Japan Geoscience Union Meeting 2011
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Improvement of web interface of the IISEE earthquake catalog

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We introduce recent developments of the web interface of the IISEE (International Institute of Seismology and Earthquake Engineering) earthquake catalog, "IISEE's CMTs, Aftershock Distributions, Fault planes, and Rupture processes for recent large earthquakes in the world" (http://iisee.kenken.go.jp/eqcat/Top_page_en.htm). In this catalog, we have been providing earthquake information (CMT, aftershock distribution, fault plane, and rupture process) determined by the analytical techniques developed by the IISEE and visiting researchers since 2008.

We have modified the top of the search page of this catalog so that registered events are shown on the Google Map. Users can select an event on the Google Map, and display earthquake information for that event in another window. In the web interface, we have implemented a function to forward earthquake information to web calculators of PGA, PGV, intensities, etc. using a set of attenuation equations. Calculation results are shown on maps drawn by the GMT (Generic Mapping Tools. Wessel and Smith, 1998). Earthquake source parameters for this calculation can be changed by users for their purposes and conditions such as soil, earthquake type, etc. This improved web interface is now available at our web site as a test version (http://iisee.kenken.go.jp/cgi-bin/eqcatalog.newv4/eqcatalog2_eng.cgi). We plan to implement a function to download calculation results using attenuation equations. Through these developments, we are improving combination among this earthquake catalog, strong motion calculations, and the other earthquake catalog available at our web site, "Catalog of Damaging Earthquakes in the World" (Utsu, 2004. The later updates are added by the IISEE).

Keywords: earthquake catalog, attenuation equation, web interface

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A feasibility study of fast and continuous strong-motion observation

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Most earthquake early warning systems including JMA EEW predicts strong-motion parameters (seismic intensity, PGA) using estimated earthquake parameters (epicenter location, focal depth, magnitude) and attenuation equation. Thus, prediction of strong-motion parameter is affected by estimation error of earthquake parameters and inaccuracy of attenuation equation. We can, however, observe the true value of strong motion parameter at each observation site where main part of ground motion has arrived in a certain time after the earthquake occurrence. We can improve accuracy of prediction of strong-motion parameters using observed value of strong-motion parameters if strong-motion data is available in real-time. For this purpose and also real time seismic risk evaluation, National Research Institute for Earth Science and Disaster Prevention (NIED) started research and development of the real-time strong-motion monitoring system. One of the key components of the system is fast and continuous strong-motion observation.

We studied for feasibility of fast and continuous strong-motion observation using tens of K-NET strong-motion seismographs in operation. We installed an improved firmware in K-NET seismograph. The firmware can continuously send waveform data in 0.1s-length packet. Investigating packets sent by 35 K-NET seismographs in 38 hours through 64kbps best-effort type communication line, we concluded the end-to-end packet delay of most packets are shorter than 0.2s. Time delay of 0.2s is acceptable for our use.

Keywords: strong-motion observation, strong-motion seismograph, earthquake early warning

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A New Method to Extract Building Response Parameters from Microtremor Data

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Generally, a building can be considered as a system which is composed of the upper structure, the base, and the supporting ground of the building. Therefore, the response of a building system can be seen as a composition of the response of the upper building (fixed-base building) and the response of rigid-body due to the soil-structure interaction including rocking and horizontal vibration (sway). In order to fulfill the building damage analysis meticulously, extracting the response parameters of (A) the building system, (B) the fixed-base building, and (C) the soil-structure interaction from ground motion records of buildings is very necessary. There have been proposed many methods to extract the building response parameters (A)-(C) respectively. The methods so far used need to have many observation points on the first and top floors. We proposed a simple and easy method to extract all of the building response parameters (A)-(C) from the fewest points, one on the first floor and one on the top of the building. Microtremor records are often used to extract building response parameters, because they can be easily obtained at any time.

The new method to extract the building response parameters (A)-(C) from microtremor records of the 1F and the top of the building is presented based on the Deconvolution method, which was proposed by Snieder and ?afak (2006) based on the interferometry method and was improved by Todorovska (2009a, 2009b). It is a very good method to extract the response parameters of fixed-base buildings and the base rocking vibration. The feasibility of this method to extract the response parameters from observed records on buildings during earthquakes has already been proved by the proposers. Based on the deconvolution method, in this paper, a method to extract the response frequencies of the building system ( ),the fixed-base building ( ), rigid-body rocking ( ), and rigid-body sway ( )from microtremor records on the top and the base of buildings is proposed. The feasibility of our method is examined by comparing the extracted building response parameters from microtremor data recorded on a 6-story building (Building No.2 in the Yakusa campus of the Aichi Institute of Technology) with those extracted from earthquake records on the same building and the numerical analysis results obtained based on the multi-degree-of-freedom model of this building. This method not only makes the extraction of building response parameters easier using only the records of the base and the top floor of buildings, but also provides an approach to extract the S-wave velocity traveling within the buildings using the records of the inter floors.

Keywords: Microtremor, Response Paremeters, Deconvolution Method, Damage Level, S-wave Velocity

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Multiple, Three-Dimensional Interactions between the Ground and a Group of Structures Subjected to Seismic Impact

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In our earlier study, using a fully coupled, two-dimensional ground-structure model, we have investigated the dynamic interactions between a set of identical buildings in a town and shown the collective behavior of the buildings during a seismic excitation: Due to the multiple interactions through (the waves in) the ground, the eigenfrequencies of the collective building system, i.e., town, become lower than the resonant frequency of a single building. This shift of eigenfrequencies may be called the "town effect" (or "city effect"). Our analysis is different from the conventional ones where each structure is handled individually, and the frequency shifts and "unexpected" structural behavior may be recognized only if the mechanical movement of the structural group is analyzed jointly. In the study, however, we have just considered the anti-plane shearing of a linear elastic half space on which identical buildings, each consisting of an elastic spring that connects a concentrated mass at the top and the rigid foundation at the bottom, stand. In this contribution, we shall briefly summarize some quantitative information about the two-dimensional anti-plane town effect and show its significance by investigating the actual structural damage patterns found on the occasions of several earthquakes in Europe and Japan. Then, we shall further consider the in-plane and three-dimensional cases and generalize the mathematical statement of the related problems. Since the "town effect" may be induced by dynamic structural impact in general (e.g., blasting), the simple analytical models handled here may contain the essential features that will play an important role in evaluating the dynamic performance of a group of structures in urban environments around the world.

Keywords: earthquake hazard, collective behavior, city effect, town effect, dynamic ground-structure interaction

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Seismic intensity of the two earthquakes (Dec.17-18,2009) off the east Izu Peninsula, based on a questionnaire survey

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A questionnaire survey was made to clarify the detailed distribution of seismic intensities of the two largest earthquakes (M5.0 and M5.1 on December 17-18, 2009), which were associated with the earthquake swarm off the east coast of the Izu Peninsula, Japan. We distributed questionnaire sheets, which were based on the method by Ota et al. (1998), to 10 elementary schools in Ito City and requested them to be answered by all the households of their schoolchildren. In addition, we made the same surveys on the households lived in the middle parts of Ito City (Nagamiyo, Komuro-icchome, Komuro-nichome, and Joboshi areas), where severe damages were reported. 2557 available answers were collected and converted to JMA seismic intensity at each locality. These intensities were mapped and compared with topographic and geologic maps. While the mean intensity in Ohara shows 4.6 (5 lower in JMA scale), which is the same as that measured by a seismic intensity meter, the intensities at many points in Nagamiyo and Komuro-icchome show 6 lower and the mean value is 5.4 (5 upper). The mean intensity (5 lower) in Komuro-nichome is the lowest in the above four sections. This was probably caused by the hard basement, that is composed of thick lava flows from Komuroyama Volcano.

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Examination of construction methodology of source model in case of multi-segment rupture

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Investigating a fault model of the 1891 Nobi earthquake, which is one of the multi-segment rupture events, is significant for the establishment of source model construction methodology for strong ground-motion prediction. In Kuriyama and Sato (2010), we measured microtremors in the heavily damaged region caused by the Nobi earthquake to examine the relationship between seismic intensities, the ratio of the damaged houses, and the predominant period of H/V spectral ratio. We estimated the distribution map of seismic intensities by considering the local site effect of surface geology based on the above mentioned relationship. From these results, we found that the microtremor-measurement stations with questionnaire-based intensity of 7 in the Nobi Plain are almost linearly distributed only along the northern part of the Gifu-Ichinomiya Line (hereafter, GI Line) of the Research Group for Active Fault of Japan (1991). In this study, we conduct strong ground-motion simulations of the 1891 Nobi earthquake for three multi-segment rupture cases: (1) including the GI Line, (2) omitting the GI Line, and (3) including northern part of the GI Line.

For strong ground motion simulations, we construct three characterized source models (Irikura and Miyake, 2001). This type of model is one of the most reliable approaches for broadband strong ground-motion prediction. We conduct strong ground-motion simulations using the stochastic Green's function method for each third area mesh in the Nobi Plain. The horizontal acceleration waveforms are simulated on the seismic bedrock to examine the effect of the causative faults on the generation of the destructive ground motion. Here, we use the subsurface structure model of the Chukyo area of Horikawa et al. (2008). Based on the distribution of the simulated seismic intensities, we discuss the fault model of the Nobi earthquake.

Here, we compare the distribution pattern of simulated seismic intensities on the seismic bedrock in each case with that of estimated seismic intensities by considering the local site effect of surface geology in Kuriyama and Sato (2010). We could not find the linear distribution of larger seismic intensities that were present in Kuriyama and Sato (2010) along the GI Line from the distribution of simulated seismic intensities on the seismic bedrock in the multi-segment rupture case omitting the GI Line. In the case including the GI Line, the simulated seismic intensities along the southern part of the GI Line are slightly larger than expected. Meanwhile, the distribution of simulated seismic intensity in the case including the northern part of the GI Line is similar to the distribution map of Kuriyama and Sato (2010).We will conduct strong ground motion simulations on the engineering bedrock in the Nobi Plain and discuss the fault model of the Nobi earthquake.

Acknowledgement: The subsurface structure model of the Chukyo area of Horikawa et al. (2008) is used in this study.

Keywords: The 1891 Nobi earthquake, Predominant period of H/V spectral ratio of microtremors, Questionnaire-based intensity, Strong ground motion simulation, Source-model construction methodology

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Broadband ground motion simulation for great earthquakes along Sagami Trough

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Possible scenarios of great earthquakes along Sagami trough are modeled combining characteristic properties of the source area and adequate variation in source parameters in order to evaluate possible ground motion variation due to next Kanto earthquake.

We assume the rupture area of 1703 Genroku Kanto earthquake as the possible largest rupture area which consists of three fault segments. On the segment which also ruptured during the 1923 Taisho Kanto earthquake, we assume two sticking asperities which are derived commonly among source inversion analyses of this earthquake.

We construct many earthquake scenarios varying extent of the rupture area, the average stress drop, the average rupture velocity, hypocenter location and random heterogeneity of the source parameters with scale smaller than asperities. Variations of the average stress drop and the average rupture velocity are estimated from the variations of these values among the source models of past earthquakes.

The ground motions are computed with a four-step hybrid technique. We first calculate low-frequency ground motions at the engineering basement, which in this study is taken to be the depth at which the S-wave velocity exceeds 0.5 km/s. We then calculate higher-frequency ground motions at the same position, and combine the lower- and higher-frequency motions using a matched filter. We finally calculate ground motions at the surface by computing the response of the alluvium-diluvium layers to the combined motions at the engineering basement.

A comparison of ground motion distributions in the Kanto basin from the various earthquake scenarios suggests that source parameters which largely change the ground motion level in the wide are relocation of hypocenter and the average stress drop.

Keywords: ground motion prediction, Kanto earthquake, interplate earthquake, asperity, variation of parameter

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Feasibility of near-real-time imaging of the rupture of megathrust earthquakes by normalized short-period envelopes

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1. Introduction

After a great earthquake, real-time estimations of rupture area and locations of asperities are important to assess hazards due to tsunami and ground shaking. However, it takes long time to analyze source process by the waveform inversion. Aoki et al. (2010, 2011) developed a method for near-real-time imaging of earthquake rupture by normalized short-period envelopes, and succeeded in depicting rough image of rupture processes of the 2003 Off Tokachi Eq. and the 1994 Far E off Sanriku Eq.

When Tonankai and Nankai Eqs. occur simultaneously in near future, the fault length will be 500km long, and the magnitude will be about M8.5 [ERC, 2001]. The megathrust earthquakes would have a lot of asperities on the fault. It is supposed that the rupture will start at off the Kii peninsula and will propagate bilaterally. We have applied our method to the earthquakes of M8.0 or smaller with unilateral rupture. Thus it is very important for us to evaluate the applicability of the method to a great earthquake with complex ruptures. In this study, we discuss the resolving power and application technique based on the simulated envelopes of the presumed Tonankai and Nankai Eqs.

2. Method

Our method is based on the Source-Scanning Algorithm [Kao & Shan, 2007]. It is applied for identifying the rupture plane. The brightness of a grid point is calculated by summing the amplitudes of normalized short-period envelopes with the correction of the S-wave travel times at all stations. The grid points are arranged not on the prescribed fault plane, but in the 3D source volume. The composite image of the brightness at all grid points illuminates the locations and timings of seismic rupture (e.g. asperity).

We used fixed stations to image the brightness for all grid points because the analyzed earthquakes had the fault length no more than 150km. However, in the case of the Tonankai and Nankai Eqs., the capability of our method is still unknown. In this study, we compare two cases. Case 1: imaging all grid points with the all stations. Case 2: dividing the grid points into some local sub-volumes, and imaging gird points in a sub-volume with limited stations near the sub-volume.

A simulated envelope was calculated by convolving the time series of the energy radiations with a synthetic envelope on the basis of the scattering theory including the effect of intrinsic absorption [Saito et al., 2002, 2005]. The energy radiation was estimated on the basis of the distribution of 9 asperities by the CDPC (2005).

3. Feasibility study for the Tonankai and Nankai Eqs.

In the case 1, the grid points were arranged in and around the presumed focal region (1000km (along the trough axis) x 200km (orthogonal to the axis) x 95km (depth)) at 4km interval. In the case 2, we divided the volume of the case 1 into 9 sub-volumes (200km x 200km x 95km) with an overlap of 100km along the axis. The brightness of each grid was calculated for 180 sec after the initial rupture. Simulated envelopes were evaluated at the locations of the JMA inland accelerometers and the cable-type OBSs installed by the JMA and JAMSTEC.

In the case 1, we used 84 stations within 500km from the epicenter. Consequently, we can roughly image only the nearest asperity from the epicenter in the side of Tonankai area, and cannot image the other asperities as the peak of the brightness more than 0.7.

In the case 2, we used 20 to 37 stations within 250km from a reference point in each sub-volume. As a result, we can image 7 asperities as the neighboring peaks of the brightness with 0.7 or greater. The two smallest asperities cannot be depicted. Though the ghost peaks tend to appear in the edge of the sub-volume, we can evaluate the reliance of the image due to the overlap of the sub-volumes.

We conclude that the case 2 is preferable for great earthquakes with complex ruptures. We plan to investigate the proper volume of the grid points for suppressing the ghost image and getting high resolution.

Keywords: Near-real-time processing, Source process, Simulation, The Tonankai and Nankai Earthquakes

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Source inversion using curved fault model: Application to the two intraslab earthquakes in northeast Japan

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We have developed a new source inversion method using a curved fault model. The curved surface is constructed from the interpolation using Non-Uniform Rational B-Spline (NURBS). The multi-time-window linear waveform inversion method is implemented to the curved fault model. Applicability and effectiveness of the developed method are examined by applying the method to the two intraslab earthquakes that occurred in northeast Japan, the 2003 Miyagi-oki and 2008 northern Iwate earthquakes. They are considered to have the complex fault geometry from the source inversion analysis using strong-motion records (Wu and Takeo, 2004; Aoi et al., 2005; Suzuki et al., 2009). The waveform records of these earthquakes do not much suffer from the secondary generated seismic waves and clearly reflect the change of source mechanisms during the earthquake.

The slip distribution derived using the curved fault model shows that a large slip extends to an area that is a gap for a two rectangle fault plane model for the 2008 northern Iwate earthquake. This indicates that the curved fault, which would approximate the fault geometry more appropriately, could illuminate the slip that cannot be modeled by the planar fault model. The curved fault model gives the seismic moment closer to that derived from the moment tensor inversion than the two rectangular fault model. The moment tensor calculated from the slip distribution still differs from that derived from the moment tensor inversion. We will further investigate more appropriate fault model, which could give the moment tensor closer to the moment tensor solution. In the analysis of the 2003 Miyagi-oki earthquake, we can use the information of the aftershock distribution as well as the source mechanism and waveform fittings to construct the curved fault model. After we obtain the most appropriate fault model referring to the moment tensor calculated from the slip distribution and to the comparison of the waveforms, we will examine the effectiveness of the developed method compared with the inversion result using the rectangular fault model, particularly focusing on the extent of the asperities and the distribution of the stress change.

Keywords: source inversion, curved fault, strong motion, intraslab earthquake

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Improvement of Source model for simulating strong ground motions during the 2008 Wenchuan earthquake

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1. Introduction

The Wenchuan earthquake with a moment magnitude of 7.9 (United Statue Geological Survey,USGS) struck the western part of Sichuan Province on 14 May 2008, China, resulting in about 70,000 fatalities as well as huge damage to infrastructures and buildings. Causes of serious damage of structures should be attributed to characteristics of strong ground motions and vulnerability of structures.

The strong motion records during the Wenchuan earthquake will be very useful not only in making source modeling for estimating strong ground motion but also in clarifying the relation between structural damage and strong ground motions through reproduction of ground motions at damage sites. We estimated the characterized source model for simulating ground motions using the empirical Green's function (EGF) method and the hybrid method for the 2008 Wenchuan earthquake (Kurahashi and Irikura,2010). However, it has some problems. One of the problems is that the ground motions at Wolong station (WCW) in backward direction to Asperity 2 have smaller amplitudes, compared with the observed. Second, the contribution from asperities on the north-east segment to ground motions was not considered. In this study, to improve these two problems, the analysis was performed by the discrete wave number method. This model is a tentative version.

2. Analysis

We adopt basically the characteristic source model for the south-west segment reported by Kurahashi and Irikura (2010). The best model was determined by try and error. We used the observed records at 13 stations including the WCW, SFB and MZQ near the source fault. We find that the observed records at WCW are reproduced considering the rupture starting point of Asperity 2 not at the edge of the asperity area but inside it. This means that the rupture on Asperity 2 propagated not uni-laterally but bi-laterally. As a result, the area of Asperity 2 became larger of fit the observed records in forward direction such as SFB and MZQ as well as those in backward direction such as WCW.

Next, we estimated the contributions of asperities on the north-east segment to ground motions as stations in north-east direction.

There are several observation stations near the northeast segment. Remarkable wave pulses at the stations were not observed.

In this study, the best model was determined by try and error comparing the observed and the calculated motions. As a result, we presumed four asperities at the north-east segment. The stress drops on asperities are taken from 10 to 13 MPa. In future, we attempt to simulate ground motions using the empirical Green's function method.

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Simulation of Strong Ground Motions during the 2009 Suruga-bay Earthquake using Empirical Green's Function and 3D-FEM

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Strong ground motions during the Suruga-bay earthquake occurring on August 11, 2009, were observed in the Hamaoka Nuclear Power Plant. The maximum acceleration on the basement of unit No. 5 reactor twice bigger than other sites was obtained during the main shock. In this study, we tried to simulate the strong ground motions of observation sites in the Hamaoka Nuclear Power Plant during the main shock using the hybrid method of the empirical Green's function method and the 3-D finite element method.

First, we tried to simulate strong ground motions at underground observation sites (3G1S) by the empirical Green's function method during the main shock. We selected an aftershock as the empirical Green's function for each segment of the source fault. For the asperity 1 and asperity 2, the observed records from an aftershock occurring at 12:42 on August 13, 2009 and those from another aftershock doing at 18:11 August 13, 2009 are used, respectively.

Next, strong ground motion in the seismic bedrock with Vs of 3.0km/s during the main shock was simulated considering 1-D velocity structure model.

Finally, strong ground motions at observation sites in the Hamaoka Nuclear Power Plant during the main shock were simulated using the three-dimensional finite element method considering three-dimensional velocity structure down to 10km, and input ground motion in the seismic bedrock mentioned above. The results indicate that the maximum accelerations in simulated waveforms were similar to the observed one.

Keywords: empirical Green's function method, 3-D finite element method, 2009 Suruga-bay earthquake, simulation of strong ground motions

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Source process inversion of the 2007 Chuetsu-oki earthquake using theoretical 3-D Green's functions

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The strong motion waveforms are inverted for the source process of the 2007 Chuetsu-oki, Niigata, earthquake. One of the authors of this study has already performed the inversion analysis using theoretical Green's functions which are calculated with optimized 1-D horizontally stratified velocity models (Hikima and Koketsu, 2008). However, observed waveforms strongly suggest the existence of complex subsurface structures. Especially, the waveforms observed within the Kashiwazaki-Kariwa nuclear power station (KK NPS) are affected by fold structure beneath the KK NPS (Tokumitsu et al., 2009). So we have constructed 3-D velocity structure model and present the result at this meeting (Hayakawa et al., 2011). In this study, we calculate Green's functions for the source process analysis using this 3-D velocity structure and perform a inversion analysis.

Tentative analyses are preformed with same fault geometry and data set with Hikima and Koketsu (2008). We used 3-D Green's functions only for the stations in the KK NPS, because the 3-D model is not properly tuned in the area outside the KK NPS. So we used former 1-D Green's functions for the station except for the KK NPS. The inversion result is not so different with the result of Hikima and Koketsu (2008). However an asperity existing at the southern part on the fault plane moved toward the south and the coastline. Those results are consistent with other studies (ex. Shiba, 2008). However, time development on the fault is somewhat complex. We need detailed verification for the results.

Although the results have some problem, the observed waveforms in the KK NPS are well reproduced by the inversion analysis. Those results suggest that the fold structure beneath the KK NPS strongly affect the observed waveforms in the main shock of Chuetsu-oki earthquake.

Keywords: Chuetsu-oki earthquake, Source process, 3-D velocity structure, strong motion

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Source model of the 2007 Chuetsu-oki earthquake based on precise aftershock distribution and 3-D velocity structure

Yoshiaki Shiba[1*], Kazuhito Hikima[2], Tomiichi Uetake[2], Hiroyuki Mizutani[2], Kenichi Tsuda[3], Takashi Hayakawa[3], Shinya Tanaka[4]

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In general it is necessary for a source inversion analysis to previously determine a fault plane model based on the focal mechanism and aftershock distribution. However, in case of the 2007 Niigata-ken Chuetsu-oki earthquake, the resolution of the aftershock distribution was rather low because of the source region lying offshore and the complex subsurface structure, hence the geometry of the main shock was difficult to determine. Precise aftershock distribution was eventually obtained using the records of the ocean bottom seismometers temporally installed on and around the source region after the main-shock occurrence, and it revealed a fault plane of the main shock dipping to the southeast (Shinohara et al., 2008). Moreover the detailed aftershock distribution shows a slight change in the alignment angle along the dip direction of the main shock, which suggests a distorted fault plane for the main shock. In this study we assume such a bending fault plane as an initial model for the source inversion analysis, and reconstruct the characterized source model for the broadband strong-motion simulation based on the inversion result.

The fault plane of the main shock is divided into three parts, which are the north, center, and south fault areas. The north and south faults are planar and only the central fault area implies a distorted plane. The dip angles for the north and south fault plane are assumed to be 40 and 30 degrees, respectively. The strike angle is 39 degrees throughout the whole fault. All the fault areas lie within the assumed seismogenic zone, the upper and lower limits of which are respectively 6 and 17 km. The length of the whole fault is assumed to be 28 km, being composed of 7 km for the north, 10 km for the center, and 11 km for the south fault area. The inversion analysis was carried out using the search method combining the empirical Green's function method and the simulated annealing, developed by Shiba and Irikura (2005). The estimated source model showed a similar slip distribution to the model obtained by Shiba (2008) assuming the totally planar fault plane, except for the location of the asperity close to the hypocenter, which slightly moves to the northwest. We further constructed the characterized source model that reproduces the strong-motion records observed at the base mats of the reactor buildings within the Kashiwazaki Kariwa nuclear power station (KK NPS). The optimal source model estimated by the forward modeling approach shows the 20% smaller in area and 10% lower in the stress drop for the asperity closest to the hypocenter, comparing with the previous model by Shiba (2008).

Furthermore, we attempt to simulate the distinct pulse waves observed at the KK NPS, showing obviously different amplitudes among the stations distributed within about 2 km. When the waveform-records of the aftershock occurring near the hypocenter of the main shock were used as the empirical Green's function, such variations of the pulse shapes among the observation stations could not be distinguished, probably due to inconsistent wave-propagating path with that from the southwestern asperity. In this study we employ the synthetic waveforms calculated by the finite difference method with the three-dimensional velocity model including fold structure beneath the KK NPS site (Hayakawa et al., 2011) and the observed records of the small aftershock of Mw 3.5, as the theoretical and empirical Green's functions. As a result the large pulse waveforms observed in the EW component at the KK NPS stations are successfully reproduced through the hybrid simulation.

Acknowledgements: We are grateful to Prof. Shinohara of ERI for providing us with the aftershock hypocenter data of the 2007 Chuetsu-oki earthquake based on the observation using ocean bottom seismometers.

Keywords: the 2007 Niigata-ken Chuetu-oki earthquake, source model, aftershock distribution, 3-D velocity structure model, source inversion analysis, hybrid simulation

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Modeling 3D Velocity Structure in the Fault Region of the 2007 Niigataken Chuetu-oki Earthquake with Folding Structure

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Introduction

The large ground motions were observed at the Kashiwazaki-Kariwa Nuclear Power Plant (KKNP) for the 2007 Niigataken Chuetsu-Oki earthquake (M6.8). This earthquake produced the large ground motion variations even in the narrow area such as inside the KKNP site. Previous studies, such as Tokumitsu et al. (2009), reported that this ground motion variation might come from the folding structure light below the site. This indicates that the folding structure is necessary to be considered for ground motion prediction. In this study, we have constructed the velocity model including the folding structure and validated it based on the simulation for moderate sized event.

Construction of Velocity Model

The velocity model developed including broad Chuetu area by Japan Nuclear Energy Safety Organization (JNES) (JNES, 2008) has been used as the basic model. The folding structure developed by Tokumitsu et al. (2009) is built into the broad model. We connected smoothly those two models to eliminate the artificial waves generated on the boundary area. We picked three events for the model validation. Two comes from the aftershocks of Chuetsu-Oki earthquake and the other comes from the aftershock of 2004 Chuetsu earthquake.

We could reproduce the general feature of ground motions at the KKNP site by the simulation for moderate sized events. The ground motion level was larger for south side of KKNP site than it for north side of KKNP site. These results suggest that the folding structure played an important role for ground motion during the main shock of Chuetsu-Oki event.

Summary

We have constructed the velocity model including the folding structure. We could reproduce the general features of ground motion by the simulation for moderate sized events. The results of simulation indicate that the folding structure played an important role during the main shock of Chuetsu-Oki earthquake.

Keywords: 2007 Niigataken Chuetsu-oki Earthquake, Kashiwazaki-Kariwa Nuclear Power Plant, 3D velocity model, Fold, ground motion simulation

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Three Dimensional Attenuation Structure beneath the Northern Kinki Region, Japan

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Spectrum inversions assuming uniform Qs value (UQSI method) have been studied among many part of the country. Amaike et al.(2006) reported that the Qs obtained using the UQSI method depend on data ranges on hypocentral distances and the Qs decreases with the data ranges. Although, the causes of this phenomenon has not been cleared.

In this study, we obtained 3-D Qs structure using 3-D Qs spectrum inversion method (3DQSI method) with the discrete block size of 0.2 deg.$*$ 0.2 deg. $*$ 10 km and 0.2 deg.$*$ 0.2 deg. $*$ 20 km, and compared the 3-D Qs results with Qs by UQSI method reported by previous paper.

Data set are same as Nakamura et al.(2010), the 14,831 seismograms from K-NET and KiK-net from 1997 to 2007 that recorded 362 shallow and small earthquakes (h<=30 km and 4.0<=M<=6.0) were used for tomography. The ground acceleration Fourier spectra for inversion were calculated by using the S-wave portion and taking the geometric mean of the spectrum within +-0.5 Hz of central frequencies from 1 to 10 Hz every 1 Hz. The ground motion traces from the shallow earthquakes frequently have many later phases that consist of surface waves, therefore, the S-wave portion of records was selected to compare with the theoretical S-wave arrival time according to JMA2001. Other conditions for the tomographical calculations were in accordance with Nakamura(2009).

The Niigata-Ken Chuetsu area, Aichi-Gifu area and the northern Kinki region also show the good resolution in 1st layer (0-10 km in depth) and 2nd layer (10-20 km in depth). The active and quarternary volcanoes tend to show low-Qs at 0-10 km depth.

Fig.1 shows the relations between average Qs and frequency obtained by taking the average Qs over three study areas (A area:135.4-136.6 deg. E, 35.0-36.0 N, B area:135.2-136.2 E, 35.0-36.0 N, C area:135.4-136.6 E, 35.0-35.5 N) at layers 1 (0-10 km depth) and 2 (10-20 km depth).

Relation developed by Satoh et al. (2007) is also shown in this figure, they obtained $Qs=50f^{1.1}$ by using the UQSI method and data of 60 km in hypocentral distance. The C area employs only good resolution blocks, and the A and B areas contain some blocks which are not good resolution.

Differences among these areas are small, and the results at the shallow layer (0-10 km depth) are in good agreement with Satoh et al. (2007).

Theoretical ray paths from sources at 10 km depth calculated using JMA velocity model shows only upward traveling to stations within about 60 km in epicentral distance, although in the case for the stations distant from epicenter, the rays travel downward once, and, next upward.

Satoh et al. (2007) used the data within 60 km on hypocentral distance. Therefore, the result, $Qs=50f^{1.1}$, mainly reflects Qs of upper crust, and average Qs at layer 1 (0?10 km depth) in this study agrees well with $Qs=50f^{1.1}$.

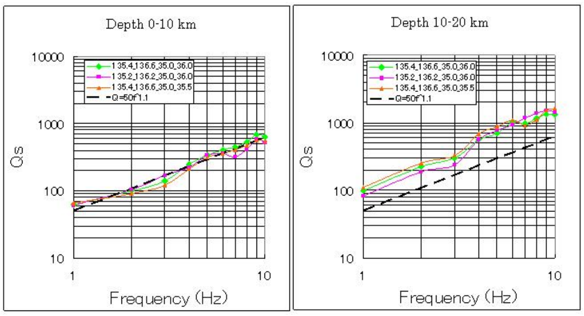

Fig.1 Comparison of Q_s values at the north Kinki region. Color solid lines: average Qs by 3DQSI method (This study). Broken line: Qs by UQSI method after Satoh et al(2007))

Keywords: 3-D attenuation structure, Qs, spectral inversion, tomography, depth dependence, the Kinki region

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Characteristics of long-period ground motion in the Tokyo bay area

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It is well known that the long-period seismic ground motions at a period of several to more than a dozen seconds are predominant in the Kanto plain. We have compared the observation records of the broadband strong-motion seismometers installed in the thermal power plants in the Tokyo Bay area with the three-dimensional seismic simulations. We pointed out the possibility of the relation between the focal depth and the thick sedimentary basin in Sagami bay affects the later arrivals of the E-off Izu peninsula earthquakes with a magnitude of 5 occurred in 2006.

In this report the off Ibaraki Prefecture earthquake occurred on May 8, 2008 was used for inbestigating the characteristics of long-period seismic motions in the Kanto plain. We used an underground structure model with the range of longitude 138.2-142.0 degrees east and latitude 34.5-36.5 degrees north of the Headquarters for Earthquake Research Promotion (2009). We performed three-dimensional simulations by using a finite difference method with the grid point interval of 400m in horizontal direction and 100-400m in vertical direction. The duration of the calculated velocity waveforms are 300 seconds, which are 30,000 steps with an interval time of 0.01 seconds. We compared the waveforms with the velocity records at a frequency range of 0.08 to 0.12 Hz, which is 7 to 12 seconds in period.

We assumed two cases of the source models of the off Ibaraki Prefecture earthquake of 2008 as a point source. One is the deep source model at a depth of 50km derived from the JMA hypocentre with a F-net mechanism and the other is the shallow source model derived from JMA CMT mechanism at a depth of 28km. We also assumed two cases of the Q-values at each layers of the underground structure model. One is the original value of Q=Vs/5 and the other is Q=Vs/2.5. We introduced the Grave(1996)'s Q-value model in the finite difference method and the reference frequency was 0.1Hz.

From the results of the comparisons between the two Q-value models with a deep hypocenter, no significant changes in amplitudes and later phases were seen in the frequency range of 0.08-0.12Hz. The calculated waveforms at IBR018 and IBRH20, which are the nearest the hypocentre, and from CHB004 to the observation stations in the eastern side of the Tokyo bay area are underestimated and are 1/3 to 1/4 in amplitude compared with the observed wavforms. Especially the later arrivals with large amplitude observed at the eastern bay area were not reproduced. On the other hand, the reproducibility at the western bay area is considerably better than the eastern area.

The results of the two kinds of different hypocenters showed great differences in amplitude and wave groups. It seems that the shallow case generally showed a better agreement with the observation. Yamanaka(2008) determined the focal depth of the off Ibaraki Pref. earthquake at 19km from the teleseismic analysis in NGY seismology note No.7. The focal depth might be shallower than 50km. However, the influence of the source process remains unsolved because we assumed the point source despite of M=7.0.

Keywords: Long-period seismic ground motion, Kanto plain, Sedimentary basin, Three-dimensional simulation, Broadband strong motion observation, Off Ibaraki Pref. earthquake in 2008

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Long-Period Ground Motion in the Tokyo Bay area from the Chichi-jima Kinkai earthquake (Mj=7.4) of Dec. 22, 2010.

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The shallow large event of Mjma=7.4 occurred in Chichi-jima kinkai region on Dec. 22, 2010. The ground motion records of the event observed in the Tokyo bay area had long duration and were rich in the long-period motions. In this article, the characteristics of the records were described.

Tokyo Electric Power Company has 13 observation stations around the Tokyo bay area. 5 stations are located on the east shore and 8 stations are located on the west shore. The velocity type sensors are used in observation. The event trigger system was adopted for recording the data. Sensors had been installed on the basement of low-storied buildings and this condition did not disturb the observation of the long-period ground motions. The epicenter distance was ranged from 990 km to 1,030 km and the azimuth was ranged from 337 to 340 degree.

The duration time of the records was over 1,800 s and many latter arrivals were identified.The waveform characteristics are different between the eastern side and western side. There were large later arrivals about 180 s after S wave arrival in the waveforms of eastern side and the characteristics of this wave packet were different among the observation points. On the other hand, there were no significant later arrival in the waveforms of west side. The peak velocities of the horizontal motion were 1.1-1.7cm/s in the east side and 0.5-0.8 cm/s in the west side. On the other hand, as for the up-down motion, the peak velocities were 0.2-0.3 cm/s at all stations. Peak ground velocity was recorded in the later arrival part composed of surface waves more than 180 s after the S wave arrival.

The results of multiple filter analysis showed that the later arrivals consisted of the motion in period of around 10 s. The predominant period of Ooi station in west side was about 8 s and that of Anesaki station in the east side was longer than 10 s.

The smoothed peak in period range from 8 to 12 s was shown in the velocity response spectra of 5% damping factor of the west side stations. The steep peak at period of 10 s was shown in the velocity response spectra of the east side stations. The peak value of east side stations were 6-9 cm/s and it was more than double in comparison with the peak value of west side. This difference became more remarkable in the response spectra with low damping factor. In the response spectrum with 0.1% damping factor, the peak value was around 10cm/s at the stations in west side but the value at the stations in the east side reached 30cm/s. But no significant peak was shown in the vertical component, and the response value of the vertical motion was small in comparison with the horizontal motion. It is around 2cm/s in case of 0.1% damping factor and 1cm/s in case of 5% damping factor.

In addition, the peak response time of response waveform with low-damping factor showed the large delay from the peak value time of velocity and acceleration. The duration of acceleration wave form was about 1 minutes, it was important that the peak response of the structure with low-damping factor was late for many minutes from the peak acceleration time.

Keywords: Long-period Ground Motion, Tokyo Bay Area, Chichi-jima Kinkai Earthquake, Response Spectrum

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Regional characteristics of the long-period ground motion observed at the super-dense seismic observation network

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The 2003 Tokachi-oki earthquake caused great damage to oil storage tanks in Tomakomai about 250km away from the epicenter. The damage was found to be caused by sloshing excited by long-period ground motion. The 2004 Niigata-ken Chuetsu earthquake caused damage to many elevators of skyscraper buildings in Tokyo Metropolitan area some 200km away from the epicenter since the long-period ground motion resonated with these buildings. These types of earthquake damage confirmed the importance of countermeasures for long-period ground motion. The earthquake-proof elevator guideline for the skyscraper buildings recommended the elevator control systems that respond to long-period ground motion. However, these systems are not adequately installed to the existing skyscraper buildings because the costs of their installation and maintenance are expensive. On the other hand, since the long-period ground motion is less affected by the local site effects, the warning system of long-period ground motion for the skyscraper buildings will be developed inexpensively by using data observed around these buildings (around-site warning system). For the purpose of the development of the around-site warning system, we evaluate the regional characteristics of the long-period ground motion response observed at the super-dense seismic observation network (SUPREME).

Keywords: strong motion observation, long-period ground motion, K-NET, skyscraper, elevator, warning system

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Estimation of Underground Stracture with Pseudo-Inverse Matrix Calculation

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To estimate the under ground structure, we usually use the observational data of gravity anomaly. We can write the relation between the density anomaly underground and the gravity anomaly at the surface as Ax=b, where vector x represents the density anomaly, vector b is the gravity anomaly, and matrix A is defined by Newton's law of universal gravitation, respectively. This relation is liner, and the reconstruction of density structure from the gravity anomaly can be expected with matrix inversion.

To perform the matrix inversion, we introduce the Moore-Penrose pseudoinverse A^+, since the number of observation data N and the number of model point M are usually different. The theory shows that matrix A can be decomposed as $A = USV^T$, where matrix U and V are orthogonal matrices, and S is an diagonal matrix, whose diagonal elements are singular values s_i. The Moore-Penrose pseudoinverse A^+ is defined as $A^+ = VS^+U^T$, where S^+ is the diagonal matrix, whose diagonal elements are $1/s_i$.

In the calculation of matrix V, the eigenevectors calculation of A^TA is needed. It is usually performed by QR algorithm, whose computational cost is of the order of $O(M^3)$. Since this part is the most time consuming part in the program, we adopt the I-SVD algorithm instead of traditional QR algorithm. I-SVD algorithm is a good algorithm and the computational cost is $O(M^2)$. Unfortunately, the next time consuming part of pre-transformation procedure is $O(M^3)$. So, the total computational cost remains $O(M^3)$.

The matrix inversion, in the terms of underground estimation, is sometimes ill-conditioned. In such case, a round-off error becomes important. Therefore, we introduce the multiple precision arithmetic or arbitrary-precision arithmetic library in our program. The round-off error can be minimised. Since we can easily switch off this option in the program, the comparison between the multiple precision calculation and the usual double precision calculation with the same program is also easy. Various tests show that the introduction of approximate pseudoinverse, whose diagonal elements less than the noise level in the observation data are replaced by 0, gives good results. The optimisation of computational speed by minimising the multiple precision calculation and the evasion of the ill-conditioned problem by introducing an new physics, such as the magnetic data, are the future work.

Keywords: density structure, gravity survey, inversion, pseudoinverse

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Prediction of average S-wave velocity for deep subsurface structure from fundamental mode Rayleigh wave phase velocity

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In this paper, an empirical relationship between phase velocity for fundamental mode Rayleigh wave and average S-wave velocity of deep subsurface structure.

It is evaluated numerically using three-dimensional subsurface structure model proposed by National Research Institute for Earth Science and Disaster Prevention (Fujiwara, 2009). First, one-dimensional subsurface structure model is extracted from the three dimensional model. Then, phase velocity for fundamental mode Rayleigh wave in horizontally-layered medium is calculated for wavelength from 100 to 1000 meters using a program provided by Hisada (1997).

Calculated phase velocities are similar to average S-wave velocities in most cases. An average S-wave velocity over a certain length is empirically about 1.1 times as large as a phase velocity with the same wavelength.

It is expected that Average S-wave velocity, or S-wave profile, will be constructed with reasonable accuracy from micro-tremor array observation on ground surface in near future.

Keywords: Rayleigh wave, Average S-wave velocity, Deep subsurface structure, Phase velocity

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Estimation of Complex Spectral Ratio of Surface and Borehole Seismometry and Numerical Tests

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I compared 4 estimation methods of complex spectral ratios from seismic vertical array records and the results of numerical tests of noise-added synthetic records by these methods. Phase difference spectra are useful to identify velocity and attenuation structure using the spectral ratios. Examined estimation methods are two least-square approaches (H_1 and H_2), a geometrical mean of H_1 and H_2 (H_3), and geometrical mean of the Fourier spectra (H_G). These methods are different ways of assumption of noise.

The two least-square approaches assume that one of the surface or borehole records (y(f) and x(f) in the frequency domain, respectively) includes noise and the other one is noise-free. The least-square solution of the observational equation that is assumed that surface record y(f) includes noise is $H_1=C_{xy}(f)/S_{xx}(f)$, where C_{xy} is the ensemble mean of the cross spectra of x(f) and y(f) and S_{xx} is the one of the power spectra of x(f). The solution that borehole records includes noise is $H_2=S_{yy}(f)/C_{yx}(f)$, where S_{yy} is the ensemble mean of the power spectra of y(f). Phase difference spectra of H_1 and H_2 are identical.

The effects of the noise are shown in the expected value. The noise is no effects on the expected value of C_{xy}. This causes that the phase differences are expected to be robust. The expected values of S_{xx} and S_{yy} are affected by the variance of the noise of x(f) and y(f), respectively. This indicates that the H_1 and H_2 are different for the same x(f) and y(f).

I applied these 4 methods to estimate the spectral ratios of the spectra of noise-added synthetic surface and borehole records. The noise-free surface and borehole synthetic records were calculated with the exact transfer function of the vertically incident plain wave in the homogeneous medium with the surface. I made noise-added synthetic records by adding 20 different white noise on the noise-free synthetic records.

Stacked spectral ratios were calculated by the 4 methods. Mean values of cross and power spectra of the 20 pairs of noise-added synthetics were calculated. H_1, H_2, and H_3 were calculated from the mean values. H_G were calculated with geometrical mean of the spectral ratios of the Fourier spectra y(f)/x(f). The result of H_1 indicates small error in the frequencies between peaks of the exact transfer function, whereas, at the peak frequency of the transfer function, H_1 underestimates the peaks due to the noise in the borehole records. H_2 indicates clear peaks, whereas it overestimate the valleys. H_3 are the geometrical mean value that is robust, but indicates unclear peak compared with H_2. H_G are close to H_3. Phase difference spectra of H_1 and H_2 are very close to the exact transfer function.

Smoothed spectra of noise-free synthetic spectra are very similar to the stacked spectra. H_1, H_2 and H_3 were calculated from smoothed cross and power spectra. H_G are the geometrical mean of the spectral ratios of the smoothed Fourier spectra x(f) and y(f). Parzen window was used as a smoothing window. The spectra applied both of stacking and smoothing also results similar to the stacked spectra.

Keywords: seismic vertical array, complex spectral ratio, transfer function

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Estimating small-scale site effect as functions of the frequency range from 2 to 4Hz by observing microtremors

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[1]TRIES

Remarkable amplifications of seismic waves caused by shallow ground soil generate seismic damages. The frequency of characteristic vibrations of popular wooden houses in Japan ranges from 2 to 4Hz and is same to the range of the seismic magnification of shallow ground soil, and may be called the site effect. Accordingly it is essential for mitigation of seismic hazards to estimate the site effect quantitatively in detail within the area concerned. Since the observation of microtremor amplitudes is comparatively simple and carried out anytime, it will be one of effective and simple methods, if the observed amplitudes are significantly related with those of the maximal amplitudes of seismic waves. Thus we have investigated the spectral characteristics of acceleration records observed at TRIES network. Analyzed data are the amplitudes of microtremors, the biggest part of surface waves caused by distant and large earthquakes such as the 2004 Off Kii Peninsula Earthquakes and S waves by local and small earthquakes observed at the same network since 1999. We calculated spectral amplitudes of microtremors, the surface and S waves by Fourier transform. Spectral amplitudes of microtremors were obtained from the same seismograms recorded during about 10 seconds from the start of recording by the trigger signal to the arrival of initial seismic P wave. We define the site effect as a magnification function of seismic spectral amplitudes in the three directions of UD, NS or EW, depending on the frequencies in the range of 2 to 4Hz. Since our investigations depend on the stationarity of the spectral amplitudes of microtremors at the point concerned, it is fundamental to show that our assumption holds with high credibility, as well as mitigation of seismic hazard by using our site effect will be possible or not. Though preliminary analyses of microtremor amplitudes give a credibility of about 70% of the seismic magnification, we are continuing further data analyses of the relation between maximal seismic waves and microtremor amplitudes.

Keywords: microtremor, ground soil, site effect, characteristic oscillation, Fourier transform, maximal amplitude

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Spatial distribution of predominant period derived from H/V spectra in Kochi Plain

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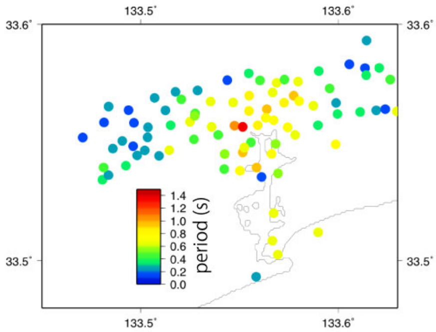
If the Nankai Earthquake occur, Kochi city will be damaged by both strong ground motion and submergence due to ground subsidence and Tsunami. These disasters will be concentrated in thick sediment region and/or high subsidence region. Thus sediment/Basement structure around the Kochi city is important to understand nature of the disasters. We conducted microtremor observation around Kochi city. We used JU210 seismometer for microtremor by Hakusan Coop. We observed microtremor 88 points around Kochi city and analyzed H/V spectra. Obtained dominant period distribution is shown in Figure. Both ends of east-west extending Kochi plain, short period dominant frequencies are recognized (western region 0.3s or less; eastern Kochi city 06.s or less). In contrast, central region faced to Urato-Bay area, longer period distribution are observed(larger than 0.6s up to 1.45s). Structure modeling to explain these observations is important issue in future study. In central area faced to Urato-Bay, provision for both submergence and strong ground motion with longer dominant period.



Keywords: Micro tremor, Predominant Period, Surface Basement, Kochi Plain

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Estimation of subsurface structure using microtremor H/V spectral ratio in the Shimabara peninsula

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Recently, the estimation of long-period strong ground motions is getting more important in accordance with construction of large-scale building structures. According to the contour map of peak period in the long-period ground motions in Japan (the Central Disaster Prevention Council, 2008), they estimated that the long-period ground motions are amplified not only in sedimentary basin like the Kanto plains in the central Japan, but also in volcanic area of the Shimabara peninsula in Kyushu, Japan. Especially, in the Yadake region of the center part of the peninsula, the long-period ground motions amplify to the same extent as Tokyo area in the Kanto plains. In order to estimate a ground structure in the Shimabara peninsula by paying attention to microtremor H/V spectra (horizontal-to-vertical spectral ratio) as an evaluation method of the ground structure, we carried out microtremor observations at 60 points in the whole area of Shimabara peninsula.

The microtremor observations using a three-components wideband portable seismometer of characteristic period 120 second were carried out at each observation site. The data of microtremor were recorded by a portable data-logger with 100Hz sampling.

Power spectrum of UD, NS, and EW were calculated and smoothed by using the ensemble average of thirty times, and power ratio of the horizontal and vertical spectrum (H/V spectra) was estimated, where the horizontal spectra are the geometric mean of the NS and EW components.

By using data from 60 observation sites, we traced a contour map of primary natural peak period (the longest peak period that exists from 1 to 10 seconds). Peak period of 5-6 s in H/V spectra was obtained at a lot of observation sites at east side of the Shimabara peninsula, where volcanic sediments are thickly distributed. It is thought that the thick volcanic sediment layer is a cause of such longer peak period in H/V spectra.

In the central western area of the Shimabara Peninsula, there are no remarkable peaks in the observed H/V spectra. According to explosion seismic research (Explosion seismic research group of Unzen Volcano, 1995), this area corresponds to rock layer having Vp=3.5km/s, which distributed in shallow to ground surface as a solid lava layer. This structure is reflected in shape of H/V spectra; the value of H/V spectra in this area is nearly constant in the frequency of microtremor.

Next, we are going to estimate subsurface structures in the peninsula using the observed H/V spectra. Using P wave velocity that had been obtained by the explosion seismic research, S wave velocity and density were calculated by relation estimated by Ludwig et al. (1970). During a trial-and-error estimation process, S wave velocity, P wave velocity and density were fixed, and we adjusted the thickness of the sedimentary layers to find a reasonable fit of primary natural peak period of the calculated H/V spectra and the observed H/V spectra to determine the ground structure. Then, the depth to Vs=600m/s layer is estimated as 1.2km at the boring site USDP2 in east side of Shimabara peninsula. Our result is consisting with boring-core sampling data from the borehole.

The horizontal component of long-period microtremor, locally exceed in Yadake site of the center part of Shimabara peninsula. If the ground structure is determined by using the same parameter as surrounding sites, the depth to the basement in Yadake site should be estimated as about 1000 m. However, nearby tectonic map and the result of explosion seismic research do not show such a steep basin structure under Yadake site. Thus, we changed S wave velocity of shallow part of the underground structure, and we found that the very low-velocity layer exists beneath surrounding of Yadake site. Because the rich hot-spring sources exist in around the Yadake site, it is thought enough that existence of the low-velocity layer, which causes the increase of the long-period strong ground motions.

Keywords: microtremor, H/V spectral ratio, subsurface structure, long-period ground motion

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Period-Dependent Site Amplification and Source Process for the 2008 Iwate-Miyagi Nairiku, Japan, Earthquake Sequence

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The 2008 Iwate-Miyagi Nairiku earthquake on 14 June 2008 mainly struck the Tohoku region, northeastern Japan. The JMA magnitude M_{JMA} was estimated to be 7.2 and the moment magnitude M_W by Global CMT Project was 6.9. The 5% damped acceleration and velocity response spectra maps reveal different features in the source area and at other stations out of the source area. The predominant period was shown in a short period range of 0.1-0.2 s. AKTH04 station which is located at 22 km away from the source area was recorded a JMA-intensity of 6 upper as large as in the source area. The large acceleration amplitude was observed at short periods at the same station. Large velocity amplitudes at stations MYG005 and MYG006 were observed at periods of 2, 3, and 5 s to the south of the source area. In this study, we use aftershock data to obtain amplification factors in and around the source area. The H/V spectral ratios were investigated at 27 station sites close to the source area. The data recorded by K-NET and KiK-net were used for five aftershocks. The spectral ratios of the horizontal components (H/H spectral ratio) of surface and borehole data were investigated for KiK-net stations. H/H spectral ratios of soft soil sites to hard rock sites were also calculated for comparison with previous studies. Amplification factors of 3 to 6 at short periods of 0.1 to 0.5 s are observed at many stations such as AKTH04, AKTH06, IWTH19, and so on. The stations of MYG005, MYG006, IWT011 and IWTH20 have shown amplification factors of 3 to 5 at long periods of 3 to 5 s. On the other hand AKT023, IWT010, and MYGH04 show flat response spectra compared to hard rock sites. The results reveal that the different features shown by response spectra can be attributed to the site effects. The H/V and H/H spectral ratios were used to get information about the predominant periods and the amplification factors at the station sites. The peak velocity amplitude distribution maps were calculated for different period ranges of 0.1-0.2, 0.2-0.3, 0.3-0.5, 0.5-1, 1-2, 2-3, 3-5, and 5-10 s. We are going to collect site amplification factors for the mentioned period ranges. The collected data will be used to retrieve the period-dependent source process for the 2008 Iwate-Miyagi Nairiku earthquake.

Keywords: 2008 Iwate-Miyagi Nairiku earthquake, source process, amplification

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Microtremor array survey in southern Osaka plain

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We conducted microtremor array survey at six locations in southern Osaka plain using 7 to 10 velocity seismometers arranged to multi-triangle array. Applying SPAC and E-SPAC method to the observed data, we estimate phase velocities (dispersion curves) from 0.3-0.5 km/s up to 1.0-1.5 km/s at frequency range 3-5 Hz down to 0.3-0.5 Hz. Then, S-wave velocity structures satisfying the dispersion curves are searched using GA method, assuming three layers (Vs=0.35, 0.55, 1.0 km/s) or gradually increasing velocity structure overlaying seismic bedrock (vs=3.2km/s). As a result, we successfully obtain velocity structures of which depths to the bedrock consistent with previous studies.

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Keywords: SPAC method, S wave velocity structure, GA

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Explorations of S-wave velocity structure around the K-NET stations in Ishigaki and Iriomote island, Japan

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We conducted microtremor array measurements for the 3 sites in the Ishigaki island and Iriomote island to estimate 1D S-wave velocity profiles of deep sedimentary layers over the basement with a Vs about 3.0km/s. In this presentation, we will discuss the details of the observation and analysis. We will analyze the data and get the S-wave velocity profiles at the 3 sites.

Keywords: Microtremor array measurements, S-wave velocity structure, Ishigaki & Iriomote Islands

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Determination of subsurface structure of Tottori dunes and around Koyama Pond in Tottori Plain from Microtremor Observat

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Microtremor observations were conducted in the area of the north / the east bank level of Koyama Pond and Tottori dunes in Tottori Plain. The area has been developed since late 20th century. Three components observations were carried out for surveying predominant period distribution in the area. H/V spectral ratios are used to obtain predominant period at observation sites. Array observations were also executed in the area. Alternatively, SPAC method and CCA method are applied for 4 or 5 stations arrays with diameter 2.5 to 50 meters. Through the study, obtained predominant period distribution agrees well with past topographies. Subsurface structures derived from array observation consist with borehole data, previous explorations, and the predominant periods coincide with analysis result mentioned above. Following the results, we are interested in the underground structure beneath Koyama Pond. It is important to reveal the structure to conduct simulations of wave propagation in this area.

Keywords: Microtremor, Tottori dunes, Koyama Pond, subsurface structure

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Determination of underground structure of Padang, Indonesia by microtremor observations

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Serious damages occurred by the strong ground motions during the 2009 Southern Sumatra earthquake in the area. Microtremor observations have been carried out in Padang, Indonesia and determined a subsurface structure by Noguchi et al. (2010). The deep S-wave velocity structure models at the 3 sites were determined from array observation records. The predominant period at 63 sites were obtained from 3-componet observation records. S-wave velocity of a bottom bedrock layer is 1500m/s and depth to the bedrock was about 200m maximum from obtained underground model at 3 sites array observation. The predominant period was 1.5-3.0 period that H/V spectral ratio has clear single peak and double peaks. It was found that soft alluvial layer was distributed whole area from S-wave velocity structure.

Keywords: Microtremor observation, S-wave velocity structure, H/V, Padang, Inonesia

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Estimation of velocity structure using seismic interfenometry at Hsinchu, Taiwan

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Hsinchu is one of important areas in Taiwan, because there are many IT and IC industries are located and they are most important resources for Taiwanese economy. We can remember that the price of memories for computers has jumped up immediately after the 1999 Chi-Chi earthquake. This means that the business continuity plan (BCP) for the companies in this area is critical issue for the Taiwanese economy. For this purpose, we need an appropriate estimation of earthquake ground motion in a specific site, however, enough information is not available until now.

We have continued to model a ground structure around this area to apply to an estimation of earthquake ground motion. Shosaka et al. (2007) proposed three-dimensional shape of bedrock based on the gravity survey. In their model, the depth to the bedrock is deeper in the south-eastern mountainous area than in the north-western seashore area. To confirm this results, Kawatsure et al. (2009) and Iwahori et al. (2009) carried out array observation of microtremors, however, they could not reach the deepest bedrock because of the limitation of sensors.

Thus, to break this wall, we apply new observation systems and technique of seismic interferometry. We developed a new data logger with extremely low noise and applied simple moving-coil-type velocity sensors with 0.5-second natural period. We set 5 velocity sensors around the area with deep bedrock and observed continuously the microtremors for 50 days.

The technique of seismic interferometry was applied to the observed data, and Green's functions for vertical components are obtained among the sensors. Furthermore, applying multiple filter analysis for 7 sec to 1 sec, and the group velocities are estimated between 7 to 1 sec. In this time, although we can estimate an averaged structure between the sites, they suggested that a part of velocity structures estimated from microtremors does not agree with the density structure obtained from the gravity survey. For future analyses, we will try to explain the differences between the velocity and density structures around this area.

Keywords: Seismic interferometry, Green's function, microtremor

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Estimation of inter-station Green's functions by CEORKA continuous data for validating velocity model of Osaka basin

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The Committee of Earthquake Observation and Research in the Kansai Area (CEORKA), which is arraying stations throughout the Kansai district, has obtained records from large earthquakes to small local earthquakes with taking advantage of broadband velocity seismograph. Since the observation started in April 1994, the CEORKA network has used trigger method for obtaining ground motion records. Since 2009, the committee is engaging to build new observation system, which can send continuous data in real-time, with introducing a new data logger for aiming to transmit seismic early warning in real-time.

To evaluate the accuracy of records obtained by the new data logger, the microtremor records obtained simultaneously by the data logger and SMAR-6A3P, which is widely used to microtremor observation, were compared. The results clarified that the data logger can obtain microtremor records in the frequency range of 0.2 to 30Hz. In this study, we start estimate inter-station Green's functions applying the seismic interferometry method using the continuous record obtained by the new data logger. The inter-station Green's function can be used for verification of the basin velocity model of the Osaka basin.

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Simulation for retrieving Green's function with seismic interferometry

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Seismic interferometry is widely used in various kinds of seismology to retrieve the Green's function from long-term ambient noise data. It is sometimes difficult to estimate proper the Green's function from actual data, such as non symmetrical correlation in negative and positive delay times. In this study we conducted numerical simulations for retrieving the Green's function from synthetic microtremor data calculated using a 3DFD code.

A surface vertical loading was set on the surface around two stations (10km apart) to simulate microtremor data. The synthetic velocities were used to generate a correlation. The correlations from 120 sources were stacked with the seismic interferometric way. We confirmed that the correlation agrees with the surface wave portions of the Green's function between the two sites. However, body wave part could not be reconstructed with the correlation. This is due to the lack of sources in vertical direction in the simulation. Since most of possible sources of microtremors are located on the surface, these phenomena can be essential in a correlation from microtremors.

We also conducted similar simulations with S-wave velocity models having irregular tnterfaces. We have difficulties to retrieve Green's function correctly when the basin has strong lateral heterogeneities. The vertical interface of the basin generates waves as secondary sources that violate the assumption of equal source distribution.

Keywords: seismic interferometry

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Estimation of application conditions for seismic interferometry based on numerical simulation

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The seismic interferometry reconstructs the pseudo shot record (Response function) from observed seismic data simultaneously by auto-correlation or cross-correlation function. The Response function provides us with useful information for imaging the subsurface structure. However, it is important to evaluate the applicability of this technique. One of the conditions of response functions is characterized by filtering or source characteristics of the observed seismic data. In this study, we examined the application conditions for the seismic interferometry estimated from auto-correlation by using theoretical waves. Next we also applied it to the observed strong motion records in the Osaka basin.

First, we examined the appropriate frequency range of the response function corresponded with the depth of the basement structure. Assuming the basement structure model beneath a receiver, we calculated theoretical waveforms with a variety of rise times and filtering. The Green's function is calculated by using discrete wavenumber method (Bouchon, 1981) with the reflection and transmission matrix (Kennett and Kerry, 1979). We obtained a sufficient database for various frequency range and rise time for imaging an assuming depth of the basement. The appropriate rise time is less than 0.5s to estimate basement depth from 100 m to 1000 m. we also found that low-cut filtered waveforms by 1.0 Hz are relatively available to estimate basement depth shallower than 500 m.

Second, we compared the SN ratio of the response function with number of stacked records using above database. Signals of the response function have sufficient SN ratio with stacked records up to 50. Using the observed seismic data, however, more stacked records will be required for sufficient SN ratio because of various noises exist in the seismograms.

Finally, we applied the seismic interferometry to estimate seismic basement structure in the Osaka basin using observed strong motion records. The basement depth estimated from the seismic interferometry agrees with the basin model in the Osaka area (e.g. Kagawa *et al*., 2004). At some station, however, especially near the edges of the Osaka basin, the depth estimated from the response functions did not agree with the Osaka basin model.

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Keywords: seismic interferometry, auto-correlation function, numerical simulation, application conditions, Osaka basin