilt record, and volumetric strain change by the estimated source fault. After the earthquake, the velocity has recovered approximately by 50% for 2 months except for N.OTNH.

Keywords: a large earthquake, seismic interferometry, auto correlation functions, velocity reductions, Hi-net

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Subsurface velocity structure beneath Kirishima volcanoes inferred from ambient seismic noise tomography

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Shinmoe-dake, one of Kirishima volcanoes, experienced magmatic eruptions in 2011. The analysis of ground deformation shows that the pressure source locates 5 km to the northwest of the Shinmoe-dake summit at a depth of 8 km, which implies the existence of a magma reservoir. We are trying to resolve it by seismic procedure toward ensuring its existence and deriving precise crustal structure.

The technique we employed is the seismic wave interferometry, which extract the seismic wave propagation between two seismic stations by taking a cross correlation of random wavefields, such as the ambient seismic noise or the seismic coda wave, recorded at two stations. The cross correlations of random wavefield recorded at two receivers can be represented as if the source is at one receiver and the recorder is at the other. This technique is suitable for exploring local structure since the extracted wave is sensitive to the internal structure between two stations.

We inferred the crustal phase velocity anomaly using the vertical component of the ambient seismic noise recorded by seismic array between April 2011 and December 2013. A Rayleigh wave is extracted by taking cross correlations. We derived its dispersion curve using all pairs of stations as a reference, then measured a Rayleigh-wave phase-velocity anomaly against the reference for each pair in some frequency bands.

The phase velocity anomaly we thus obtained shows that most paths crossing Kirishima volcanic body have negative velocity anomaly for all frequency bands, indicating that the entire volcanic body has the characteristic of low velocity against the outside. The shallower part shows relatively high velocity at the location where the source of the ground deformation is estimated.

Keywords: Kirishima volcanoes, subsurface velocity structure, ambient seismic noise tomography

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Study on vibrational characteristics of Mt.Fuji for applicability of monitoring volcanic activity

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Mt.Fuji is Japanese representative volcano. If it erupts, its influence is immeasurable. So it is important to predict its eruption to prevent the volcanic disaster. However, there are still many problems with a volcanic eruption prediction study, and we need to develop new observation techniques and establish it in the future.

In this study, as a method for monitoring Mt.Fuji activities, we attempted to apply the technique based on microtremor measurement which is used for vibrational characteristic evaluations such as buildings. First, we verify if we can estimate the frequency characteristics of Mt Fuji 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 0.21 Hz in the NS' component and around 0.20Hz in the EW' 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 influence of the higher mode is greater than that of lower mode in the area lower than the 6th station.

We also conducted FEM analysis for vibrational characteristics of the real model based on the digital elevation model data. The primary natural frequency of the model is about 0.22 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. Next, we conducted FEM analysis of the magma model, and we found that detection of the volcanic activity may be possible from the change of vibrational mode shape or the contribution ratio of higher mode. However, it is necessary to improve the accuracy of the observation.

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, vibrational characteristics, volcano, microtremor observation

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Effect of seismic attenuation on S-wave polarization anisotropy

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In order to verify whether or not seismic attenuation has an influence on S-wave polarization anisotropy, we investigated shear-wave splitting of Ps phases that are identified on synthetic P-wave receiver functions calculated for a seismic velocity model of three-layer structure. Top two layers of the velocity model are anisotropic and anelastic medium, and bottom layer is a semi-infinite isotropic elastic body. Horizontal c-axis is assumed to lie in the anisotropic layers, and anisotropy intensity is set at 2 % for P-wave velocity and 5 % for S-wave velocity. Azimuth of the c-axis is 35 degrees from the north in the first layer and 65 degrees in the second layer. Thicknesses of the two anisotropic layers are 35km. Attenuation quality factors, Qp and Qs, of P and S waves are 50 and 25 in the first layer and 100 and 50 in the second layer. Appropriate values are assigned to the isotropic P and S wave velocities and density of the velocity model.

Three-component response functions caused by P-wave incident on the bottom layer is calculated as a function of back azimuth for the three layer structure by layer matrix method (Crampin, 1970). Incident angle is set at 10 degrees measured from the vertically downward direction. The radial and transverse components of P-wave receiver functions for different back azimuths are constructed from the P-wave response functions by water level method (Langston, 1979).

We compared P-wave receiver functions calculated in two cases: one is a case where seismic attenuation exists and the other is a case where there is no seismic attenuation. The receiver function with seismic attenuation shows smoother waveform than that in the case of no attenuation, because high-frequency components of the receiver functions are attenuated by anelasticity of the anisotropic layers. We identified two conspicuous phases on the receiver functions as Ps-converted phases generated at layer boundaries. By using stripping method (Oda, 2011), we estimated splitting parameters, fast polarization direction and split time, of the Ps phases. Values of the estimated splitting parameters, with or without seismic attenuation, are approximately in agreement with those predicted from the anisotropic parameters of the three-layer velocity model. Thus we can say that the seismic attenuation does not have a significant influence on the shear-wave polarization anisotropy of Ps phases.

Keywords: seismic attenuation, S-wave polarization anisotropy

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Q estimation by transforming VSP measurement configuration with seismic interferometry

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Although seismic attenuation measurements have great potential to enhance our knowledge of physical conditions and rock properties, their application is limited because robust methods for obtaining reliable attenuation estimates have not yet been established. The combined use of velocity and attenuation data reduces the uncertainty in characterizing such conditions and properties. Although Vertical seismic profile (VSP) measurement is considered to be best suited for attenuation studies and the spectral ratio method is a popular means of measuring seismic attenuation, this method is not stable because it is strongly subject to the variation of the S/N in the spectra. In the present paper, we propose attenuation estimation methods for VSP data by combining seismic interferometry and a robust attenuation estimation method developed for sonic waveform data. Seismic interferometry allows VSP data to be converted from the VSP configuration to the sonic logging measurement configuration. Then, we can apply the robust attenuation estimation method developed for sonic waveform data to the converted VSP data. We adopt two different types of seismic interferometry, one based on deconvolution interferometry and one based on cross-correlation interferometry. By applying the proposed methods to synthetic and field VSP data, we demonstrate the advantages of the proposed methods over the conventional spectral ratio method. For the case without noise, we demonstrate the applicability of deconvolution interferometry and the incompleteness of cross-correlation interferometry for attenuation estimation. The application of cross-correlation interferometry cannot provide absolute attenuation but can provide relative attenuation from the slope information of the attenuation results curve. The bias of cross-correlation interferometry is due to the incorrectness of the amplitude information, that is, the phase information estimated from cross-correlation interferometry is correct, whereas the amplitude information is not adequate for attenuation estimation. In the case of the application of cross-correlation interferometry, we have also pointed out the relationship between the magnitude of attenuation and the biased attenuation results. For the case with random noise, deconvolution interferometry does not have an advantage over the conventional spectral ratio, whereas cross-correlation interferometry is less sensitive to random noise than the application of deconvolution interferometry and the conventional spectral ratio method. This is because a cross-correlation operation improves the S/N ratio, i.e., not only the cross-correlation between random noises but also the cross-correlation between signal events and random noise is ideally zero, whereas the cross-correlation between signal events is enhanced. Sensitivity tests on borehole irregularities, such as unnecessary residual events after wavefield separation, also reveal the advantage of the proposed methods using deconvolution interferometry over the conventional spectral ratio method. The inverted attenuation results from field data obtained by deconvolution interferometry do not completely correlate with those obtained by the spectral ratio method, except for the high-attenuation zone. The difference between these inverted attenuation results might be the difference in sensitivity to borehole irregularities, such as unnecessary residual events after wavefield separation. Furthermore, the difference in quality and resolution among the inverted attenuation results obtained by cross-correlation interferometry is relatively small compared to the two other cases. This might be due to the lower sensitivity of cross-correlation interferometry to noise.

Keywords: seismic interferometory, seismic attenuation estimation, VSP data

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Separation of scattering loss and intrinsic absorption under Tateyama volcano

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Tateyama volcano (Midagahara volcano) locates in southeastern part of Toyama prefecture. The volcanic activity of Tateyama volcano is quite low. Previous studies have suggested a low-Q zone beneath the region near Tateyama volcano. Katsumata et al. (1995) studied in more detail and suggested the presence of regions with low-velocity and low-density as well as low Q anomaly near Tateyama volcano.

Iwata et al. (2014) estimated S wave attenuation beneath Tateyama volcano using twofold spectrum ratios, and suggested that regions with high seismic attenuation exist in the southern or the southeastern region of Tateyama volcano. Q parameters in these regions were estimated to be around 50-200.

There are well-known two key factors which characterize seismic wave attenuation: scattering loss and intrinsic absorption. Scattering loss is caused when seismic waves are scattered by crustal heterogeneity. On the other hand, intrinsic absorption is considered to be due to the fact that energy of the seismic waves mainly changes into frictional heat energy along their paths. Magma chambers can make scattering loss and intrinsic absorption strong in volcanic regions. In this study, we investigated the scattering loss and intrinsic absorption in localized volcanic region, beneath Tateyama volcano.

The relative contribution by scattering loss and intrinsic absorption in the seismic waves changes with the lapse time. Due to scattering effect, the direct waves decay and coda waves are generated. Therefore, a part of the energy of the direct waves from the seismic sources is distributed among coda waves, but total energy is maintained constant. On the other hand, intrinsic absorption makes the total energy of the entire seismic wave lowered.

The Multiple Lapse Time Window Analysis (MLTWA) is often used to estimate scattering loss parameter, and intrinsic absorption parameter, at the same time (e.g., Fehler et al., 1992; Hoshiba, 1993; Carcole and Sato, 2009). We used this method and compared the seismic energy integrated over the time windows and the one which is derived from an approximate analytic expression (Paasschens, 1997). After trial and error, we found suitable scattering loss and intrinsic absorption values.

We used seismograms at five Hi-net stations near Tateyama volcano for nineteen small, local earthquakes (M 2.5-4.0) that occurred from January 2012 to December 2013.

We considered the following frequency bands: 1-2, 2-4, 4-8 and 8-16 Hz. We used the normalized mean square amplitude after S wave arrival time.

Previous researches that applied MLTWA used three 15 s time windows from the direct S time, but we take different time windows which is more appropriate for the used data. In addition, we consider the effect of the error in estimation of S wave arrival time.

Acknowledgments:
We are grateful to those who have made continuous efforts to run and maintain the Hi-net and its database. Our appreciation also goes to those who have made continuous efforts to develop JMA unified hypocenter catalog.

Keywords: Tateyama volcano, Scattering loss, Intrinsic absorption, MLTWA

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Body wave microseisms from a distant storm revealed by Hi-net data

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Although observations of microseisms were firmly established in 1940's [e.g. Gutenberg, 1947], the excitation mechanisms are still old and new problem. Their common excitation sources are ocean wave activities. Microseisms can be categorized into two ones according to the excitation mechanisms. One is primary microseisms from 0.05 to 0.1 Hz, which correspond to a typical frequency of ocean swell. Observed dominance of Love waves of primary microseisms suggests that they are generated by pressure load of ocean swell acting on a sloping coast [Darbyshire and Okeke, 1969]. The other is secondary microseisms from 0.1 to 0.5 Hz, which double the frequency, indicating the generation of the former through nonlinear wave-wave interaction of the latter [Longuet- Higgens, 1950]. Observed amplitudes of secondary microseisms are larger than those of primary microseisms.

Because microseisms are excited by forces acting on the seafloor, surface-wave excitations are dominant. Recently body wave microseisms from a distant storm, however, have been focussed [e.g. Gerstoft et al. 2006, Landes et al. 2010]. They show clear teleseismic P waves excited by distant storms. A back-projection method could constrain source distribution, which gives clues to their excitation mechanisms. Most studies focused, however, only vertical components. In this study, in order to constrain excitation mechanisms of microseisms, we conducted three-component array analysis using the high-sensitive seismograph network (Hi-net) operated by NIED, when a strong weather bomb hit the Atlantic ocean on 12/9th 2014.

We analyzed 3-component velocity-meters with a natural frequency of 1 Hz at 202 stations in Chugoku district. The instrumental response was deconvolved by using inverse filtering technique [Maeda et al. 2011] after reduction of common logger noise [Takagi et al. 2015]. Their frequency-wavenumber spectra [Nishida et al., 2008] were calculated at 0.07 (PM) and 0.15 Hz (SM). The spectra of a vertical component and a radial component at 0.15 Hz show that clear teleseismic P-wave, whereas that of a transverse one does not show body wave. The slowness of about 0.05 [s/km] and the back azimuth of -5 degree are consistent with that of the P wave traveled from the weather bomb in the Atlantic ocean. At 0.07 Hz, no teleseismic p wave was detected, although they show strong Rayleigh wave traveled from north, which is consistent with a past study [Matsuzawa et al., 2012]. Lack of P-wave microseisms in primary microseismic band suggests that shear traction on the seafloor is dominant in the frequency. Although these results are preliminary, we plan to discuss the excitation mechanism based on the array analysis.

Keywords: ambient noise, microseisms

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Evaluation of long-period ground motion generated from intraplate earthquakes around Ibaraki and Fukushima prefectures

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After the occurrence of 2011 Tohoku-Oki earthquake, phenomena of long period ground motion have been observed at seismic observation stations around the coastal region of Ibaraki prefecture for the occurrence of shallow depth intra-plate earthquakes (including 2011 Fukushima Hamadori earthquake) around Ibaraki and Fukushima prefectures. Before the occurrence of Tohoku earthquake, there was little noticeable intra-plate large earthquake, and physical mechanism and characteristics of generation of long-period ground motion mostly remain unclear. Therefore, we believe that better understanding the physical mechanism and characteristics of generation of long-period ground motion will lead to improving the evaluation of nature of seismic wave propagation and ground motion around the coastal region of Ibaraki prefecture. And also, it will lead to more reasonable evaluation of earthquake-proof safety of important infrastructures and subsurface structure around this region.

In this research, as main factor generating long-period ground motion, we focus on nature of basement underground structure model beneath the coastal region of Ibaraki prefecture. First, we constructed 3D underground structure model beneath this region, on based on the underground structure model of the Headquarters for Earthquake Research Promotion of Ministry of Education Culture, Sports, Science and Technology in Japan (http://www.jishin.go.jp/main/chousa/12_choshuki/, Koketsu et al., 2008, Koketsu et al., 2009). Based on the structure model and using finite element method, we performed seismic wave propagation simulation of intraplate crustal earthquakes (moderate scale, M<6.0), generated around Ibaraki and Fukushima prefecture. For optimizing the 3D underground structure model, we used seismic observation stations of KIK-net and Japan Atomic Energy Agency around this region. In the analysis we evaluated the generating factors of long-period ground motion by comparing the results of waveform modeling based on 1D layered structure model and on 3D structure model.

As the result, we confirmed that 3D structure model could better generate the long-period ground motion which 1D layer structure model could not, and understood that generation of long-period ground motion is originated from the nature of basement structure beneath seismic stations. Furthermore, we performed waveform modeling of 2011 Fukushima-ken Hamadori earthquake and confirmed availability of 3D underground structure model for evaluating intraplate large earthquakes around Ibaraki region.

Keywords: 3D structure, Seismic wave propagation, Hamadori, FEM simulation

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S-wave attenuation structure in southwestern Japan and Nankai trough

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Seismic waves at high frequency (>1 Hz) of local earthquakes are complex and broadened due to wave scattering and attenuation in the lithosphere. Three dimensional imaging of random velocity inhomogeneity and intrinsic attenuation structures is important to describe such complex wave trains. We have proposed imaging methods of random inhomogeneities (Takahashi et al., 2009) and attenuation (Takahashi, 2012) on the basis of a statistical method called the Markov approximation. This study estimated the 3-D distribution of S-wave attenuation in southwestern Japan by applying the inversion analysis of S-wave maximal amplitudes (Takahashi, 2012). We have analyzed seismic waveforms recorded by onshore and offshore stations. Onshore stations are composed of Hi-net and F-net stations that are developed and maintained by the National Research Institute for Earth Science and Disaster Prevention of Japan. Offshore stations are the ocean bottom seismograms (OBS) that were deployed by the Japan Agency for Marine-Earth Science and Technology for passive seismic observations. Some of the OBS observations were conducted as a part of "Research concerning Interaction between the Tokai, Tonankai and Nankai Earthquakes" funded by the Ministry of Education, Culture, Sports, Science, and Technology, Japan. We measured S-wave maximal amplitudes of RMS envelopes that were composed of velocity seismograms of horizontal components at 4-8Hz, 8-16Hz and 16-32Hz. Apparent amplitude attenuation due to multiple forward scattering was evaluated by using the random velocity inhomogeneities in this study area (Takahashi et al. 2014, AGU fall meeting).

Estimated attenuation structure shows relatively high-attenuation around the top of the subducted Philippine Sea plate. At 0-20km depth, high 1/Q areas are imaged at the most of Nankai trough from Enshu-nada to Hyuga-nada. 1/Q near the top of subducted slab decreases as depth increases. At 40-60km depth, high 1/Q area is imaged only beneath west Shikoku. Attenuation structure of overriding plate shows high 1/Q beneath the Quaternary volcanoes and around the Osaka-Plain. High attenuation beneath the volcanoes would reflect magma intrusions. High-attenuation in Osaka-Plain distributes from the crust to the top of the subducted Philippine Sea plate. In a recent study, Kusuda et al. (2014) concluded that non-volcanic hot-spring in this area can be explained by a dehydrated component of subducted Philippine Sea slab. This spatial coincidence implies that high 1/Q around the Osaka-Plain is related with the dehydration process.

Keywords: Nankai trough, attenuation structure, random media

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Extraction of Po-to-s converted waves from OBS records

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Po/So wave has been frequently observed by ocean bottom seismometers (OBSs) at frequencies higher than 2 Hz with long wave duration, e.g., a few hundred seconds. These waves are primarily generated by earthquakes within subducting slabs, and propagate along the mantle in the oceanic plate for long distances due to scattering effects. With propagating within the mantle, a part of Po and So wave energies goes upward through the oceanic crust and sediment from the mantle, and are observed at the seafloor. This implies that P-to-s and S-to-p converted waves should be generated at the Moho and basement below the observation sites in the case that the impedance contrast at the boundaries is large. Here, in order to extract such P-to-s (Pos) converted phases from Po coda waves, we deconvolved records in the vertical component from ones in the radial component for Po coda portion, i.e., receiver function (RF). If such converted waves are extracted, it would greatly contribute to understand in details seismic structure for oceanic crust and sediments.

We used records of earthquakes during 2010-2014 with magnitudes greater than 5.5 and epicentral distances less than 30^o, which were observed at 18 broadband OBSs deployed by NOMan project. We selected Po records with good S/N, and hand-picked their arrival times. For deconvolution, the time window was set to be -2 ~ 25 s from the arrival time of Po wave. The used frequency was 2-5 Hz. As a result, we totally collected 1063 traces from 233 events.

RF traces showed clear Ps converted phases from the basement and Moho. In addition, they showed PwPs from the basement and Moho. Here, PwP is the first water reverberation, and PwPs is P-to-s reflected wave from interfaces below the seafloor. At the seafloor, upgoing P wave incidence mainly generates upgoing transmitted P wave and less downgoing reflected P wave. As a result, P-to-s converted waves associated with PwP are often emerged in the RF traces in the seafloor observation.

Since the location of OBSs deployed by NOMan project is good for collecting earthquakes from the Aleutian, Kuril, Japan, Izu-Ogasawara, and Mariana trenches, the back azimuth coverage of Po wave is excellent. Also, since higher frequency components are enough in Po coda waves, RF traces showed clear converted phases, which enable us to investigate seismic structure of oceanic crust and sediment in details.

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On estimation of scattering coefficient and intrinsic absorption from spatial distribution of seismic energy (3)

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It is possible to separately estimate the scattering coefficient and intrinsic absorption in the lithosphere by interpreting the observed spatiotemporal distribution of high-frequency seismic wave energy by the radiative transfer theory (RTT). One of such an estimation method is the multiple lapse-time window method (Fehler et al., 1992; Hoshiba, 1993), in which the seismic wave energy respectively observed at different positions is integrated using multiple time windows and then its spatial variation is to be interpreted by the RTT. We recently proposed another method to estimate the scattering coefficient and intrinsic absorption (Saito et al., 2013, Abst. Seism. Soc. J. Fall Meet.). In this method, the seismic wave energy respectively observed at different times is integrated using multiple space windows to obtain "apparent energy" , whose temporal variation is to be interpreted by the RTT. We applied the method to the Hi-net records of an earthquake in the Chugoku region, Japan, and thus estimated the scattering coefficient as ~ 0.002 km^{-1} and the intrinsic Q^{-1} as ~ 0.0075 for 1 - 2 Hz S waves in the southwestern Japan (Saito et al., 2014, Abst. Seism. Soc. J. Fall Meet.). However, the observed apparent energy showed complex temporal fluctuations, which could not be fully reproduced in the synthesis by the RTT.

We infer that this inconsistency is largely attributed to the inappropriate choice of the 1-D S-wave velocity structure model used for computing the RTT solutions. We thus adopted an average 1-D S-wave velocity structure model for the Chugoku and Shikoku regions, which was produced on the basis of the 3-D seismic wave velocity structure model of Matsubara and Obara (2011). We also fixed the extents of the space windows in contrast to our previous analysis, in which the windows expanded proportional to the expansion of the direct wave front. We confirmed that these changes largely improved the agreement between the observed and synthetic apparent energy.

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Keywords: seismic wave energy, scattering, intrinsic absorption

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Simulation of three-dimensional vibrational characteristics of mountains

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Natural frequencies of soil and buildings are controlled by their physical property and regarded as one of fundamental characteristics in their vibration. We usually can identify a natural frequency from a largest peak of spectrum of vibration data. However, identification of a natural period is sometimes difficult for a building with a three-dimensionally complex shape. Kojima (2013) focused on the natural frequency of Mt. Fuji, from an analysis based on microtremor observation data and interpreted the vibration characteristics from finite element analysis[1]. However, many mountains existing in Japan have mountain-range shape such as Tateyama Mountain range and Yatsugatake Mountain. It is considered that their natural frequencies are more complex than a mountain with single-peaked shape such as Mt.Fuji.

In this research, I simulated vibration of various mountains with different shapes using finite element method (FEM). I firstly conducted FEM analysis using an elastic mountain models with simple three-dimensional shapes considering mountain range. Natural frequency for the mountain range model differs from single peak mountain model indicating large effects of three-dimensional shapes. I next conducted FEM analysis for vibration characteristics of mountain model with real shapes of Mt. Yatsugatake based on the digital elevation data. The results show that natural frequencies in long-side and short-side directions are different from each other. And vibration modes are also different between in higher and lower locations. This clearly indicated that sensor direction and installation site must be carefully oriented in a field observation of vibration in Mt. Yatsugatake.

Reference

[1]Kojima K (2013), Study on natural frequency of Mt.Fuji, Graduation thesis, Tokyo Institute of Technology

Keywords: mountains, vibration characteristics, natural frequency, vibration mode, finite element method, Mt.Yatsugatake

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Application of deconvolution interferometry to extract quality factor of high-rise buildings

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Deconvolution interferometry has been proved an effective method over cross correlation interferometry and coherence interferometry to monitor the health of buildings, extracting the shear velocity and quality factor from earthquake ground motion data or microtremor data (Snieder and Safak, BSSA, Vol. 96 (2), 2006; Nakata et al., BSSA, Vol.103 (3), 2013); Nakata and Snieder, BSSA, Vol. 104(1), 2014). Wang et al. (JAEE, Vol. 13(2), 2013) extended this method to monitor a multi-story damaged building in stricken city with microtremor by extracting the story-by-story shear velocity propagated inside the building during the 2011 Tohoku earthquake. However, the application of this method to estimating the quality factor of the buildings has not been fully investigated.

In this study, we focus on extracting the quality factor of shear waves from deconvolved waves with reference record on the ground floor. We conducted the microtremor measurement simultaneously in five floors for an hour by employing five sets of velocity seismometers with an 800 Hz record logger in several high-rise buildings being over 20 stories. The measurement is accomplished by moving four sets of equipment sequentially with one set fixed at the reference floor. The extracted quality factors of the buildings are expected to provide a reference for damping factor in the analysis of structural response.

Keywords: Deconvolution interferometry, quality factor, microtremor, high-rise buildings